Appendix 3A of BD5104
Ecological Vegetation Assessment
(Richard A. Lindsay)

The purpose of this Appendix is to provide an ecological narrative for plot-level vegetation data obtained at the Nidderdale, Whitendale and Mossdale blanket bog sites as part of the BD5104 project and further describe the interpretation relating to vegetation surveys and measures outlined in Appendix 3 and which are described in Sections 4.2.5 and 4.2.6 of the main body of the report for project BD5104.

This narrative should be read in conjunction with the two Excel spreadsheets:

1. *Comparison of initial site conditions between sites and their sub-catchments (Appendix 3A_1_RLindsay_Review_initial conditions)*

2. *Comparison of individual treatment (management) effects across years and sites (Appendix 3A_2_RLindsay_Review_treatment effects)*

These spreadsheets attempt to present the vegetation data assembled by the BD5104 research programme into a more readily understood ecologically-focused format by which it is then possible more easily to compare the initial conditions of all three study sites, their sub-catchments, their plot-level treatment plots, and the responses of these treatment plots to their respective treatment (management).

1. Initial conditions (i.e. 2012 survey)

1.1 Nidderdale

1.1.1 1 m x 1 m quadrats

This set of quadrats is dominated by a dwarf-shrub canopy of *Calluna vulgaris* and a moss layer somewhat dominated by *Hypnum jutlandicum*.

The quadrats also contain some evidence of poor-fen conditions, perhaps in the form of small erosion gullies or micro-erosion colonised by *Sphagnum fallax*, together with a number of 'feather mosses' or hypnoid mosses that can be found either on drying bog conditions or in association with poor-fen vegetation. It is perhaps worth noting that none of these poor-fen species (or species associated with mild enrichment) occur within the area selected for burning management, suggesting that perhaps there are no recolonising erosion features within that small-scale monitoring component.

In terms of typical bog species, only the cotton grasses *Eriophorum angustifolium* and *E. vaginatum* are recorded across all plots, with the latter substantially more abundant than the former, though still at relatively low cover values. Bog vegetation is thus reduced to one of its simplest expressions, and is accompanied by species which are more typical of wet or dry heath, including the constant presence of *Cladonia* lichen species.

There is some bare ground, though apparently small and scattered. The constant presence of the liverwort *Lophocoloea bidentata* may be associated with such patches.

1.1.2 5 m x 5 m quadrats

The picture does not change very much with the sampling of 5 m x 5 m plots. A few more poor-fen species or species associated with mild enrichment, such as *Sphagnum fimbriatum*, *S. palustre*, *S. subnitens*, *Polytrichum commune* and *Aulacomnium palustre* are recorded at low cover values, presumably associated with recolonising erosion or micro-erosion gullies or areas where past burning has

made micro- and macro-nutrients available. Some of these species are recorded from the area selected for burning treatment and so are present here if not in the 1 m x 1 m quadrat recording.

Feather or hypnoid mosses remain constant at low cover values, indicating drying conditions on the bog elements of the microtopography. The two cotton grasses remain the main bog indicators, though there are occasional small patches of *Sphagnum capillifolium* too but not in the 5 m x 5 m plots selected for burning treatment. Whether the small occurrences of *S. cuspidatum* are associated with anything remotely resembling a bog hollow, or whether these records are associated with recolonising erosion features cannot be determined from the available information.

1.2 Whitendale

1.2.1 1 m x 1 m quadrats

This set of quadrats is characterised by a slightly less-dominant canopy of *Calluna vulgaris* than at Nidderdale and somewhat reduced moss layer of *Hypnum jutlandicum* compared to that at Nidderdale.

Slightly greater cover of 'poor-fen' species is recorded from these quadrats than at Nidderdale, although as at Nidderdale, these species are not recorded on the area selected for the burning treatment. It is impossible to say whether these species indicate recolonising erosion features or not.

A largely similar assemblage of feather mosses of hypnoid mosses to that recorded from Nidderdale was recorded at Whitendale, suggesting either drying or poor-fen influence. The characteristic bog species now includes the dwarf shrub *Empetrum nigrum* (indicating somewhat dry conditions) as well as patches of *Erica tetralix*, *Vaccinium oxycoccos*, *Sphagnum capillifolium* and *S. papillosum*, this last species with at least one significant patch. This assemblage, though still limited in extent and generally not present in the area selected for burning treatment, represents a reasonable expression of characteristic bog vegetation.

