The Differential Response of Vegetation to Grip-Blocking

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Executive summary

This study compares the conditions affecting revegetation of grips which have been blocked within the Allenheads region of the North Pennines AONB. The problem investigated is one where blocking and slope conditions were apparently the same between two grips, but the revegetation response was quite different. To gain more context an additional five grips were also surveyed. This small-scale pilot study aimed to determine some of the reasons for differences in revegetation so future blocking maximises vegetation regrowth, especially of peat-forming species.

The primary finding was that deep pools created through some grip blocking are not conducive to revegetation and shallow pools are preferred.

It was also found that:

- Well vegetated grips tended to be narrower and shallower than those grips that were poorly vegetated.
- Reduced light penetration, as a result of increased water depth and higher water colour may inhibit vegetation growth
- Shading from overhanging vegetation inhibits in-grip vegetation growth.
- Revegetation, especially by sedges and S*phagnum*, is more likely to occur on shallower slopes.
- The vegetated grip reaches had a lower pH, lower conductivity, lower DOC concentration and water colour, higher ammonia, lower nitrite, higher Cu, K and Zn and lower Al and Fe concentrations than unvegetated grip reaches.
- Shallower slopes are associated with higher in-grip vegetation cover of peat-generating types, higher solute content (electrical conductivity), lower pH, higher DOC concentration, and higher water colours than steeper slopes.
- Burning notably influences grip water geochemistry.
- Sedge cover, including common cotton grass, and *Sphagnum* cover are greater on the down-slope side of blocked grips while heather is more dominant on the up-slope side.
- *Sphagnum* species were typically associated with low concentrations of aluminium and ammonia.

Consequently the following actions can be taken to improve vegetation colonisation after blocking:

- Ensure pools created by grip blocking are shallow enough to allow sufficient light penetration.
- Trim overhanging vegetation when blocking grips.

  Ensure water ponds in the grips to wet up the downslope side and promote the growth of peat generating species. It should be noted that this practice may be at odds with objectives for revegetation within the grip itself if the pools are too deep for colonisation. Therefore some thought is needed as to whether grip recolonisation should be maximised as opposed to downslope revegetation and this is a matter of how aspects of revegetation are prioritised within restoration projects.

1.0 Introduction

Grip-blocking is a widespread practice used to restore drained peatlands throughout the UK. However, there is very limited research into the hydrological and ecological response to blocking. One of the primary aims of blocking is to increase or re-start peat accumulation through encouraging the growth of peat generating species (primarily *Sphagnum* and common cotton grass).

Within the North Pennines Area of Outstanding Natural Beauty (NP AONB) several areas have been subject to grip-blocking and many further areas have been selected by Natural England for grip-blocking in the near future. Subsequent to blocking some grips are colonised by *Sphagnum* and cotton grass while others remain unvegetated many years after blocking has taken place. *Sphagnum* and cotton grass are key indicators of healthy, active and accumulating peatlands. Therefore, examination of vegetation response to grip-blocking is essential to ensure all future blocking encourages the rapid colonisation and growth of peat-generating species. In addition to peat-generation, vegetation is also important in terms of insects and animals (including grouse and sheep), water quality and erosion.

2.0 Aims and objectives

This project is a small-scale scoping study which aims to provisionally identify some factors controlling vegetation response to grip-blocking. This is the first study which specifically examines, and attempts to explain, factors controlling vegetation response to blocking.

The objectives of the project are:

1. Assess the characteristics of paired grips at Allenheads (Figure 1), and their catchments.
2. Establish what caused the difference in vegetation response in the grips examined in objective 1.
3. Assess the characteristics along the length of five additional grips with different slopes, aspects and vegetation types at Allenheads.
4. Establish what caused the variation in vegetation response along the length of the five grips examined in objective 3.
5. Identify actions which can be undertaken to promote the growth of peat generating species (based on objectives 2 and 4).

3.0 Study Site

Allenheads has some of the oldest grip-blocking and some of the most extensive areas where grip-blocking has taken place in the NP AONB. Field visits to Allenheads, as part of a broader scale survey of grip-blocked sites, identified different vegetation responses to apparently similar blocking. Two examples of this are:

(1) Two parallel grips, with similar slopes, catchment areas, vegetation and peat depths, one of which is full of *Sphagnum*, the other which contains no *Sphagnum* (Figure 1).

(2) Different vegetation responses to blocking along the same grip (evident throughout the site and at other sites throughout the UK).

Consequently, Allenheads was selected to undertake this piece of research.

Figure 1. A – grip with no *Sphagnum* (NY 87471 48679), B & C – grip with *Sphagnum* (NY 87474 48665).

4.0 Methods

4.1 Field survey

Seven grips were surveyed in detail. There were two grips surveyed as part of the paired test outlined by Objective 1 which were on the same slope with similar surrounding conditions. Five further grips were surveyed to fulfil Objectives 3 & 4 and were different in terms of their size, dominant vegetation and extent of burning. There were three sampling locations in each of the paired grips and six sampling locations (3 vegetated and 3 unvegetated) in each of the additional 5 grips.

Grip morphology was measured by taking cross-sectional measurements at each sampling point and slope measurements along the grip. Vegetation bordering grips and within grips was assessed. The percentage cover of each vegetation type in the grip was noted along the length of the grip and at the sample locations the absence or presence of vegetation in the grip was recorded. The bank side data was determined on the upslope and downslope sides as a percentage cover within a 2 m by 0.5 m rectangle centred on the water sampling point. Water samples were taken from the grips by hand and analysed in the laboratory. However, at each sampling location conductivity and pH were measured in situ. The possible impact of any other land management, for example burning, was noted for each sampling location.

4.2 Laboratory analysis

The samples collected in the field were analysed for nutrients (nitrate, nitrite, ammonia (all reported as N content), and phosphate) using an auto-analyser; metals (aluminium (Al), boron (B), barium (Ba), bismuth (Bi), calcium (Ca), copper (Cu), iron (Fe), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), sodium (Na), silicon (Si), strontium (Sr), zinc (Zn)) using an ICP-MS; DOC using a TOC analyser; and absorbance at 254 nm, 400 nm 450 nm, and 650 nm using a UV-VIS spectrometer.

5.0 Results and interpretation

This section is split into two discrete parts which detail (1) the outcomes from the paired grips (Objectives 1 and 2) and (2) outcomes from the five additional grips. Each of these are divided into further sub-sections based on morphology and geochemistry.

5.1 Paired grips

5.1.1 Observations and morphology

Field observations indicated that the paired grips are of similar size, orientation, aspect and slope. There is no obvious distinction between the two grips except that one is vegetated with *Sphagnum* and one has no *Sphagnum* present. Water in both grips was stagnant and both were full to the surface. Grip cross-sections show that the vegetated grip is approximately 10 cm narrower than the unvegetated grip and is also generally shallower (Figure 2). It is not possible to conclusively discern if the vegetated grip has a smaller cross-sectional area as a result of vegetation growth or because the small cross-section promoted the vegetation growth. However, light penetration, which is limited by water colour and depth, is a restricting factor on vegetation growth (Middelboe & Markager, 2003). In addition, the authors and Russell (pers comm.) have observed that vegetation more commonly grows in shallower peat pools. Furthermore, peat accumulation rates in the Pennine uplands are generally in the order of 1 mm per year (Tallis, 1998) and consequently it is unlikely that sufficient peat accumulation has occurred since the grips were blocked.

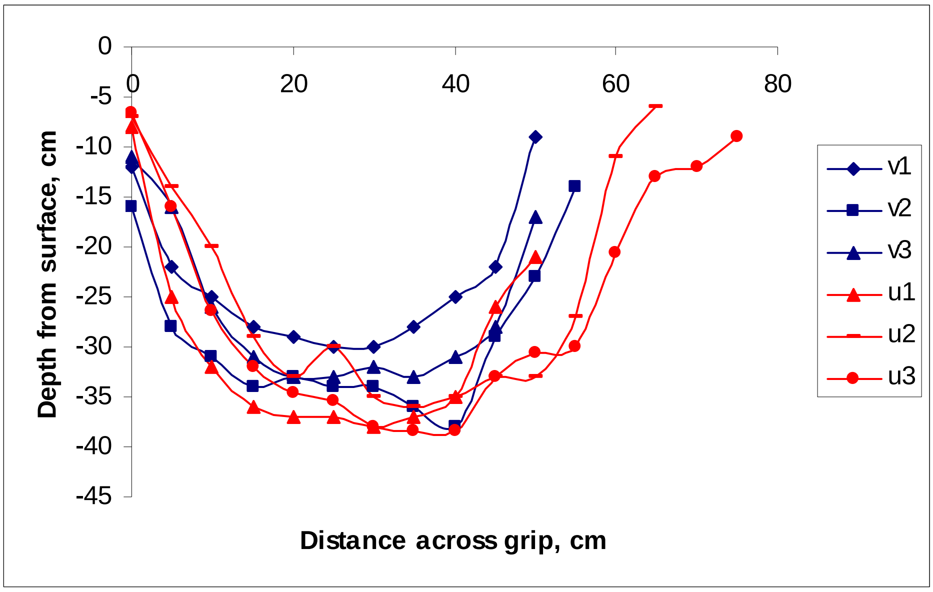

Figure 2. Example cross-sections of the vegetated and unvegetated grip transects. Vegetated grip transects: v1-v3. Unvegetated grip transects: u1-u3.

