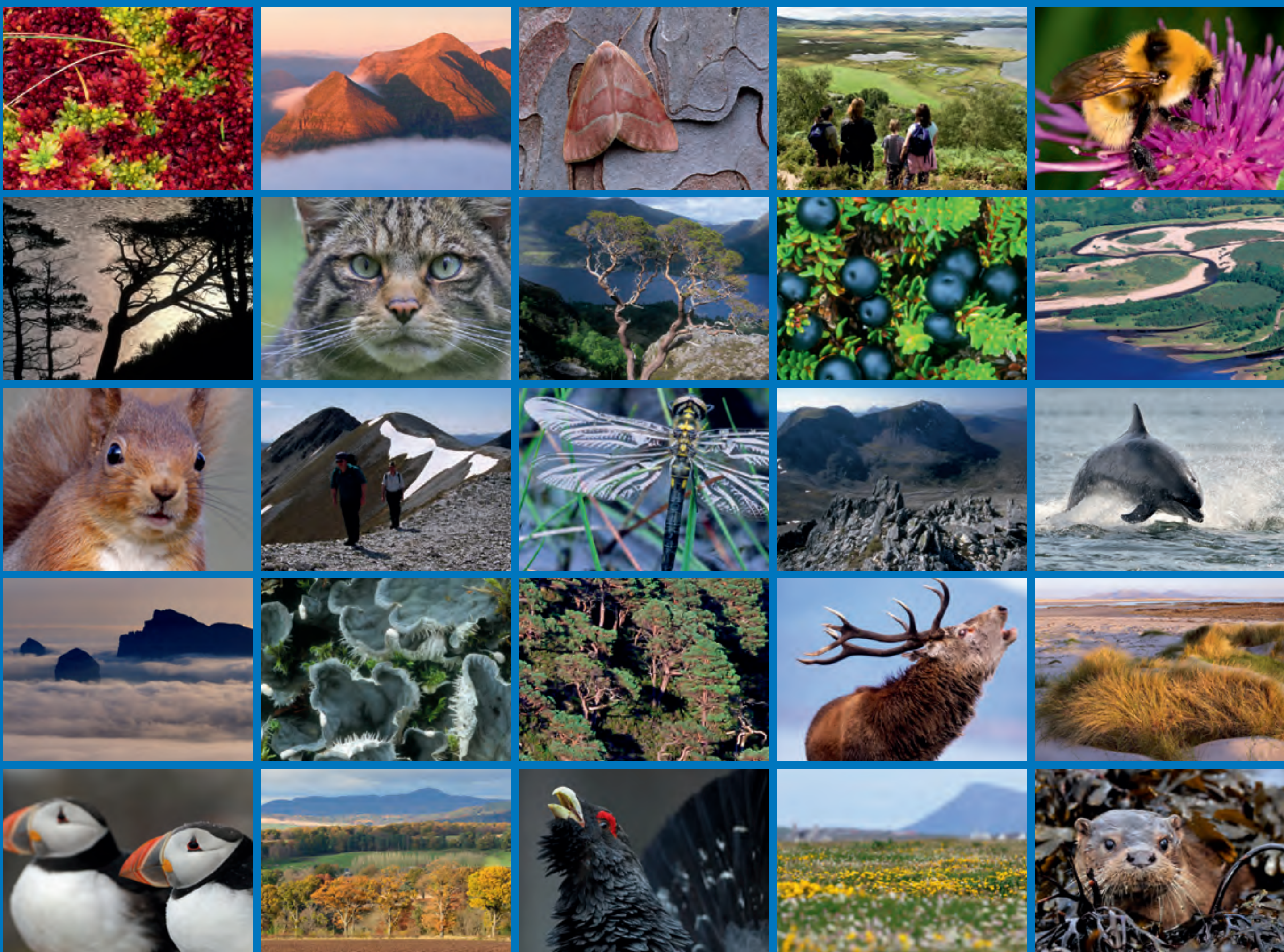
Scottish Natural Heritage
Commissioned Report No. 527

A deer population and habitat-impact assessment of the Monadhliath SAC, Inverness-shire, UK



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COMMISSIONED REPORT

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A deer population and habitat-impact assessment of the Monadhliath SAC, Inverness-shire, UK

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COMMISSIONED REPORT

Summary

A deer population and habitat-impact assessment of the Monadhliath SAC, Inverness-shire, UK

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Background

The Monadhliath is a large and mountainous upland area located in Inverness-shire, UK. The site was designated as a Special Area of Conservation (SAC) in 2003 because of the importance of its blanket bog. Recent herbivore impact studies by Scottish Natural Heritage (SNH) concluded that if there is no change to deer management at higher altitudes the condition of the blanket bog will continue to deteriorate.

This new study measured patterns of deer and sheep occupancy on the site using faecal pellet group counts, and also gathered habitat condition data from the blanket bog. The aim was to investigate the spatial and temporal relationships between deer occupancy levels and habitat condition.

Main findings

- A grid of sampling points (n=217; spacing of 705m between points) was visited. The faecal accumulation rate (FAR) of deer/sheep was quantified. Blanket bog condition data were gathered including: confirming bog extent; measuring peat depth; quantifying the level of erosion and the types of erosion present; confirming the cover of bare peat and the level of colonisation with new plants; assessing the nature and level of impacts on intact bog habitat and eroding land by deer.
- Data gathered shows the site once contained a very large blanket bog complex. It was markedly more extensive at higher altitudes and was most extensive on shallow-angled slopes. Much of the original bog surface has now experienced major erosion and 30-40% of the original peat mass has been lost. Losses increase with altitude.
- Up to 50% of eroded surfaces have recolonised but spontaneous colonisation of bog on deeper peat seems to occur most frequently at low altitudes whereas at higher altitudes the peat surface appears to strip down markedly or completely before being able to recolonise.
- A very considerable proportion of the bog is still eroding actively especially at higher altitudes (20% cover of bare peat) and so losses from the peat mass will continue for the foreseeable future. The intact remnants of the original bog also currently show signs of new surface erosion especially at higher altitudes. These may also contribute to an increased level of erosion and hence to further loss of the original bog surface in the near term.
- Large mammal abundance for the period studied (summer-autumn 2011) was shown to be approx. 2900 deer/sheep (maximum of 10% attributable to sheep) or a density of 27 per km^2 on average. There were marked variations in occupancy across the site. There

was a preference where available for utilising heaths/grasslands rather than bog. The southern part of the site (low altitude) held the highest densities and the north-west the lowest densities.

- A range of impacts typical of an upland site were encountered including: browsing of dwarf shrubs, grazing of grasses, uprooting of mosses and trampling of plants generally. The most notable was the level of *Calluna vulgaris* Heather off-take which is causing cover to contract locally.
- There was a wide range of impacts on the blanket bog specifically, both on eroded and un-eroded sections, including: trampling of bare peat surfaces, over-deepening of bare peat caused by regular traversing of paths by deer, breakage of hagg edges by trampling, puncturing of hagg top vegetation and intact bog vegetation by hooves, rupturing of deer paths on the vegetated bog surface through regular use, grazing of new colonising plants on bare peat and trampling of new colonising plants on bare peat.
- It was clear from the data gathered that many forms of deer impact on intact and eroded bog appear to increase broadly in line with occupancy level.
- The impacts on the *intact* bog at higher altitudes will, if they continue, likely move the site to less favourable condition. The impacts of deer on eroded bog, including on bare peat and on new colonising plants, also increase broadly in line with occupancy but their significance appears in part to depend on the altitude at which they occur. Impacts at the very highest altitudes may be over-ridden by weathering processes which seem to produce more intense effects (i.e. deer impacts on bare peat and colonising plants might not necessarily be 'additive' at the highest altitudes). With decreasing altitude any impacts of deer appear to be of increasingly greater significance.
- It is difficult to be sure of the seriousness of many of the impacts observed at higher altitudes. The uncertainty is partly because we do not at present understand enough about the previous dynamics of the blanket bog and the deer population that was using the site at the time, nor about the likely future dynamics of the blanket bog on the Monadhliath SAC and the way the deer population will use it. However, it is also in part due to a lack of research on high-altitude eroding peatlands such as the Monadhliath, and specifically research on interactions between wild deer impact and blanket bog surface integrity and recolonisation processes after erosion occurs. We make a range of recommendations about the best way to address this uncertainty so that future management decisions are adequately informed.

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- Finally, we thank the Strath Caulaidh staff for the effort required to undertake this study perhaps most notably during the fieldwork which was exceptionally demanding.

NON-TECHNICAL SUMMARY

Note for readers: this section of the report comprises a 7-page non-technical summary of the main report. It is designed for those readers who want more information than is contained within the Executive Summary but do not have the time available to read the main body of the report.

Study background

The Monadhliath is a large and mountainous upland area located above the villages of Newtonmore and Laggan in Inverness-shire, UK (Appendix 1 – Map 1). The land is owned by seven estates (Appendix 1 – Map 2), and is currently managed for deer stalking, grouse shooting and hill sheep grazing.

The Monadhliath range was designated as a Special Area of Conservation (SAC) in 2003 following its notification as a Site of Special Scientific Interest (SSSI) in 1974. SAC status was granted because of the European importance of the blanket bog, an Annex 1 habitat under the European Habitats Directive. The site supports one of the most extensive areas of high-altitude blanket bog in the UK and it is relatively remote from the sea, thus contrasting with the numerous areas of oceanic blanket bog.

Since its designation as a SAC, Scottish Natural Heritage (SNH) has undertaken a range of assessment and monitoring work, in order to understand more about the nature and state of the blanket bog present. Key conclusions of this work are perhaps best encapsulated in the most recent herbivore impacts study of 2009 which concluded that if there is no change to the management of large herbivores on the higher altitude sections of the Monadhliath SAC the prognosis is that the condition of the vegetation on the blanket bog will continue to deteriorate and the extent and depth of peat erosion will increase.

Study aims

The fact that the blanket bog is judged by SNH to be in unfavourable condition led SNH to commission a new study in summer 2010. The purpose of the study was to obtain additional information for SNH and land managers to use in discussions over the site - the study had the following aims:

1. Design and implement a baseline study on the population of red deer utilising the Monadhliath SAC area based on faecal pellet group counts. The study should also involve gathering readily-obtained additional habitat data from the blanket bog on site.
2. Investigate the spatial and temporal relationships between deer population parameters and habitat condition using the data gathered and report the findings.

Methods

A grid of 217 evenly-spaced sampling points was visited (705m intervals; Appendix 1 – Map 2) and a range of assessments undertaken. The assessments included measuring the faecal accumulation rate (FAR) of deer/sheep over the period summer-autumn 2011. Appendix 2 provides some technical background to the pellet group count method. The locations at which deer and sheep were seen during surveys were mapped.

A range of data were also gathered which could be used to describe the blanket bog physically as well as ecologically. This included: confirming bog extent; measuring peat depth; quantifying the level of erosion and the types of erosion present; confirming the cover of bare peat and the level of colonisation with new plants; assessing the nature and level of impacts on intact bog habitat and eroding land by deer.

Key findings

Blanket bog extent & status

On the basis of evidence obtained from site, it is clear that the SAC once contained a very large blanket bog complex - the feature was markedly more extensive at higher altitudes than at lower altitudes, and was more extensive on shallower slopes than on steeper slopes (Appendix 1 – Maps 4 & 5).

Much of the original bog surface has now experienced major erosion – we estimate from models built as part of the study that 30-40% of the original peat mass is no longer present. A notably higher proportion of the original surface has been lost as altitude increases.

A surprising proportion of this land has completely recolonised at all altitudes (up to 50% of eroded surfaces have recolonised), although spontaneous colonisation of bog on deeper peat seems to occur most frequently at low altitudes whereas at higher altitudes the peat surface appears to strip down markedly or completely before being able to recolonise; the early-stage plant assemblages in these eroded but recolonised higher-altitude areas tend to have more minerotrophic influences acting upon them which make them appear drier, although signs of bog recovery are present.

Whilst a large proportion of eroded land has recolonised a very considerable proportion is still eroding actively, notably so at higher altitudes (c. 20% cover of bare peat present at higher altitudes; bare peat cover is a useful proxy for the extent of active erosion). Therefore the site will undoubtedly lose considerably more peat mass from these active areas before this current phase of erosion ends.

The intact remnants of the original bog also currently show signs of new surface erosion being initiated in many places, notably so at higher altitudes. These may also, depending on their response in the near future, contribute to an increased level of erosion and hence to further loss of the original bog surface in the near term.

Deer population assessment

An estimate of large mammal abundance for the period summer-autumn 2011 was obtained, which showed that on average c. 2900 deer/sheep had been present over the period accumulation was measured. We estimated that no more than 10% of the occupancy measured on site related to sheep, based on counts of live sheep and the extent of other signs of sheep (e.g. wool trapped on Heather). The deer occupancy level measured in this study – a minimum of 2600 deer - broadly mirrored the most recent live deer count by SNH in July 2010 of c. 3000 animals, although this data was derived from a single flight over the site and hence any similarity may simply be coincidence.

The occupancy level measured from summer-autumn 2011 equates to a large mammal density of c. 27 per km^2 on average. However, marked variations in the level of occupancy were apparent across the site (Appendix 1 – Map 6). Animals in most parts of the SAC showed a preference for utilising habitat types other than bog (e.g. heaths, grasslands) where they were present locally. The highest densities of large mammals were present on the southern edges of the SAC, and the lowest densities to the north-west

The site was divided up into Utilisation Zones on the basis of the large-scale geographic differences in faecal accumulation rate (FAR) apparent (Appendix 1 – Map 7). The division of data into Utilisation Zones was to facilitate analysis of impact data, the aim of the analysis being to ascertain the extent to which the level of deer impact in each zone was related to its deer occupancy level. Zone 1 had an occupancy level equal to c. 11 animals per km^2, Zone

2 had a level equivalent to c. 24 per km^2 and Zone 3 had a level equivalent to c. 36 per km^2. Densities locally with Zone 3 were markedly higher at over 50 per km^2 in places.

Herbivore impacts & the relationship with occupancy

The range of impacts that would typically be expected on an upland site was encountered, including: browsing of dwarf shrubs, grazing of grasses, uprooting of mosses and trampling of plants generally. Perhaps most notable amongst these was the level of off-take of *Calluna vulgaris* Heather which in many places was high enough to be causing cover to contract.

There was also a wide range of impacts on the blanket bog specifically, both on eroded and un-eroded sections, including: trampling of bare peat surfaces, over-deepening of bare peat caused by regular traversing of paths by deer, breakage of hagg edges by trampling, puncturing of hagg top vegetation and intact bog vegetation by hooves, rupturing of deer paths on the vegetated bog surface through regular use, grazing of new colonising plants on bare peat and trampling of new colonising plants on bare peat. Appendix 4 includes a range of images illustrating the nature of these impacts, as well as a wide range of images showing the nature of the bog on site generally and the range of physical processes which shape it. For interested readers Appendix 5 provides some technical background to the way in which blanket bog forms, and the ways in which it can be damaged.

It was clearly the case from the data gathered that many forms of deer impact on the bog and eroded bog area appear to increase broadly in line with occupancy level, which implies that their frequency of occurrence and their intensity will likely decline if deer occupancy levels decline; the corollary is that they may also increase if occupancy levels in increase.

Interpretation

Whether or not the current impact levels observed have serious consequences depends to an extent on their nature, and on the context in which they arise:

- The impacts on the intact bog at higher altitudes and in some places at lower altitudes will, if they continue, likely move the site to less favourable condition especially when it is considered that superficial micro-erosion is also fairly widespread in these areas and may be a precursor to the onset of further major surface erosion.
- The impacts of deer on eroded bog, including on bare peat and on new colonising plants, increase broadly in line with occupancy but their significance appears in part to depend on the altitude at which they occur. The significance of impacts at the very highest altitudes may be over-ridden by weathering processes which seem to produce more intense effects (i.e. deer impacts on bare peat and colonising plants might not necessarily be 'additive' at the highest altitudes). With decreasing altitude though, as these weathering effects quickly reduce in severity, any impacts of deer appear to be of increasingly greater significance.

That said, the interim conclusions on the significance of impacts listed above are predicated on several assumptions which to date have not been tested empirically, including that:

- Deer were not in any way implicated in the onset of erosion - more work is required to ascertain this important fact.

Deer density on the site in the past, when recolonisation occurred previously, was not any lower than it is now because this might have allowed recolonisation to occur more easily - more work is required to ascertain this important fact.

Conclusions

The data gathered by SCL so far confirms that deer are having a range of impacts on the site. However, it is difficult at this present juncture to be sure of the seriousness of many of the impacts observed notably at higher altitudes.

The uncertainty is partly because we do not at present understand enough about the previous dynamics of the blanket bog and the deer population that was using the Monadhliath site, nor about the likely future dynamics of the blanket bog on the Monadhliath SAC and the way the deer population will use it. However, it is also in part due to a lack of research on high-altitude eroding peatlands such as the Monadhliath, and specifically research on interactions between wild deer impact and blanket bog surface integrity and recolonisation processes after erosion occurs.

Our concern is that the lack of understanding in relation to the Monadhliath site might well lead to inappropriate decisions on the future management of the site being made. This could be serious given its status as an SAC and as a significant store of terrestrial carbon, but also because of its status as privately-owned land of significant local socio-economic interest.

As a consequence, we believe that it would be prudent to spend a period of 3 years studying the site in more detail, as part of SNH's ongoing program of work as already planned, prior to deciding on the best way to manage the site going forward. The reason we feel this course of action is justified is that the extent of changes to the bog that will occur in this time are unlikely to be large enough to warrant any greater concern than already exists at the time of writing. Moreover, undertaking further research on site, and developing a better understanding of the processes at work in the SAC, has great relevance to the wider debate over the importance of bogs as terrestrial carbon stores as well as related debates over land use and climate change.

Reccomendations

We make a raft of recommendations to SNH about how to deal with the site over the next 3 years, with a very strong emphasis on ensuring that a fit-for-purpose package of research and monitoring is developed and implemented as part of any wider SNH work program for the site.

1. INTRODUCTION

1.1 Site overview

The Monadhliath is a large and mountainous upland area located above the villages of Newtonmore and Laggan in Inverness-shire, UK (Appendix 1 – Map 1). The land is owned by seven large estates (Appendix 1 – Map 2), and is currently managed for deer stalking, grouse shooting and hill sheep grazing.

The Monadhliath range was designated as a Special Area of Conservation (SAC) in 2003 following its notification as a Site of Special Scientific Interest (SSSI) in 1974. The site was originally designated as a SSSI for the mosaic of upland habitats present, which include blanket bog, montane grasslands (including species-rich *Nardus* grassland), montane heaths and montane willow scrub. It was also notified for its vascular plants, breeding birds and the rare *Glacies coracina* Black mountain moth, which occurs above 600 m where the larvae feed on *Empetrum nigrum* Crowberry.

SAC status was granted because of the European importance of the blanket bog – an Annex 1 habitat under the European Habitats Directive. The site supports one of the most extensive areas of high-altitude blanket bog in the UK, and it is relatively remote from the sea and thus contrasts with the numerous areas of oceanic blanket bog. The vegetation reflects the high altitude, with species including *Racomitrium lanuginosum* Woolly hair-moss, *Empetrum nigrum* ssp. *hermaphroditum* Mountain crowberry, and *Vaccinium myrtillus* Blaeberry. Lichen-rich bog with *Cladonia* spp. is extensive on the high plateau. A significant proportion of the bog is noted as being eroded. The conservation objectives for the SAC are:

- To avoid deterioration of the qualifying habitat (*blanket bog*) thus ensuring that the integrity of the site is maintained and the site makes an appropriate contribution to achieving favourable conservation status for each of the qualifying features; and

- To ensure for the qualifying habitat that the following are maintained in the long term:
  - Extent of the habitat on site
  - Distribution of the habitat within site
  - Structure and function of the habitat
  - Processes supporting the habitat
  - Distribution of typical species of the habitat
  - Viability of typical species as components of the habitat
  - No significant disturbance of typical species of the habitat

1.2 Study background

Since its designation as a SAC, Scottish Natural Heritage (SNH) has undertaken or commissioned a range of assessment and monitoring work, in order to understand more about the nature and state of the blanket bog present, including:

1. Site Condition Monitoring (SCM): routine assessment of the site by SNH in 2004 and again in 2008 (SNH, unpublished) found that the overall mosaic of upland habitats and the breeding bird assemblage were considered to be in favourable condition but that the blanket bog habitats, vascular plant assemblage and dotterel population were considered to be in an unfavourable condition. The condition of the blanket bog habitat was considered to be unfavourable due to the extent of bare and eroded peat in some areas. Bare and eroded peat were considered to be the result of a combination of herbivore impacts (trampling and browsing) and natural processes such as erosion by wind and rain.

2. Herbivore Impact Assessments (HIA): a baseline survey in 2006 (Dayton, 2006) reported that there were high levels of trampling impacts and chronic high levels grazing impacts on the high plateau and that this correlated with areas of bare peat. However low-moderate impacts were apparent on the valley sides and lower slopes where vegetation was considered to be in generally good condition. A follow up study in 2009 (Headley, 2009) concluded that if there was no change to the management of large herbivores within the Monadhliath SAC the prognosis is that condition of the vegetation on the blanket bog will continue to deteriorate and the extent and depth of peat erosion will increase.

3. Experimental enclosures: experimental enclosures were set up from winter 2006 – summer 2007 to quantify the impact of deer trampling and grazing on rates of vegetation recolonisation. Monitoring of the enclosures in summer 2009 was undertaken, at which stage it was found that there was very little evidence to suggest that the removal of the grazing / trampling pressure had led to the re-vegetation of eroded blanket peat or prevented the further erosion of blanket bog (Hewison *et al*, 2011).

4. Bare peat extent: a study quantifying change in areas of vegetated and bare peat surfaces on the blanket bog habitats, based on use of aerial photography from 1946 and 2005, reported that the extent of bare peat in the select parts of the site studied may have declined by 80% over the period (Jarman et al, 2010). However, the authors also reported that the results obtained were fairly unreliable because of inherent difficulties with interpreting the imagery used.

5. Live deer counts: the most recent count found that *c*. 3000 Red deer were present in the 10,671 ha area of the SAC (SNH, unpublished). This equates to a density of *c*. 29 deer per km^2. Variations in density, as calculated for each section of estate land within the SAC, ranged from 4 – 85 per km^2 on the day of the count.

1.3 Study aims

The unfavourable status of the blanket bog, and concerns over the reported density of deer present on the site, led SNH to commission a new study in summer 2010. The purpose of the study was to obtain information for SNH and land managers to use. The study had the following aims:

3. Design and implement a baseline study on the population of red deer utilising the Monadhliath SAC area, to include:

    a. Information on occupancy and levels of utilisation by deer in summer and autumn 2011- the method should be consistent with those set out in Forestry Commission Bulletin 128 (Swanson *et al* 2008).
    b. Habitat data: the method is expected to make provision for the collection of readily-obtained additional habitat data to help better understand the relationship between utilisation by deer and the condition of blanket bog in the Monadhliath SAC.

4. Investigate the spatial and temporal relationships between deer population parameters and habitat condition using the data gathered and report the findings.

2. METHODS

2.1 Deer population assessment

2.1.1 Data collection

A systematic sampling grid of 217 locations spaced at 700m intervals was created within the SAC extent[1] (Appendix 1 – Map 2). Each point was located in the field using GPS and if the terrain was safe for surveyors to access then data collection proceeded. From the point an 80 m long transect was run out on a pre-determined random bearing. Points on the transect were marked with short bamboo canes and the start and end marked with wooden posts. A GPS reading at the start and at the end of the transect was recorded, and photos taken of each point.

Each deer/ sheep faecal pellet group was identified on the first site visit (mainly in July 2011; the last plots in early August 2011). Each group was marked with a wooden lollystick and its physical state of decay recorded (fresh through to highly decomposed). The likelihood that each group had been deposited in summer 2011 (fresh appearance; often of fused appearance[2]) was assessed. No formal attempt was made to distinguish between sheep and deer pellet groups, as in our experience it is an error-prone process. All deer groups were assumed to be from *Cervus elaphus* Red deer even though several *Capreolus capreolus* Roe deer had been witnessed during one visit on the lower southern section of the site.

The plots were then left to accumulate new pellet groups and were re-visited in early November 2011 at which point the number of new pellet groups accumulated was ascertained. These groups were again marked and assessed for decay state, in case a third visit to the site was required. The decay state of the original groups was also ascertained. Unfortunately, the second visit was complicated by access being prevented during hind stalking in Coull, and by the time permission had been granted the winter snow had arrived. This area, along with Garrogie (for logistical reasons), was finally visited in March 2012 after a period of thaw (a total of 54 transects were affected by this problem)

During all visits to site the number and location of live deer seen was recorded. The presence of sheep, and sheep signs, was also recorded on transects and more widely when traversing the site.

2.1.2 Data analysis

The density of new pellet groups was calculated on a per transect basis and this data was used to quantify the faecal accumulation rate (FAR) on the site as a whole over the study period (see Appendix 2 for technical background on the FAR technique). The FAR data were also used to identify areas of higher and lower deer occupancy within the site by producing an interpolated surface (see Appendix 3 for technical background). The FAR data were also used to explore patterns of deer use according to altitude, slope angle and habitat type.

Due to the delay in timing on Visit 2 in part of the area, an adjustment was made to the FAR data on each of these transects prior to their use in the above analyses, to account for them being left out longer. The process of adjustment involved removing any pellet groups judged

[1] We advised SNH that it would have been more appropriate both ecologically and from a hydrological perspective to assess an area which was larger than that of the SAC, but the Scope of Works was restricted to the SAC as described in the tender.

[2] From late autumn through to early spring, vegetation tends to have a lower moisture content and a higher fibre content than in summer, which tends to mean that defecations consist of groups of individual faecal pellets; in summer these pellets often stick together into a single entity and become partly deformed which we term ‘fused’ (see Swanson *et al* 2008 for images).

to have accumulated between November and March from the counts and reducing the time between the Visit 1 and Visit 2 surveys accordingly. The effect of the adjustment was that all transect data then had an accumulation period of July – early November.

A further adjustment was then made to the entire FAR data set so that all accumulation judged to have occurred in summer 2011 was included in the analysis . The approach taken was that on the first visit to site in July all pellet groups which appeared to have been recently defecated (i.e. in the early summer period from June-July) were identified – the decision was based on their morphology and decay state, with all pellets groups showing no signs of decay (mucous coating present, or otherwise with no breakdown of the pellet surfaces) or only very limited decay (roughness of pellet surface, but no loss of shape) considered to have been defecated recently . These ‘early summer’ groups were treated in the analysis as ‘new accumulation’ along with the pellet groups which actually accumulated between the first and second visits to site, the result being that we produced a set of accumulation rate data relating to the entire summer and autumn period (start of June until early November) – the time between survey visits was extended accordingly for each transect, the result being that accumulation was in effect quantified on the site over a 160-day period from June – early November 2011 as opposed to the actual survey period which was from late July – early November for most transects, and July – March for the subset on which access was prevented in the autumn .