Perhaps surprisingly, despite the presence of several typical bog species and increased cover of *Sphagnum* compared with Nidderdale, the Whitendale 1 m x 1 m quadrats have larger areas of bare peat – indeed the largest across the three sites. It is impossible to say whether these areas of bare peat are un-vegetated erosion features or not [Heinemeyer comment: Whitendale also showed leggy/old heather which had partly fallen over and prevented anything growing underneath].

1.2.2 5 m x 5 m quadrats

In terms of the community dominants *Calluna vulgaris* and *Hypnum jutlandicum* these 5 m x 5 m quadrats show the same pattern as that shown by the 1 m x 1 m quadrats.

The presence of 'poor-fen' species is, however, more marked, with *Sphagnum fimbriatum*, *S. palustre*, *S. subnitens* and *Polytrichum commune* as constants across the treatments, albeit at low cover values. *Sphagnum fallax* and *Aulacomnium palustre* are also recorded. What precisely these species are associated with cannot be determined from the available data, but recolonising erosion features would be a likely possibility.

Turning to the typical bog species, it is worth noting that, between the three sites, *Eriophorum vaginatum* occurs here at the highest abundances, though not in the area selected for burning treatment. Typical bog species are *Erica tetralix*, *Vaccinium oxycoccos* and *Empetrum nigrum*, the last species characteristic of somewhat drier bog vegetation, which perhaps also explains the presence of moss species such as *Campylopus flexuosus*, *Dicranum scoparium*, *Pluerozium schreberi*, *Rhytidiadelphus loreus* and *R. squarrosus*. *Sphagnum capillifolium* is the constant bog species, again pointing to the drier end of the typical bog spectrum, but *S. papillosum* is also recorded for all areas except those identified for burning treatment [Heinemeyer comment: but *S. palustre* was recorded and could have been overlooked or mistaken for *S. papillosum* as it was recorded in the following years once exposed after burning – see Appendix 3A_2]. A relatively rich assortment of leafy liverworts, as recorded here, can often mean that a

bog community is not as wet and vigorously-growing as it might be [Heinemeyer comment: mostly these were found at the base of *Calluna* stems but even more so within the sedgy hummocks.].

Within these larger quadrats the extent of bare ground is less than that recorded from Nidderdale, though still present consistently. The nature of this bare ground, and its implications for the likely trajectory of the vegetation, cannot be determined.

1.3 Mossdale

1.3.1 1 m x 1 m quadrats

These quadrats, though with a fairly dominant canopy of *Calluna vulgaris*, have a relatively low moss cover of *Hypnum jutlandicum*. It is perhaps worth noting that the area selected for burning treatment has the greatest dominance of *C. vulgaris* of all the plots across all the sites and also has a high cover of *H. jutlandicum*. This is in marked contrast to the other treatment plots on this site which have the lowest cover of *C. vulgaris* and by far the lowest cover of *H. jutlandicum*.

The Mossdale plots are described (in Section 4.2.6.3 of the main report) as being the most *Sphagnum*-rich, but this is a comment which needs to have certain caveats attached to it. One of the relatively abundant *Sphagnum* species (much more so than *Hypnum jutlandicum*, except for the burning plots) is the 'poor-fen' species *Sphagnum fallax*. At such levels of cover it would usually be associated with significant re-vegetating erosion features. The constant presence of *Polytrichum commune* and *Aulacomnium palustre* also suggest as much. These erosion features might be the micro-erosion channels between *Eriophorum vaginatum* tussocks, where such an assemblage often becomes established, and these quadrats have the highest cover of *E. vaginatum*, suggesting this as a possible scenario.

In contrast, the relative abundance of *Sphagnum capillifolium*, at least in the areas not to be subject to burning [Heinemeyer comment: although burnt plots also show considerable amounts of cover for *S. capillifolium*], combined with *Erica tetralix*, *Vaccinium oxycoccos* and *Empetrum nigrum*, point to other areas of more typical bog vegetation at the drier end of the characteristic spectrum.

1.3.2 5 m x 5 m quadrats

The pattern of *Calluna vulgaris* and *Hypnum jutlandicum* is largely as for the 1 m x 1 m quadrats, with largely the same distinction between ground which is to be subject to burning treatment compared with the other treatments.

Indeed the overall pattern is the same as that described for the 1 m x 1 m quadrats, with the exception that *Sphagnum palustre* joins the 'poor-fen' species as a constant feature with low cover, while *Polytrichum strictum* also becomes a constant with low cover, typically on areas of moss which have been subject to fire damage in the past.