5.1.2 Geochemistry

In the following section the pH, conductivity, nutrient and metals data are analysed. Potential patterns and reasons behind these patterns are given. However, it must be borne in mind that this is a scoping study within a limited area of Allenheads and that these data are a snapshot during midsummer under baseflow conditions.

The pH of the vegetated grip is significantly lower (more than 90% confident) than that of the unvegetated grip with means of 4.33 and 4.77 respectively. The conductivity of the vegetated grip is also lower than that of the vegetated grip (44.7 and 52.8 microsiemens per centimetre respectively) although the relationship is less significant (84% confident). It is not possible to conclude that the *Sphagnum* colonised the vegetated grip due to more favourable pH and conductivity or whether the *Sphagnum* caused the decrease in these parameters. *Sphagnum* is known to increase the acidity of water (i.e. lower the pH; Kuhry *et al.*, 1993; Clymo, 1987). Furthermore, few species can survive in such low pH conditions and so promoting nutrient poor acidic conditions favours the growth of *Sphagnum*.

The vegetated grip is associated with lower water colour and DOC concentrations (Figure 3). Although the differences are not statistically significant (p = 0.30 to 0.50), with the exception of sampling point v1, all of the parameters for the vegetated grip are lower than those for the unvegetated grip. Consequently reduced light penetration may explain the lack of vegetation in the unvegetated grip, although there may be feedback between vegetation and water colour.

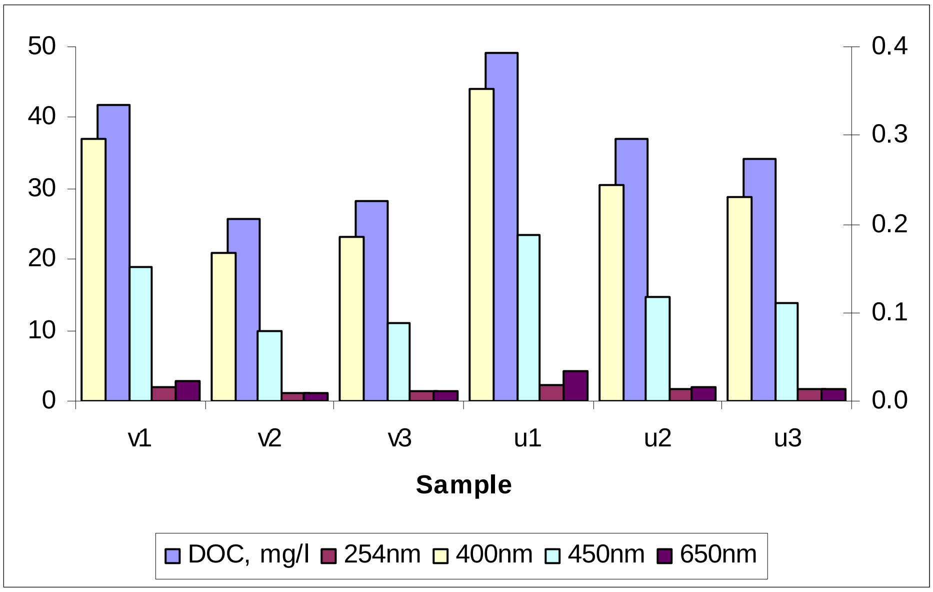

Figure 3. Water colour (on right axis) and DOC concentrations (on left axis) of water sampled from the vegetated (v1-3) and unvegetated (u1-3) grips.

The different measures of water discolouration (absorbance at different wavelengths) are related to organic materials in the water. These absorbance values are often correlated with DOC concentrations in order to identify a difference in DOC type (not all DOC is coloured). A scatter matrix of all these parameters shows linear relationships for these data (Figure 4). The results suggest that there is no difference in the DOC composition between the two grips. This allows us to tentatively suggest that the difference in water colour observed between the two grips is not a result of the presence or absence of *Sphagnum*.

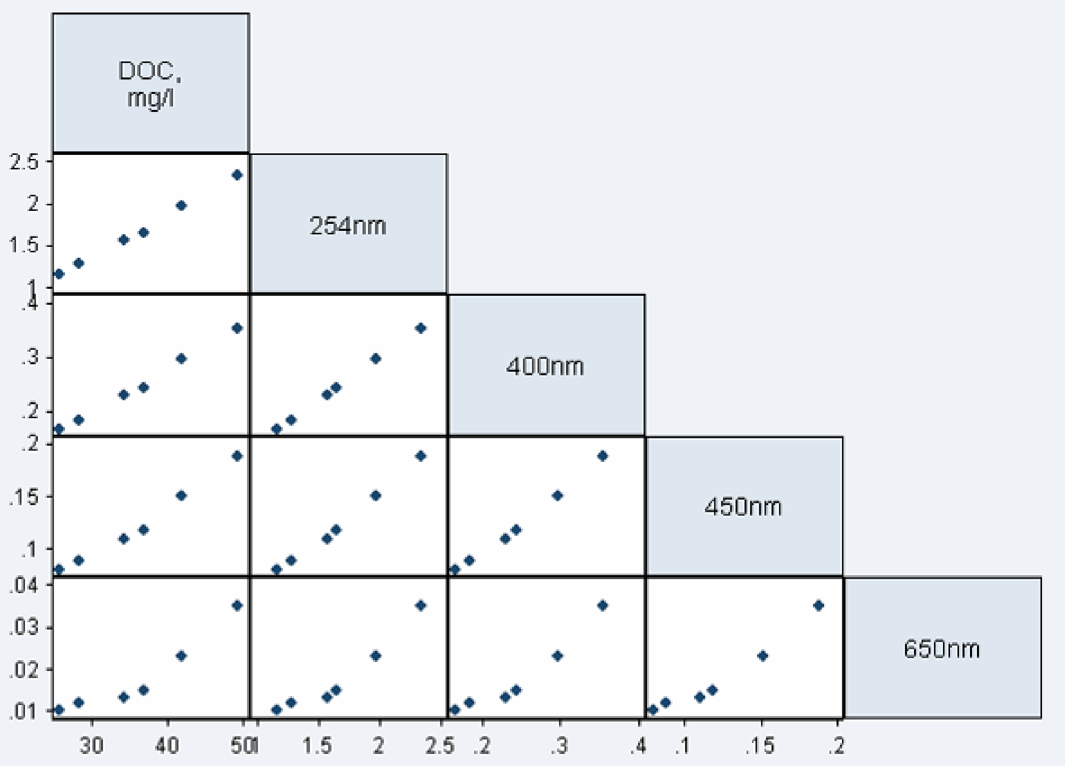

Figure 4. Relationship between DOC and the different colour parameters.

There were no differences in the nitrate or phosphate concentrations between the water sampled from the vegetatated and unvegetated grips. In contrast, ammonia was significantly higher in the vegetated grip (82 % confidence). The confidence level is lower than usually accepted in statistical analyses (normally we want to be more than 90 % confident) but the analysis from v1 is much lower than from v2 and v3 and hence decreases the p value). Nitrite is significantly lower (98 % confidence) in the vegetated grip.

The mean ammonia value was approximately three times higher in the vegetated grip (0.158 mg l^{-1} versus 0.05 mg l^{-1}) than the unvegetated grip while the mean nitrite values were approximately half that of the unvegetated grip (0.006 mg l^{-1} and 0.010 mg l^{-1}). If the nutrient concentrations are solely controlling vegetation growth then altering the nutrient values to those found in the vegetation grip should promote *Sphagnum* colonisation in the unvegetated grip. However, once again it is not possible to ascertain from these data whether the vegetation caused the difference in nutrient concentrations or the difference in nutrient concentrations promoted or restricted vegetation growth.

Examination of the metals data suggest that there were elevated levels of Cu (0.006 compared with 0.003 mg l^{-1}), K (0.632 compared with 0.211 mg l^{-1}) and Zn (0.046 compared with 0.027 mg l^{-1}) in the vegetated grip. Conversely there were elevated concentrations of Al (0.124 compared with 0.093mg l^{-1}), and Fe (1.094 compared with 0.616 mg l^{-1}) in the unvegetated grip. Out of these the only significant differences are for K (86 % confidence) and Zn (85 % confidence). Fe is associated with increased DOC concentration (Kay *et al.*, 1989), so this may explain the heightened DOC levels in the unvegetated grip. Higher levels of Cu and Zn in the environment are often related to mining activity which may be the case at Allenheads. Although metals can inhibit vegetation growth *Sphagnum* tolerates it and is used as a record of atmospheric deposition as it accumulates metals (Kempter & Frenzel, 2007).

5.1.3 Summary

In summary, the vegetated grip is narrower, shallower, and contains water which has a lower pH, lower conductivity, lower DOC concentration and water colour, higher ammonia, lower nitrite, higher Cu, K and Zn and lower Al and Fe. Both grip morphology and water colour variables indicated that light penetration may be the reason why one grip is vegetated and one is not: higher water colours and larger grip morphology are associated with the unvegetated grip. This, and field observation by the authors and Russell (pers. comm.), suggest that vegetation growth is more common in shallower water. Consequently, a way to promote vegetation of grips is to ensure light penetration is maximised by keeping water depth to a minimum. While some of the data suggest that altering water pH, conductivity, nutrient and metal concentration may provide conditions which promote vegetation growth the data is too limited and a full experimental manipulation under both field and laboratory conditions of all aspects of such intervention would have to be undertaken. However, this pilot work has pointed in the direction of some useful future research.