The presence of sheep signs (wool trapped on heather; characteristic large piles of faecal pellets; ‘sheep scrapes’ in the hillsides) was mapped along with the locations of live sheep and live deer counted. These data along with pellet group accumulation rate data were then input to ArcGIS and used to inform the analysis of the habitat and impact data.

2.2 Habitat and impact assessment

2.2.1 Data collection

Data were gathered under a number of different protocols:

- 1x1m quadrat assessment, with a quadrat located at the 10, 30, 50 and 70m points along the 80m line.
- 2x1m quadrat assessment, with a quadrat located at the 10, 30, 50 and 70m points along the 80m line.
- 0.3x0.3m micro-quadrat assessment, based on a quadrat of this size located at the 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70 and 75m points along the 80m line.
- 80m transect assessment, using a 30m width (15m either side of the centre line).

The 1x1m assessment involved recording:

- % Cover of *Calluna vulgaris* Heather; mean height (cm); percentage of foliage affected by die-back; percentage of 2010 season shoots utilised (Visit 1 to site; V1); percentage of 2011 shoot utilised to date (Visit 2 to site; V2).
- % Cover of *Empetrum nigrum*; percentage 2011 shoots utilised (V2).
- % *Vaccinium* spp. shoots utilised from 2011 growth (V2).

The 2x1m assessment involved recording:

- Presence/absence of signs of breakage by trampling on dwarf shrub stems.
- Number of visible hoof marks on vegetated land (and percentage quadrat cover) and no. of marks visible on bare peat if present (and percentage quadrat cover) (counted on V1 and V2).
- % Cover of *Sphagnum* spp. Bog mosses and *Racomitrium lanuginosum*; percentage of cover of each uprooted (V2).
- % Cover of *Eriophorum vaginatum* Hare’s tail Cottongrass and *E. angustifolium* Common Cottongrass (V2); percentage of leaves utilised (V2).

- Presence/absence of *Lepus timidus* Mountain hare faecal pellets and *Lagopus lagopus scoticus* Red grouse faecal pellets.

The 0.3x0.3m assessment involved recording:

- Habitat type (blanket bog; eroded bog; wet heath; dry heath; grassland; other – included flushes & bracken) (Table 1).
- Peat depth (cm; only if bog or eroded bog).
- Landform (Intact, Hagg top, Gully wall/hagg apron, Gully base/peat flat) (Table 2).
- % *Sphagnum* cover (*S. capillifolium*; other species).
- Bog water table position (visible at surface; appeared with pressure applied; no appearance even with pressure).
- % Cover of bare peat.
- Rock exposed: Y/N.
- Hoof marks visible: Y/N.
- Bare peat over-deepened by deer: Y/N.
- Bare peat surface appears re-deposited: Y/N (by wind or surface wash processes).
- % Bare peat recolonised with new plants (attempt made to distinguish between new plants and older plants from original mire surface).
- % Colonising leaves grazed.
- % Colonising leaves trampled.

Table 1 - Basic habitat classification used during the survey.

Habitat type	Abbreviation	Description
Blanket bog	BB	Peat depth normally of 0.5m or more; generally dominated by the plant species *Eriophorum* spp., *Sphagnum* spp. along with other species often occurring on bog such as *Erica tetralix* Cross-Leaved Heath.
Wet heath*	WH	Peat depth of < 0.5m but normally 0.3m or less; plant species generally as above but without *Eriophorum* spp.
Dry heath*	DH	Peat either absent or shallow (normally < 0.1-0.2m); dominated normally by *Calluna vulgaris* and with *Erica cinerea* Bell Heather, but typically with much less abundant *Sphagnum* spp.
Grassland*	GRASS	Peat either absent or very shallow (normally < 0.1-0.2m); dominated normally by true grass species e.g. (*Nardus stricta, Deschampsia spp., Agrostis spp.*) or at higher altitudes often with *Racomitrium lanuginosum*.
Eroded bog	BB(E)	Land which has clearly once held blanket bog as described above, but now has experienced direct surface erosion and now has peat haggs present in the immediate vicinity or close by to provide evidence that a deeper layer of peat was once present in the survey area. The land typically includes a mixture of habitat types as listed above (BB, WH, DH, GRASS). Some land classified as BB(E) may have previously been wet heath as opposed to blanket bog, but the de-watering and collapse of peat haggs now makes it difficult to judge how deep the peat originally was.
Bracken*	BR	Land dominated by *Pteridium aquilinum* Bracken and

		otherwise with a lower layer of true grass species and non-*Sphagnum* mosses.
Flush*	FL	Small channels of land which are typically wet underfoot, often dominated by *Juncus* spp. Rushes at lower altitudes.
Scree/rock*	SC/R	Bare rock or scree covered areas, which may also have some lower plants, often lichens, present.

N.B All habitats marked * were included within the category 'Other' for many of the analyses presented in the report.

Table 2 - Landform classification used during the survey - applies only to areas classified as BB or BB(E). Appendix 4 includes some images of these landforms.

Landform type	Description
Intact	All BB was classified as this, along with any sections of an erosion complex – BB(E) – on which peat haggs were > 10m in width across their shortest axis.
Hagg	Peat haggs < 10m in width at their narrowest point; protruding above the gully base or main peat flat level (as defined below); covers a wide range of features from haggs of just under 10m width with a bog water table present in their centre down to 'collapsed' features of 1m width or less without a bog water table.
Wall / apron	The angled side of an erosion gully (gully wall) or the angled side of a peat hagg (hagg apron).
Base / flat	The flat bottom of an erosion gully (gully base) or the sections of a peat flat which did not comprise haggs as defined above.

The 80m assessment involved:

- Recording the characteristics of blanket bog (or eroded bog) in the target area:
    - % Original bog extent affected by major erosion[3].
    - Erosion type (% gully, percentage sheet, percentage mixture of gully / sheet).
    - Level of hagg edge sealing (% closed, percentage open, percentage part sealed).
    - % Line intersecting bare peat[4].
    - Deer impacts on bog and eroded bog (see Appendix 4 for a range of images illustrating these impacts):
        - % Intact bog surface or haggs with the acrotelm punctured by hoof marks
        - % Deer paths on intact bog / hagg tops that are over-deepened (i.e. vegetation surface destroyed; bare peat now present).
        - % Hagg edges with notches.
        - % Gully walls/hagg aprons with terrace paths.
    - % Intact bog / hagg tops affected by micro-erosion.

[3] The fact that bog habitat thins out to become wet heath and then other habitats caused some difficulty when this transition zone was eroded. In these circumstances it was sometimes difficult to decide whether erosion had occurred on bog or on wet heath because the difference in plant assemblages normally used to identify the interface between the two zones was highly modified by erosion and hence drainage effects. Images in Appendix 4 illustrate this point clearly.

[4] All measures of bare peat extent were made as overhead cover, and did not take account of the 3-dimensional nature of bare peat e.g. on hagg walls. The physical surface area of bare peat (m^2) is in essence higher than that indicated by the percentage cover of bare peat as quoted in this report.

    - % Micro-eroded features recolonised.
- Assessing the percentage cover of *Calluna* on the transect and then the percentage judged to be of atypical growth form due to chronic over-browsing (drumstick, topiary or carpet) (assessed using a 1.5m width and not the 30m width)
- Checking for the presence of signs of sheep (live animals, wool, sheep scrapes etc).
- Checking for signs of recent muirburn.
- Checking for signs of land drainage on sections of mire.

2.2.2 Data analysis

Data were input into Microsoft Excel© on a 'per transect' basis and summaries prepared. A range of plot attributes were extracted using ArcGIS (e.g. altitude, mean slope angle, estate etc) and joined to the 'transect' summary data. Data were then analysed using pivot tables and summarised graphically. 95% confidence limits were calculated as appropriate[5].

[5] As there was no data available to us that could be used to ascertain the likely nature of the sampling locations in terms of their erosion status and extent of landforms present, the methods we used in this study resulted in unbalanced sample sizes being obtained e.g. the nature of the upper plateau means that there was more eroded land sampled than intact bog. This means that the sample sizes for the rarer features are not as large as one might ideally prefer, but this cannot easily be avoided in the baseline stage of a study such as this. See Recommendations for our proposed approach to increasing sample sizes where needed.

3. FINDINGS

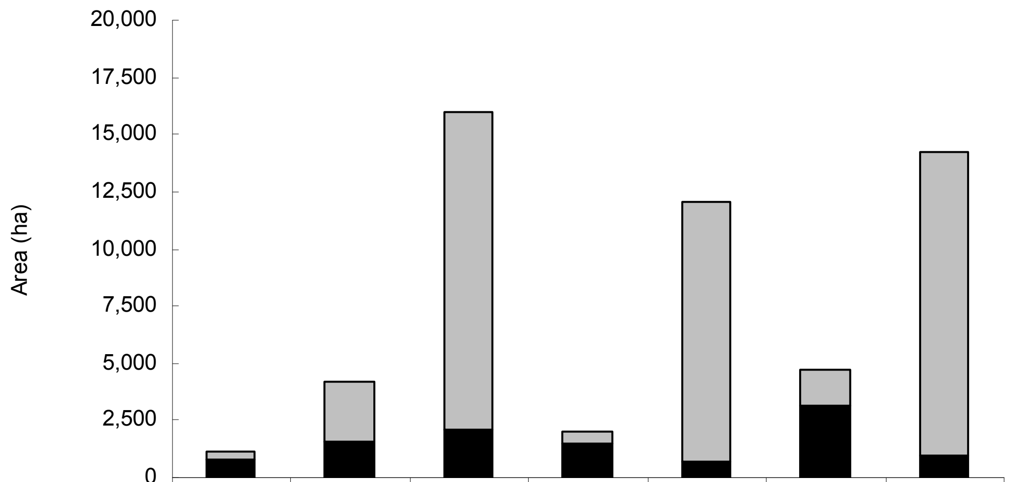
This section of the report is divided into three parts describing:

1. The extent and nature of the blanket bog present on the Monadhliath SAC, focussing on the processes that erode the peat and those that lead to vegetative recolonisation of eroded ground.
2. The nature of the deer population using the site, focussing on patterns of occupancy, overall abundance, reproductive output, the culls recently taken and the likely effect these are having on patterns of occupancy.
3. The impacts that deer are having on the plants generally, and on the blanket bog specifically, according to variations in deer density but also taking account of physical weathering processes.

3.1 Quantitive site description

3.1.1 Land ownership

The SAC comprises 10,761ha of land owned by seven estates, although the estates all own adjacent land outwith the SAC also (Figure 1; Appendix 1 – Map 2).



	Blaragie	Cluny	Coignafearn	Coull	Garrogie	Glenbanchor	Glenshero
Out of SAC	420	2,696	13,902	595	11,334	1,632	13,285
In SAC	747	1,538	2,108	1,454	728	3,119	977

Figure 1. The area of land (ha) owned by each estate inside and outside the SAC boundary.

3.1.2 Topography

The SAC comprises a broad and extensive high plateau area, which has been glacially incised to the south forming deep valleys and corrie features but with gentle rolling terrain in the north (Appendix 1 – Maps 2 & 3).

The land within the SAC ranges in altitude from *c*. 350 to c. 950 m above sea-level, but with the majority (c. 70%) lying above 650 m and with very little (*c*. 5%) below 450m (Figure 2).

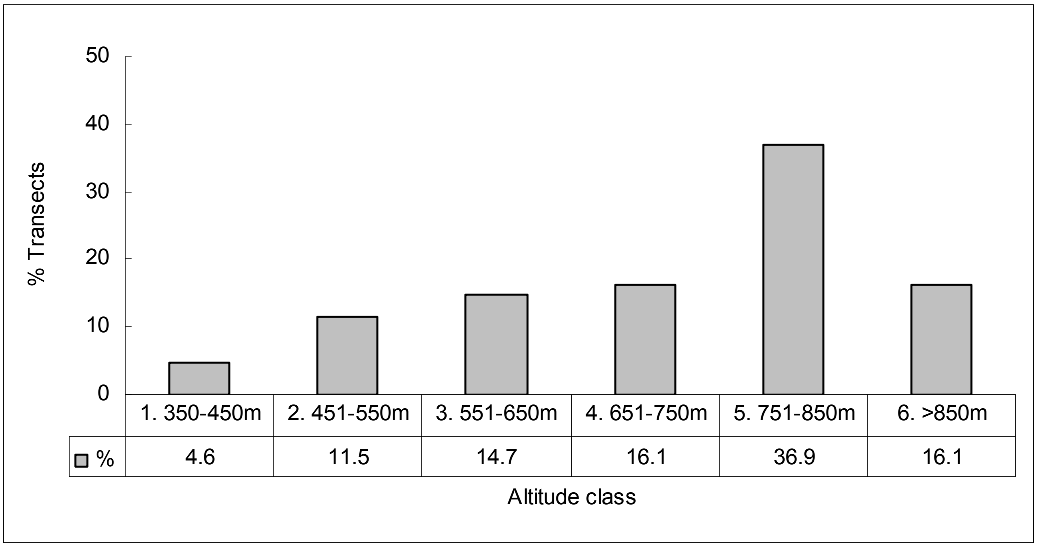


Figure 2. The percentage of land in a range of altitude class as within the SAC boundary.

Slope angle varies markedly, with the majority of slopes (*c*. 70%) being less than 15 degrees but with a considerable area (*c*. 17%) comprising slopes steeper than 20 degrees (Figure 3; Appendix 1 – Map 3). The majority of steeper slopes are located at lower altitudes whilst the majority of gentler slopes are located at higher altitudes (Figure 4).

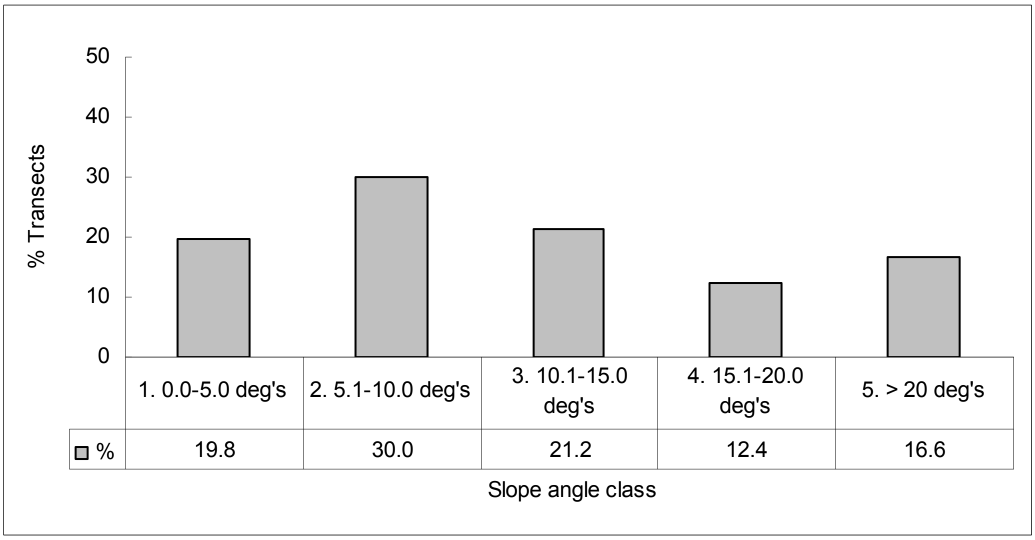
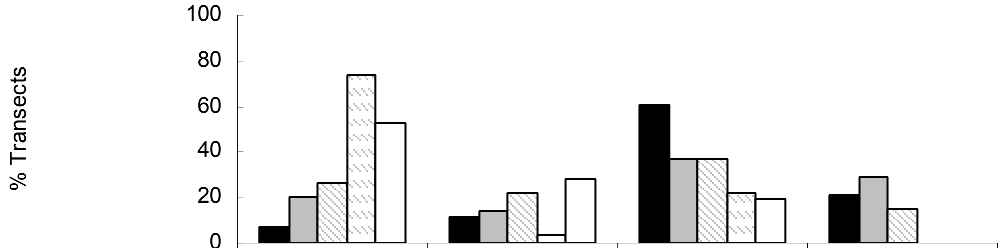


Figure 3. The percentage of land in a range of slope angle classes within the SAC boundary.



	1. < 650m	2. 651-750m	3. 751-850m	4. > 850m
0.0-5.0 deg's	7.0	11.6	60.5	20.9
5.1-10.0 deg's	20.0	13.8	36.9	29.2
10.1-15.0 deg's	26.1	21.7	37.0	15.2
15.1-20.0 deg's	74.1	3.7	22.2	0.0
> 20 deg's	52.8	27.8	19.4	0.0

Altitude class

Figure 4. The percentage of land in a range of slope angle and altitude classes within the SAC boundary.

A major watershed is located towards the middle of the site, with drainage waters flowing south to the River Spey and north to the River Findhorn and the River Killin (Appendix 1 – Map 1).

3.1.3 Climate

The climate of the site is typically montane, with the higher reaches reported to receive over 1690 mm of rainfall a year on average (Dayton 2006). Snow is present for up to c. 100 days a year and temperatures are often at or below freezing point on the plateau (Dayton 2006). The altitude and location of the plateau means it is exposed to very strong winds for much of the year. The plateau is therefore a very challenging environment for plant establishment and growth. Lower lying parts of the site are much less exposed and have a more benign climate, thus have a longer growing season for plants.

There is a wide range of soils present on site, with typical brown soils, podsols, gleys and alluvium in the lowest reaches and with peat deposits, mineral soils and tallus boulder fields in the middle to upper reaches. Scree is also common on the steeper valley slopes where it tends to lie below exposed bedrock features.

3.1.4 Habitat types and extents

The range of habitat types present is typical of an area with widely varying topography, elevation and soils (Figure 5 upper). Shallow peats and mineral soils occur most often on steeper slopes and tend to be dominated by dwarf shrubs (Figure 5 lower). Habitats in which deeper peat is the dominant component are more common on shallower-angled slopes, and the plant assemblages they support tend to reflect the higher soil moisture and lower nutrient status of such soils (Figure 5 lower).

The most common habitat type on the site was eroded blanket bog BB(E)[6], which accounted for 51% of all the quadrats sampled (Figure 5 upper; Appendix 1 – Map 4). Blanket bog which was 'intact' (BB) accounted for 6% of quadrats sampled and wet heath (WH) for 11%.

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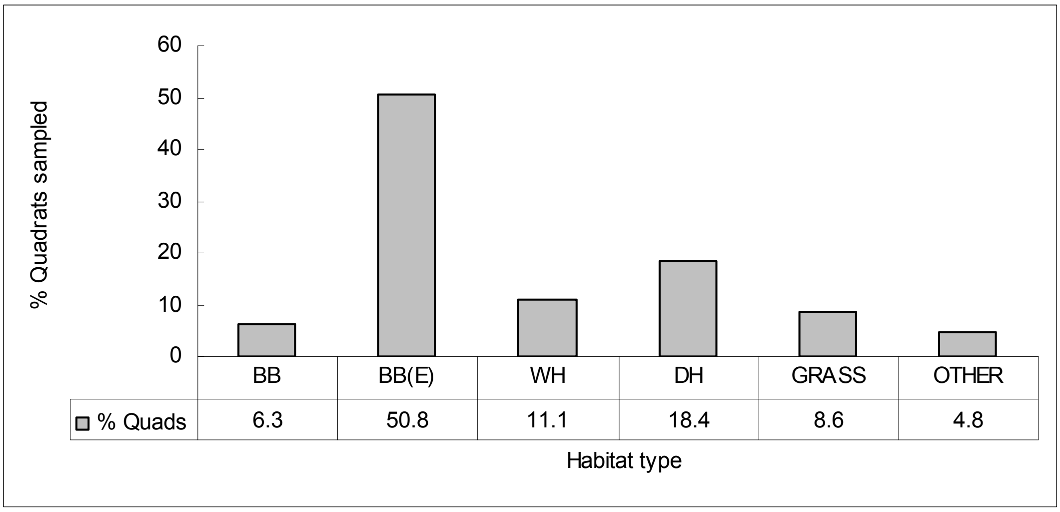
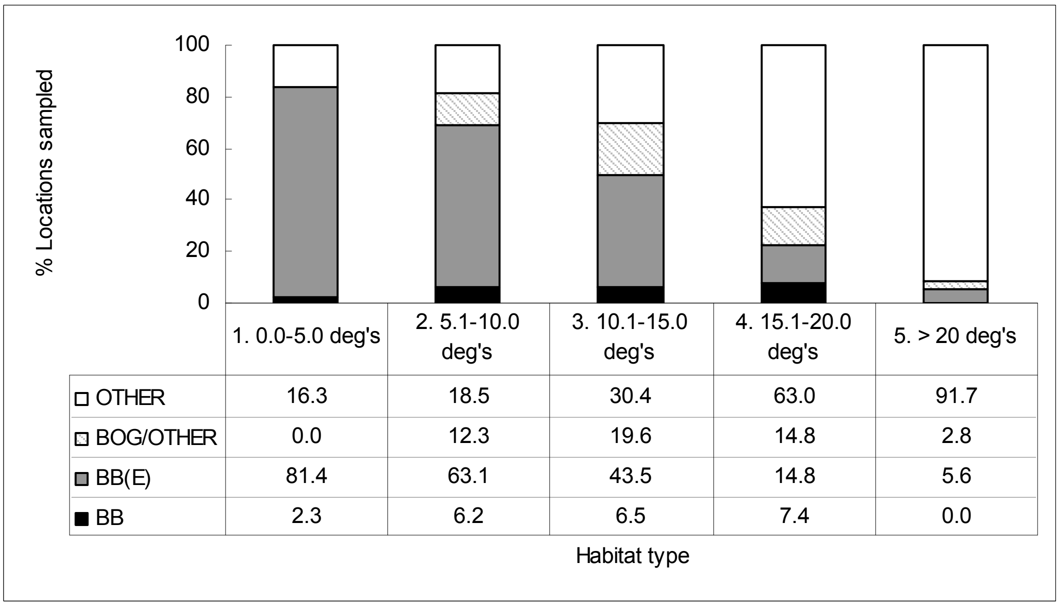
[6] Which will have included some areas that prior to the onset of erosion may have been classified as wet heath; subsequent erosion has made it difficult, because of disruption to hydrology and consequent changes, to be sure what habitat was present prior.

Land on which mineral soils or very shallow organic horizons were dominant were found on 32% of micro-quadrats sampled – the habitats found therein included dry heaths (DH) dominated by dwarf shrubs (18% of quadrats), grasslands (GRASS) (9% quadrats) and the much less common other habitats (OTHER; see Table; 5% of quadrats) (Figure 5 upper).



	BB	BB(E)	WH	DH	GRASS	OTHER
% Quads	6.3	50.8	11.1	18.4	8.6	4.8



	1. 0.0-5.0 deg's	2. 5.1-10.0 deg's	3. 10.1-15.0 deg's	4. 15.1-20.0 deg's	5. > 20 deg's
OTHER	16.3	18.5	30.4	63.0	91.7
BOG/OTHER	0.0	12.3	19.6	14.8	2.8
BB(E)	81.4	63.1	43.5	14.8	5.6
BB	2.3	6.2	6.5	7.4	0.0

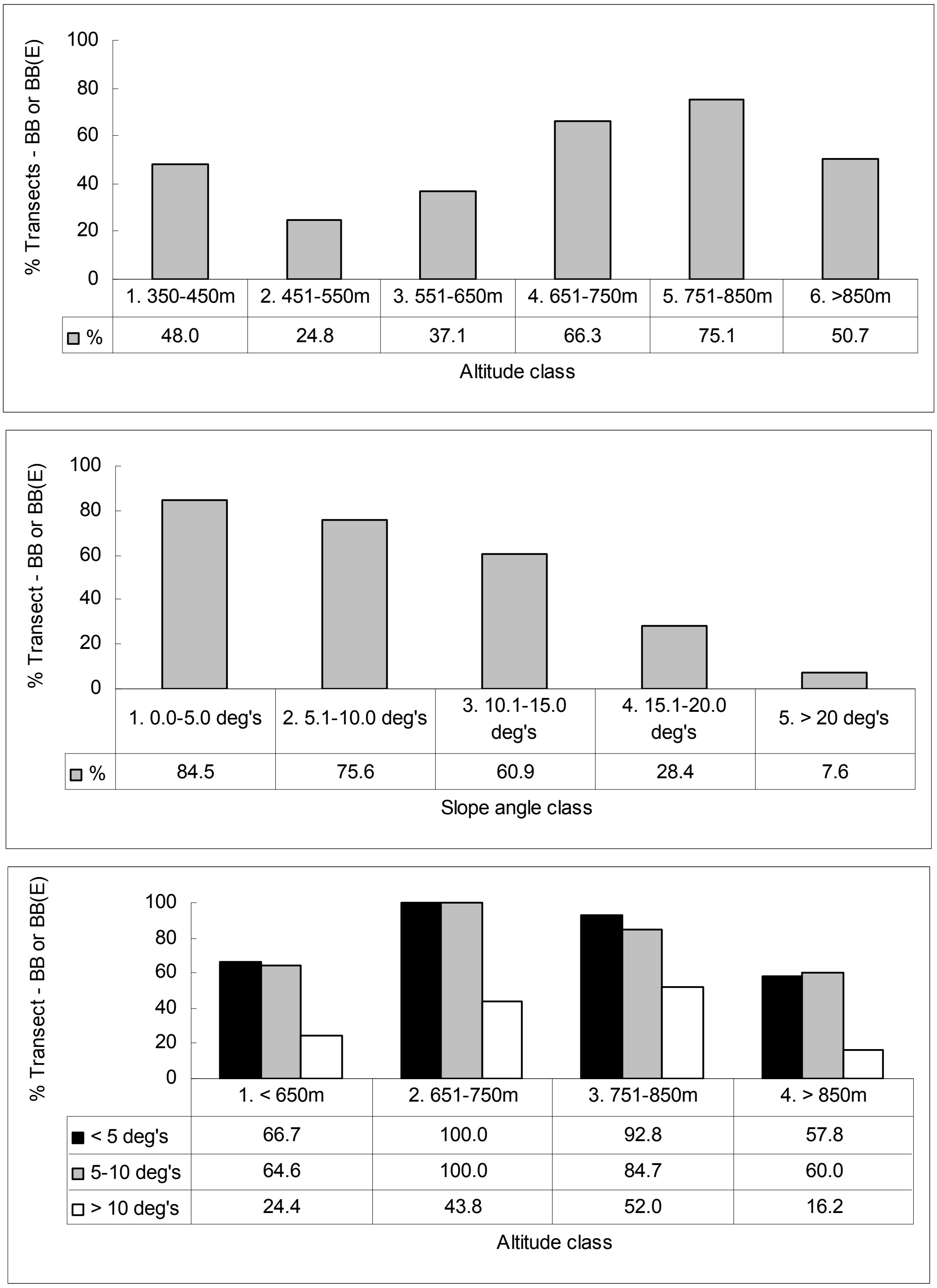
Figure 5. The percentage of micro-quadrats which fell on each broad habitat type (upper) (BB = blanket bog, BB(E) = eroded bog, WH = wet heath, DH = dry heath, GRASS = grasslands, OTHER = other habitats e.g. flush, bracken etc as defined in Table 1) and variation in the extent of habitat type (simplified; lower) according to slope angle (OTHER = non-bog habitats incl. WH, DH, GRASS and OTHER; BOG/OTHER = transects with a mixture of bog and non-bog habitat).