1.4 Summary of initial conditions

Without a clear aerial photograph view of each site and treatment plot, it is impossible to be sure of the ecological conditions which prevail across each of these, but it would seem likely that all sites, plots and quadrats contain micro-erosion features to some degree. These may be substantial erosion gullies or merely micro-erosion channels between upstanding blocks of bog vegetation or cotton-grass tussocks [Heinemeyer comment: from the individual plot level pictures – available on request – it is micro-erosion not substantial erosion gullies, which were excluded from monitoring plots during the initial plot selection process]. The presence of such erosion features, some of them evidently substantial, is hinted at by comments within the mowing methodology, which talks of mowing being at times constrained by the presence of erosion gullies.

Particularly where these erosion features are showing some degree of re-vegetation, such zones of focused water movement will tend to take on the character of poor fen. This is important because poor fen can be expected to display very different GHG budgets from areas of bog. Indeed, some of the vegetation assemblages could in certain cases be describing actual fen seepage zones, although whether they are or not could only be determined with further data from the study plots [Heinemeyer comment: such seepage was only observed at Nidderdale for plots 30-34]. Equally, erosion features are likely to result in more rapid surface-water losses from the adjacent bog surfaces, putting pressure on the system in terms of its capacity to support 'active bog' development.

Perhaps the most curious feature of the initial conditions across the three sites is the fact that the areas designated for burning treatment appear to differ somewhat consistently from other treatment plots across all three sites. [Heinemeyer comment: notably, at all sites the sub-catchment management was allocated at random, and the initial site assessment did not reveal any major differences between them, which highlights the importance of pre-management monitoring to be included in an overall analysis (as done in this study) and the danger of using space for time substitution (which assumes sites are the same) in assessing management impacts on ecological processes]. For Nidderdale and Whitendale the burning plots appear to have no poor-fen component in the 1 m x 1 m quadrats though poor-fen species were noted from the 5 m x 5 m quadrats. . Meanwhile at Mossdale the burning treatment plots have very low cover of typical bog species in the 1 m x 1 m quadrats but a marked presence of poor fen conditions compared to the burning treatment plots of the other two sites. For all sites, both *Calluna vulgaris* and *Hypnum jutlandicum* have greater cover, in the case of Mossdale substantially so, in the burn than the other treatment plots in the mown-subcatchment.

The overall ecological impression of these initial conditions is that a mixed response could be expected from all three sites in terms of GHG responses from the separate bog and poor-fen components [Heinemeyer comment: across a spectrum of less (Mossdale) to more (Nidderdale) modified blanket bog with Whitendale as intermediate but closer to Mossdale], while the areas selected for burn treatments appear to differ consistently from other treatment plots across all three sites but not always in the same manner.

2. Treatment (management) responses (i.e. 2013 – 2016 surveys)

An important factor to bear in mind when reviewing and comparing treatments is that many species are recorded at very low cover values. Observer error is an important factor in such circumstances, in the sense that a relatively small change in perceived cover-value when recording can bring about apparently significant changes within these small values. Consequently it is often better to treat low cover values more as presence/absence data than quantitatively meaningful data. This is because it is unlikely that a field recorded will incorrectly identify the presence (or absence) of a species even if they are not entirely consistent in their estimates of cover value. [Heinemeyer comment: in effect, the very low cover values recorded presence/absence, but (+) records were converted to 0.1% purely to enable statistical analysis].

Given the above, the descriptions below will focus largely on major evident changes, plus presence/absence behaviour, but will also highlight consistent trends even if those trends are based on relatively low cover values.

2.1 Do nothing (uncut control)

2.1.1 1 m x 1 m quadrats

In terms of the initial community dominants, *Calluna vulgaris* and the moss *Hypnum jutlandicum*, the picture across the three sites is somewhat mixed. At Nidderdale both *Calluna* and *Hypnum* remain relatively constant over the study period, whereas at Whitendale the *Calluna* cover declines while the *Hypnum* moss carpet expands somewhat [Heinemeyer comment: however, most likely this reflected heather dieback due to frost without snow protection and heather beetle damage revealing more *Hypnum*]. At Mossdale the *Calluna* cover expands steadily, as does the cover of *Hypnum*, but for the latter species it does so from a low cover to a moderate cover and at its maximum it is still little more than the lowest recorded covers for *Hypnum* at the other two sites.

Such a pattern would suggest that conditions at Nidderdale have remained relatively constant throughout the study period, while at Whitendale conditions are becoming somewhat wetter (after a period of drier conditions) but not sufficiently so to inhibit growth of *Hypnum*, whereas at Mossdale those parts which are essentially bog rather than poor fen habitat are becoming drier.