5.2 Five individual grips

5.2.1 Observations and morphology

All five of the individual grips examined were blocked using peat turves using the same blocking style. The within-grip vegetation along the five grips was broadly similar: they all had a mix of common cotton grass, *Sphagnum* and bare zones, with bare zones dominating for all the grips (Figure 5). Grip 4 differed as it had some burnt heather in it (shown as 'other' on Figure 5).

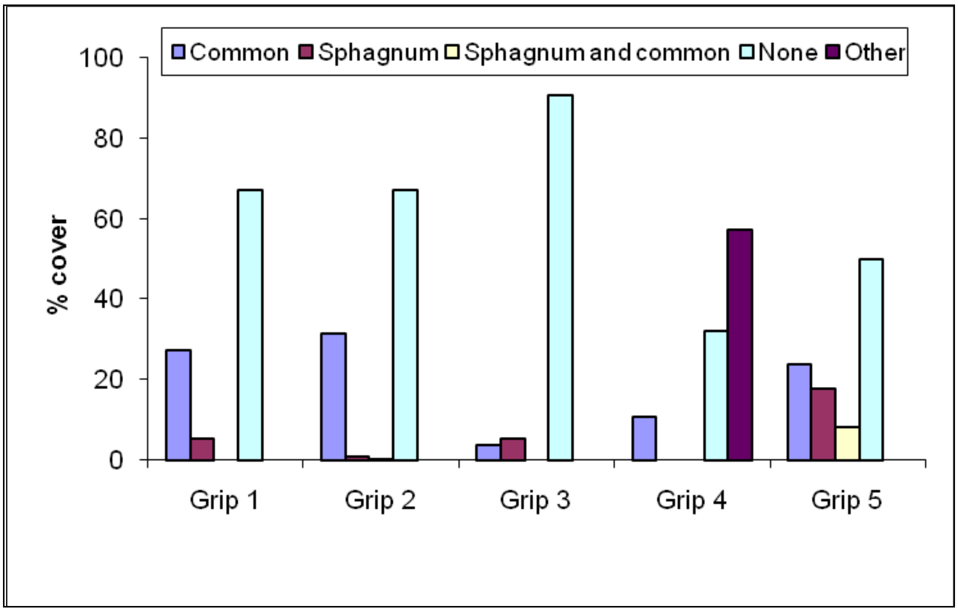

Figure 5. Percentage cover of common cotton grass, sphagnum, mix of sphagnum and common cotton grass, bare and other vegetation along the length of each of the five individual grips surveyed.

There were some slight differences in the grip water pH between the grips (Figure 6). In contrast there is a large difference in the conductivity of the grip water between grips with grip 4 having a significantly higher conductivity (98% confidence or greater) (Figure 7). Grips 1 and 5 are on slightly shallower slopes than grips 2, 3 and 4 (Figure 8).

There was much variation in the water content along the lengths of the grips but broadly grips 1, 2, and 5 contained notable amounts of water while grips 3 and 4 had limited water stored in them. These were also the grips which were on the higher slopes (Figure 8) and had the higher conductivities (Figure 7) and lower pHs (Figure 6). Consequently it can be hypothesised that the higher conductivities are a result of evapoconcentration (Anderson & Stedmon, 2007) or more differences in water flow pathways between grips with different water table depths. The higher conductivities in grip 4 may also be due to the recent burning.

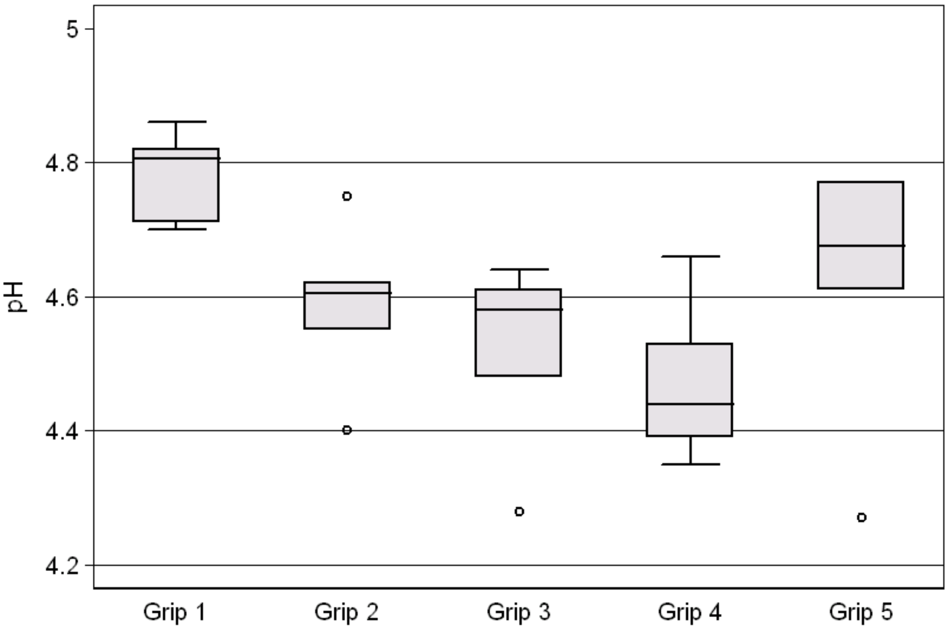

Figure 6. Box graphs showing the pH of water sampled from each of the five individual grips.

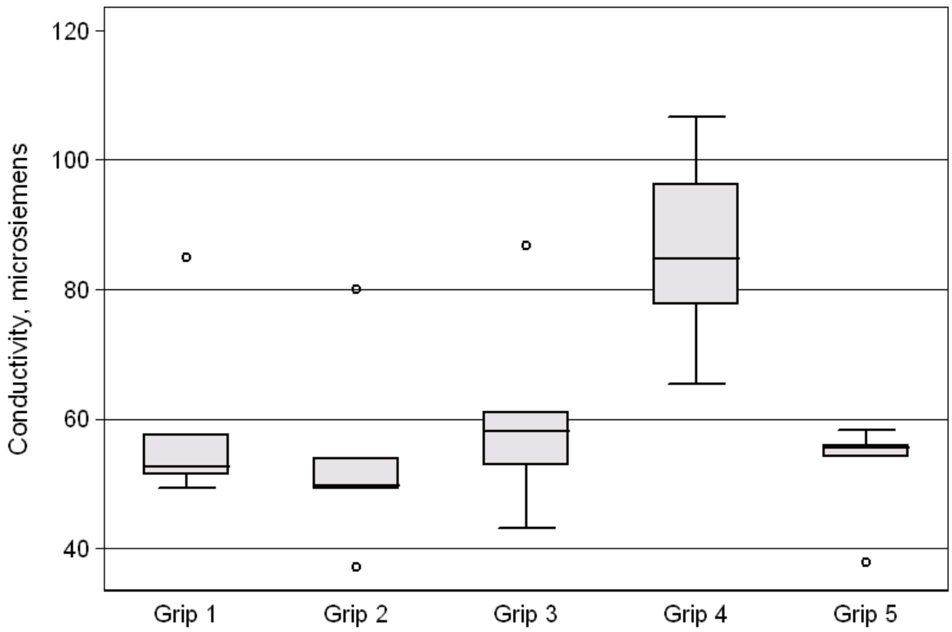

Figure 7. Box graphs showing the conductivity, in microsiemens, of water sampled from each of the five individual grips.

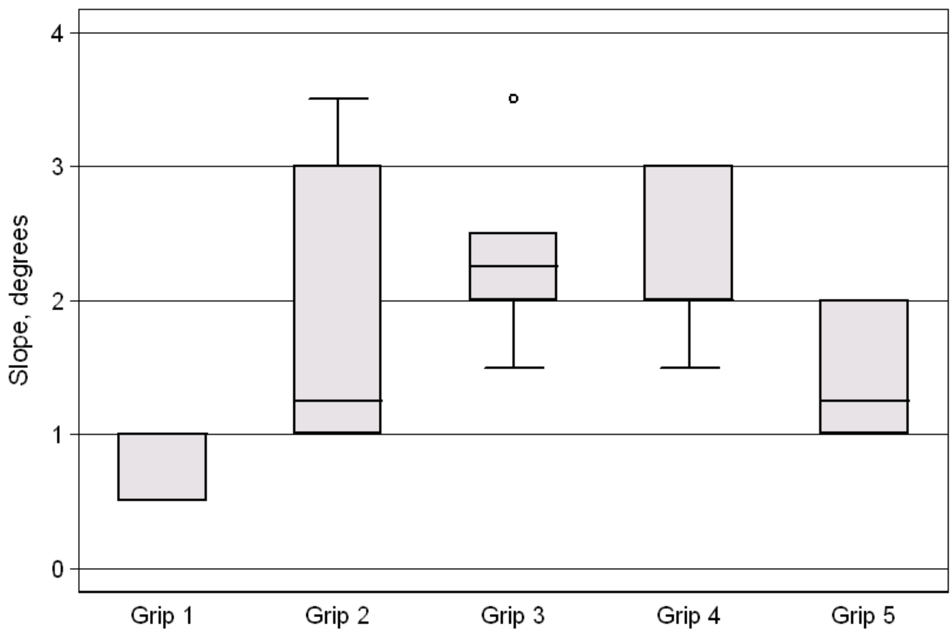

Figure 8. Box graphs showing the slope of each of the sample locations on the five individual grips.