3.1.5 The original extent of blanket bog

The data gathered indicate that at some point in the past, 57% of the SAC comprised active blanket bog habitat (BB and BB(E) extents combined; see Figure 5 upper and also Appendix 1 – Map 5) with a further 11% of habitat on shallow peat (WH) which can be considered either as (i) a climax habitat, often present on the margins of blanket bog or (ii) a transitional habitat type which may, with time, develop into blanket bog in certain circumstances.

The extent of this original blanket bog complex appears to increase with altitude (Figure 6 upper). Figure 6 shows that the lower altitude areas have at one point in the past had a blanket bog cover of 25-50%, whereas areas at higher altitudes on the main plateau have had a blanket bog cover of 75%. However, the summit domes and some other parts of the plateau seem not to have experienced extensive peat formation.

The extent of this original bog complex appears to have been strongly controlled by slope angle. The extent was greatest on the shallowest slopes and was most limited on the steepest slopes (Figure 6 middle). The decline in bog extent with slope angle is consistent with altitude (Figure 6 lower), which helps explain why bog was fairly common at the lowest altitudes (which have some shallow-angled valley bottoms), much less common in the 450-650m zone (where the steepest slopes are concentrated) and most common in the upper reaches on the plateau where slope gradients are generally shallow (Appendix 1 – Map 5).



	1. 350-450m	2. 451-550m	3. 551-650m	4. 651-750m	5. 751-850m	6. >850m
%	48.0	24.8	37.1	66.3	75.1	50.7

	1. 0.0-5.0 deg's	2. 5.1-10.0 deg's	3. 10.1-15.0 deg's	4. 15.1-20.0 deg's	5. > 20 deg's
%	84.5	75.6	60.9	28.4	7.6

	1. < 650m	2. 651-750m	3. 751-850m	4. > 850m
< 5 deg's	66.7	100.0	92.8	57.8
5-10 deg's	64.6	100.0	84.7	60.0
> 10 deg's	24.4	43.8	52.0	16.2

Figure 6. The percentage of land on which active blanket bog is estimated to have been present at some point in the past (BB = intact bog and BB(E) = eroded bog), by altitude (upper), by slope angle (middle) and showing the interaction (lower).

3.1.6 The extent of erosion

Note to readers: Appendix 5 provides some technical background on blanket bog formation and factors affecting its disturbance, as well as some background on the geomorphology of upland peatlands with a particular focus on peat erosion. It is recommended that readers review Appendix 5 before reading the next section of this report because of the concepts explained within it are of fundamental importance when considering the survey results presented herein.

In past times, the original blanket bog surface would have been intact and peat would have been actively developing. However, the bog now exists in a range of states. Only 20% of the original bog extent still comprises 'intact' bog, existing either independently (e.g. in topographic depressions or on the margins of erosion complexes) or on top of large haggs within erosion complexes (Figure 7). The vast majority of the original bog extent is now affected either directly by major surface erosion[7] (i.e. the original bog surface is now an erosion gully or peat flat) or indirectly by proximity to erosion features (i.e. original bog surface now comprises only small, peat haggs).

The range and extent of landforms currently present on the original blanket bog extent is as follows:

- 11% of the land comprises 'intact' bog surface.
- 9% is also 'intact' bog surface but is located within erosion complexes and hence is potentially vulnerable.
- 25% comprises 'hagg' tops within erosion complexes, with appearance ranging from 'larger haggs of 5-10m with an intact bog water table' in their centre through to 'de-watered and collapsed haggs of 1-5m with no bog water table' existing within an otherwise completely eroded landscape.
- 55% comprises surfaces from which the original vegetated surface has been lost to erosion:
    - 16% of the original bog extent currently comprises gully walls or hagg 'aprons'.
    - 39% of the original extent currently comprises gully bases or peat flats.

[7] Major erosion is defined as erosion which has removed a marked proportion of the surface, typically at least 50cm of peat in depth terms, as distinct from surface micro-erosion (which is also present on site) but tends to be more superficial i.e. < 50cm in depth.

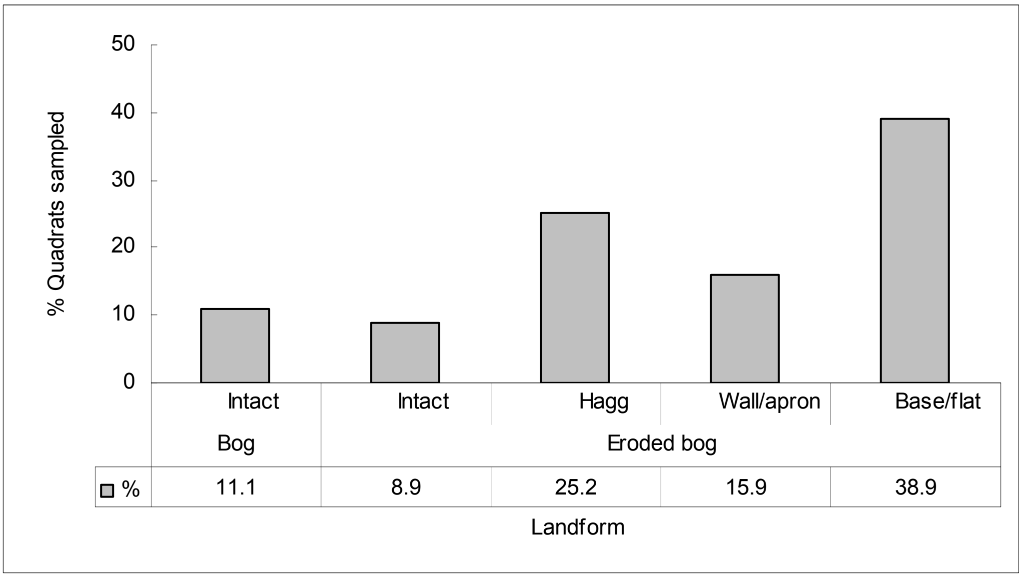


Figure 7. The percentage of quadrats by landform, within the area of land judged formerly to have comprised active mire (i.e. the BB and BB(E) extents combined) (Bog = BB; Eroded bog = BB(E))

Taking the land comprising wall / apron and base / flat landforms together as directly 'eroded' original surface, Figure 8 upper shows that the percentage of the original bog surface affected directly by erosion increases markedly with altitude. At 350-450 m, only 14% of the original bog surface has, to date, been directly eroded; however, at 751-850 m 66% of the original surface has, to date, been directly eroded (see also Appendix 1 – Map 5).

The percentage of bog eroded declines with increasing slope angle, with an average of 61% of the original surface eroded on slopes in the shallowest angle class through to an average of 33% in the steepest slope angle class (Figure 8 middle).

A complex interaction occurs between altitude and slope angle, with the percentage of original bog surface lost at lower altitudes being fairly similar for all slope angles but at the highest altitudes the percentage surface lost is much higher for the steeper slopes (Figure 8 lower).

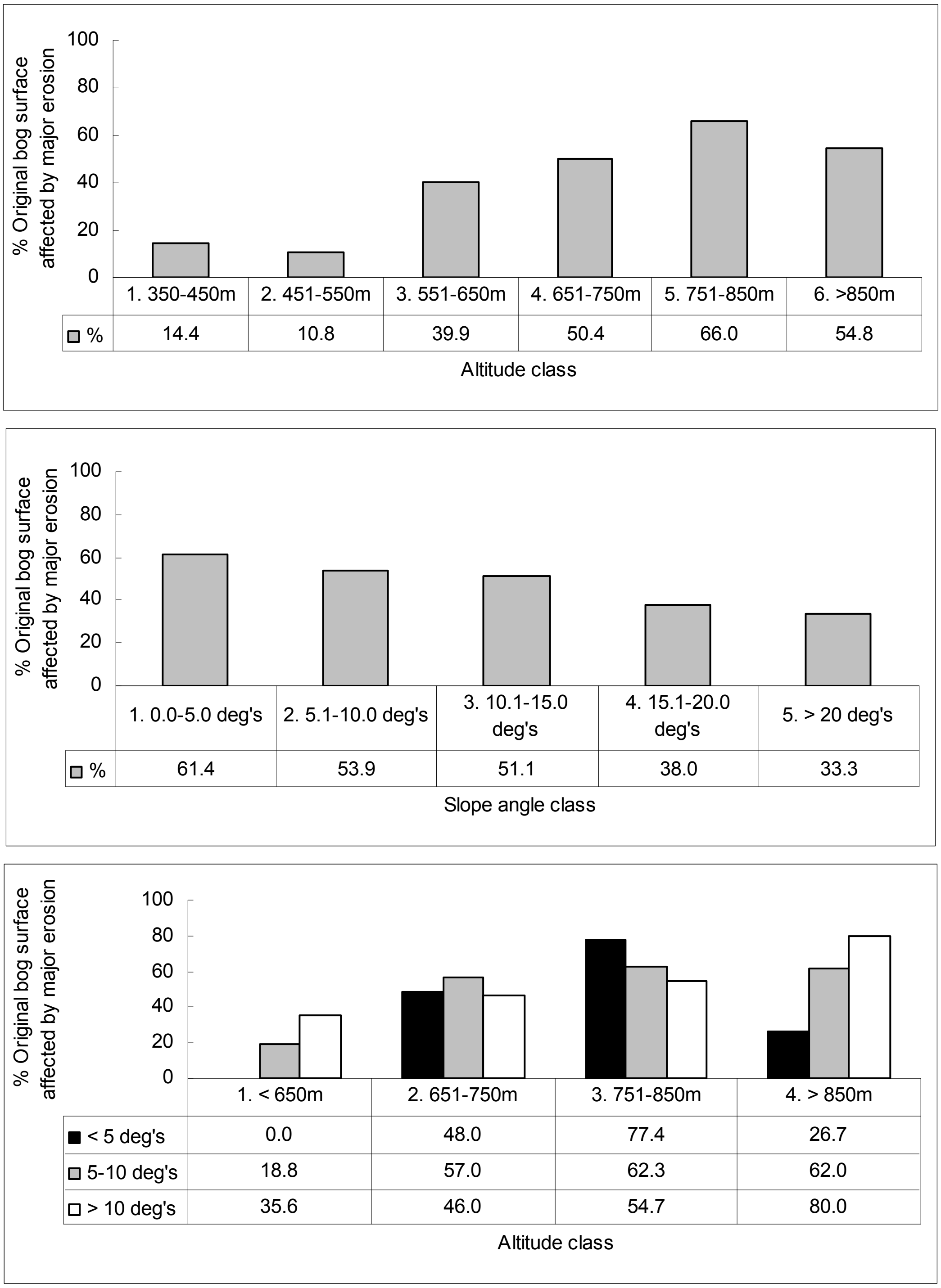
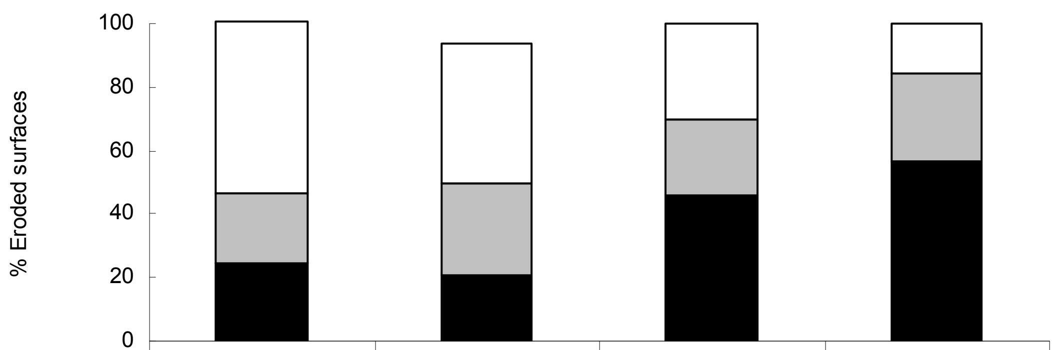


Figure 8. The percentage of the original bog surface that is eroded by altitude (upper), by slope angle (middle) and the interaction (lower).

3.1.7 The nature of erosion and its effects

The type of erosion that has occurred on the site varies according to altitude, with the gully form of erosion most prevalent at lower altitudes and the sheet form of erosion most prevalent at the highest altitudes (Figure 9; see also images in Appendix 4).



	1. < 650m	2. 651-750m	3. 751-850m	4. > 850m
Gully	54.4	44.0	30.2	15.9
Mix	21.6	29.2	24.1	27.3
Sheet	24.8	20.6	45.9	56.8

Altitude class

Figure 9. The type of erosion that has occurred according to altitude (gully = linear gully; sheet = sheet erosion; mix = mixture of processes).

Measurements of the extent of bog at each altitude and depth of peat present on eroded and un-eroded features therein was used to produce estimates of the volume (m^3) of the original peat mass lost since the bog was last fully intact.

Figure 10 summarises the general relationship between peat depth, landform and altitude. The model built used depth and extent estimates for each transect sampled. Depending on the parameters employed[8], a minimum total of 31-34% ('mean' model; 'maximum' model) of the original peat mass is estimated to have been lost since the bog was last fully intact.

Figure 11 presents the output of the model according to altitude, and shows that the percentage of the original peat volume lost is < 10% at the lowest altitudes but rises steeply to 40-45% at the highest altitudes.

[8] One model (mean) was run using the mean depth of peat present on peat haggs (or otherwise on intact mire) on each transect. Another model was run using the maximum depth recorded on the haggs at each location.

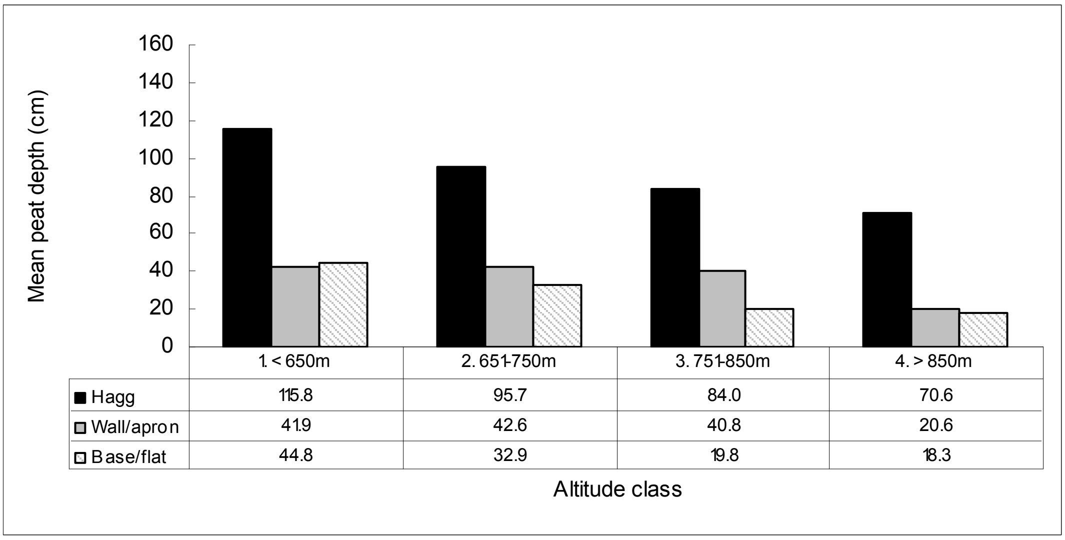


Figure 10. The mean depth of peat on hagg features and on major erosion features (wall / apron and base / flat) according to altitude.

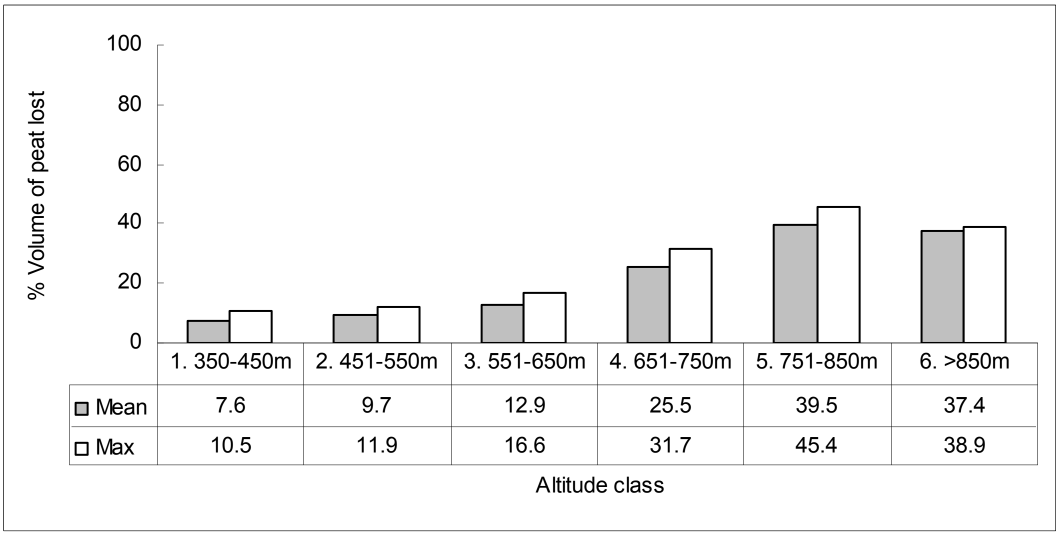
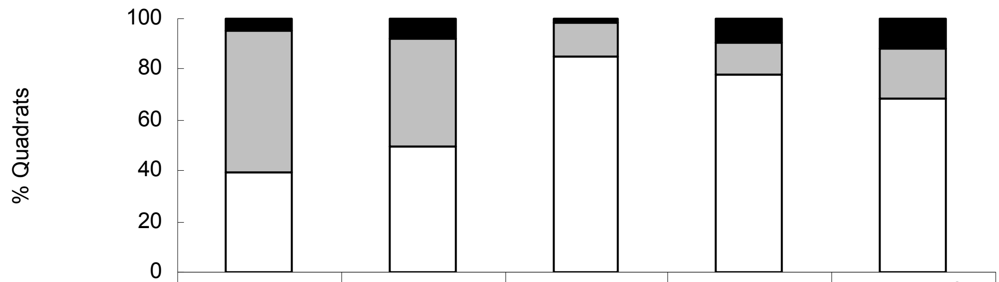


Figure 11. Modelled estimates of the volume of peat lost from the Monadhliath site, based on the estimated original bog extent and using two types of parameter to estimate the original peat depth ('mean' depth per transect and 'maximum' depth per transect) on un-eroded landforms (intact/hag) and on eroded landforms (wall / apron and base / flat). The model will, irrespective of which depth parameter is used, tend to underestimate volume losses because the remaining peat used to obtain depth estimates on intact/hagg landforms will to some extent have been de-watered and hence will now be shallower than before the onset of erosion.

Erosion of the bog appears to have caused marked changes in surface hydrology to occur. Intact bog located outwith erosion complexes had a water table close to the surface at over 60% of locations sampled. However, on remnant areas of intact bog within erosion complexes there was a decline in the frequency with which higher bog water table levels were recorded (Figure 12). Within erosion complexes, hagg tops had a lower frequency of sites with a bog water table at the surface than flats or gully bases. This is because the flats/bases receive drainage water from surrounding land and also, depending on the situation, have recolonised with vegetation, which means a bog water table can develop again in the remaining peat present.



	Intact	Intact	Hag	Wall/apron	Base/flat
	Bog	Eroded bog			
■ Visible	4.9	7.9	1.3	9.2	11.8
▨ Pressure	55.8	42.7	13.9	12.5	19.5
□ None	39.3	49.4	84.8	78.3	68.7

Landform

Figure 12. The percentage of sampled micro-quadrats on which a bog water table was visible at the surface, appeared when pressure was applied (i.e. surveyor standing on ground adjacent) or did not appear with pressure, according to erosion landform.

Much of the bog across the study area is still in an erosional phase, with different areas being at different stages of this phase. Bare peat cover, often used as a proxy for the percentage of land likely to still be 'actively' eroding, increases markedly with altitude (Figure 13 upper; Appendix 1 – Map 5) but declines markedly with slope angle (Figure 13 middle). The decline in bare peat cover with slope angle is consistent across most altitudes (Figure 13 lower).

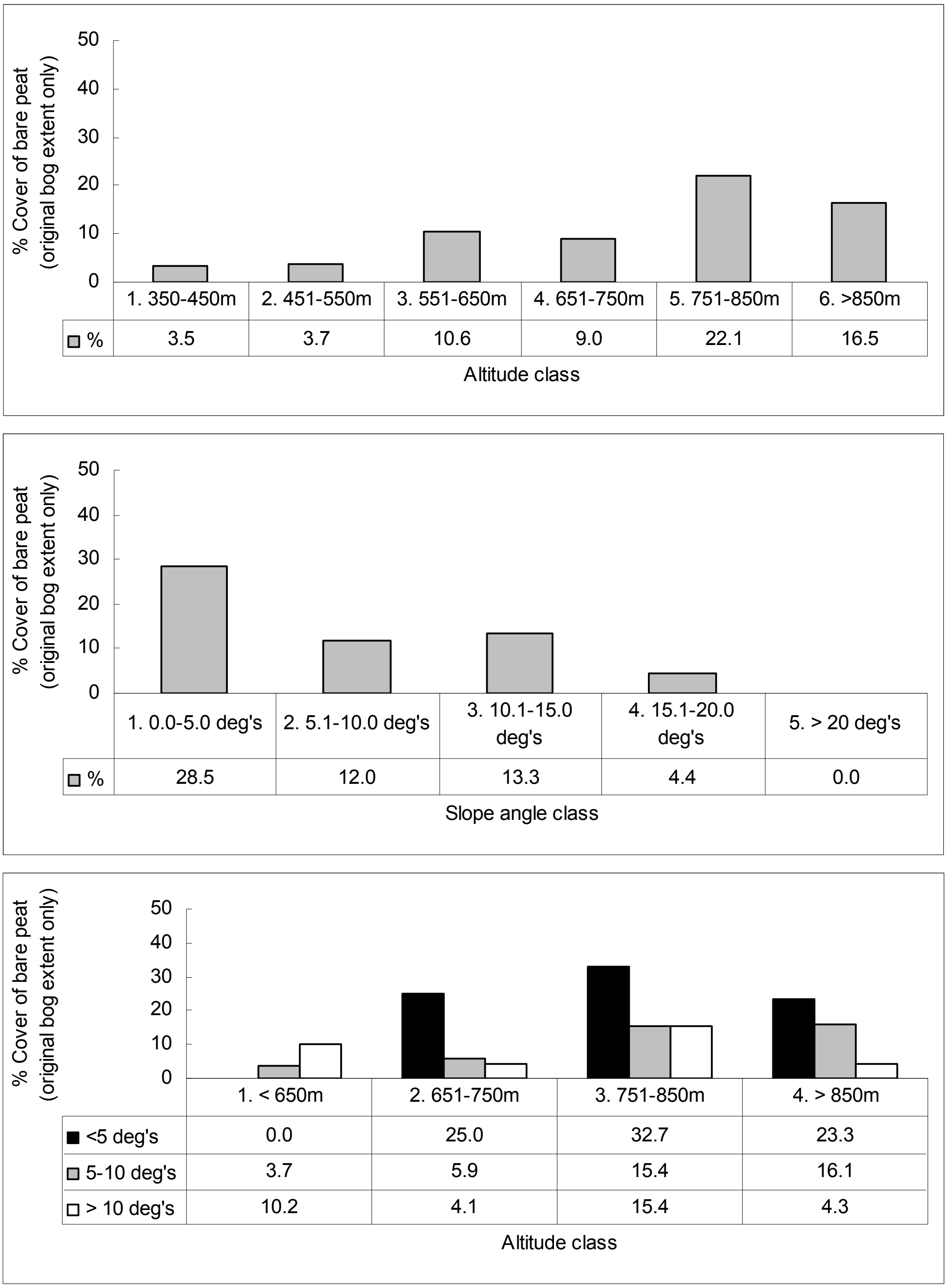


Figure 13. The percentage cover of bare peat on the original bog extent by altitude (upper), by slope angle (middle) and showing the interaction (lower).

The percentage of bare peat cover present is strongly influenced by landform, with the highest cover levels of bare peat being recorded on the wall / apron and base / flat landforms (Figure 14).

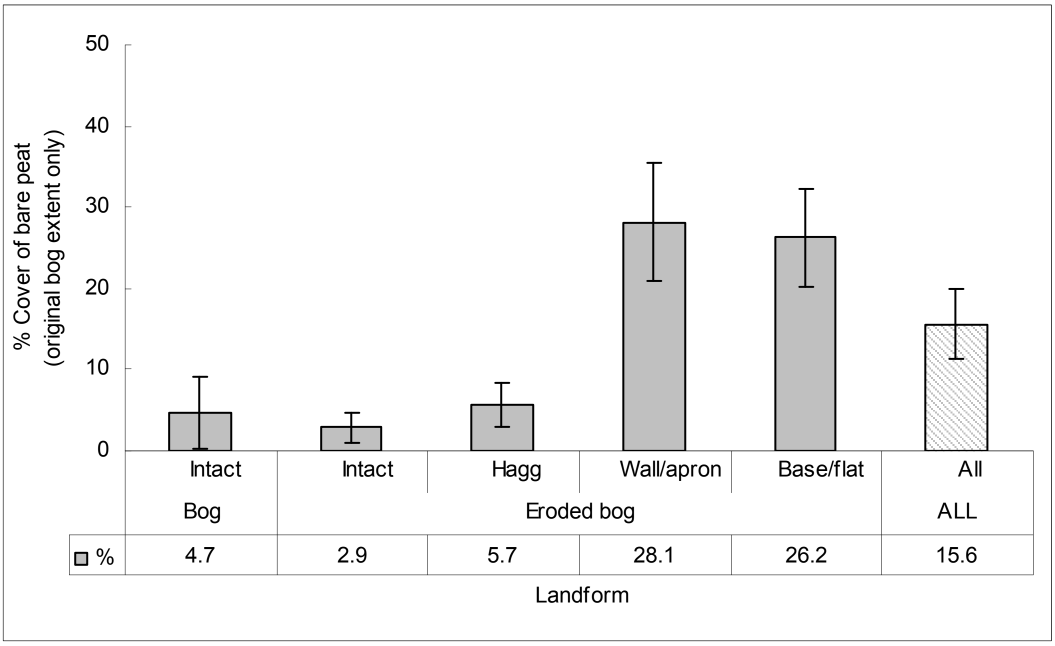


Figure 14. The percentage cover of bare peat on the original bog extent, according to landform.

A very high percentage of the transect locations at which bare peat was recorded as present also had signs of peat sediment recorded as present, either on the surface (e.g. lying in vegetation) or in watercourses, which helps to confirm that active erosion of the surface is occurring in many areas, notably those above 650m (Figure 15).