All three sites possess a largely constant poor-fen component in the form of *Sphagnum fallax* and a number of other species distributed variously across the three sites, including *Aulacomnium palustre*, *Polytrichum commune*, *Sphagnum subnitens* [Heinemeyer comment: except at Mossdale], *Carex spp.* and *Sphagnum fimbriatum*. Mossdale is notable for the marked increase in *Sphagnum fallax* during the study period. Whether this reflects increasing re-vegetation of erosion features – be they evident erosion gullies [Heinemeyer comment: gullies were not part of any of the monitoring plots] or micro-erosion channels, or channels between *Eriophorum vaginatum* tussocks – cannot be determined from the data available, although the decline in cover of *E. vaginatum* at Mossdale over this same period appears to make it more likely that evident erosion features are being colonised.

All three sites show a relatively constant presence at low cover values of feather/hypnoid mosses associated with drier conditions than those which prevail in *Sphagnum*-dominated communities, though the precise moss assemblage varies across the three sites.

Nidderdale supports only the barest minimum of typical bog species – namely the cotton grasses *Eriophorum vaginatum* and *E. angustifolium* and even these at relatively low cover values – highlighting the dry and damaged condition of its bog component areas Whitendale supports a more typical low-ridge/high-ridge bog community consisting of *Sphagnum papillosum*, *Vaccinium oxycoccos*, *Empetrum nigrum* and low presence of the hummock-forming *Sphagnum capillifolium*. It also displays a steady, if modest, rise in *Eriophorum vaginatum*, potentially at the expense of *Calluna* [Heinemeyer comment: although again, this also relates to exposing undercover vegetation following frost and heather beetle

damage to heather shoots]. Mossdale, on the other hand, supports a community more characteristic of hummock-level bog vegetation, consisting of the dwarf shrubs *Erica tetralix*, *Vaccinium oxycoccos* and *Empetrum nigrum* together with substantial quantities of *Sphagnum capillifolium*. [Heinemeyer comment: this supports the interpretation in the main report of Nidderdale being the more modified bog of the three sites and Mossdale the least modified site with Whitendale being intermediate but closer to Mossdale]. There may be an inverse relationship at this site [Mossdale] between the increasing cover of *S. capillifolium* and that of *Eriophorum vaginatum*. [Heinemeyer comment: but this could also be a result of competing for space with increasingly re-growing heather shoots].

2.1.2 5 m x 5 m quadrats

Within the larger quadrats the response of *Calluna vulgaris* over the study period is less varied than in the 1 m x 1 m quadrats. At Nidderdale and Mossdale, *Calluna* cover remains largely constant, while at Whitendale there is an initial decline in cover but then conditions remain stable after that [Heinemeyer comment: but see above comment on frost and heather beetle damage, also a decline at Mossdale in 2014/15]. For the moss *Hypnum jutlandicum*, however, there is a consistent and substantial expansion of cover across all sites, the least marked change being at Whitendale. Such a pattern would suggest that all sites are perhaps becoming wetter but are not yet sufficiently wet to discourage dominance of hypnoid mosses and encourage *Sphagnum* mosses. [Heinemeyer comment: moreover, in terms of *Calluna* die-back at Mossdale and Whitendale, it is important to bear in mind that if the plant is stressed - by, for example, a wetter conditions following rising water table - the plant is far more susceptible to pests and frost; notably, uncut plots were located within the mown sub-catchment becoming wetter (rising water table) over time compared to the burnt catchments].

All sites have a significant poor-fen component, characterised by the presence (and in the case of Mossdale, relative abundance) of *Sphagnum fallax*, accompanied by a range of species at low cover values including *Sphagnum palustre*, *S. russowii*, *Aulacomnium palustre* and *Polytrichum commune*.

Feather/hypnoid mosses associated with drier conditions than those favoured by *Sphagnum* are constant at low value and include *Campylopus flexuosus*, *Dicranum scoparium*, *Plagiothecium undulatum*, *Rhytidiadelphus loreus*, and, showing a steady increase over the study period, *Pleurozium schreberi*, one of the last such mosses to be replaced when conditions become suitable for *Sphagnum* dominance.

Of the typical bog species – other than the cotton grasses – Nidderdale has the simplest assemblage but even this contains constant *Sphagnum capillifolium* at low cover values. Whitendale has similar presence of *S. capillifolium* but this is accompanied by a similar level of *S. papillosum* and the three dwarf shrubs *Erica tetralix*, *Vaccinium oxycocos* and *Empetrum nigrum*. Mossdale is similar, but with greater (if variable) cover of *S. capillifolium*.