Grip depth was between 46 and 100 cm and the mean grip depth is between 17 and 31 cm (Figure 9). There were no significant differences between the grip widths and depths.

Given the limited number of samples taken from each grip and the overlap between the grip characteristics, with the exception of grip 4, the rest of this section amalgamates the data from the five individual grips in order to identify trends.

There is a positive relationship between grip width and slope which is expected given higher stream power at higher slopes and therefore more erosion (Figure 10). Deeper grips on steeper slopes, as a result of erosion, would also be expected but we found no such relationship. This can be explained by (1) erosion of the grip floors down to the substrate where further deepening would be slower than erosion through peat or (2) material falling into the grip as a result of undercutting.

There is a relationship, although based on limited sample numbers, between slope and within-grip vegetation type (Figure 11). This shows that the peat generating species, *Sphagnum* and common cotton grass, are associated with more gentle slopes. This may be a result of reduced water velocities in grips with lower slopes and higher water tables.

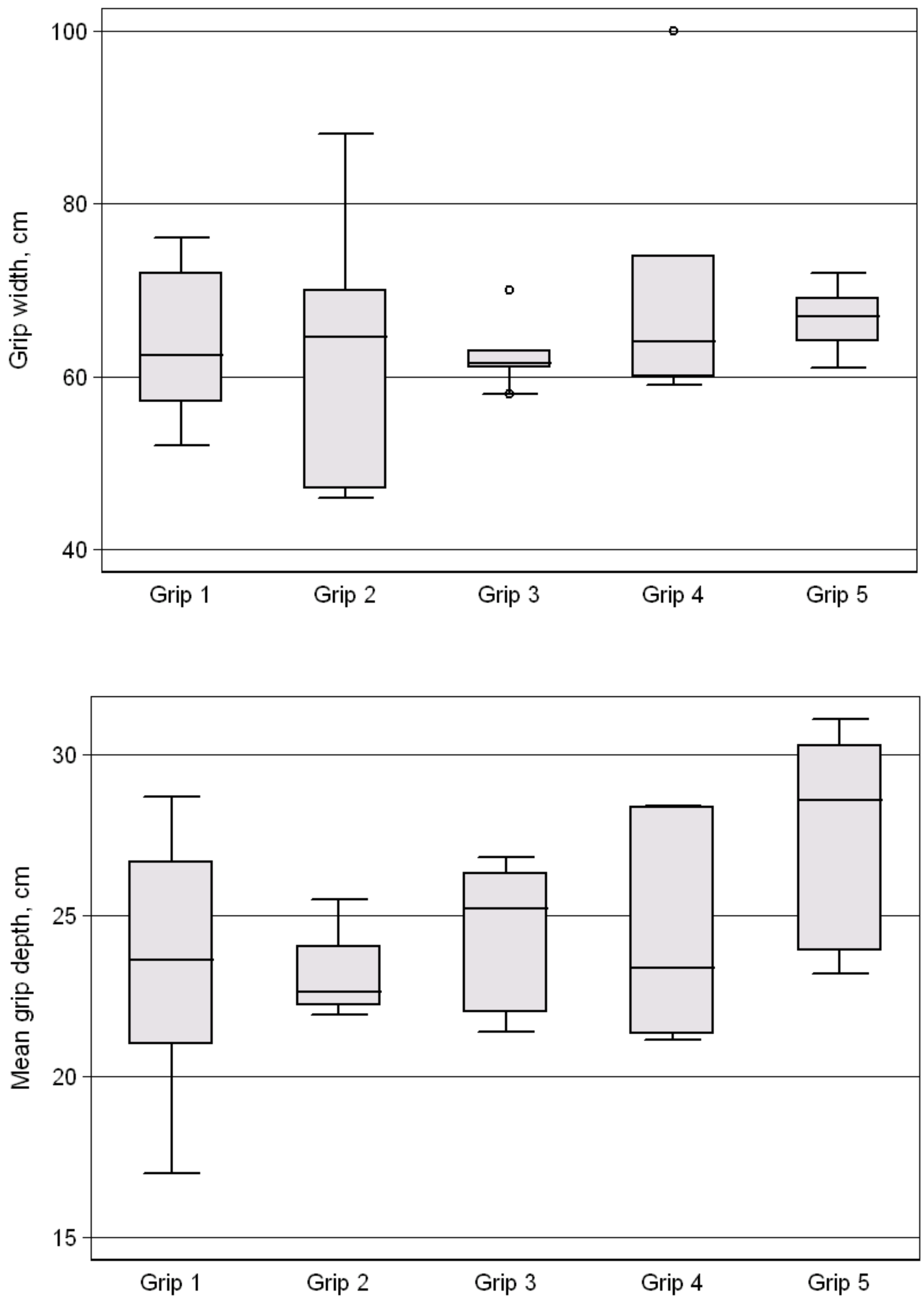

Figure 9. Width and mean depths for each of the five individual grips.

At Allenheads, as evident at other sites surveyed by the authors, it was apparent that blocked grips with overhanging heather generally had less vegetation within them than those without and this can be assumed to be due to decreased light penetration. Consequently, it is suggested that if vegetation growth in grips is desired, any overhanging vegetation, particularly heather, should be trimmed.

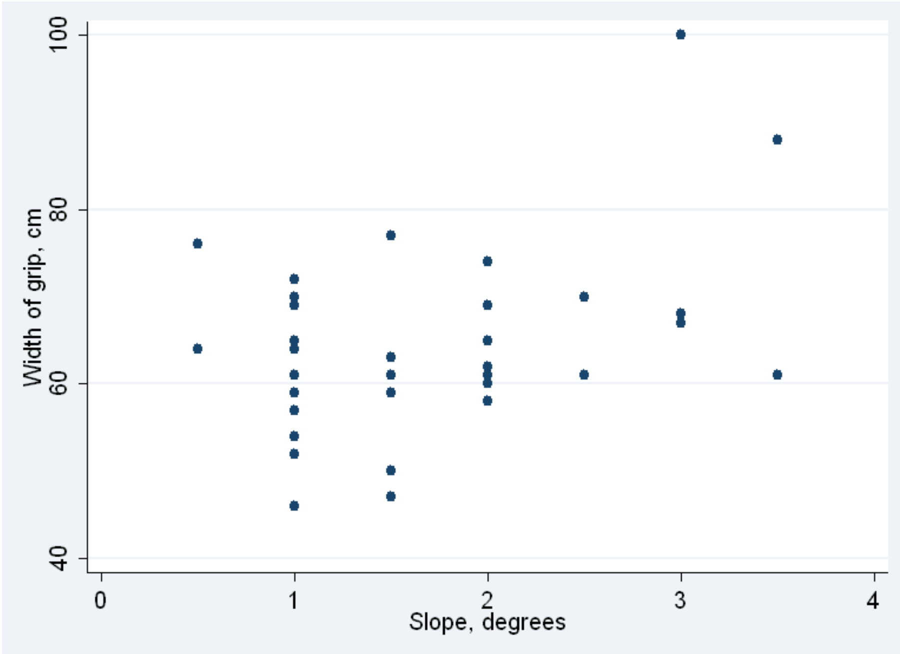

Figure 10. Relationship between grip width and slope degrees.

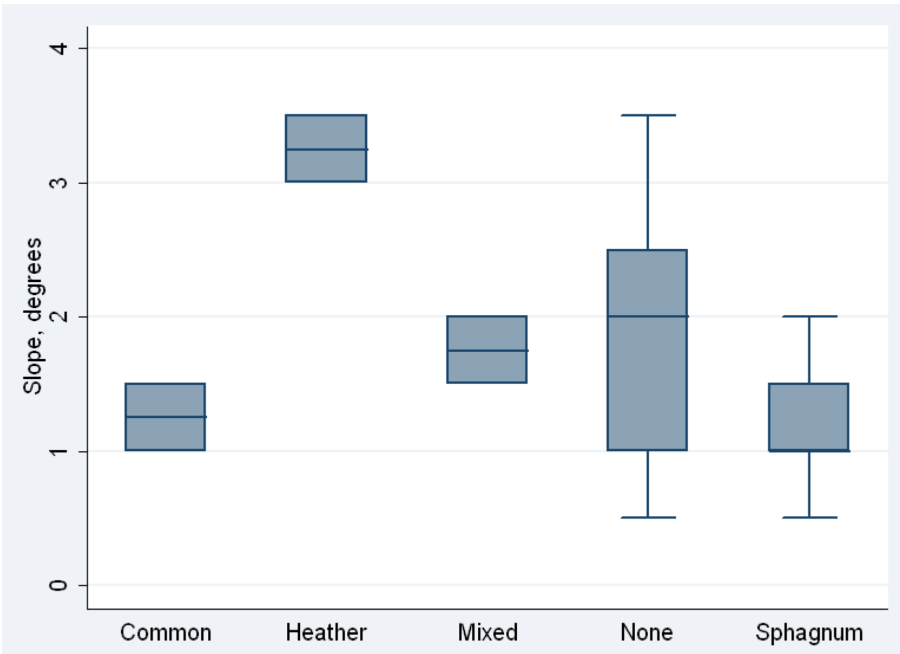

Figure 11. Relationship between in-grip vegetation type and slope. Limited numbers for some vegetation types (common = 4, heather = 2, mixed = 2, none = 19 and Sp*hagnum* = 9).