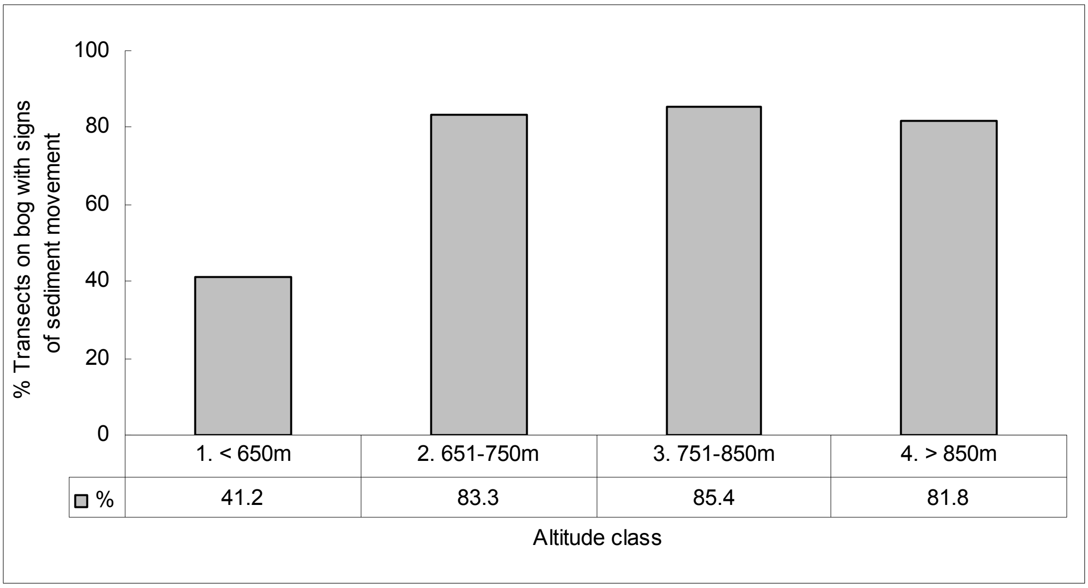


Figure 15. The percentage of transects on the original bog extent which had obvious signs of peat sediment being transported by fluvial action.

The more detailed assessment using micro-quadrats supported these findings by confirming on the first visit to site in July that transport of peat sediment was widespread at a local scale – this sediment was most obvious on peat flats (51% of quadrats sampled) but was also present on bare peat surfaces within many other landforms (Figure 16). This demonstrates the very active nature of erosion on the site wherever there are bare peat surfaces present, and also confirms the possibility that deposition of eroded peat can create new landforms and affect recolonisation and erosion processes (e.g. swamping of recolonising plants, smothering of existing vegetation on intact surfaces etc).

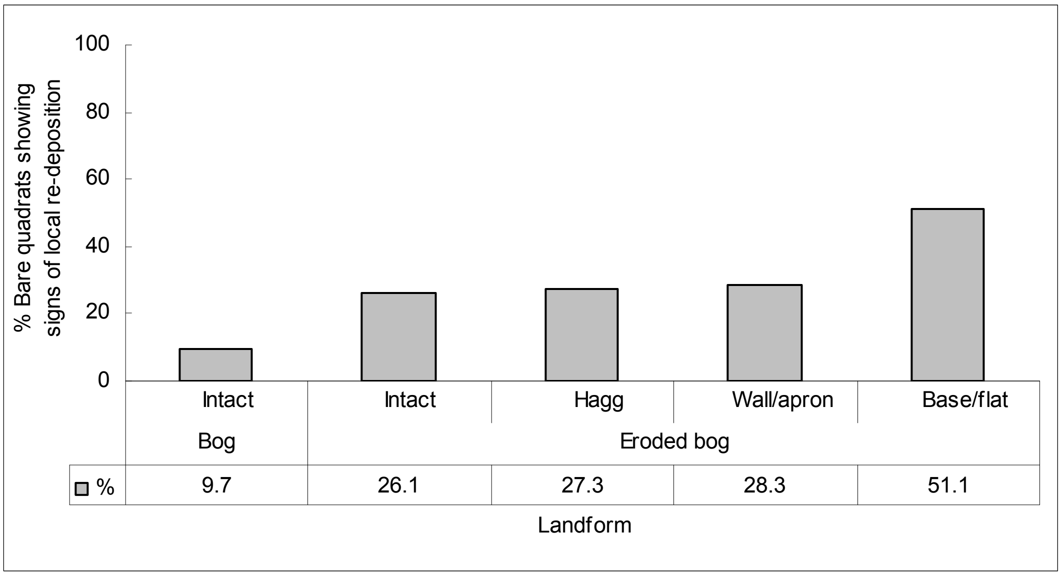


Figure 16. The percentage of micro-quadrats which had bare peat present, but also had signs of re-deposited peat sediment lying on the bare peat within the quadrat (according to landform).

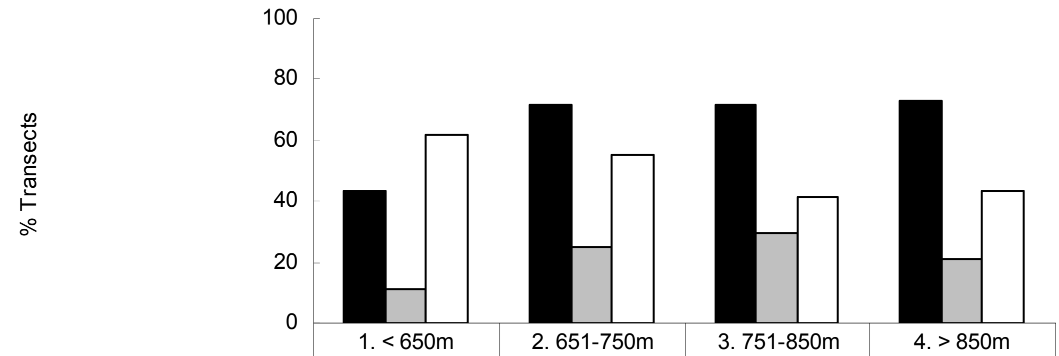
The general appearance of most bare peat areas on the first visit to site in July 2011 confirmed that widespread production and transportation of sediment is likely to occur. Evidence for this included that most surfaces in the middle and upper reaches of the site still had widespread signs of frost fluff present from when the weather had been colder (see images in Appendix 4). Frost fluff is one of the major routes by which peat sediment is mobilised in the uplands – frost fluff arises after needle ice forms in the peat surface during cold spells causing the upper surface to separate, and when the ice melts it leaves a layer of loose peat (the fluff) which, is highly susceptible to erosion. The transport mechanisms can include pluvial, aeolian and fluvial action (see images in Appendix 4). Other mechanisms by which bare peat surfaces can become 'prepared' for erosion include physical factors (e.g. desiccation by the sun and cracking leading to production of 'plates'; rain splash) and mammalian activity (e.g. deer trampling, hill-walking activity).

It is to be expected in an actively eroding landscape that bare peat will be found on hagg wall and gully base / flat landforms. Moreover, it is entirely expected that peat haggs within erosion complexes will, to some extent, continue to break down throughout the active erosion phase because of their inherent hydrological instability coupled to the action of weathering on their edges. This is confirmed by the presence of bare peat on hagg tops (Figure 14; 5.7%), most notably on haggs which are in the latter stages of breaking down.

However, the occurrence of bare peat on intact mire surfaces (Figure 14; 4.7%), including those within erosion complexes (2.9%), is potentially more significant as it could be an indication that the integrity of some of the remaining original bog surface is compromised – whilst this might not be entirely surprising either, given that at least 50% of the surface has previously broken down as evidenced by the extent of direct erosion already present, it does have numerous potentially significant implications. The most obvious is whether or not any of the active mire originally present on site and still remaining at the time of writing will actually survive this current ‘erosional phase’, most notably on the upper reaches of the site. There are a number of possible reasons as to why bare peat is present on intact bog surfaces, but a very common feature observed was ‘micro-erosion’ (sometimes termed ‘micro-broken’ mire; see images in Appendix 4).

The overall percentage of bare peat cover on the intact, un-eroded features may appear to be relatively low at < 5% (Figure 14), but the frequency with which bare peat was detected on these landforms is relatively high with approximately 12% of all micro-quadrats located on un-eroded areas (intact or hagg) having at least some bare peat present on them. Data gathered at the transect scale indicate that 64% of transects which had un-eroded bog present also had at least some signs of micro-erosion present, although the frequency of encounter on transects was somewhat lower at the lowest altitudes compared to the middle and upper reaches of the site (Figure 17).

Estimates of the total area which has micro-eroded features present within the un-eroded areas showed them to cover on average 22% of the un-eroded surface, but with a lower percentage at the lowest altitudes (10%) and higher percentage at the mid and upper altitudes (20-30%; Figure 17). Approx. 50% of the transects on which micro-erosion features were recorded showed either some signs of micro-erosion recolonisation or were completely recolonised. The percentage of recolonising features decreased with increasing altitude (Figure 17).



	1. < 650m	2. 651-750m	3. 751-850m	4. > 850m
■ Micro-erosion present	43.8	72.0	71.9	72.7
% Surface affected	11.0	25.0	29.5	20.9
□ Features re-colonising	61.9	55.6	41.3	43.8

Figure 17. The percentage of transects with un-eroded bog present on which micro-erosion features were noted as present (black bars). The extent of the features on the surface (grey bars) and the percentage of those features which were noted as recolonising or recolonised (white bars) are also shown.

Appendix 6 includes the notes from a geomorphological pilot study we undertook in the Monadhliath, the aim of which was to ensure that a reasonable understanding of surface processes was obtained prior to us preparing this report. Readers might find this to be a useful additional source of information, as it will allow them to gain a better understanding of the way in which physical processes on site act to break down the bog surface and to erode peat once it is exposed.

3.1.8 Recolonisation: status and processes

Whilst actively eroding bare peat is frequently observed across the site on major erosion features, recolonised major erosion features are also readily found. These features are discussed in this section. The following definitions help in understanding these features:

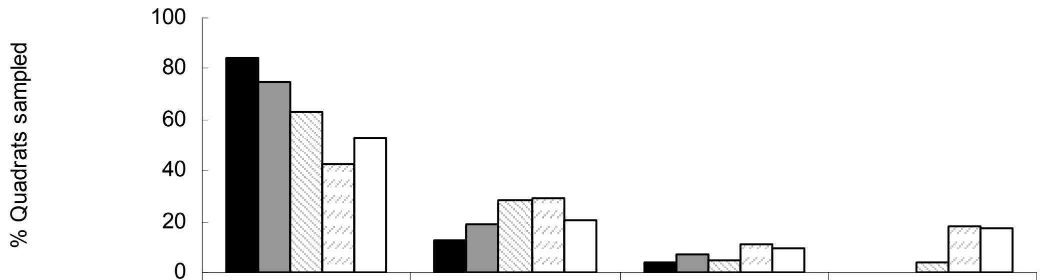
- 'Major erosion' features include the wall / apron and base / flat landforms, as distinct from the 'micro-erosion' features on intact bog and haggs as described previously, which can take the same form as major features but are much more superficial in comparison with the depth of peat present.
- 'Recolonised' eroded land is defined as a total lack of bare peat cover on a sampled quadrat – that is, a quadrat needs to have 100% plant cover, or almost complete plant cover but with some rock showing, and no bare peat present (clearly though, the vegetation on quadrats defined here as being 'recolonised' may well continue to develop in terms of species diversity, species abundance and plant stature).
- 'Recolonising' land is defined as eroded land on which some signs of plant establishment and growth are present but on which bare peat is also still present.

The analysis of recolonisation processes focused on the status of the 'base / flat' landform, because it is the degree to which these features erode before recolonising that determines the nature of the plant communities which develop afterwards. Intense erosion of these features results in most or all of the peat disappearing before colonisation occurs – it is unlikely in the early stages to result in bog habitat spontaneously redeveloping because the peat has disappeared and mineral soil is the major substrate; remaining peat haggs will 'lie proud' of the surface for long periods of time before new peat builds up around them. Less intense erosion of the base / flat features means that a deposit of peat is left, and a bog water table might still reside within the peat – therefore bog specialist species are more likely to re-establish, and in turn peat formation is likely take place straight away; peat haggs will be less prominent and the landscape will have a gently undulating form.

The percentage of micro-quadrats which were entirely recolonised (i.e. had 0% cover of bare peat) was *c*. 53% for the base / flat landform type on the Monadhliath site (Figure 18 upper). However, the depth of peat on completely recolonised base / flat areas varied with altitude; the depth of recolonised quadrats averaged 51cm at < 650m but this declined consistently with altitude to 6 cm above 850m (Figure 18 middle). Incidentally, the relationship between peat depth and altitude was less clear for quadrats in base / flats which still had bare peat present because the presence of bare peat implies that erosion is ongoing hence the system is not yet in a stable equilibrium.

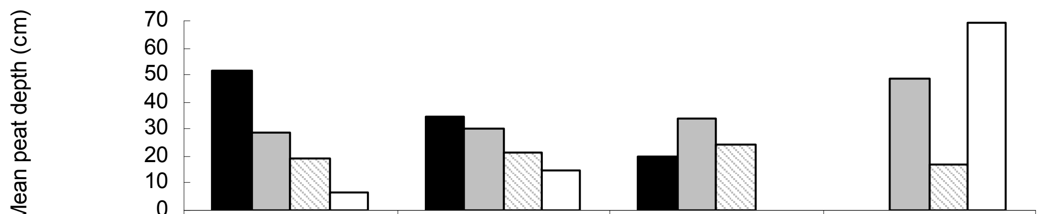
Further insight into the recolonisation process at high altitude is gained by examining the depth of peat on the set of fully recolonised base / flat quadrats located above 750m, which is the area that broadly coincides with the Monadhliath 'plateau'. The vast majority of quadrats (71%) in this area are located on very shallow peat (< 20cm) and only a few are located on deeper deposits (Figure 18 lower).

Overall, 28% of quadrats located in the base / flat landform had signs of bare rock present which further illustrates the volume of peat eroded from the site before recolonisation can take place.



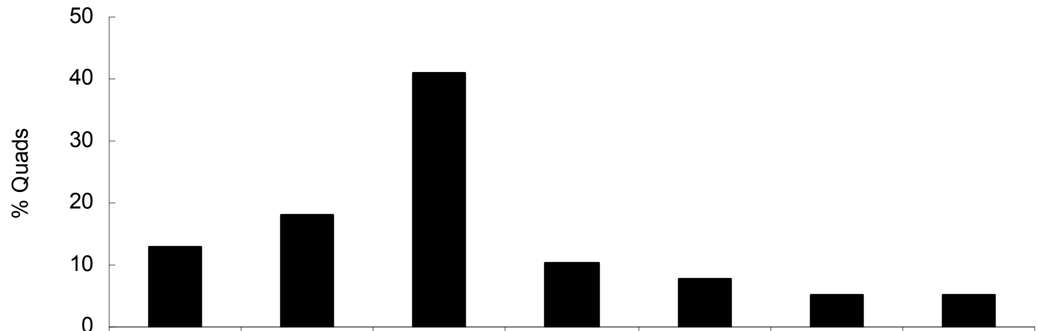
	1. 100%	2. 67-99	3. 34-66	4. 0-33
■ BB Intact	83.9	12.5	3.6	0.0
■ BB(E) Intact	74.4	18.6	7.0	0.0
□ Hagg	63.3	28.1	4.7	3.9
□ Wall/apron	42.5	28.8	11.0	17.8
□ Base/flat	52.8	20.5	9.2	17.4

% Cover of plants



	1. 100%	2. 67-99	3. 34-66	4. 0-33
■ < 650m	51.3	34.8	20.0	
■ 651-750m	28.4	30.0	34.0	48.3
□ 751-850m	19.0	21.2	24.1	17.1
□ > 850m	6.4	15.0		69.5

% Re-vegetated class

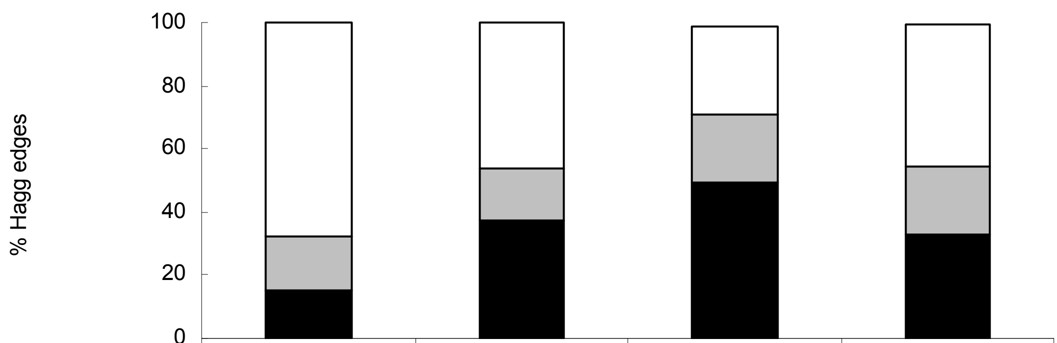


	1. 0cm	2. 1-10cm	3. 11-20cm	4. 21-30cm	5. 31-40cm	6. 41-50cm	7. > 50cm
■ %	12.8	17.9	41.0	10.3	7.7	5.1	5.1

Peat depth class

Figure 18. The percentage of micro-quadrats with varying plant cover levels according to landform (upper), the mean depth (cm) of peat present on quadrats in base / flats by altitude class and according to levels of vegetation cover present (middle) and variation in the depth of peat (cm) on quadrats located in directly eroded landforms (wall / apron and base / flat) above 750m which have full vegetation cover (lower).

The data held also show that base / flat landform tends to recolonise before the wall / apron landform. That is partly because the plants are probably sheltered in the bases and flats while the walls / aprons often sit proud of the landscape and are thus exposed to the weather. That said, what was also clear was that walls / aprons do eventually 'seal up' with time in most circumstances (see image in Appendix 4). The time at which the recolonised base / flat merges with the old hagg top vegetation and thus sealing occurs was more frequently observed at lower altitudes and less frequently observed at the higher altitudes (Figure 19), The relatively high level of sealing at the highest altitudes appeared to be due to the inherently shallower nature of the peat deposits there, and the fact that a small absolute difference in depth between haggs and the gully base or peat flat (i.e. the size of the gap on the gully wall to seal is much smaller) means that the sealing process seems to occur more readily.



	1. < 650m	2. 651-750m	3. 751-850m	4. > 850m
□ Sealed	67.6	46.3	27.6	45.3
▩ Part sealed	17.0	16.3	21.5	21.6
■ Open	15.4	37.5	49.6	32.6

Altitude class

Figure 19. The percentage of hagg edges judged to have 'sealed', 'partly-sealed' or not sealed (i.e. remain open) according to altitude.

The assemblage of plants present in gully bases / peat flats once fully recolonised was not studied in detail but appeared to be different in some key respects to the remnants of intact bog. Notable features (Figure 20 upper and lower) included that:

- The abundance of *Sphagnum capillifolium* was relatively constant across all landforms once colonised[9], whereas the abundance of other *Sphagna*, of which by far the most important was *S. papillosum*, was much higher on the intact bog compared with all other landforms. *S. papillosum* is a useful proxy for the presence of an undisturbed water table in deeper peat, with *S. capillifolium* common across a wider range of habitats because it is able to cope with a wider range of water table fluctuations and also disturbance (e.g. it is often still found on mires damaged by drainage whereas *S. papillosum* is often not found in drained areas).
- The frequency with which true grass species were encountered was highest on recolonised bases / flats and lowest on intact bog and haggs. These species tend to be most dominant where peat is shallow or absent, and also where conditions tend to be somewhat drier, which corresponds well with the nature of areas affected by severe erosion.

[9] Intact bog and haggs retain the original bog surface, whereas the other landforms have been directly affected by erosion and must therefore have developed a new cover of vegetation once erosion ceased.

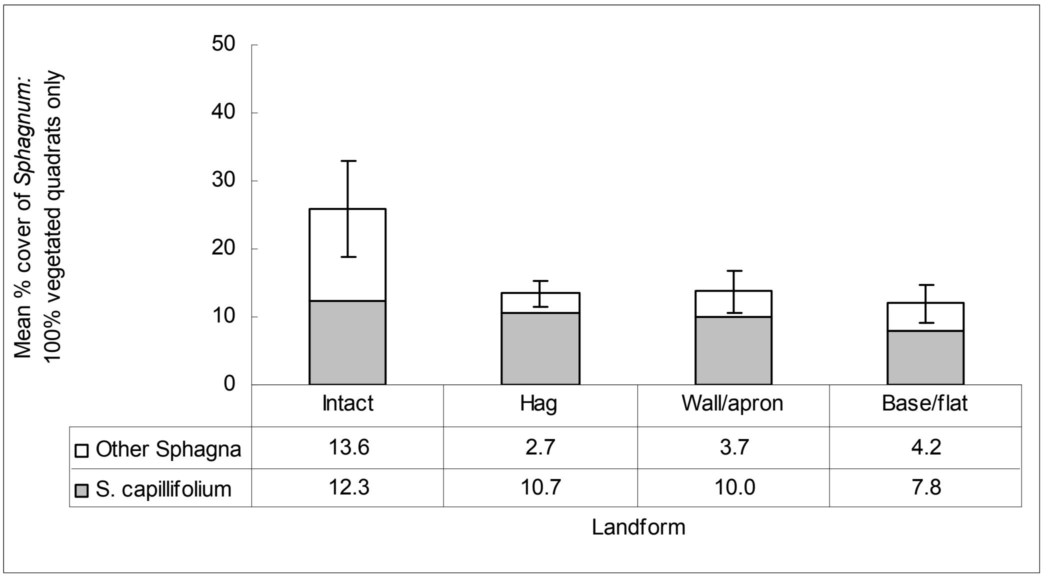


Figure 20. The mean percentage cover of Sphagnum spp.[10] recorded on fully-vegetated quadrats on various landforms within the original bog extent (upper) and the percentage of quadrats on which true grasses[11] (e.g. Nardus, Agrostis spp.) were recorded as present on the same quadrats (lower).

[10] 'Other Sphagna' included a range of species but the most common was *Sphagnum papillosum* which is a common species found on intact blanket bog.
[11] As distinct from Cotton-grasses in this study.

The fact that successful recolonisation of eroded surfaces by plants does occur in the Monadhliath is of significant interest, but the actual process by which plants eventually recolonise bare peat is equally important to consider. The literature on peat erosion, well summarised by Evans and Warburton (2007), mentions a number of what are termed 'topographic controls' on the colonisation process:

1. Peat dead flats onto which *E. angustifolium* can colonise at the edges where a relatively stable layer of sediment can build.
2. Turves falling from hagg edges which can cause sediment to back up behind them in gully bases and hence *E. angustifolium* can often colonise.
3. Turves falling from hagg edges, as above, but with the assemblage of species present on the turf then expanding onto the deposited sediment.

A number of other forms of colonisation are apparent in the Monadhliath[12], including:

4. Colonisation of plants onto bare rock exposed by extreme erosion, by the usual process of lichen growth followed by moss development and hence skeletal soils suitable for vascular plants to establish on.
5. The vegetative spread of hagg remnants which are left on peat flat surfaces following major erosion events.
6. The vegetative spread of plant fragments, notably *Sphagnum* fragments, trapped during the process of slope wash long enough to take hold.
7. Plants left behind after the collapse of a peat pipe roof surviving to recolonise bare land on the edges of the collapse - the surviving vegetation is often modified in appearance.
8. Colonisation of *E. angustifolium* from seed, in areas sheltered by the remains of dead *E. vaginatum* root masses left from the original mire surface.
9. Creep of plants, notably dwarf shrubs, from hagg edges out onto bare peat notably where the wind deposits blown sediment.

It is also very obvious that the process of recolonisation on the Monadhliath site does not necessarily involve the germination of a plant followed by guaranteed 'ongoing survival'. There are in fact a range of processes which lead to plant death either in the period soon after germination or after establishment, the corollary being that plant colonisation does eventually seem to happen but can involve many interim stages when plants colonise then disappear again. The data already presented show that the eroding surfaces do seem to have particular characteristics (according to altitude) which seem to determine the point at which complete vegetation cover develops on the eroded surface. The situations in which plants colonise but then subsequently disappear, which are perhaps most notable and important on the upper reaches of the site, include:

1. New plants being swamped by sediment washing down from upslope, or from peat pipes which spew sediment out of holes in their roofs during storm events.
2. New plants being undermined and swept away by fluvial action (and possibly on occasions pluvial action; mainly very young plants) during major storms.
3. New plants being undermined by wind, when it creates pedestals which expose the plants' roots and kill through stress.
4. New plants being lifted out of the ground by frost heave, during thaws following cold weather when needle ice has formed.

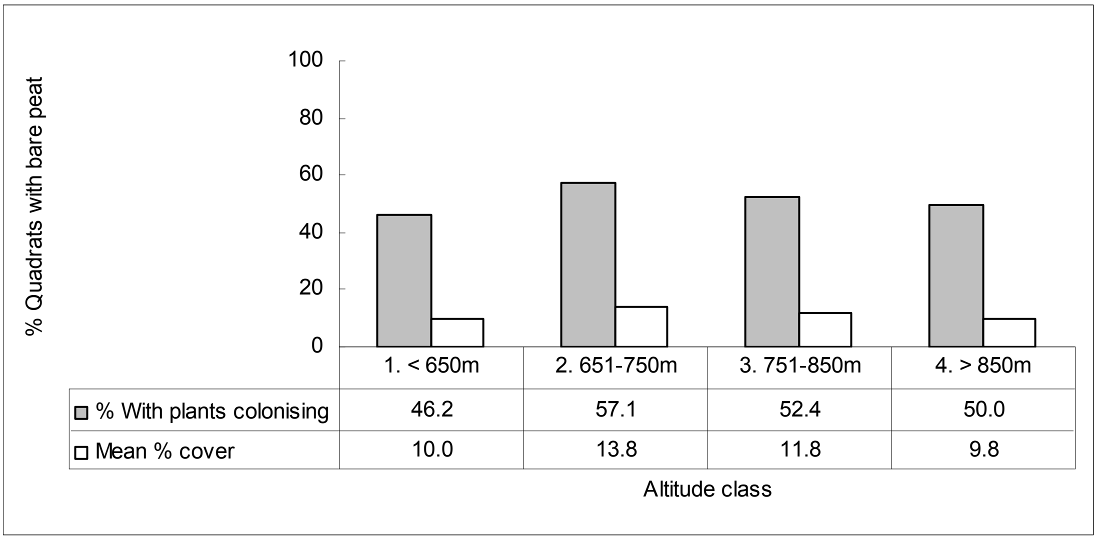
[12] Much of the recent academic work done on peat erosion in the UK has been undertaken in the North of England where peat deposits, and notably those being eroded, exist at much lower altitudes where the weather processes are not as extreme as in the Monadhliath. Hence some of these processes are not mentioned in the key texts.