2.1.3 Summary of 'do nothing' control – i.e. underlying background trajectory

Nidderdale is undoubtedly the driest, most damaged (i.e. modified) of the three study sites, at a stage where internal successional processes are only just moving towards establishment of a feather/hypnoid moss cover. The underlying nature of the bog habitat is indicated by the marked presence of cotton grasses, and the consistent presence at low values of *Sphagnum capillifolium*, the *Sphagnum* species most resilient to dry conditions, suggests that advantage can subsequently be taken of more extensive favourable conditions should they develop.

Conditions at Whitendale already appear somewhat more favourable, with low-cover presence of both *Sphagnum capillifolium* and *S. papillosum*, together with a small number of characteristic dwarf shrubs, though the constant presence of *Vaccinium myrtillus* at varying if relatively low degrees of cover points to ongoing dry conditions which perhaps explains the continued low cover of bog Sphagna.

Mossdale presents a largely similar picture to Whitendale but Mossdale was characterised by vegetation indicating the overall least modified bog conditions, though the relative abundance of *Sphagnum*

capillifolium could either indicate the predominance of hummock-favouring hydrological conditions, or could be associated with the margins of poor-fen areas which have re-vegetated.

Within the parameters of successional processes for bog systems recovering from damage, none of the sites could be described as 'declining in quality', though it is clear that Nidderdale is at an early stage of the trajectory towards recovery while Whitendale and particularly Mossdale are somewhat further along this trajectory.

2.2 Burning

2.2.1 1 m x 1 m quadrats

In terms of the responses of the two initial community dominants, *Calluna vulgaris* and *Hypnum jutlandicum*, the former almost vanishes after burning treatment (albeit unsurprisingly so) but then steadily recovers until it is almost 50% of its original cover value by 2016. *Hypnum jutlandicum*, in contrast, survives the burning treatment to a modest degree and then almost attains its original degree of cover by 2016.

Other species to show a marked response are *Eriophorum vaginatum* and the moss *Campylopus introflexus*. The latter species rises from nothing to 19% cover value by 2016 at Nidderdale though shows more modest increases on the other two sites. It is a species of dry bare peat, particularly burnt peat, suggesting a steady expansion of such habitat over time although interestingly the record of 'bare peat' does not reflect this [Heinemeyer comment: although the sum of bare/burnt/brash ground was significantly higher on burnt compared to either of the mowing management plots]; perhaps it is largely hidden beneath this and other feather-moss species, including *H. jutlandicum*. Also of note is the substantial increase in *Sphagnum capillifolium* at Mossdale, from 5% to 21% between 2012 and 2016. The context of this increase cannot be determined – whether it be a general expansion across the quadrat, expansion of particular hummocks, or growth within the margins of wetter re-vegetating erosion gullies.

The rise in *Eriophorum vaginatum* over time at all three sites most likely reflects its fire-resisting life strategy by forming dense tussocks and thus its increasing presence is largely to be expected. The generally much smaller but nonetheless steady increase in *Eriophorum angustifolium* over time reflects its deep-rooted fire-avoidance life strategy, enabling it to re-grow rapidly after fire and in particular to occupy areas of bare peat.

Other species responses are smaller, but of particular note is the appearance across some or all of the three sites of various poor-fen species such as *Sphagnum palustre*, *S. subnitens (but excluding Mossdale)*, *S. fimbriatum*, *Juncus squarrosus* and *Polytrichum commune* following burning treatment, plus the appearance of *Carex nigra* at Nidderdale. This may reflect nutrient-release from ash, or post-fire development of small micro-erosion features which are then colonised by poor-fen species. The effect is least at Mossdale, but then it appears that the initial conditions at Mossdale already included a distinct poor-fen component in terms of a *Sphagnum fallax* sward with a consistent *Aulacomnium palustre* and *Polytrichum commune* component.

Other species responses of note, though largely at the scale of presence/absence, are the appearance and relatively consistent appearance or even rise of species indicative of drying, including *Vaccinium myrtillus, Dicranum scoparium*, *Campylopus flexuosus* and *Pleurozium schreberi*. Nidderdale possesses only one typical bog species other than the two cotton grasses, and this is *Empetrum nigrum*, which is associated with the drier end of the bog spectrum. Whitendale, identified in Section 1 of the present narrative as possessing the most 'typical' bog assemblage, records the appearance and steady increase of the dwarf shrubs *Erica tetralix*, *Vaccinium oxycoccos*, and *Empetrum nigrum*, together with the appearance, then small but steady increase, of *Sphagnum capillifolium* and *S. papillosum*. Mossdale, in contrast, gains a low but increasing presence of *Vaccinium oxycoccos* and *Rubus chamaemorus*, the combination of which is associated with somewhat wetter bog conditions than those that typically support *Empetrum nigrum*.