5.2.2 Geochemistry

There is a positive relationship between slope and grip water conductivity (Figure 12), especially when grip 4, which was recently subject to prescribed burning, is removed from the graph. A slight slope control is also evident for pH: as slope increases pH decreases (Figure 13).

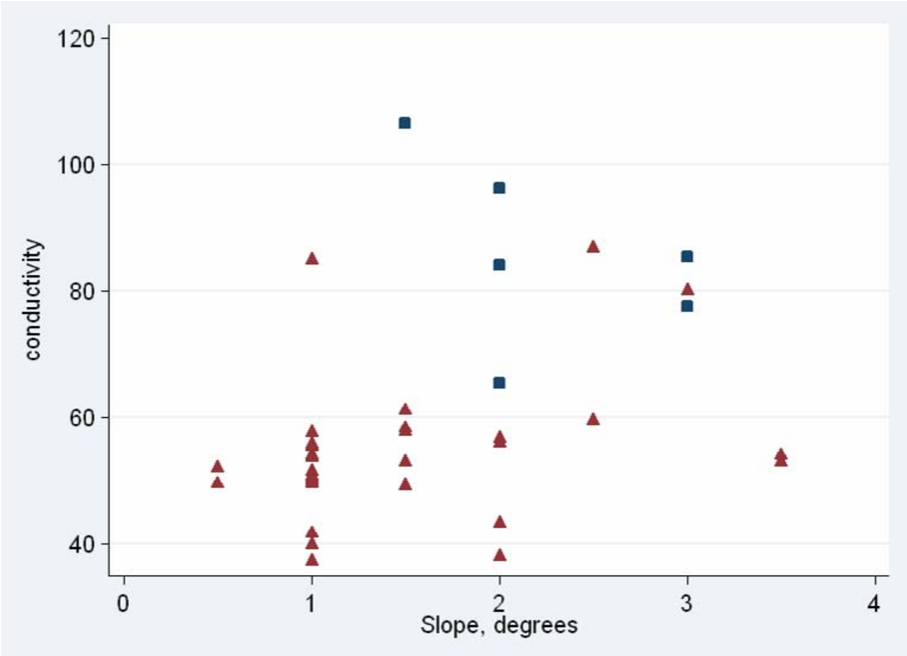

Figure 12. Relationship between grip water conductivity in microsiems and grip slope. Grip 4 data points are highlighted as blue squares.

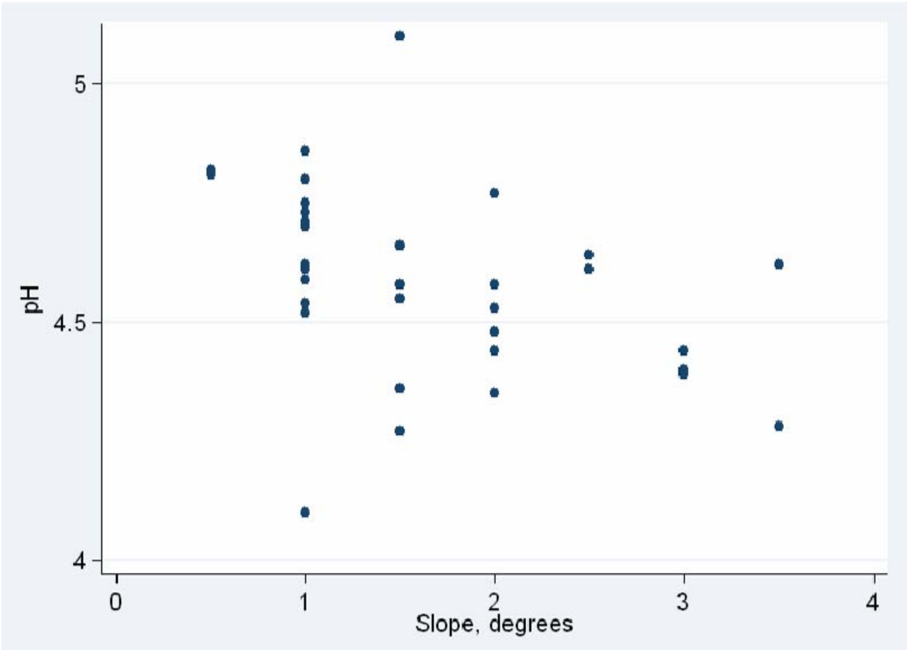

Figure 13. Relationship between grip water pH and grip slope.

As with conductivity, there is a positive relationship between DOC concentration and slope for all data, except grip 4 which was recently burnt (Figure 14). The same pattern is also reflected in the water colour data at all absorbances measured (although only absorbance at 254 nm is shown in Figure 14 for simplicity).

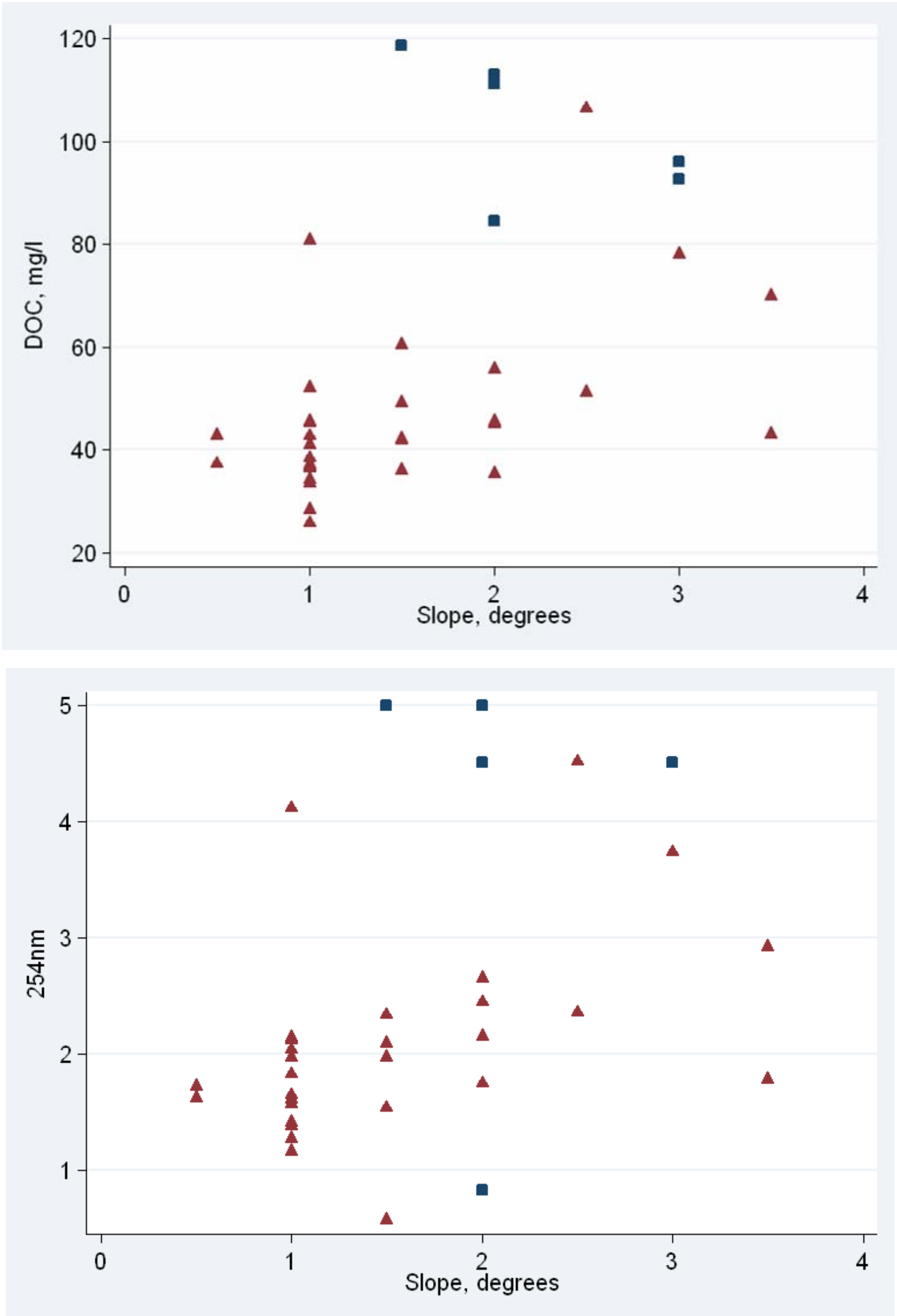

Figure 14. Relationship between (a) DOC concentration and (b) absorbance at 254 nm and grip slope. Blue squares are for grip 4 (burnt)

There is a positive linear trend between conductivity and DOC concentration (Figure 15) but there is no clear relationship between pH and DOC concentration (Figure 16), although other authors note a positive trend (Reeves *et al.*, 1996).