5. New plants being disturbed and carried away by the creep of frozen snow packs, or by abundant melt waters at the downslope side of melting drifts in spring.
6. New plants being blasted continuously by mineral grains, produced by frost action on exposed eroded bases / flats which are then carried across the surface during wind storms.
7. New micro-erosion forming, which causes stresses in areas where plants are colonising.

Appendix 4 includes a range of images showing some of the processes by which new plants arrive on site and then disappear after colonising.

Current levels of plant recolonisation on bare peat surfaces are in some senses difficult to measure from a single visit to site, as the surveyor has to judge what is new plant cover (germinated on the bare peat) and what is old plant cover (i.e. remnants of the original mire surface, sitting on the bare peat). Certain plants are typical of a recolonised surface, perhaps most notably *E. angustifolium* on the Monadhliath site, so a sensible judgement of the minimum percentage cover of new plants can normally be made. Where quadrats had bare peat present, the percentage of the bare surface judged to have colonised with new plants was assessed.

Approximately 50% of all quadrats containing bare peat also had signs of new plants colonising the bare peat, but the percentage cover of these plants was on average only 10-15% (Figure 21 upper). It was also noticeable that there was little difference between altitude bands in terms of the percentage of quadrats colonising, or the percentage cover of colonising plants.



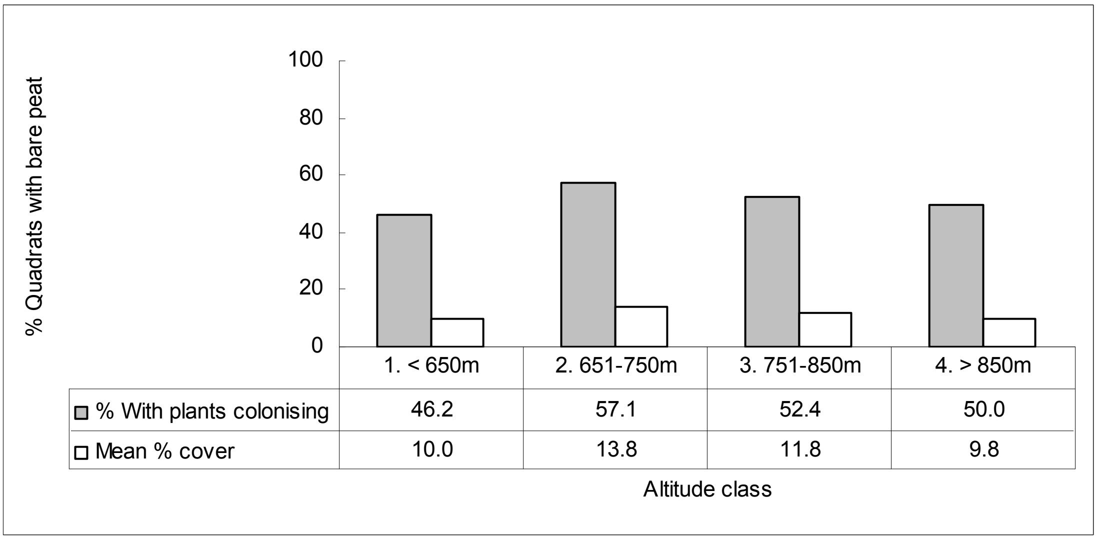


Figure 21. Levels of recolonisation of new plants on bare peat by altitude (upper; showing percentage of quadrats with colonisation signs and percentage cover of colonising plants) and landform (lower).

On quadrats on intact landforms the bare peat supported quite variable levels of new plant cover, although the majority had low cover levels; on the directly eroded landforms (e.g. base / flats) the majority of quadrats had no or little cover of new plants present on the bare peat (Figure 21 lower).

This section of the report has provided a general description of the patterns of bog and eroded bog occurrence on the site, as well as some of the key factors which appear to influence bog extent, character, erosion and recolonisation with plants. The next sections investigate (i) the pattern of deer usage within the study area and (ii) the effects deer might be having on current condition of the site (i.e. their impacts).

3.2 Deer occupancy levels

3.2.1 Pellet group density estimates

The rate of accumulation of faecal pellet groups (deer and sheep) across the study site as a whole was 663 per km^2 (95% CL +/- 11.2%; Figure 22). However, marked variations in rate were apparent between estates; the rates in Garrogie and the Coull / Blaragie area were around 50% lower than the rates in Glen Banchor, Glenshero and Cluny (Figure 22; see also Appendix 1 – Map 6). The rate in Coignafearn was intermediate between the lowest and highest values.

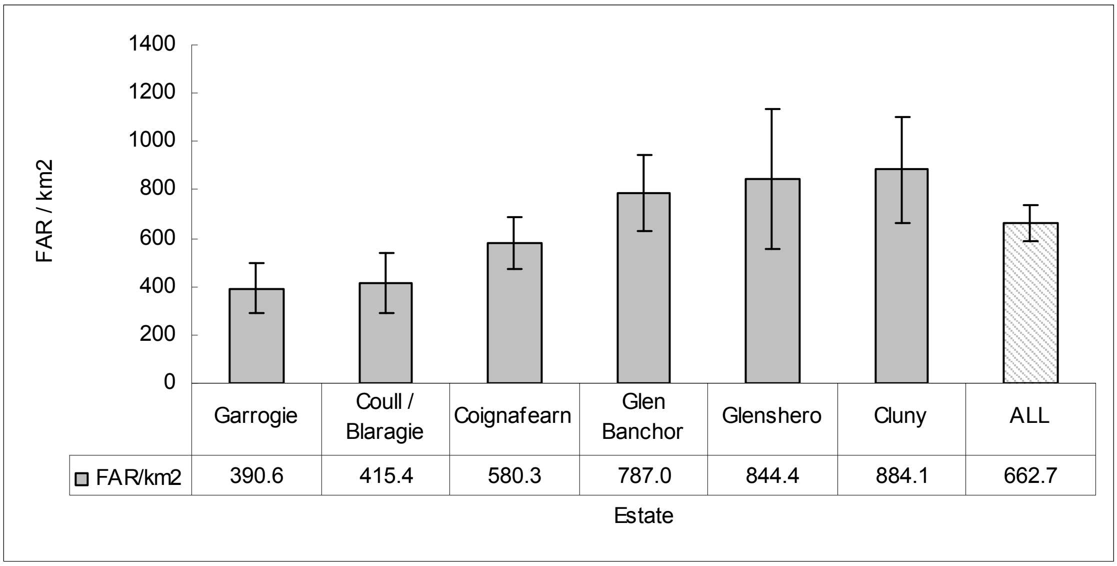


Figure 22. The faecal accumulation rate (FAR) for summer-autumn 2011 by estate (with 95% CL's).

The FAR also varied with altitude and slope angle. Utilisation levels were higher in the lower altitude band than in the other bands (Figure 23 upper; Appendix 1 – Map 6). The lowest (altitude) band is where the majority of sheep sightings were made on both visits to site, and this may partly explain the elevated levels herein.

Utilisation levels also generally increased with slope angle; this pattern was fairly consistent with altitude, albeit differences were somewhat less pronounced with increasing elevation. Slope angle is a useful proxy for broad habitat type, the corollary being that large mammals on the site show a preference for habitats such as dry heath and grassland over wet heath (bog) at all altitudes although the strength of the preference appears to decline somewhat with increasing altitude. The overall preference is likely to arise because of the general differences in palatability and digestibility of the forage available in these broad habitats.

The pattern of reducing habitat preference with altitude is likely to be due partly to the progressive decline in extent of preferred habitat types as altitude increases Furthermore, the preferred habitats tend to occur more frequently as 'islands' within the wider mire complex at higher altitudes. Grazing mammals will therefore have to traverse less preferred habitat to get to a preferred one, increasing the likelihood of utilising resources in the less preferred one.

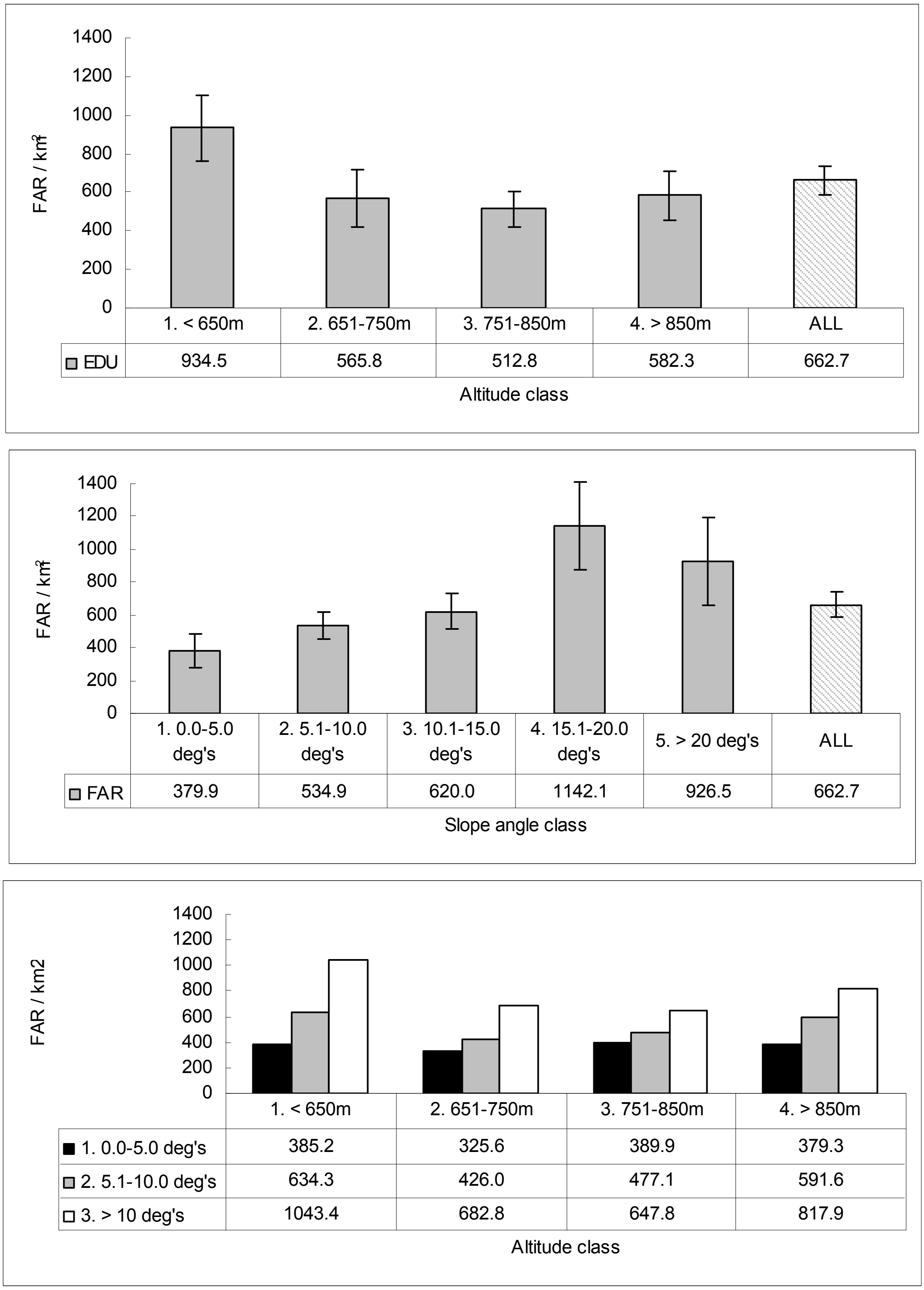
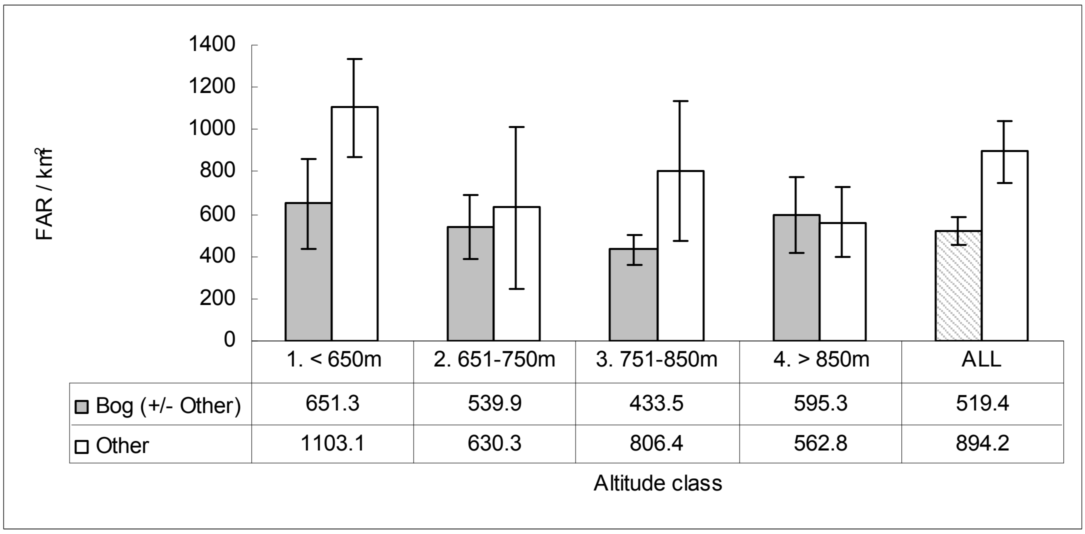


Figure 23. The faecal accumulation rate (FAR) for summer-autumn 2011 according to altitude (upper), slope angle (middle) and the interaction (lower).

Analysis of the rate of faecal accumulation by broad habitat type and according to altitude confirms that there is a general trend towards increased levels of utilisation with increased grazing quality (Figure 24 upper) and that this preference is even apparent at the scale of the individual transect (Figure 24 lower).



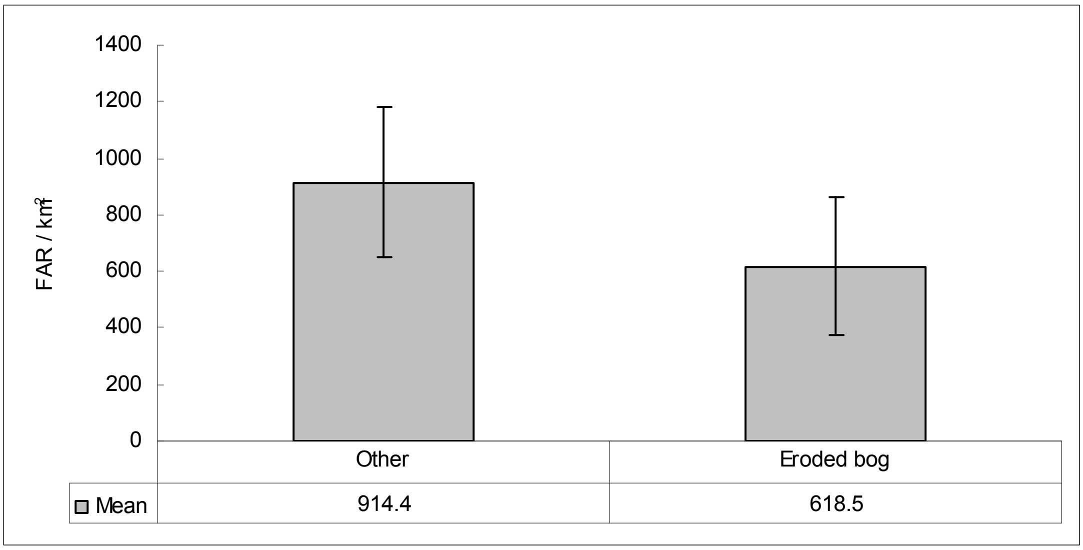


Figure 24. The faecal accumulation rate for summer-autumn 2011, with altitude according to the dominant habitat type recorded on transects (upper) and only for pairs of transects on which the two more common habitat types (Eroded bog and Other) were both present.

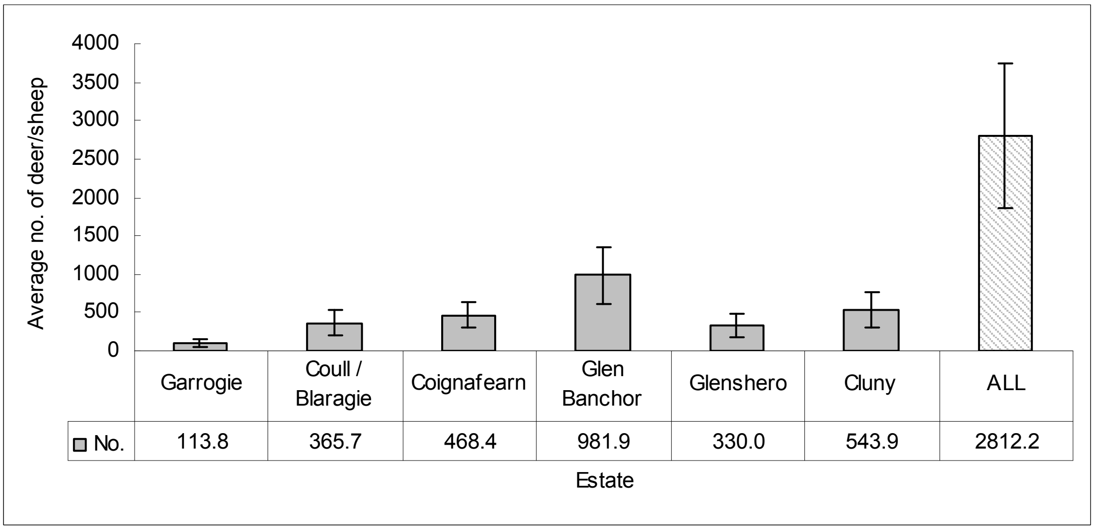
3.2.2 Estimates of deer abundance

The pellet group accumulation rate data can be used to produce estimates of deer density and hence deer abundance for the study site. The standard analysis involves transformation of the pellet density data using estimates of the average deer defecation rate, as described in Swanson *et al* (2008). As FAR studies are normally carried out over the winter period a rate of 20 groups per day (Mitchell and McCowan 1984) is used. However, this study measured the rate of accumulation over the summer-autumn period and the rate in Scottish upland conditions is thought to be higher at this time of year (25 groups per day; Mitchell and McCowan 1984) because of factors including the higher proportion of water and the lower proportion of fibre in the diet. The extent to which this is true for the Monadhliath site has never been studied, and so the 25 groups per day estimate is employed as the best estimate available. The use of the lower rate of 20 groups per day would increase any density estimates presented here by 25%. The defecation rate for upland sheep when studied by Welch (1982) was shown to be fairly similar to that of deer in equivalent conditions – this is relevant because the pellet group density estimates for the site have sheep as well as deer present and so a common rate needs to be used.

The average number of deer/sheep estimated to have been using the site over the study period was 2812 (95% CL +/- 33%[13]), assuming the defecation rate of 25 groups per day. The average abundance estimates for each estate varied markedly, as did the density estimates for each area calculated using the abundance estimates and the area (ha) of land each estate has within the SAC (Figure 25 upper and lower).

The number of sheep included within the abundance estimates cannot be confirmed with certainty because the site was only visited twice during the accumulation period (start and end) to check sheep numbers. On the basis of counts undertaken, the number of sheep seen on any one visit to site never exceeded 200 within the SAC although there were more on its immediate margins. We conclude that sheep contributed no more than *c*. 10% of the accumulated pellet groups measured. Interestingly, sightings of sheep were predominantly on lower slopes and on heath and grassland habitat rather than at higher altitudes where bog habitats are much more common.

[13] The 95% CL of the abundance estimate incorporates the variance associated with the defecation rate estimate as well as that of the pellet density estimate which is why the 9% CL is much wider for the abundance estimate than for the pellet density estimate.



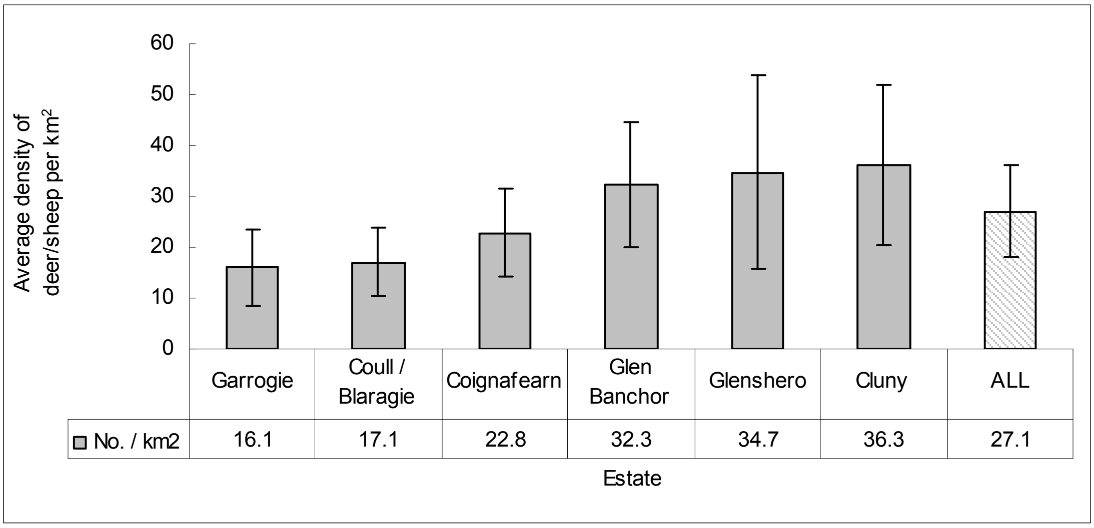
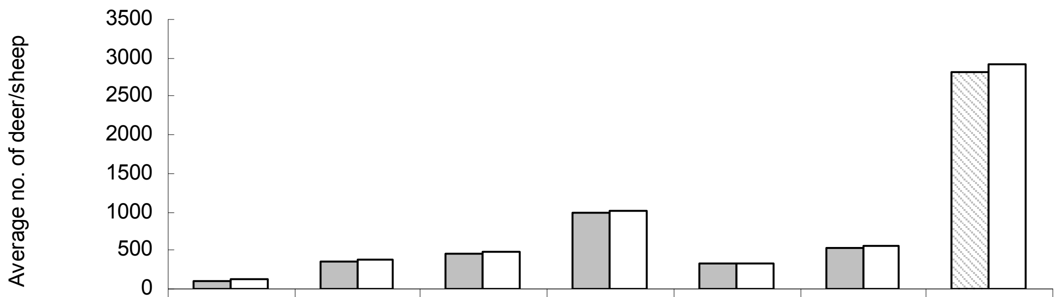


Figure 25. The average abundance of deer / sheep present over the study period (upper) and the average density of deer/sheep per km^2 (lower) as determined by faecal accumulation rates.

The pellet group density and abundance estimates presented above contain a number of known biases:

1. 'Ghost groups': FAR studies undertaken over a period that deer are being culled will include within the final measured accumulation a proportion of pellet groups which came from deer now dead. Unfortunately, SNH was unable to provide detailed information on the number and location of the deer shot within the SAC boundary and hence no adjustment for ghost groups could be made. However, even in very heavily shot populations these adjustments rarely result in anything more than a c. 5% downwards adjustment to density estimates for data gathered over winter on sites with intense culling. Therefore, given the site does not appear to be culled intensively (see data in next section) biases due to the presence of ghost groups are unlikely to be any more than 1-2%.
2. Intermediate decomposition: studies undertaken over a period when pellet groups are actively decaying can be biased if any of the new pellet group accumulation after the first visit to site decomposes entirely before the second visit to site. Monitoring shows that 14% of pellet groups that were fresh on the first visit had decomposed entirely by the time of the second, although most of these were not on bog habitats (i.e. were on grasslands, bracken stands and dry heath etc). Modelling indicates that

a maximum of 3.5% of the new groups which accumulated between V1 and V2 decomposed before V2 and hence the pellet density estimates should on average have been higher. An underestimate of 3.5% would act to increase the quoted abundance estimates by the amounts shown in Figure 25.



	Garrogie	Coull / Blaragie	Coignafearn	Glen Banchor	Glenshero	Cluny	ALL
Original	113.8	365.7	468.4	981.9	330.0	543.9	2812.2
Adjusted	117.9	379.0	485.4	1017.5	342.0	563.7	2914.2

Estate

Figure 26. The average abundance of deer / sheep present over the study period based on the unadjusted original data (grey bars) and the data set adjusted to allow for intermediate decomposition (white bars).

The pellet density estimates specific to the Monadhliath might also contain another normally uncommon form of bias relating to the slope wash processes that occur frequently on bare peat surfaces. It is possible that pellet groups deposited on bare peat surfaces might be washed, or potentially even blown, away during the period between site visits and hence the resultant abundance estimates might be biased downwards.

An estimate of this bias can be made by considering in theory the maximum likely level. The actual percentage of land covered by bare peat varies in the Monadhliath according to altitude, being only 2.1% of total land cover at the lowest altitudes (< 650m) rising to 7.2% at 651-750m and to 16.2% at 751-850m before falling back to 9.7% at > 850m. Given that deer show no preference for utilising bog habitat, and in fact seem to prefer other habitats, one would expect that the bias arising due to 'slope-wash losses' on bare peat is certainly unlikely to account for any greater than a 15-20% underestimate in pellet group density in the altitude band where bare peat is most common – of course the bias will likely be proportionately lower in the other altitude bands. However, quoting this degree of bias presupposes that all groups on bare peat will be lost to slope-wash and that none of these pellet groups would be seen elsewhere (e.g. lower down the slope). A considerable proportion of the bare peat present on the site is located on large bare peat flats where slope wash appears to be common and longer-distance movement of pellet groups is most likely, but some of the bare peat is situated in patches located within otherwise well-vegetated areas where slope wash processes are (i) unlikely to move groups far and (ii) are unlikely to bury them so deeply as not to be discovered at all. In fact, when surveying the site pellet groups were observed as being present on the bare peat on both visits and hence one would assume at least some of them are not moved (or are moved at all).

The actual data gathered on site suggests that there is relatively little evidence to support an elevated level of loss from this process given that in total only 7% of marked groups on Visit 1 were subsequently not found at all across the site as a whole on Visit 2 (i.e. pellet groups and markers both disappeared) but that rates of loss were around this level irrespective of the percentage of bare peat recorded on the transects assessed. It is not to say that some losses did not arise due to slope-wash; rather, that the level of loss appears to have been relatively low and only probably significant on parts of the highest reaches of the site where large actively-eroding peat flats are present. On the basis of the evidence gathered it was decided not to try and adjust estimates for this form of bias as it appears to have been localised.