Thus while both sites continue to support a range of characteristic bog species, Whitendale remains perhaps the drier of the two.

2.2.2 5 m x 5 m quadrats

The response of the initial community dominants (*Calluna vulgaris* and *Hypnum jutlandicum*) across the larger quadrats is the same as for the 1 m x 1 m quadrats, as indeed is the response of both cotton grass species and to some extent *Campylopus introflexus* (particularly at Nidderdale).

Over the larger area of these 5 m x 5 m quadrats, the response of *Sphagnum capillifolium* at Mossdale is much reduced, with only a very modest increase compared with initial conditions. It maintains its low cover at Whitendale and is not present at Nidderdale.

As with the smaller quadrats, there is a distinct increase in the appearance of poor-fen species following burning treatment particularly at Nidderdale, while at the other two sites the increase in poor-fen species also occurs but is more limited and pre-existing poor-fen species remain consistently at relatively low cover values.

For species indicative of drier conditions all three sites display a consistent low cover of pre-existing species, with just one or two new species being added after burning treatment.

In the case of typical bog species, Nidderdale shows a consistent but low-cover increase in pre-existing *Erica tetralix* and *Empetrum nigrum*, together with small sporadic presence of *Sphagnum cuspidatum* and *S. papillosum*. Whitendale and Mossdale, in contrast, show a largely steady presence of *Erica tetralix* and *Empetrum nigrum* and *Vaccinium* oxycoccos, with the former site also adding *Andromeda polifolia* and the latter adding *Rubus chamaemorus*. In addition, Mossdale gains, then loses, *Sphagnum magellanicum* while Whitendale gains *S. papillosum* which then diminishes [Heinemeyer comment: however, the change in *S papillosum* vs. *S palustre* could have reflected mistaken cover allocation between the two species during field identification – when not every patch can be verified or assessed].

2.2.3 Summary of burning effects

Overall, the response to burning has been that of the initial community dominants, *Calluna vulgaris* has recovered about 50% of its original cover value while recovery of *Hypnum jutlandicum* ranges from 50% of its original cover to almost 100%.

Alongside recovery of the community dominants, the vegetation has become increasingly characterised by tussocks of *Eriophorum vaginatum* and to a lesser extent mats of *Eriophorum angustifolium* leaves.

Existing poor-fen species persist but further poor-fen species appear, perhaps because of the nutrient flush from the ash and decomposition of the peat, or because new micro-erosion gullies are generated by burning – and presence of bare dry peat is colonised by stands of the moss *Campylopus introflexus*. Similarly, moss species indicative of dry conditions either persist or are joined by new species, but all at low cover values.

The main response of typical bog species (other than the cotton grasses) is seen in dwarf shrub species which can root deeply into the peat – and are often associated with the drier end of the bog spectrum. These either persist, or appear and then persist, at low cover values.

Sphagnum, other than poor-fen species, displays a somewhat patchy response at low levels of cover, apart from *Sphagnum capillifolium* at Mossdale where its initial modest cover displays a small increase over time. The immediate [ecological] context occupied by this species in terms of its micro-topographic setting would need to be clarified in order to understand the dynamics here.

2.3 Mowing plus leaving brash

2.3.1 1 m x 1 m quadrats

At Nidderdale, the driest and most damaged of the study sites, after treatment by mowing and leaving the brash *in-situ* the initial community dominants *Calluna vulgaris* and *Hypnum jutlandicum* displayed rather different responses. *Calluna* declined substantially but had recovered to almost 50% of its former cover by 2016 (similar to burnt plots) while *Hypnum jutlandicum* declined only slightly and then returned almost immediately to its former level of cover. The effect of mowing may have been to compress the surface layer closer to the water table and thus inhibit somewhat the re-growth of *Calluna* whilst providing at least a level of moisture sufficient for *Hypnum* to grow well [Heinemeyer comment: however, the bulk density and peat depth assessment (see Section 4.2.3) showed no lasting impact of mowing; a more likely reason was the remaining brash layer keeping the peat wetter, which was confirmed by soil moisture measurements as part of the cranefly assessment, see Section 4.5.2 in the main report]. At Mossdale the *Calluna* appears to have recovered even more quickly, albeit at lower overall cover while the very low cover of *Hypnum* remained largely un-altered by the mowing. At Whitendale the mowing and brash also appear to have had little impact on the *Hypnum* but the effect on *Calluna* is much more dramatic – it seems that the treatment has resulted in long-term inhibition of *Calluna* recovery, possibly because this more typically bog assemblage (albeit still somewhat dry) is based on a peat surface which is more compressible and thus pressure from the mowing machinery has aided in supressing *Calluna* recovery by raising the water table. [Heinemeyer comment: the most likely reason, however, is the frost and heather beetle damage, which was observed across the entire Whitendale site (and also affected uncut plots). Also, the quite thick brash layer (thickness was noticeable) at Whitendale will have benefited mosses but could have supressed re-sprouting of *Calluna* shoots.].