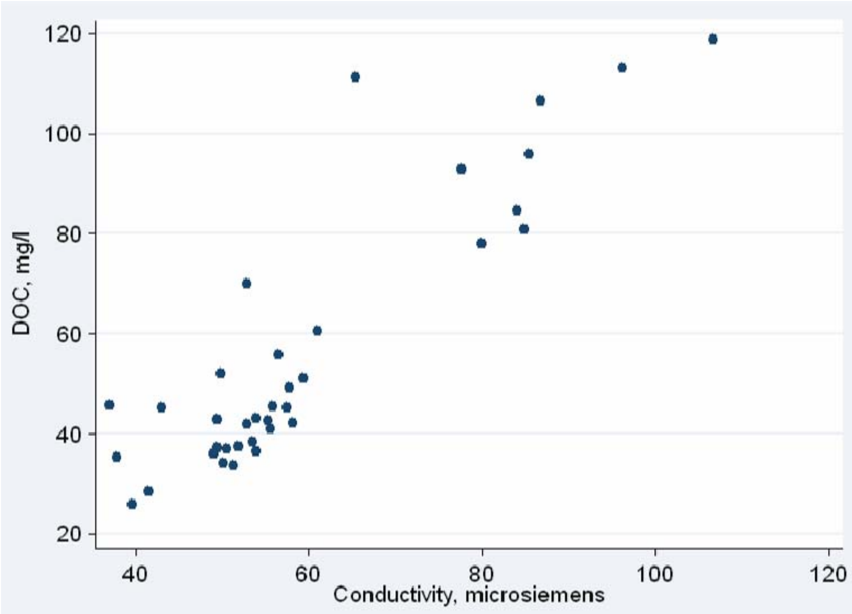

Figure 15. Relationship between conductivity and DOC.

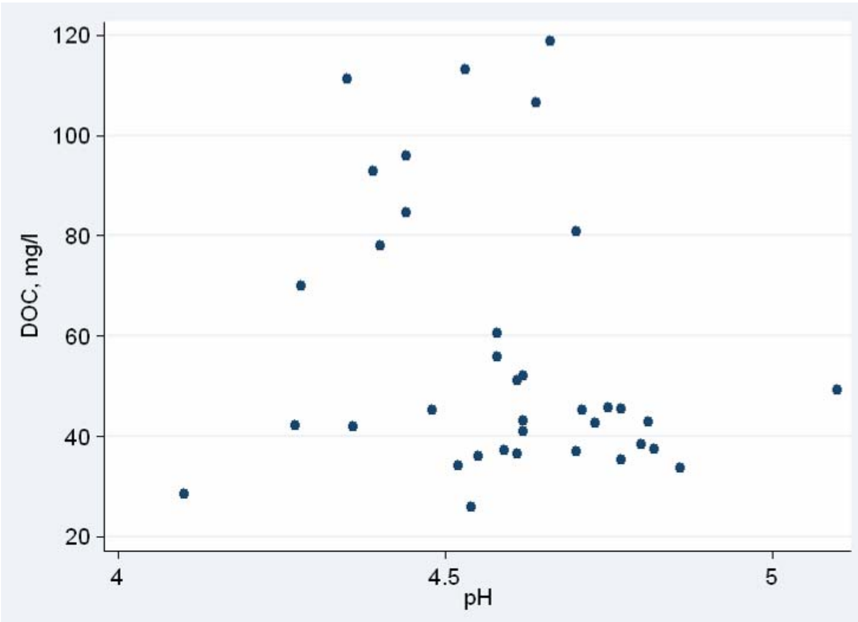

Figure 16. Relationship between pH and DOC.

The relationships between DOC and the colour parameters are more variable than for the vegetated and unvegetated grip (compare Figures 17 and 4). This suggests that there is some variability in the DOC composition between the samples. However, none of the variables measured explained this variability.

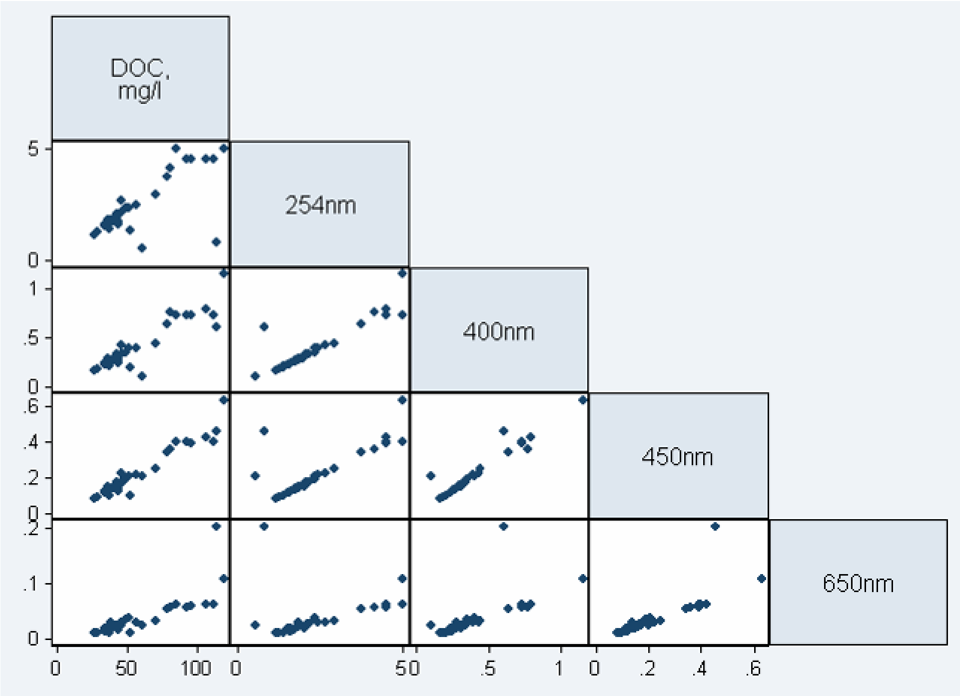

Figure 17. Relationship between DOC concentration and the colour parameters.

The relationships between bank side vegetation and the geochemical variables were investigated. Given the degree of variability expected in such environmental data several approaches were used including (i) categorising the geochemical variables as high or low as defined by the mean and then comparing with the bank side vegetation data and (ii) establishing the dominant bank side vegetation and then summarising the geochemical data by these groups. However, no patterns could be identified. Given the high number of zero values in the bank vegetation data it was not possible to identify any correlations between the cover of individual species up-slope or down-slope of the grips nor any of the chemical or environmental data. However, scatter plots indicate that *Sphagnum* species were not present in the bank vegetation at the highest concentrations of nitrate, ammonia and phosphate (concentrations greater than 0.300, 0.022 and 0.015mg l^{-1} respectively). The small number of samples at higher nutrient concentrations means that for ammonia and phosphate this relationship is not clear but for nitrate this trend was very clear (Figure 18). This is not surprising as *Sphagnum* is known to survive in (and promote) nutrient poor conditions (van Breemen, 1995).

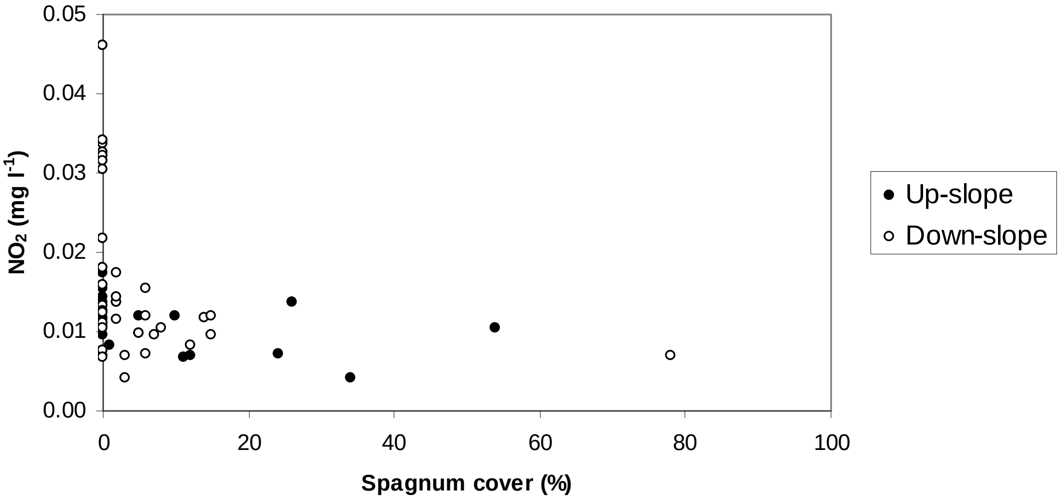

Figure 18. Cover of *Sphagnum* species up- and down-slope of grips against grip water nitrate concentration. Note that some of the zero *Sphagnum* cover values for up-slope are obscured by down-slope values that are the same.