Abundance estimates, once adjusted for any biases (e.g. due to intermediate decomposition and ghost groups) are normally analysed further, the aim being to adjust the data in order to facilitate an assessment of the likely trajectory of the population (i.e. is it rising, stable or falling?). The additional analysis work normally undertaken on the 'adjusted abundance' estimates is as follows:

1. Model the adjusted abundance estimate back to the 31st March (end of the cull season) – this takes account of any male deer shot in the months of April, May etc which many studies run into ('31st March' estimate).
2. Model the '31st March' estimate back 12 months to the start of the previous cull season ('1st April estimate') using the estimate obtained above in 1. This produces an estimate of the number of deer present before culling started in the previous year, and thus an estimate of the percentage of deer culled in the cull season just ended can be produced. This, when compared to the likely rate of recruitment over the period which can often be calculated from cull data or stalker diary records, can be used to ascertain whether the cull in that year would have caused the population to rise, stay stable or fall. Of course, the adjustment to date and subsequent calculations assume that there was no deer movement across study site boundaries over the adjustment period.
3. The '31st March estimate' can also be used to model the population forward to ascertain the likely trajectory of the population for a given rate of culling for a period of years following the survey. The most powerful test available is then to repeat the pellet group count survey in 2-5 years time and compare the actual results against the model predictions of abundance (see Appendix 7 for an example of how this works in practice).

As the estates apparently do not hold records of the number of deer culled within the SAC, it is not proposed at this juncture to perform the analyses as described above. Of course, many experienced practitioners involved in management of the site believe that large fluctuations in abundance occur within the SAC over the course of a typical year and hence some of these analyses may not be applicable anyway. Irrespective, what can be done is to consider what data are available to help understand something of the likely trajectory of the population using the SAC and the wider area around it. The SNH direct count data and SNH cull returns are central to this.

3.2.3 Direct count and cull data

SNH provided the cull returns for each estate that has land within the SAC, and also provided live deer count data both for the SAC area itself (July 2003, July 2007, July 2010) (Table 3) and for the wider DMG area which contains count data for each estate in its entirety (Table 4; March 2004 only). SNH also provided GIS data which confirmed the area of land contained within the SAC (Table 3) and the size of each estate in its entirety (Table 4).

The live count data for the SAC imply a trend towards increased numbers of deer being present between 2003 and 2010. They also show that the density on the most recent assessment in July 2010, if representative of the average level of occupancy, would be considered high for an upland site at 28.9 per km^2 (Table 1). Interestingly, the most recent live count density is not dissimilar to that obtained by the FAR study. Critically though, only one live count was undertaken each year. It is therefore not possible to draw any firm conclusions about the trend in occupancy within the SAC, especially given that the live count data supplied confirms that variation in numbers within estates between years is very marked (see Table 3). This implies that, when viewed alongside the cull data, high levels of deer movement may occur between estates within the SAC, and hence may also occur across the SAC boundaries.

Irrespective, the live count data for spring 2004 confirm that a much larger population of deer was present in the wider estates (7,438 Red deer counted at the end of February that year by helicopter) than in the previous summer on the SAC itself (1,772), and this at least shows the *potential* for large fluctuations to occur given the lack of perimeter deer fence around the SAC.

Table 3 - Live count data for the Monadhliath SAC supplied by SNH.

Estate (SAC only)	Area (ha) in SAC	July 2003	July 2007	July 2010
Cluny	1,538	381	403	61
Coignafearn	2,108	521	646	588
Coull (incl Blaragie)	2,201	369	228	608
Garrogie	728	41	278	622
Glen Banchor	3,119	226	630	965
Glenshero	977	234	6	235
ALL	**10,671**	**1,772**	**2,191**	**3,079**
Density / km^2		16.6	20.5	28.9

Table 4 - Live count data for the wider estate areas supplied by SNH.

Estate (entire)	Area (ha)	Spring 2004	Density / km^2
Cluny	4,234	964	22.8
Coignafearn	16,010	1,347	8.4
Coull (incl Blaragie)	3,216	506	15.7
Garrogie	12,062	1,155	9.8
Glen Banchor	4,751	561	11.8
Glenshero	14,262	2,875	20.2
ALL	**54,535**	**7,408**	**13.6**

By adding the 2003-04 cull figures (Figure 26 upper; 1413 animals) back onto the spring 2004 count, it is possible to obtain an approximate population estimate for the wider estates area in summer 2003 of 8821 animals[14]. The summer 2003 count data for the SAC of 1772, admittedly obtained on a single day and thus not necessarily reflective of average occupancy, comprises 20.1% of the summer 2003 population estimate for the wider estates; the SAC comprises 19.4% of the wider estates land implying that the SAC on the day of the count in July 2003 did not hold a disproportionately high percentage of the wider population.

[14] This figure ignores natural mortality, road kills and illegal taking of deer.

Whether or not this is reflective of the general situation, i.e. approx. 20% of the wider estates population tends at any one time to be present in the SAC in the summer months, is difficult to ascertain without detailed study of the site over a long time period. It would certainly be of interest to confirm, because effective management of the SAC depends to an extent on an understanding of this relationship. Whilst this relationship is best defined by a longer-term study of occupancy levels inside and outwith the SAC, there are some data available at the present which can help to shed some further light on this matter.

The summer 'live counts' were higher in the SAC in the years after summer 2003, being 2191 in 2007 and, subsequently, 3079 in 2010. The results may be a reflection of a general upwards trend in occupancy levels over the period. Of course, we could as easily argue that the live count is simply a reflection of what is present on the day of the count and cannot reliably confirm longer-term occupancy levels unless repeated numerous times over a period of months. Irrespective, we know that occupancy in summer-autumn 2011, measured reliably using a dung count technique, was much closer in level to the most recent live count than any of the previous ones. This implies that a higher percentage of the wider estates population (c. 30-40%) may use the SAC than is suggested by the 2003 count data as previously described (c. 20%). That said, calculation of this percentage depends in turn on whether or not the wider estates population has remained stable.

Given that no 'wider estates' live count has been undertaken since 2004, a population model-based approach is required to establish the likely trajectory of the wider estates population over recent years. The cull records from the estates, as submitted to SNH, were used to help parameterise a population model of the wider estate area.

The cull records for the estates since 2003-04 (Figure 27) were analysed to summarise trends in the size of the cull, and the density per km^2 of the cull, taken in the wider estates. They were also analysed to ascertain possible rates of recruitment based on information held in the cull records[15] (Figure 28 upper).

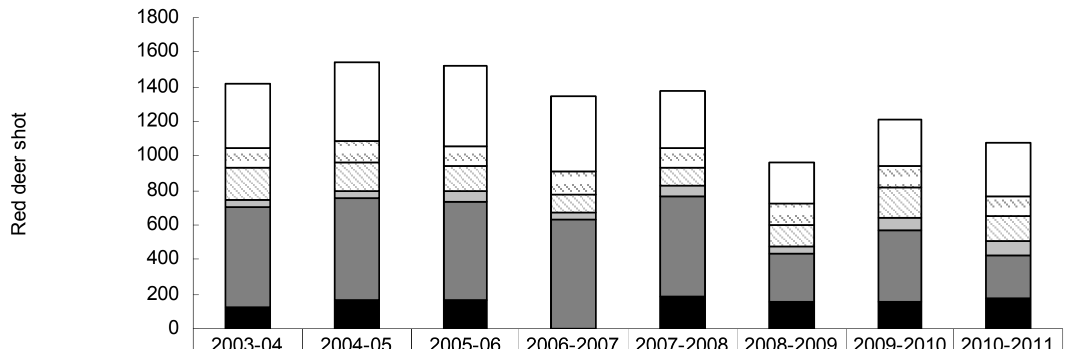
The percentage of Red deer calves at foot in the cull returns to SNH[16] varies from 19% to 49% over the eight year period supplied (Figure 28 upper). The trend in the data is towards a pattern of rising and then falling levels over the period. However, it is unclear how representative the calculated percentage in each year is because no companion data were made available (e.g. diary records) to assess the likelihood of bias, nor otherwise to assess the stalkers' policy of culling calves (versus hinds) during winter when the chance arises. Nevertheless, the percentage of calves at foot is an important factor to consider as it determines, when viewed with the actual cull taken and assuming a 'static' population is present, the likelihood that a population is rising, stable or falling.

In terms of cull numbers, the overall trend in the wider estate area was towards a declining cull in recent years (Figure 27 upper; high point of 1545 in 2004-05 and a low point of 960 in 2008-09). That said, a considerable part of this decline in recent years was because of the reducing culls in Coignafearn. Other estates show a trend towards increasing culls in recent years (e.g. Coull) whereas many had a stable pattern of culling overall. It was also noticeable, and important to consider, that some estates cull a far higher density of deer than others according to the records supplied (e.g. Cluny consistently cull a density of 3.5-4.5 deer per km^2 annually whereas Garrogie consistently cull 1.0-1.5 per km^2 annually). Culling

[15] There are a number of reasons why this calculation may be biased, most notable of which is that stalkers may selectively choose to shoot hinds over calves or vice versa and thus the ratio of calves: hinds shot might not reflect that in the population as a whole.
[16] Excluding Roe and Sika deer (*Cervus nippon*) which are rarely seen in the SAC - only 5.6% of the cull in the wider area comprises Roe and Sika deer and this wider area includes all the woodland in which both these species tend to spend most of their time.

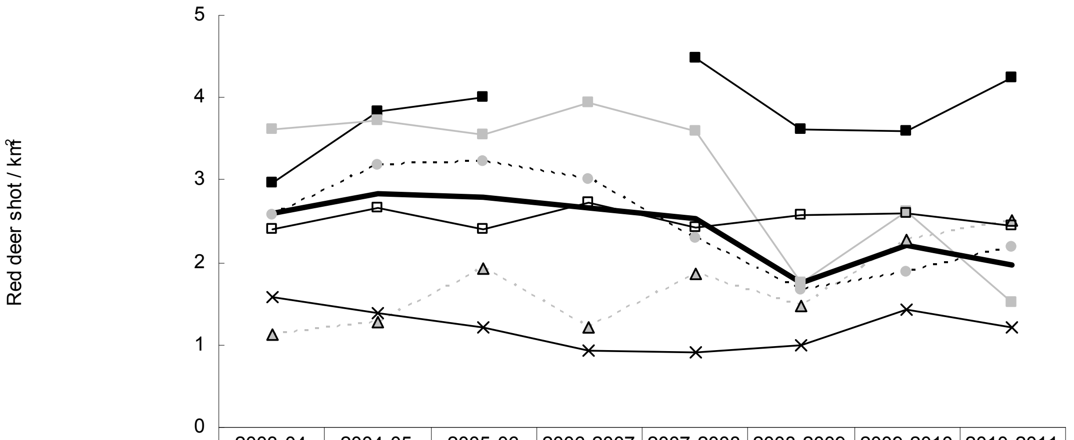
intensity might be in part a reflection of management policies followed but the occupancy data gathered in summer 2011 imply that at least some of this variation is related to densities of deer present.

Of related interest is the breakdown of the cull in terms of sex and age class (Figure 28 lower). The trend was towards a strongly declining hind cull over the period whereas the calf cull rose and then fell gently over the same period; the stag cull declined overall but at a slower rate than for the hinds. However, major differences were apparent between estates (e.g. Glenbanchor culled stags: hinds in a ratio of 2: 1 over the period whereas the ratio in Glenshero was 0.83: 1). The analysis of cull records as a whole shows that there are major differences between estates, and between years, in the size and nature of the cull taken. The corollary is that the dynamics of the deer sub- populations using the wider estates area will also be complex, and thus their relationship with the SAC will be difficult to ascertain without long-term empirical study.



	2003-04	2004-05	2005-06	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
Glenshero	366	454	459	429	328	237	268	313
Glenbanchor	114	127	114	130	115	122	123	116
Garrogie	191	166	147	112	109	121	172	146
Coull	36	41	62	39	60	47	73	81
Coignafearn	580	595	567	630	575	280	420	243
Cluny	126	162	170		190	153	152	180

Season



	2003-04	2004-05	2005-06	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
Cluny	3.0	3.8	4.0		4.5	3.6	3.6	4.3
Coignafearn	3.6	3.7	3.5	3.9	3.6	1.7	2.6	1.5
Coull	1.1	1.3	1.9	1.2	1.9	1.5	2.3	2.5
Garrogie	1.6	1.4	1.2	0.9	0.9	1.0	1.4	1.2
Glenbanchor	2.4	2.7	2.4	2.7	2.4	2.6	2.6	2.4
Glenshero	2.6	3.2	3.2	3.0	2.3	1.7	1.9	2.2
All	2.6	2.8	2.8	2.7	2.5	1.8	2.2	2.0

Season

Figure 27. The number of Red deer culled in the wider estates area over an eight-year period (upper) and the density of the cull per km^2 (lower). N.B. records for Cluny not supplied for 2006-07.

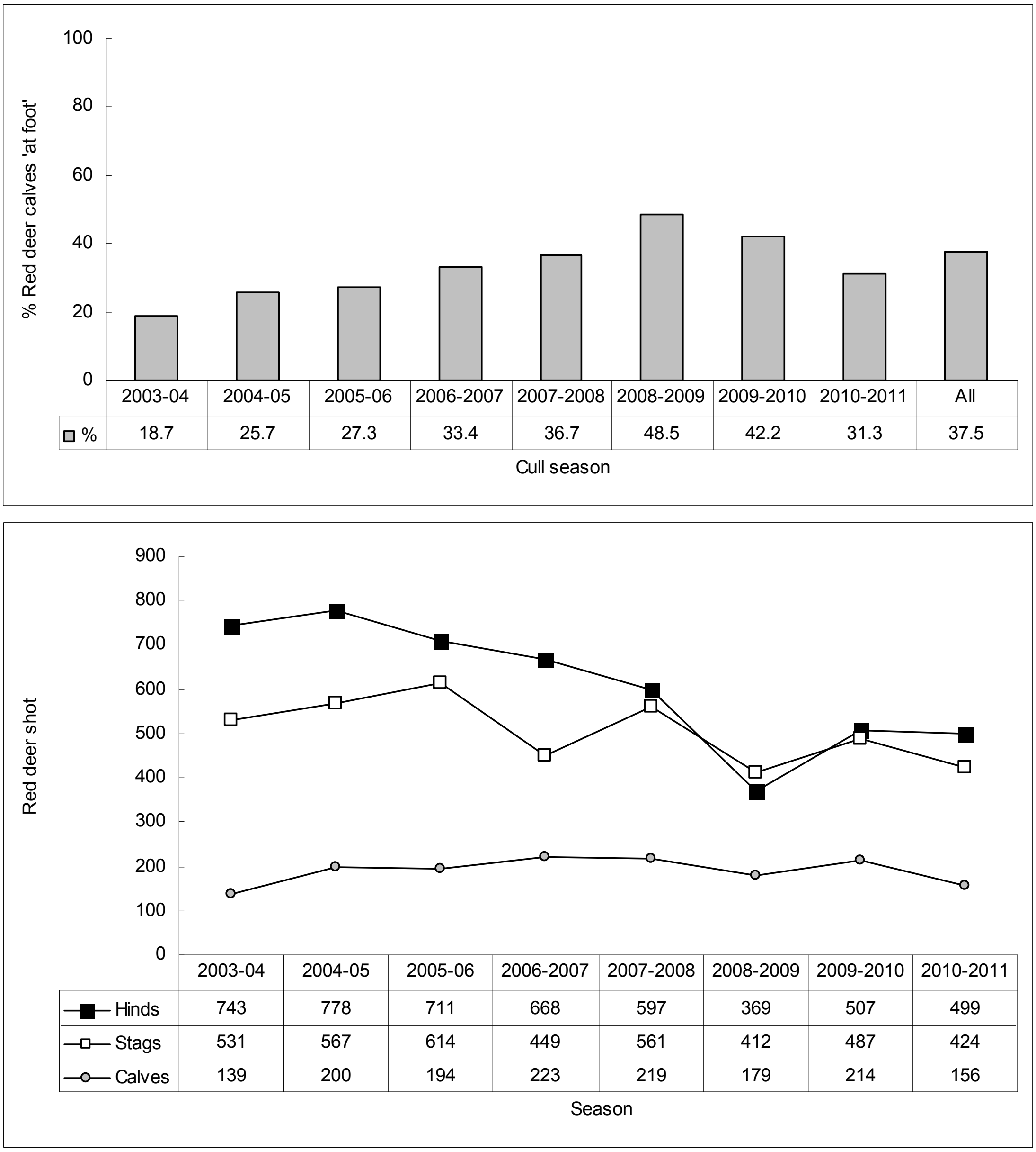


Figure 28. The percentage of Red deer calves at foot (upper) and the trend in numbers of stags, hinds and calves culled (lower) in the wider estates area as calculated from cull records provided to SNH.

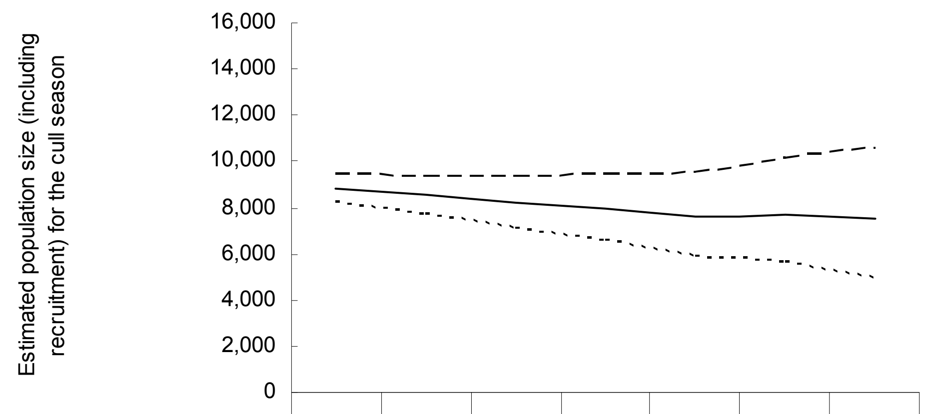
Whilst the dynamics of the individual deer sub-populations are difficult to quantify without further study the ‘estate-wide population is clearly still worthy of further study. Population models were built to investigate the likely range of responses of the ‘estate-wide’ population to culling over the period since the last count in 2004 and used the following inputs and assumptions:

1. The estate-wide population in spring 2004 was 7408, as suggested by the DCS count report supplied by SNH. However, additional scenarios were also modelled based on the spring 2004 count because over and under-counts are possible when undertaking direct census work. Two extra scenarios were modelled (“+ 5%” and “–5%”) to illustrate the effect on predictions of small variations in the ‘starting population’ size.
2. The adult sex ratio was 1: 1, based on the fact that there is little evidence to suggest a skew in the sex ratio of the wider population.

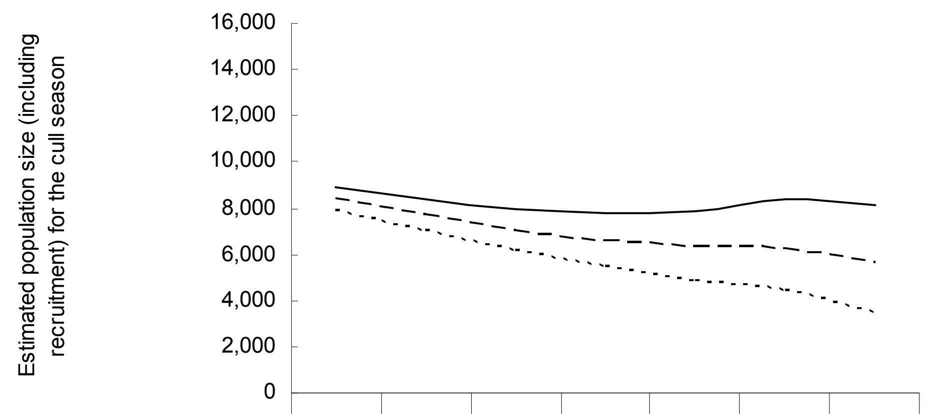
3. The juvenile sex ratio at birth was 1: 1, given the lack of evidence to the contrary.
4. Recruitment rates were calculated from the calf-at-foot ratios evident in the cull data; the rates of recruitment were modelled under two additional scenarios to account for a possible error of +/-10% in the rate used (e.g. a 50% calf-at-foot rate in the records was also modelled using 45% and 55% to investigate sensitivity).
5. Natural mortality rates were estimated to have been 1% of the population overall annually (in addition to culling) other than in 2009-10 and 2010-11 when a higher estimated rate of 2% was used to account for the severe winters. It was assumed that illegal taking did not occur within the study area, nor did road traffic accidents (RTAs) occur.
6. There was no deer movement across the boundaries of the modelled area – whilst some may have occurred, we assume it unlikely to be a substantial percentage of the population given the scale of the area being modelled.

Two versions of the model were created. The first version of the model used our estimate of the average rate of recruitment in each year (37.5% calves at foot; applied to all years in the model) and the spring 2004 count of 7408 animals (the ‘Standard’ estimate). A second version of the model was run exactly as described above, but using the calf-at-foot values calculated annually from cull records (data shown in Figure 28 upper).

The alternative scenarios run concurrently within each version of the model were “Spring 2004 count +5% and Recruitment of 37.5 calves/100 hinds +10%” (i.e. an ‘Upper-end’ estimate of the likely population size) and “Spring 2004 count -5% and Recruitment of 37.5 calves/100 hinds -10%” (i.e. a ‘Lower-end’ estimate). The approach of producing three model runs concurrently provides a visual appreciation of the level of variation in predicted population size arising from potential errors in the key inputs (Figure 29).



	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Count +5%	9421	9367	9316	9430	9519	10141	10511
Count	8833	8526	8178	7940	7609	7725	7486
Count - 5%	8259	7724	7116	6582	5911	5625	4922



	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Count	8405	7673	7040	6586	6279	6268	5643
Count +5%	8927	8361	7948	7774	7900	8363	8164
Count - 5%	7893	7010	6183	5492	4831	4446	3498

Figure 29. Population model outputs based on application of the mean recruitment rate each year within the model (upper) and using calculated annual recruitment rates for each year (lower).

The outputs of the model that employed the average recruitment rate (output presented in Figure 29 upper) suggest that it is possible the population in the wider estates rose in the period between the 2004 count and the 2011 study, were the situation on the ground best reflected by our ‘Upper-end’ scenario. The model then predicts a c. 20% rise in overall population size. However, if we assume the spring 2004 count was accurate and the calculated average recruitment rate appropriate (i.e. our ‘Standard’ scenario) then the model suggests a c. 20% decline in overall population size could have occurred.

The outputs from the model that employs the calculated annual recruitment rates (output presented in Figure 29 lower) suggests a decline of c. 10% under the ‘Upper-end’ scenario and a decline of up to c. 40% under the ‘Standard’ scenario. The ‘Lower-end’ scenarios suggest larger declines over the period for both models, but the parameters employed in these analyses are considered unrealistically low based on the evidence to hand. On a related point, the annual calf-at-foot ratios calculated for the earlier years (e.g. 19% in 2003-04) also seem unusually low and hence this model's output might in general be less reliable than the 'average rate' model.

It is difficult to predict accurately the present size of the estate-wide population with any certainty unless a repeat count is undertaken, but in the interim the outputs of the population models built can help us to predict the likely situation. The results of the modelling suggest it most likely that the estate-wide population is stable or has declined since 2004, although if it has declined it would be safest to assume that the size of the decline is not more than c.20%. Critically though, we do not know the extent to which deer move within the wider estates area and, in turn, cannot therefore be sure of the extent to which local culling rates within each estate area affect neighbouring areas. The corollary is that we cannot at present confirm the degree to which culling in the wider estates area affects the level of occupancy in the SAC itself, notably because of the lack of monitoring of occupancy levels in the SAC and wider estate area over time but also because the estates apparently do not explicitly record the level of cull within the SAC. What we can say is that the percentage of the wider estates population using the SAC in the summer-autumn period is likely to be in the region of 30% or more based on the evidence available at present.

Of course, the more important question is actually whether the occupancy level in the SAC has changed in recent years, and if so is it related in turn to changes in the wider-estate population and/or to other factors? This is a critical fact to establish because it is clearly the case that deer at an inappropriately high density have the potential on any sensitive upland site to adversely affect site condition; and a rising occupancy level makes it more likely that adverse impacts will occur on a site at some point. Unfortunately there is no sure way of ascertaining the current 'occupancy trajectory' of the SAC at present, although undertaking further dung count studies in future years will address this problem more than adequately.

3.3 Impact assessment

3.3.1 Identification of Utilisation Zones

There were marked variations in the rate of pellet group accumulation within the study area, with noticeably lower rates to the east and higher rates along the southern fringes when compared to the north-western section where densities appeared intermediate (Appendix 1 – Map 6).

The site was therefore provisionally divided, based on these obvious differences, into three Utilisation Zones for the purposes of ongoing analysis, the aim being to ascertain to what extent deer impacts were linked to present deer occupancy levels (Appendix 1 – Map 7). The boundaries between the zones were drawn by identifying places where general transitions in density were apparent. Estate 'marches' were not taken into account as the aim was to produce zones based on ecological differences and not administrative boundaries or even geographic zones (e.g. split by watersheds).

Zone 3 had the highest level of utilisation and Zone 1 the lowest level of utilisation; to Zone 2 was intermediate between the others. The occupancy level in Zone 3 was three times higher than that of Zone 1, with the level in Zone 2 lying half-way between Zones 1 and 3 (Figure 30).

Figure 30. The faecal accumulation rate for summer-autumn 2011 in the Utilisation Zones identified for further analysis.