All three sites have an evident poor-fen assemblage which is somewhat more constant than occurred within the burning plots, with species such as *Sphagnum fallax*, *S. subnitens (but not present at Mossdale)*, *S. palustre (but not present at Nidderdale)*, *Aulacomnium palustre* and *Polytrichum commune* the most prominent components. This may be in response to nutrient release from the decomposing brash.

All sites have a fairly constant assemblage of feather/hypnoid mosses consisting of *Plagiothecium undulatum* (a moss which grows well in dense shade), *Dicranum scoparium* and *Campylopus flexusous*, together with occasional *Rhytidiadelphus* species. These mosses are probably taking advantage of the somewhat drier micro-conditions offered by the brash surfaces as opposed to the peat surface itself.

On all sites, *Eriophorum vaginatum* shows a marked increase in cover, as does *E. angustifolium* albeit at lower levels of cover. It would thus seem that mowing and brash deposition encourages development of cotton grass tussocks. In terms of other typical bog species, it is noteworthy that even at Nidderdale – the driest and most damaged of the sites – and at Whitendale, *Sphagnum papillosum* appears and is sustained albeit at very low levels, with the latter site also supporting *S. capillifolium* at rather higher levels of cover. At Mossdale, in contrast, *Sphagnum capillifolium* is the only ['active'] bog *Sphagnum* species and occurs at substantially higher cover values than on the two other sites. Both of the wetter sites also support the 'standard' dwarf-shrub assemblage of *Erica tetralix*, *Vaccinium oxycoccos* and *Empetrum nigrum*.

2.3.2 5 m x 5 m quadrats

The larger plots display essentially the same response for the initial community dominants, *Calluna vulgaris* and *Hypnum jutlandicum*.

Poor-fen species display a greater consistency over time across the three study sites, with *Sphagnum fallax* showing a variable but essentially increased cover over time on all three sites but notably so on Mossdale. A larger range of poor-fen species is also recorded at low cover values, including *Juncus effusus*, *J. squarrosus* and *Carex* species.

Feather/hypnoid mosses are also somewhat more constant across all sites, though with a distinct reduction in cover of *Pleurozium schreberi*.

Of the typical bog species, *Eriophorum vaginatum* displays the most marked increase in cover over the study period. At Mossdale (the lowest initial cover) it increases from 10% to 38% while at Whitendale (the highest initial cover) it increases from 26% to 54% cover. *Eriophorum angustifolium* also shows a steady increase in cover but at much lower cover values. The pattern for bog Sphagna and other 'bog typics' is very similar to that seen in the smaller quadrats.

2.3.3 Summary of mowing effects when brash is left in-situ

The main effects of mowing and leaving brash appear to be, firstly, that poor-fen species increase and feather/hypnoid mosses are encouraged at low cover values, both potentially as a result of nutrient release, while the mosses may also benefit from shading and elevated, drier structures on which to grow but with additional moisture provision from underneath the brash layer (i.e. preventing drying out as quickly as on the more exposed burnt areas).

Secondly, *Calluna* re-growth is somewhat inhibited [Heinemeyer comment: yet only initially and mostly so compared to burnt plots (and only at the two drier sites Nidderdale and Whitendale), whilst the difference to mowing with brash removal is much less], while growth of *Eriophorum vaginatum* is encouraged.

There appears to be a small degree of encouragement for the establishment and sustaining of typical bog Sphagna, and in some cases a more marked benefit to the poor-fen species *Sphagnum fallax*.

2.4 Mowing and brash removal

2.4.1 1 m x 1 m quadrats

The effects of mowing and brash removal within the 1 m x 1 m quadrats are remarkably similar to those when brash is left *in-situ*.

2.4.2 5 m x 5 m quadrats

The larger plots display much the same overall response as the smaller quadrats but are richer in species of the poor-fen assemblage within Nidderdale and Whitendale, and then richer in the typical bog assemblage within Whitendale and Mossdale. This is initially surprising but can perhaps be explained by the potentially extensive deposition of small brash fragments that can still act as a source of nutrients as they decompose.