Bank side vegetation data was collected from the up and down slope bank edges. Theory and data from other sites suggests that the down slope bank should have a higher water table if the grip has been blocked and water has ponded in the grip. In order to investigate if the vegetation reflects these patterns data were analysed by dividing the data set between up and downslope side and calculating the mean percentage cover of each vegetation type. Given the nature of the data there is much overlap. However, if the median is examined it is evident that there was (1) a larger percentage of heather coverage on the up slope side; (2) a larger percentage of grasses on the down slope side; and (3) a larger percentage of common cotton grass on the down slope side (Figure 19). While there are some other differences it is difficult to state these with confidence. It is interesting to note that there is not a large difference in *Sphagnum* percentage cover between up and downslope sides of the blocked grips, although the median percentage is slightly higher on the down slope side. However, percentage cover data is dependent on the prevalence of all types of vegetation. A sample of *Sphagnum* was taken from each patch and its location recorded (i.e. up slope, down slope, within grips). A total of 53 samples were taken and 14 of these were from within grips, 14 from the up slope side and 25 from the down slope side. This in itself suggests that there is more *Sphagnum* on the down slope side of grips, which is expected as the water table depth is higher downslope of blocked grips (note the opposite is the case for unblocked grips). The more common species found did not show a marked preference for either up slope or down slope of the blocked grip and there was insufficient data to establish this for every *Sphagnum* species found.

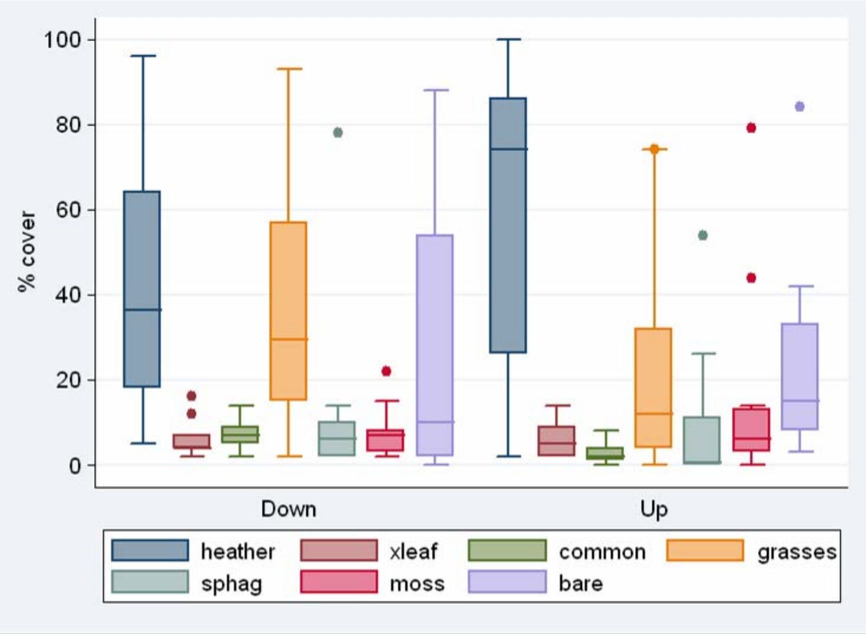

Figure 19. Mean percentage cover of the different vegetation types on the up and down slope sides of grips 1-5.

Analysing the geochemical data and the up slope vegetation community as a whole using canonical correspondence analysis showed that there was a significant correlation (forward selection with Monte Carlo-permutation test) between plant community composition and concentrations of aluminium, ammonia, pH and cadmium in the grip. Canonical correspondence analysis (CCA) is a multivariate ordination technique for direct gradient analysis. Species composition is directly related to measured environmental variables (Palmer, 1993). It assumes species have unimodal distributions along environmental gradients. The resultant ordination diagram conveys large amounts of information regarding the environmental variables and their relations to species. CCA distributes individual species in the ordination diagram in a position that reflects their net tolerance to the environmental factors based on their cover and frequency. CCA was carried out using CANOCO 4.5 (ter Braak and Smilauer, 2002).

Sphagnum species were typically associated with low concentrations of aluminium and ammonia. Bare peat was typically associated with high aluminium, ammonia and cadmium as well as low pH values (Figure 20). It is likely that these relationships represent a two way interaction between the grip and the bank vegetation as bare peat will increase erosion and reduce grip water quality but these conditions are also the least hospitable for typical grip vegetation.

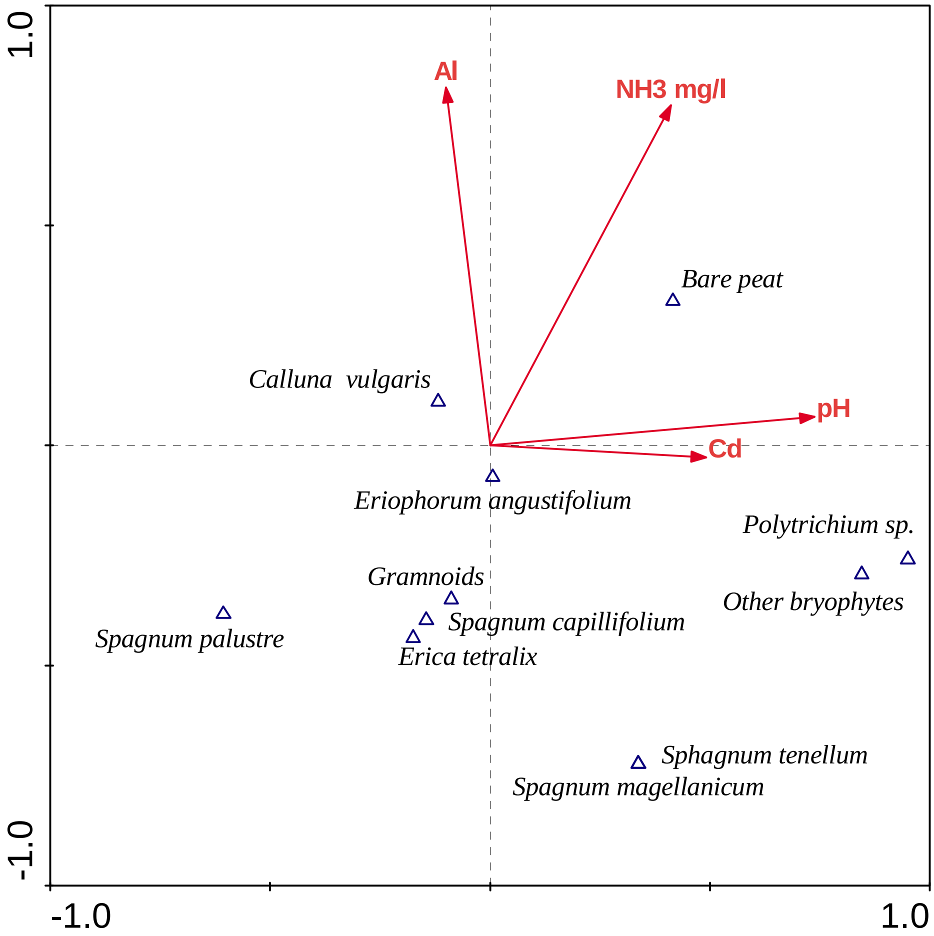

Figure 20. Canonical correspondence analysis ordination diagram (axes 1 and 2) for up-slope vegetation and significant environmental divers.

Repeating the analysis for down-slope vegetation revealed that the only significant environmental variable was potassium which did not have a strong effect on the *Sphagnum* species (Figure 21).