3.3.2 Characteristics of the Utilisation Zones

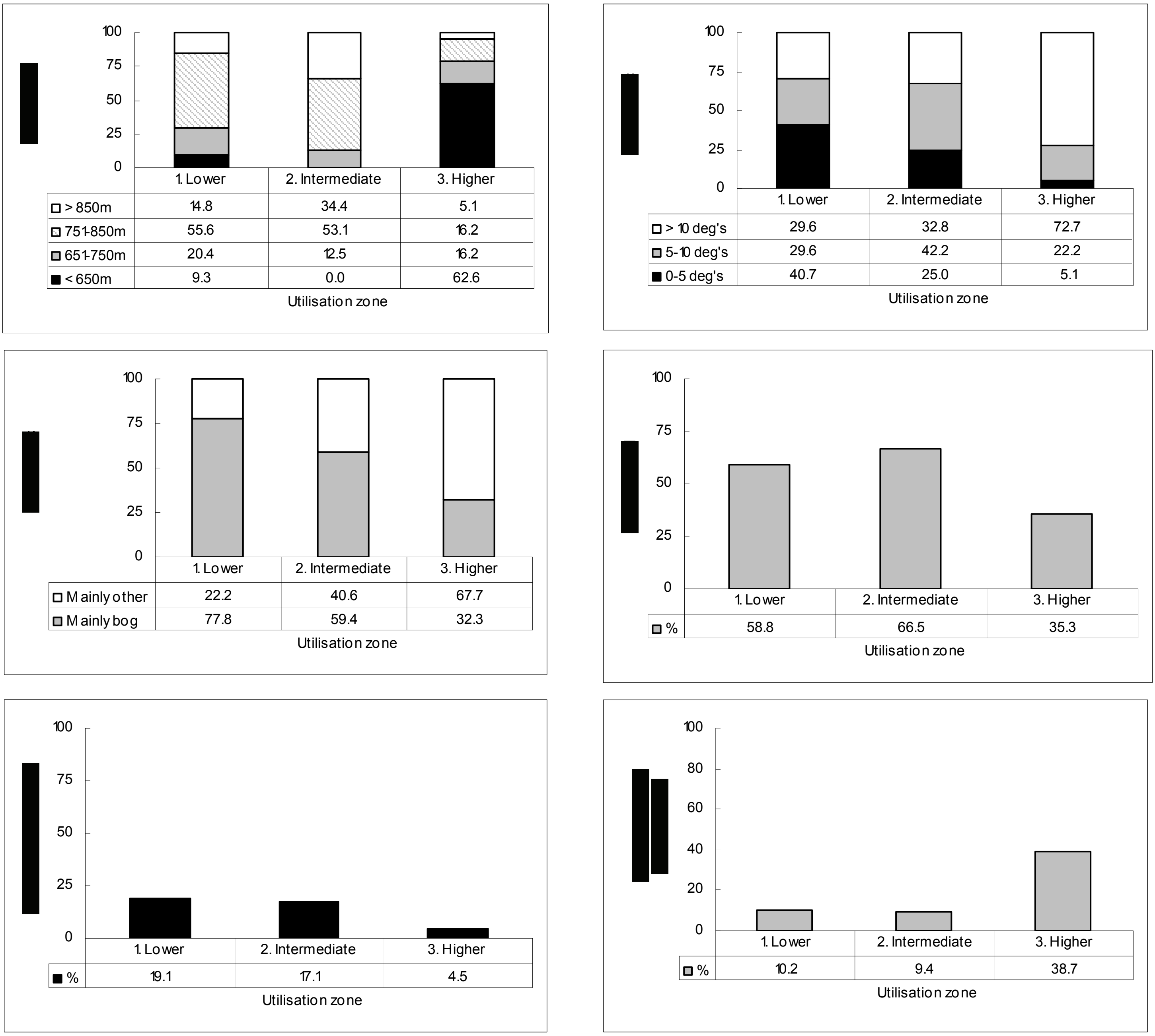
The aim of dividing the SAC into Utilisation Zones was to help ascertain the extent to which deer density affects the extent and intensity of impacts present. However, each of the zones is different in character and this will partly influence the results of analyses undertaken.

The utilisation zones selected for analysis have a number of similarities and differences in physical and ecological characteristics. These are likely to affect the extent and intensity of impacts detected, hence 'intuitive' relationships between occupancy and impact might not always be apparent (Figures 31 & 32):

- The majority of Zone 3 is located at < 650m altitude whereas the majority of Zones 1 and 2 are located at > 750m.
- The majority of Zone 3 has steeper slopes (> 10 degrees) whereas the majority of Zones 1 and 2 has shallower slopes < 10 degrees.
- A large part of Zone 1 is dominated by 'Bog' habitat whereas Zone 3 is dominated by 'Other' habitat, with Zone 2 in between the two in terms of habitat extents – that is because it has a higher proportion of the high watershed ridge and summit zone present compared to Zone 1 (i.e. it has more of the summit heath habitat type) (Appendix 1 – Map 8).
- The percentage of bog affected directly by erosion is higher in Zones 2 and 1 (*c.* 60-70%) than in Zone 3 (*c.* 35%).
- The percentage cover of bare peat is much higher on bog in Zones 2 and 1 (*c.* 20%) compared to Zone 3 (*c.* 5%).
- The percentage of sampled locations judged to have been affected by sheep grazing and trampling was much higher in Zone 3 (*c.* 40%) than in the other zones (*c.* 10%).
- The abundance of Mountain hares appears to increase somewhat with altitude whilst the abundance of Red grouse appears to decrease with altitude (Figure 32 upper), but on average there is relatively little difference in the relative abundance of each species between the utilisation zones (Figure 32 middle). However, the presence of both species indicates that a portion of impacts on key plant species (e.g. *Calluna*) will not be attributable to deer or sheep.
- In general terms, deer / sheep usage of areas dominated by bog increases in each zone broadly in line with the overall level of occupancy in each (Figure 32

lower). However, there appears to be a slight difference in the way that deer / sheep use areas dominated by Other habitats. In Zones 2 and 3, deer / sheep spend a disproportionate part of their time in the Other habitats whereas this appears not to be the case in Zone 1 (Figure 32 lower).

In summary, it is evident that Zone 2 and Zone 1 differ markedly in deer occupancy level but are otherwise relatively similar to each other physically and ecologically. Probably the key difference between them is in the proportions of habitat types present and the apparent difference in the way deer utilise the different habitats present. However, Zone 3 is markedly different to Zones 2 and 1 in physical and ecological terms, as well as in deer occupancy level. One might therefore expect that differences in occupancy level between Zones 2 and 1 will in many cases be manifest as clear differences in impact levels. However, this might not be the case for all variables when Zone 3 is included in the comparison, because of its fundamental differences in character and hence the way in which large grazing mammals might exploit it.



	1. Lower	2. Intermediate	3. Higher
> 850m	14.8	34.4	5.1
751-850m	55.6	53.1	16.2
651-750m	20.4	12.5	16.2
< 650m	9.3	0.0	62.6

	1. Lower	2. Intermediate	3. Higher
> 10 deg's	29.6	32.8	72.7
5-10 deg's	29.6	42.2	22.2
0-5 deg's	40.7	25.0	5.1

	1. Lower	2. Intermediate	3. Higher
Mainly other	22.2	40.6	67.7
Mainly bog	77.8	59.4	32.3

	1. Lower	2. Intermediate	3. Higher
%	58.8	66.5	35.3

	1. Lower	2. Intermediate	3. Higher
%	19.1	17.1	4.5

	1. Lower	2. Intermediate	3. Higher
%	10.2	9.4	38.7

Figure 31. Key characteristics of the utilisation zones: the percentage of locations sampled by altitude (upper left), slope angle (upper right), dominant habitat type (middle left), mean percentage of bog that is eroded (middle right), percentage cover of bare peat on the bog (lower left) and percentage of locations with sheep signs (lower right).

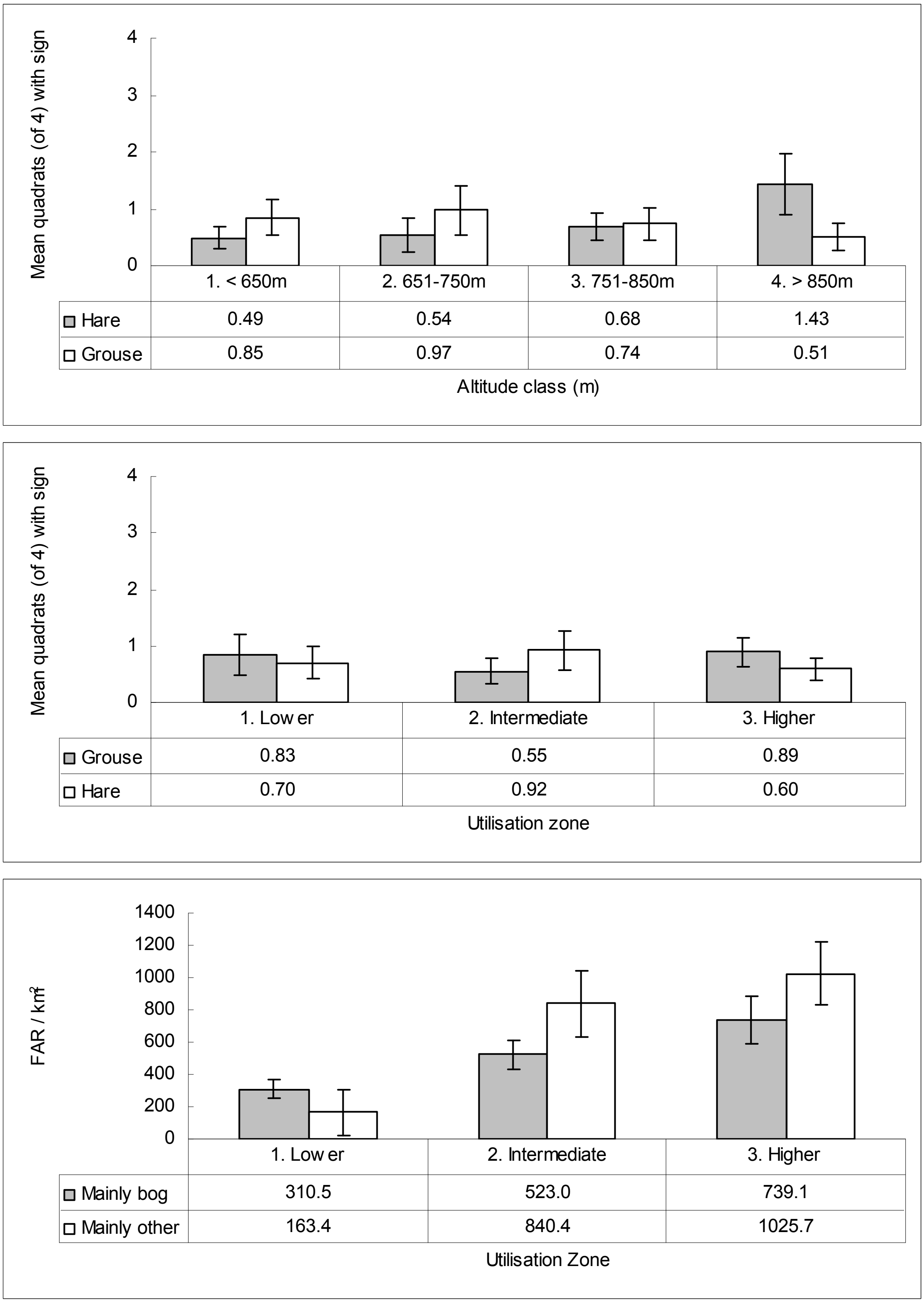


Figure 32. The mean number of quadrats (total of 4 per transect) on which mountain hare sign (faecal pellets) and grouse sign (faecal pellets) was recorded by altitude (upper) and by utilisation zone (middle) along with the FAR for deer / sheep by zone according to the dominant habitat type.

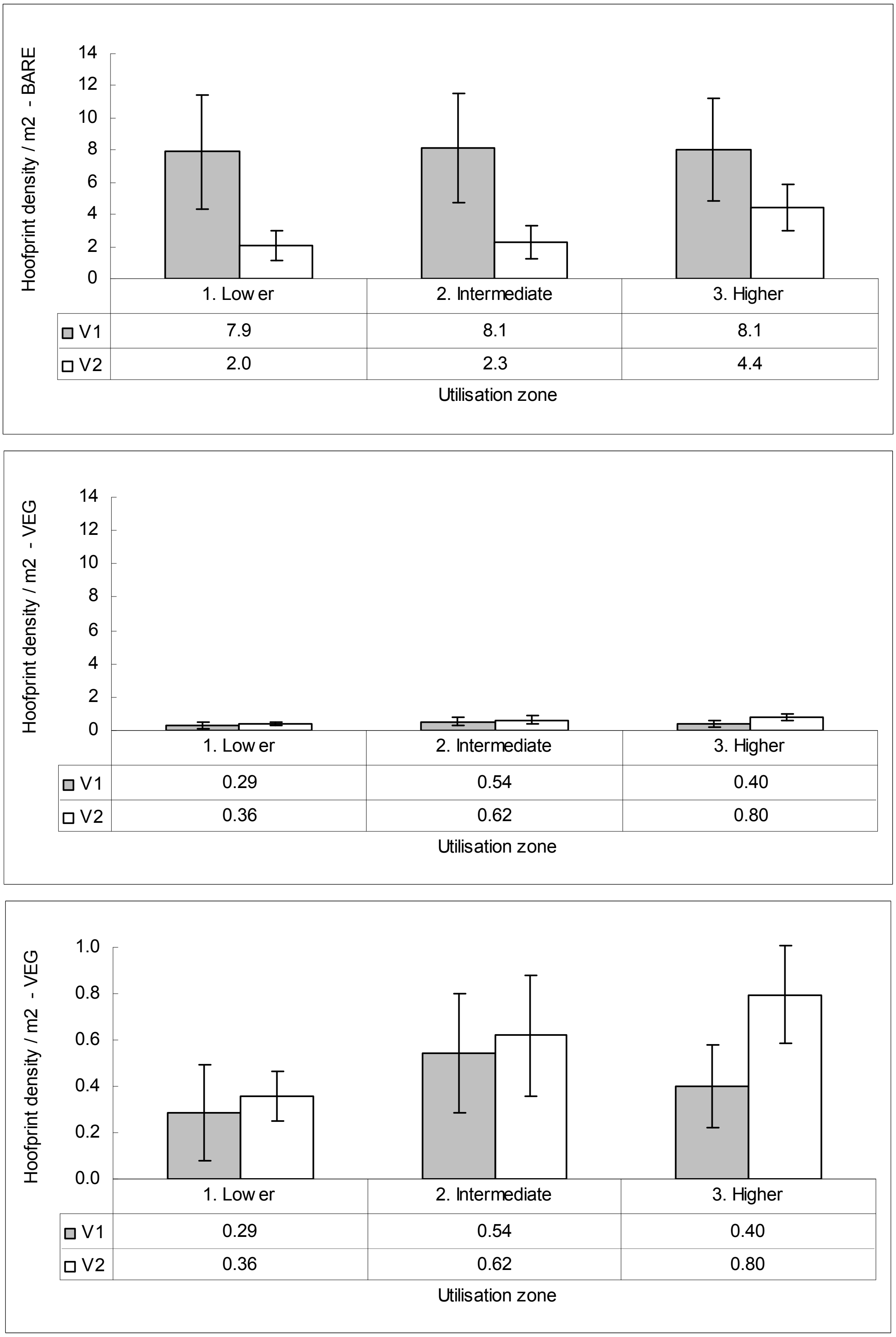
3.3.3 Impacts levels: habitats generally

NB In the following sections on Impacts some discussion is included alongside the results, because of the large number of variables analysed and the variation in patterns seen between utilisation zones. In the Interpretation section these results are brought together with those of the other analyses in a wider discussion.

On vegetated land within the study area there is a fairly clear trend towards increased hoof print density with increased occupancy level (Figure 33 lower; y-axis scale changed from middle graph which shows the same data). The density per m^2 of deer/sheep hoof prints is more than an order of magnitude higher on bare peat than on vegetated land (Figure 33 upper compared to Figure 31 middle). There was little difference in 'bare peat' print density between zones on the first visit to site, although print density as measured on the second visit to site generally rose in line with occupancy (Figure 33 upper).

The marked decline in 'bare peat' print density between the first and second visits to the site (Figure 33 upper) is of interest. The fact that 'bare peat' print density was an order of magnitude higher than that on vegetated land, even though vegetated land lay immediately adjacent, implies two potentially important points:

1. Prints on bare peat stay visible much longer than on vegetated land, and thus their density will not necessarily provide a reliable picture of deer occupancy levels.
2. A marked decline in print density occurring on exactly the same areas between the two visits could show that weathering plays an important part in determining the number of prints visible at any particular time. Certainly, the peat re-deposition and sediment data corroborate this theory. Of course, it may also be related in part to declining deer densities on the site by the time of the second visit. However, the fact that 'vegetated' print density remained at similar levels on Visit 2 tends to suggest otherwise.



	1. Lower	2. Intermediate	3. Higher
V1	7.9	8.1	8.1
V2	2.0	2.3	4.4

	1. Lower	2. Intermediate	3. Higher
V1	0.29	0.54	0.40
V2	0.36	0.62	0.80

	1. Lower	2. Intermediate	3. Higher
V1	0.29	0.54	0.40
V2	0.36	0.62	0.80

Figure 33. The density of deer / sheep hoof prints as recorded on bare land and vegetated land (2x1m quadrats) on the first visit to site (V1) and the second visit (V2) (with 95% CLs).

The integrity of moss cover is an important pre-requisite for the long-term stability of the acrotelm in bog vegetation, especially when it is *Sphagnum*-rich, like much of the intact mire at lower altitudes on the SAC. High levels of uprooting by large grazing animals might conceivably act to promote surface instability.

Recorded levels of uprooting of *Sphagnum* species and *Racomitrium lanuginosum* were very low relative to cover levels, and were also low in absolute terms (*c*. 1% and 0.5% respectively); there was no strong trend towards increasing level with increasing occupancy (Figure 34 and 35).

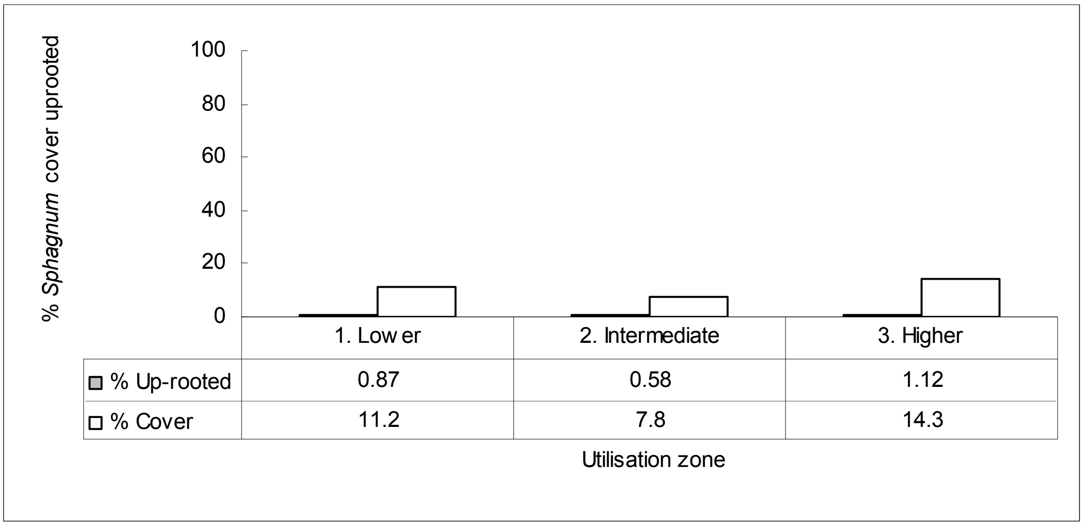


Figure 34. The percentage cover of Sphagnum moss uprooted by deer and sheep (means weighted by cover).

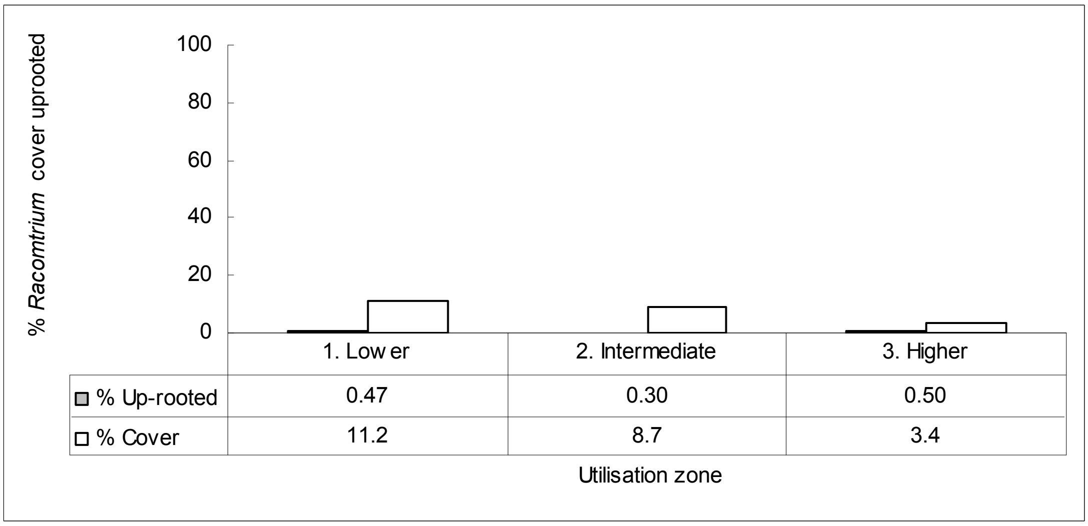


Figure 35. The percentage cover of Racomitrium lanuginosum uprooted by deer and sheep (means weighted by cover).

Dwarf shrubs are an important component of many plant communities in the SAC providing many 'ecosystem services' (e.g. vertical structure increases the range of niches for species to occupy, provides nesting habitat for grouse, and vigorously growing plants provide a very important source of food for grazing animals over winter and spring). The general characteristics of dwarf shrubs influence, to an extent, the way in which they are utilised by deer and sheep, and so this aspect is worthy of examination in advance of presenting the dwarf shrub impacts data obtained from site.

A good example of adverse effects caused by a decline in dwarf shrub abundance relates to damage by *Lochmaea suturalis* Heather beetle. Damage tends to mean that live foliage is killed. The subsequent decline in live foliage can result in atypically high subsequent levels of utilisation by deer in the following months or years whilst the plants recover, because less foliage is available for deer to eat in the interim than normal. Their browsing impacts are then focused on the remaining live foliage, thus acting to produce more intense impacts than normal.

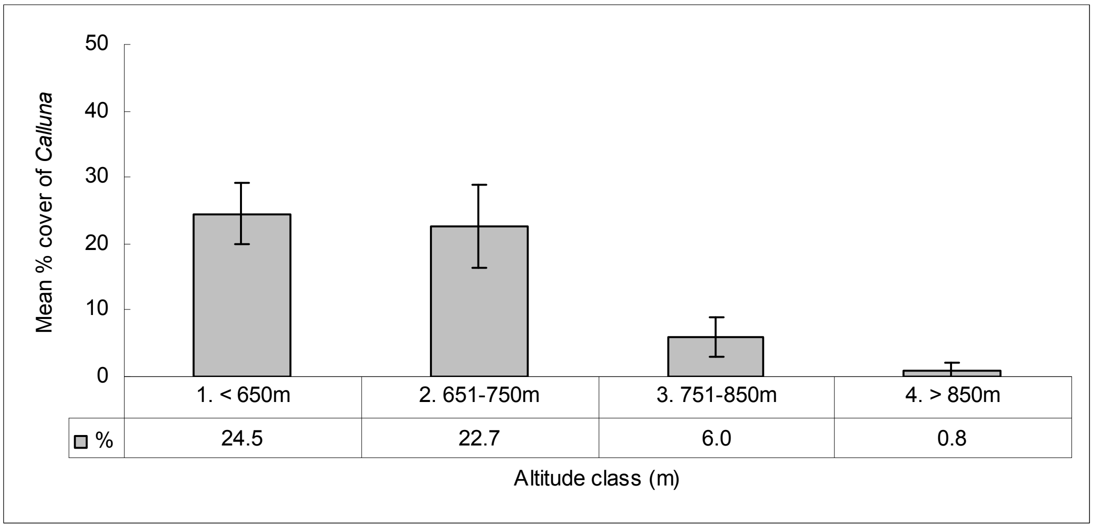
Detailed data on the characteristics of *Calluna vulgaris* were obtained in preference to those for other dwarf shrub species, because the species is much better studied and its response to browsing better understood. Also, it tends to be present across large altitudinal clines on upland sites, and therefore can be a good 'universal indicator' of site conditions whereas other species are often restricted to certain habitats or altitude ranges.

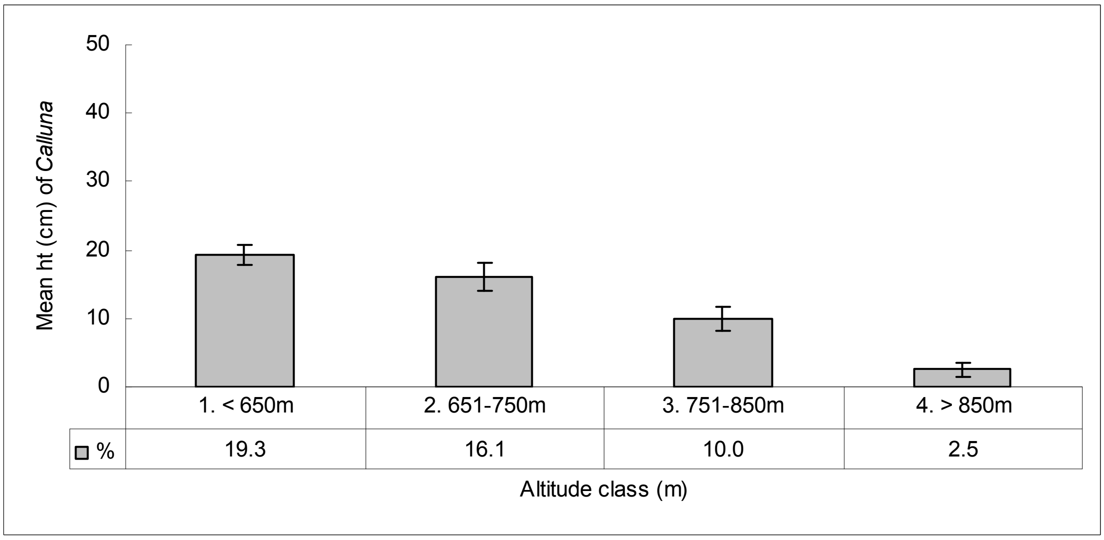
The mean percentage cover of *Calluna* on the lower reaches of the study area could be considered fairly typical of many grazed upland sites (*c*. 20-25% overhead cover) but cover is very limited above 750m (Figure 36 upper). The extent to which this lack of cover is natural, is caused by historic land management impacts (notably grazing) or is perhaps a result of other factors (e.g. erosion processes, and subsequent responses by plants to changing hydrology) cannot be ascertained with the data we presently hold.

The mean height of *Calluna* generally declines with increasing altitude (Figure 36 middle). A general decline with increasing altitude is to be expected, although heavy browsing over a long period can act to reduce the natural height of plants and hence the present height of plants is not necessarily reflective of their potential maximum height.

The extent of foliage die-back was similar across the altitude bands with the exception of the highest reaches of the site (Figure 36 lower). Beetle attacks are likely to be responsible for causing much of the foliage die-back at lower altitudes and exposure (wind / cold) is probably the reason for much of the die-back at higher altitudes. The reduced level of die-back at the highest altitudes may simply be related to the very limited extent of locations at which *Calluna* was detected in this zone, and possibly to its tendency to occur only in sheltered locations at these altitudes (e.g. behind boulders).

In summary, with so little *Calluna* present above 750m and with its stature so short at this altitude there is relatively little biomass available for utilisation in Zones 1 and 2 in comparison to Zone 3 where it is relatively abundant.