Sphagnum cuspidatum becomes a constant at very low cover values at, surprisingly, Nidderdale. It would be interesting to know what the immediate physical context of these records might be. [Heinemeyer comment: *S. cuspidatum* was only present at plots within one experimental block (plots N30-N34) which related to seepage conditions].

2.3.3 Summary of mowing effects when brash is removed

The effect of removing brash is not as dramatic as might have been expected. The ecological response is rather similar whether brash is left *in-situ* or is removed. This may be because small brash fragments left when the brash is removed can decompose more readily within the timescale of the study than larger brash fragments which can only decompose from outer layers first. The addition of shade and structure from the brash appears to provide minor benefit to *Sphagnum capillifolium* which does not respond as vigorously in the absence of brash Other *Sphagnum* species appear largely indifferent to the presence or absence of brash. [Heinemeyer comment: brash might also contain Sphagna propagules and the recorded temperature difference by brash removal compared to leaving brash was also small (only slightly greater min/max; see Section 4.2.12)].

3. Summary

3.1 The three sites differ from each other, with Nidderdale in the driest, most degraded condition, Whitendale supporting a vegetation which is most uniformly of a 'typical bog' community though still dry and somewhat degraded, while Mossdale is the wettest site, though this mainly arises from the presence of poor-fen vegetation characterised by *Sphagnum fallax* and most likely associated with recovering (micro-) erosion features or possibly poor-fen flush systems.

3.2 Within each study site, the plots selected for the burning treatment consistently differ in their initial condition from those subject to other treatments, being generally more species-poor and supporting fewer typical bog species. This distinction is particularly marked in the 1 m x 1 m quadrats but is also true of the 5 m x 5 m quadrats.

3.3 Over time, the invasive moss *Campylopus introflexus* became established and often then expanded on the burning treatment plots of all three sites, particularly at Nidderdale. This moss is particularly associated with dry bare peat. Nidderdale and Mossdale also showed an increased presence on the burning plots of grass and herb species such as *Anthoxanthum odoratum*, *Deschampsia flexuosa*, *Galium saxatile* and *Festuca ovina*, which generally point to heavily modified bog conditions – indeed more grass heath than blanket bog. Whitendale does not show this trend so markedly, but instead shows a marked increase in leafy liverworts which are generally associated with drying conditions. In general, the burnt quadrats had less overall cover of typical 'bog' *Sphagnum* species than the other treatments.

3.4 Background trends as recorded in the larger uncut 'no treatment' 5 m x 5 m quadrats indicate that *Hypnum jutlandicum* has increased substantially at Nidderdale and somewhat at Mossdale, though without an equivalent increase in cover of *Calluna vulgaris*. Such a trend suggests that the bryophyte layer may be re-establishing itself on drier parts at these sites, albeit not yet as a peat-forming vegetation. At Mossdale there is also an increase in *Sphagnum fallax*, suggesting similar recovery within micro-erosion gullies but in this case with a peat-forming sward. Whitendale, meanwhile, shows a small but steady increase in *Sphagnum papillosum* and *Eriophorum angustifolium*, which points to slow recovery of a typical bog vegetation.

3.5 The most striking effect of both mowing treatments at Nidderdale and Whitendale is the increased cover of *Eriophorum vaginatum* and the increased presence of poor-fen species, the former as a result of reduced competition from *Calluna vulgaris* while the latter may have taken advantage of enrichment from brash cover or fragments of brash left after mowing. At Mossdale there is increased cover of *Sphagnum fallax*, suggesting enhanced recovery of micro-erosion gullies and/or possible enrichment from brash cover or fragments, together with a marked increase in *Eriophorum vaginatum* and *Sphagnum capillifolium*, both of which may have benefitted from reduced competition with *Calluna vulgaris*.

3.6 In summary, therefore, burning appears to be the least beneficial form of management intervention. The uncut 'do nothing' option has few, if any, downsides although on the most damaged [modified] site (Nidderdale) there is only limited evidence for recovery of a bryophyte layer which, in due course, can be expected to give way to a peat-forming bryophyte layer. Mowing encourages expansion of hare's-tail cotton grass (*Eriophorum vaginatum*) which is a key species in re-establishment of a peat-forming community, albeit on rather long timescales. Where such expansion is also accompanied by an increase in *Sphagnum capillifolium* the timescales of recovery to a more typical bog vegetation may be significantly reduced, but this is only likely on wetter sites – such as Mossdale. Whether brash is left on-site or not does not appear to have a substantial effect on the vegetation response.