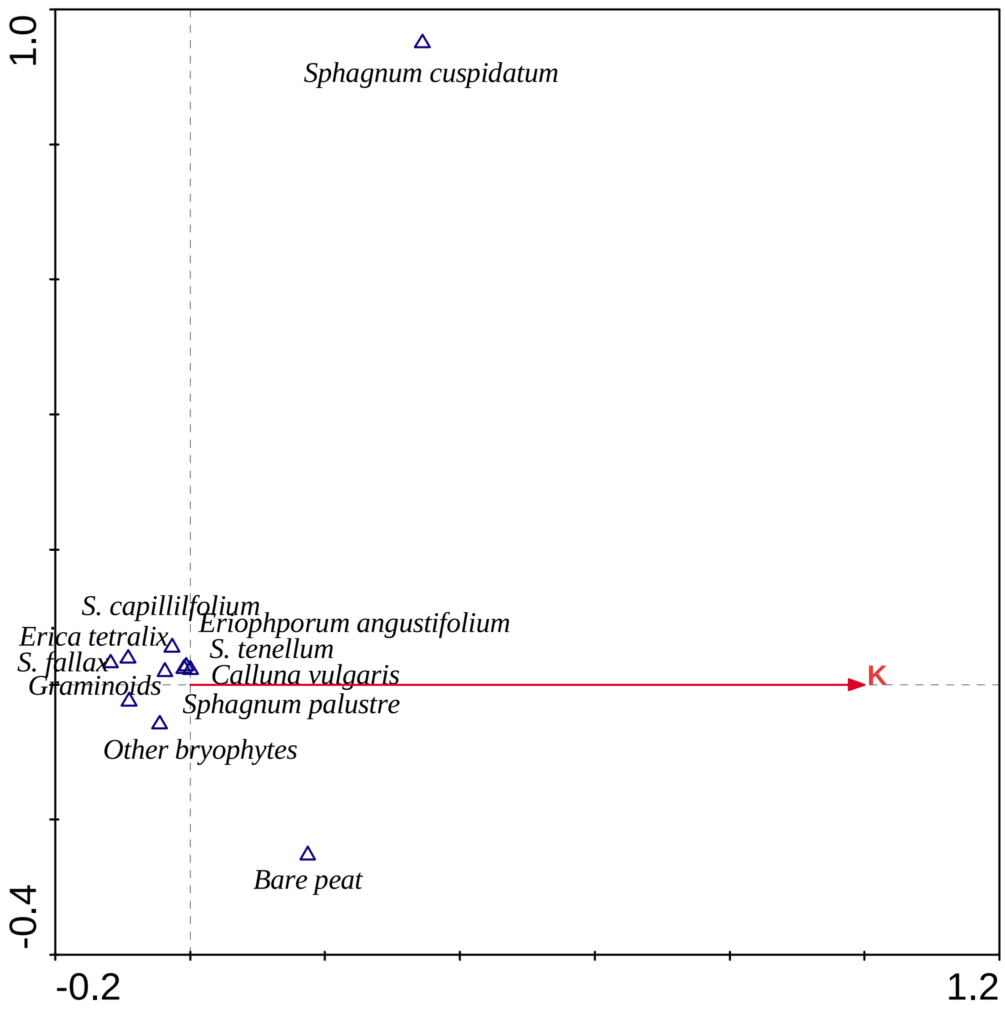

Figure 21. Canonical correspondence analysis ordination diagram (axes 1 and 2) for down-slope vegetation and significant environmental divers.

Examination of the paired grip data indicated some trends regarding within grip vegetation type. However, these were based on three data points from two grips. In order to establish if these were generic results the data collected from the other five grips were analysed in a similar way. Given the desire to promote peat forming species the geochemical characteristics of the water samples from each of the 30 locations which had *Sphagnum* or common cotton grass growing in the grip were compared with those where there was no vegetation. The outcomes were broadly similar:

(1) DOC concentration was significantly (87% confidence) higher (60.0 compared with 46.0 mg l^{-1}) in grips which had no vegetation compared with those with *Sphagnum* and/or common cotton grass.

(2) Conductivity was significantly (84% confidence) higher (61.4 compared with 53.6 microsiemens per centimetre) in grips which had no vegetation compared with those with *Sphagnum* and/or common cotton grass.

(3) While there was no significant difference in pH when comparing grips with *Sphagnum* and/or common cotton grass with those with no vegetation there was a significant difference (89% confidence) if just those grips with *Sphagnum* were compared with those with no vegetation. The pH was significantly higher in grips with *Sphagnum* (4.72 compared with 4.60).

(4) Al concentration was significantly (89% confidence) lower (0.115 compared with 0.168 mg l^{-1}) in grips with *Sphagnum* and/or common cotton grass than those with no vegetation.

(5) Fe concentration was significantly (93% confidence) lower (0.663 compared with 1.050 mg l^{-1}) in grips which with *Sphagnum* and/or common cotton grass than those with no vegetation.

However, the nutrient data are contrasting:
(1) Ammonia was significantly (97% confident) lower (0.071 compared with 0.203 mg l^{-1}) in those grips with *Sphagnum.*

(2) Nitrite was not significantly different.

(3) Nitrate was significantly (92% confident) higher (0.033 compared with 0.016 mg l^{-1}) in grips which contained *Sphagnum* compared with those with no vegetation.

(4) Phosphate was significantly (98% confident) lower (0.017 compared with 0.020 mg l-^{1}) in grips which contained *Sphagnum* compared with those with no vegetation.

Furthermore, there were significant differences in the Ti and Pb (96% and 92% confidence respectively) concentrations in grips with *Sphagnum* and those with no vegetation. Ti was higher in grips with no vegetation (0.006 compared with 0.004 mg l^{-1}) as was Pb (0.030 compared with 0.022 mg l^{-1})

6.0 Main findings and recommendations

This preliminary scoping study has led to several outcomes, some of which require further investigation while others can be implemented. Each of the objectives are summarised in turn and recommendations given.

Objective 1 - Assess the characteristics of the paired grips at Allenheads (Figure 1), and their catchments.

The vegetated grip was characterised as being generally narrower and shallower than the unvegetated grip. The water sampled from the vegetated grip had a lower pH, lower conductivity, lower DOC concentration and water colour, higher ammonia, lower nitrite, higher Cu, K and Zn and lower Al and Fe concentrations.

Objective 2 - Establish what caused the difference in vegetation response of the grips examined in objective

Both grip morphology and water colour variables indicated that light penetration may be the reason why one grip has vegetated and that other has not: higher water colours and larger grip morphology are associated with the unvegetated grip. The metals and nutrient concentrations may also have a role but it is not possible to conclude if these water quality variables cause the differences in vegetation response or are a result of it. Furthermore, the geochemical observations from the paired grips were not supported by observations from the five additional grips or existing research.

Objective 3 - Assess the characteristics along the length of five additional grips with different slopes, aspects and vegetation types at Allenheads.

The five additional grips were characterised in terms of their slope, morphology, impacts of land management (i.e. burning), and geochemistry. These data showed various correlations:

1. Grips on higher slopes contained less water with higher conducitivity and lower pH.
2. Grip width and slope are positively related.
3. DOC, water colour, pH and conductivity exhibit patterns with slope.
4. Within grip vegetation cover of *Sphagnum* and common cotton grass are associated with lower slopes.

5. Recent burning notably influences geochemistry within the grip.
6. Bank vegetation shows limited pattern with grip geochemistry, although *Sphagnum* was only found on the grip banks where there are lower nutrient concentrations in the grip water.
7. Sedge cover, including common cotton grass, and *Sphagnum* cover are greater on the down-slope side of blocked grips while heather is more dominant on the up-slope side.
8. *Sphagnum* species were typically associated with low concentrations of aluminium and ammonia and bare peat was typically associated with high aluminium, ammonia and cadmium as well as low pH values.
9. Higher DOC, conductivity, higher Al, higher Fe, higher Ti and higher Pb were found in unvegetated grips.
10. Higher ammonia, nitrite, nitrate and phosphate were found in vegetated grips compared to unvegetated grips but concentrations were lower if blocked-grip sections with just *Sphagnum* or common cotton grass are compared to bare grip sections.

Objective 4 - Establish what caused the variation in vegetation response along the length of the five grips examined in objective 3.

Given the scoping nature of this study not all the results are conclusive – it is not possible to ascertain if patterns between geochemistry and vegetation are causal or resultant. However, morphological results are more conclusive. Slope affects geochemistry and vegetation type: more gentle gradient slopes are associated with peat-generating species. Also, there is more *Sphagnum* on the downslope side of blocked grips. These are both likely to be related to a shallower water table depth as a consequence of water seeping out of blocked grip pools and flowing into and over the peat surface downslope. In addition heather, a species known to prefer slightly drier conditions, was more dominant on the upslope side of blocked grips. This is in direct contrast to what would be expected in unblocked grips where the downslope side tends to be significantly drier than the upslope side as the flow of water from upslope is cut off by the grip itself resulting in dry conditions downslope of the grip (e.g. see maps in Holden *et al*., 2006).

Objective 5 - Identify actions which can be undertaken to promote the growth of peat generating species (based on objectives 2 and 4).

This scoping study has indicated several practices which can be undertaken to promote revegetation of grips after blocking. The key outcomes are:

It is recommended that any overhanging vegetation is trimmed to promote within-grip vegetation growth. Observations strongly suggest that overhanging vegetation reduces vegetation colonisation in the grips.

Results of this study, field observations by the authors and Russell (pers. comm.), and existing research suggest that vegetation growth is more common in shallower peat water. Consequently, a way to promote vegetation of grips is to ensure light penetration is maximised by keeping water depth to a minimum.

It is recommended that further research is carried out to determine the maximum depth of grip pools that will provide conditions for sustainable revegetation.

Revegetation, especially by grasses and *Sphagnum* is more likely to occur on shallower slopes.

Given that *Sphagnum* and grasses are more dominant on the wetter downslope side of grips, ensuring that water ponds along the length of the grip will promote their colonisation on the main peat mass. Of course, this may be at odds with objectives for revegetation within the grip itself if the pools are too deep for colonisation.

While some of the data suggest that altering water pH, conductivity, nutrient and metal concentration may provide conditions which promote vegetation growth the data is too limited and a full appraisal of all aspects of such intervention would have to be undertaken. Nevertheless this small-scale pilot study has shown some worthwhile actions that could be carried out and identified some areas for future research over larger scales.

7.0. Final comment

Some thought is needed to determine what the priorities should be for revegetation and monitoring of success. This is because fully ponded grips will lead to enhancement of peat-forming species on the peat mass, but may not lead to revegetation within the grips themselves. If achievement of both is the objective then more work is required on deep grips when blocking them (e.g. perhaps by infilling them slightly) to leave shallower pools whilst still maintaining full ponding to the surface of the main peat mass. If achievement of vegetation change across the peat mass is the main priority then it may not matter if the grips themselves do not fully revegetate, at least over timescales of a decade or two. However, if this is the case then monitoring or evaluation of the success of projects will have to be done carefully as just looking at the grips themselves may not be a good indicator of how well the project has succeeded across the peat mass as a whole.

8.0 References

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