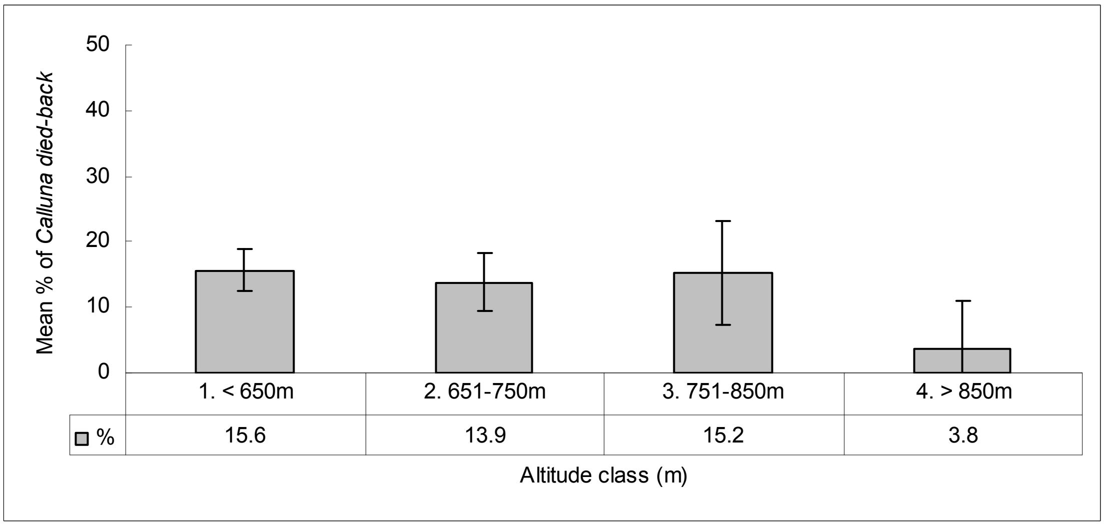


Figure 36. The mean percentage cover of Calluna (1x1m quadrats) (upper), the mean height (cm) (1x1m quadrats) and the main percentage of foliage affected by die-back (1x1m quadrats) (lower) (with 95% CLs).

The patterns of *Calluna* utilisation on the site do not necessarily follow those expected by occupancy. The weighted mean level of off-take of the 2010 summer growth, which occurred at some point over the period summer 2010 - spring 2011, was higher in Zone 1 than in Zones 2 and 3 in turn (Figure 37 upper)[17]. The same pattern of off-take was apparent for utilisation of the fresh growth from summer 2011 over the period summer-autumn 2011 (Figure 37 middle) albeit that the level of off-take of fresh shoots by autumn 2011 was only roughly half the level (in terms of proportion browsed) of the total off-take of old shoots which grew in 2010. This implies that much of the heather off-take on the SAC occurs outwith the summer-autumn period. There are a number of factors which might contribute to the pattern of heather utilisation between zones which was observed.

The high elevation habitats on the site, which are most extensive in Zones 1 and 2, have lower cover levels of *Calluna* (see Figure 37 upper) and the plants are of shorter stature (Zone 1 = 13.7cm mean height and Zone 2 = 10.4cm whereas Zone 3 = 17.7cm). They are also, in general, dominated by bog and eroded bog habitats, or otherwise by habitats with typically limited levels of high quality forage (e.g. montane acid grassland which is often dominated by *Racomitrium lanuginosum*). However, land at this elevation is also where a considerable number of deer spent much of their time over the study period presumably due to a combination of factors including the presence of sheep lower down, the relief from biting flies and the reduced level of disturbance compared to what would be experienced in the glen bottoms. Zone 3, on the other hand, has much higher biomass of *Calluna* and other dwarf shrubs.

The fact that the pattern of *Calluna* utilisation for the entire 2010-11 season, using the 2012 summer growth, is similar to that for the summer 2011 growth can be explained for the same reasons as above, especially if we assume that deer tend to spend more time in the SAC in this period of the year than in the winter-spring, as is believed to be the case by SNH staff (Iain Hope; pers. comm.).

Irrespective of the reasons why, the level of off-take of *Calluna* on the site is on average high both for blanket bog / wet heath habitats and for dry heath. In these habitats off-take rates at the local scale of > 20% and >40% respectively have previously been reported to lead to a decline in cover notably on patch edges (Figure 37 middle; Pakeman and Nolan 2009; Grant *et al* 1982). Certainly, high rates of *Calluna* off-take have, in places on the site, led to the stature of the plants becoming visibly distorted which means that cover is to an extent suppressed (Figure 38). Consequently the proportion of plants with atypical growth form is as might be expected, given the present pattern of off-take by zone. However, historic sheep densities may also have contributed given the presence of much higher densities in past decades. We assume these also remained on the lower reaches of the site and notably where the grazing was better. It is believed that Blaragie has stocked sheep on a commercial basis in the past, and this comprises a significant part of Zone 1.

It can be difficult at higher elevations to be sure of the extent to which growth form is suppressed by browsing versus climate. Hence, whilst every attempt was made to minimise this uncertainty, some bias may be present in the data presented. On the other hand, the levels of off-take recorded on the site will undoubtedly mean that in places the stature of plants is being suppressed by deer/sheep.

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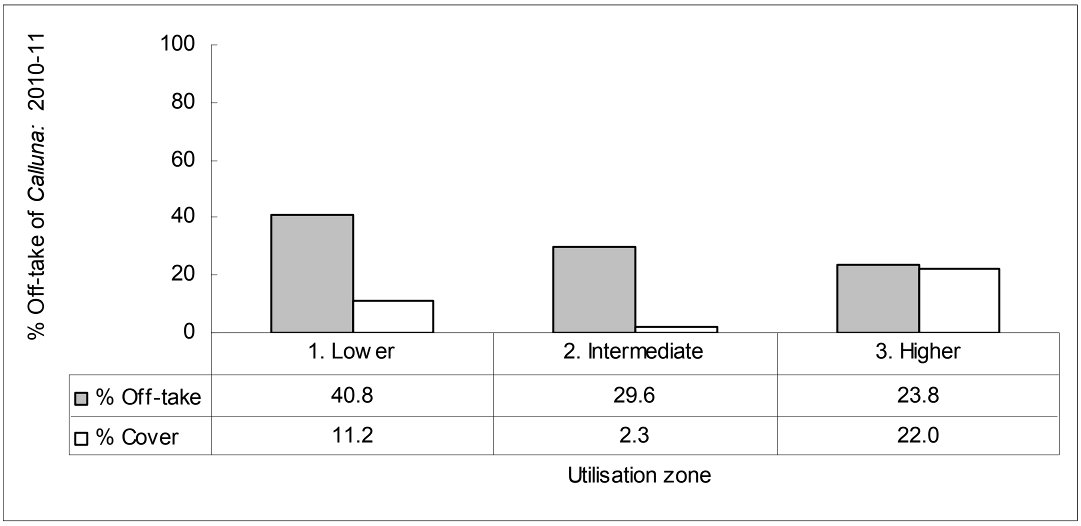
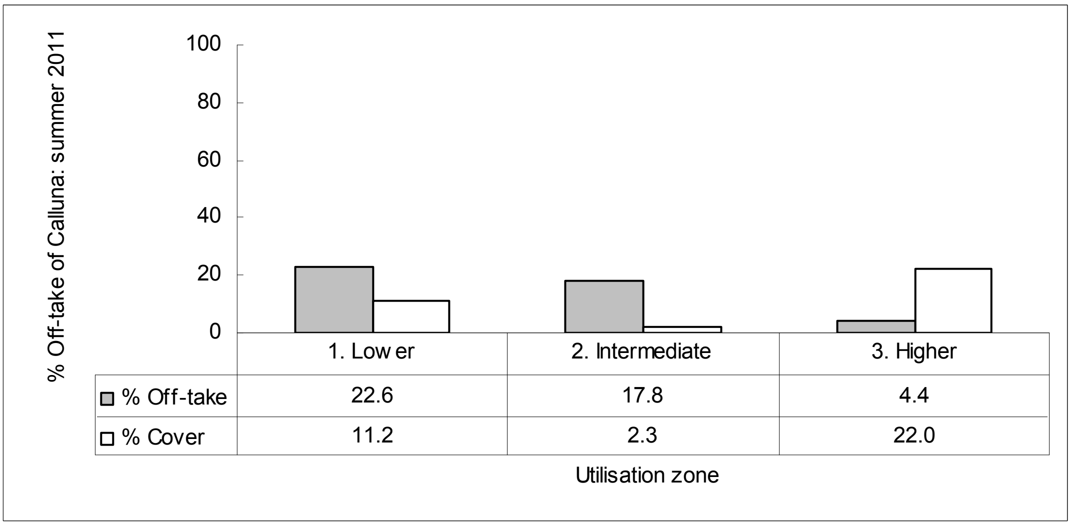
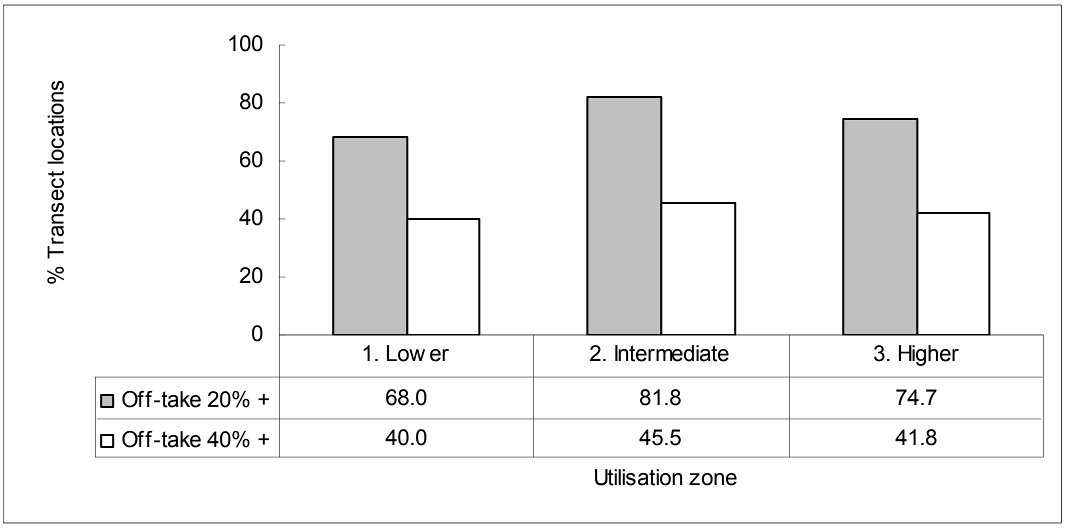
[17] Weighting involved analysing the data to account for the abundance of Heather at each point where impacts were assessed. A quadrat with 100% cover of Heather and 50% off-take would be given twice the weight of a quadrat with 50% cover and 50% off-take when the average off-take of Heather for the site was calculated. The approach used ensures that a true measure of the overall percentage of Heather utilised is obtained (the total biomass utilised is normally linked to the number of 'grazing mouths' present), as opposed to an average of many point measures which tends to produce a biased estimate unless Heather cover is exactly equal at each point where impacts are measured.



	1. Lower	2. Intermediate	3. Higher
% Off-take	40.8	29.6	23.8
% Cover	11.2	2.3	22.0



	1. Lower	2. Intermediate	3. Higher
% Off-take	22.6	17.8	4.4
% Cover	11.2	2.3	22.0



	1. Lower	2. Intermediate	3. Higher
Off-take 20% +	68.0	81.8	74.7
Off-take 40% +	40.0	45.5	41.8

Figure 37. The percentage off-take of Calluna vulgaris by deer and sheep for shoots produced in the 2010 growing season and assessed in July 2011 (upper; mean weighted by cover), for shoots produced in summer 2011 and assessed in autumn 2011 (middle; mean weighted by cover) and the percentage of sampled locations at which off-take levels averaged 20% + and 40% + (lower). The mean percentage Calluna cover assessed on 1x1m quadrats is shown for reference.

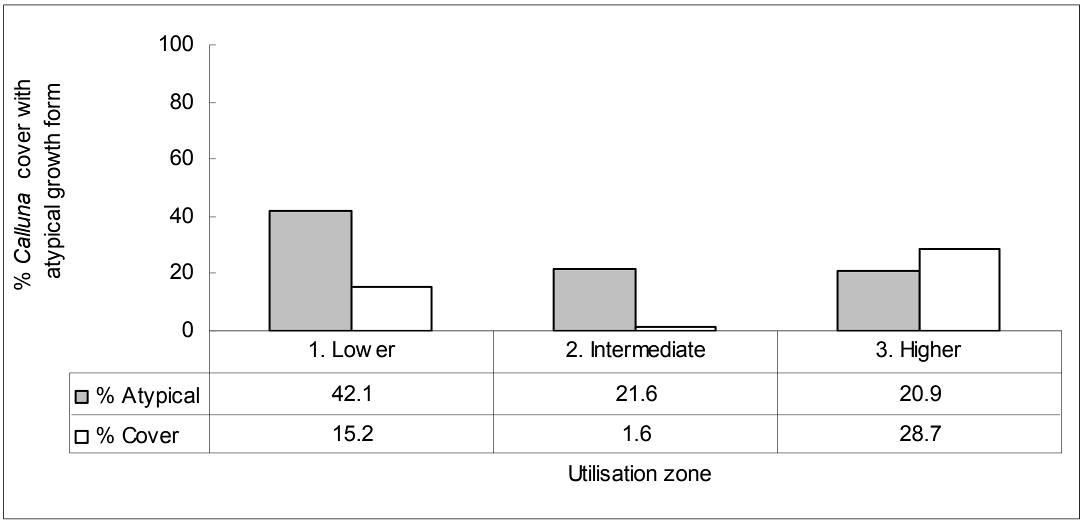


Figure 38. The percentage of Calluna vulgaris cover that was judged to be of atypical growth form due to chronic browsing by deer and sheep. The mean percentage Calluna cover assessed by eye on 80m transects is shown for reference.

The pattern of *Empetrum nigrum* off-take from summer - autumn 2011 is similar to that of *Calluna*, in that off-take declined with increasing occupancy, which is assumed to be for the same reasons as outlined above. The absolute level of off-take is much lower than for *Calluna* but this is to be expected as it is a less-preferred species.

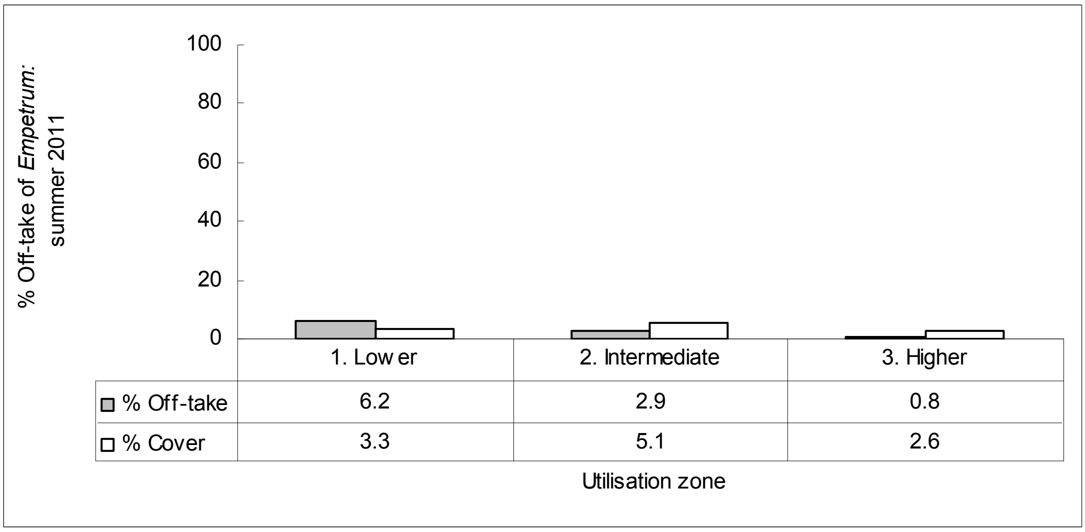


Figure 39. The percentage off-take of Empetrum nigrum by deer and sheep for shoots produced in summer 2011 and assessed in autumn 2011 (mean weighted by cover). The mean percentage cover assessed on 1x1m quadrats is shown for reference.

The trend towards increased off-take with decreasing density is not apparent for *Vaccinium* spp. in the same way as for the other dwarf shrubs assessed, but this is likely to be in part because the same type of analysis (mean, weighted by cover at each sampled location) could not be undertaken; *Vaccinium* cover data were not gathered (Figure 40). Irrespective, *Vaccinium* was utilised relatively heavily in summer 2011 given that on most sites it is normally only utilised in the winter and spring months.

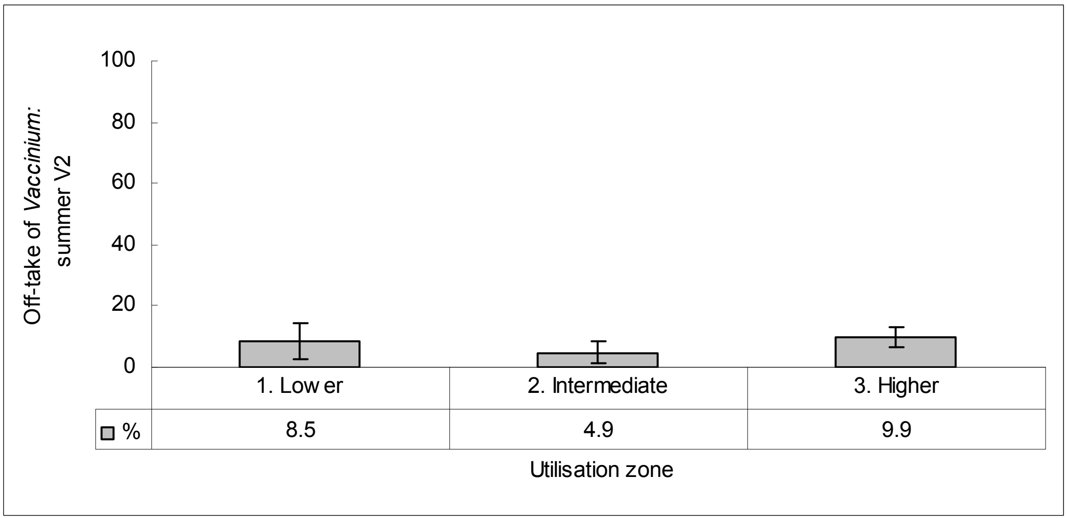


Figure 40. The percentage off-take of Vaccinium spp. by deer and sheep for shoots produced in summer 2011 and assessed in autumn 2011 (with 95% CLs).

The frequency with which breakage of dwarf shrub stems, normally *Calluna* stems, was encountered was markedly higher in Zone 3 compared with the other zones (Figure 41). A higher level of breakage would be expected where animal densities are higher, and this breakage might in turn lead to some foliage die-back, as was recorded on site. The fact that levels of breakage are lower in Zones 1 and 2 may be because *Calluna* plants were much less common. This would imply that average patch size will be smaller and hence the plants perhaps proportionately less frequently trampled; they will also be less tall on average because of the higher average altitude, and hence perhaps not as woody and thus prone to breakage.

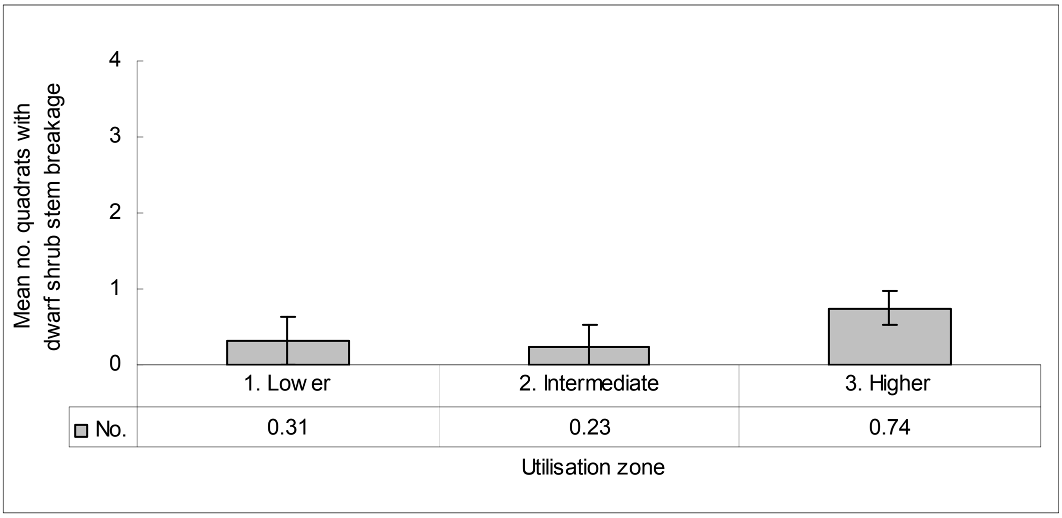


Figure 41. The mean number of quadrats (of 4) on which broken stems of dwarf shrubs (most often Calluna) were recorded as present on transects.

Eriophorum spp. Cotton grasses are often major constituents of blanket bog vegetation. *E. vaginatum* Hares tail cottongrass is common in intact mire and *E. angustifolium* Common cotton grass is a species that often recolonises the low-lying sections of eroded mire. Heavy grazing is rarely a concern on most sites because *Eriophorum* species are normally not preferred, but because of the extent of bog and lack of high value foraging sites on the main plateau of the SAC their utilisation by deer is of interest.

The grazing of *Eriophorum* species was markedly higher in Zone 1 than in the other two zones (Figure 42). Zone 1 has the highest proportion of bog habitat present and hence the lowest proportion of good grazing land and preferred species. The pattern of dwarf shrub use has already suggested this to be the case. It might be expected that *Eriophorum* grasses, rarely a preferred species when better habitats are present, would therefore be utilised most often. It is also possible that grazing by Mountain hares accounts for some of the off-take observed.

3.3.4 Impacts levels: bog specific

A key focus of this study is to quantify the nature and intensity of deer impacts on blanket bog, and specifically their impacts on the process of erosion and recolonisation. Bare peat extent has been mentioned prominently in previous SNH reports (as listed earlier), and often in the context of deer contributing to the problem.

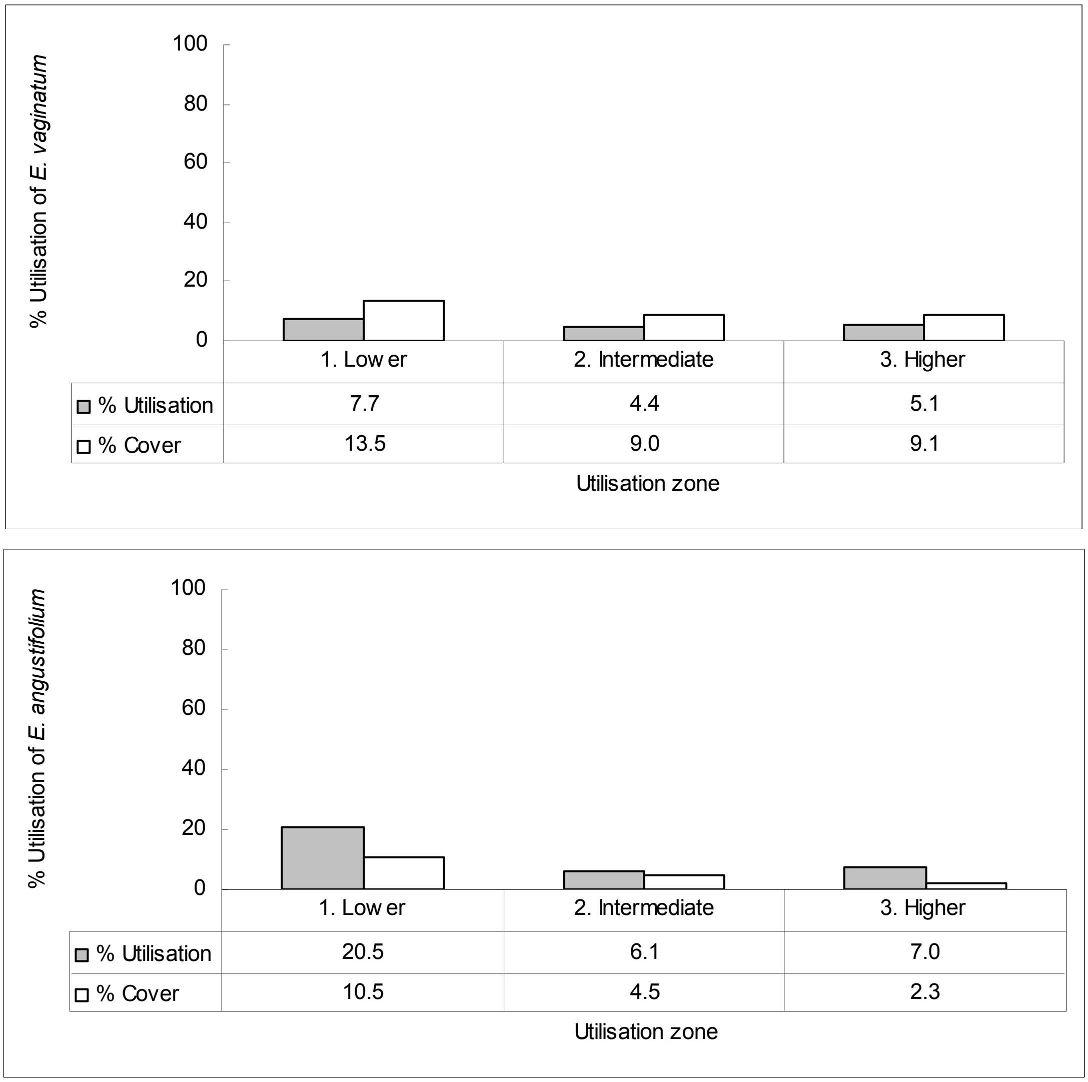


Figure 42. The percentage utilisation by deer and sheep of Eriophorum vaginatum (upper) and E. angustifolium (lower) leaves produced in summer 2011 and assessed in autumn 2011 (mean weighted by cover). The mean percentage cover assessed on 2x1m quadrats is shown for reference.

To help understand more about the problem, bare peat cover[18] was quantified in three different ways in this study:

- The percentage of the main 80m transect line intersecting bare peat cover on the second visit to site, taking account of the percentage bog present on the transect (Tran V2).
- The percentage cover of bare peat per transect, based on the 15 micro-quadrats (0.3x0.3m), located on land that is currently active bog or is otherwise located in erosion complexes (second visit to site; Micro V2).
- The percentage cover of bare peat on 2x1m quadrats used to assess various other features of the site e.g. grazing of *Eriophorum* etc (Quad V1).

All three methods produced very similar results, with estimates of 15-16% cover of bare peat across the original blanket bog extent (Figure 46).

Analysis of how bare peat cover changes with altitude, slope angle and other factors has been conducted in an earlier section of the report. Therefore, this section considers only differences between utilisation zones.

The cover of bare peat on the bog extent is similarly high in Zones 1 and 2 but very much lower in Zone 3. The lower cover in Zone 3 is to be expected, given the relatively small percentage of bog eroded at lower altitudes and the greater extent of recovery. The similarity of percentage cover in the other zones implies that the same processes may have acted over many decades to produce the situation as it is today. Climate, weather and their related processes are the most obvious factors which are common to both zones.

Data on the overall extent of direct erosion, as distinct from the present cover of bare peat *per se*, shows a similar pattern in that Zone 3 has a lower extent than the other two zones which are very similar (Figure 44). This implies that the processes that have acted to produce the major surface erosion are similar between Zones 1 and 2 or the final outcome is at least similar.

Whether or not similarity in these patterns will be apparent in Zones 1 and 2 in the future is less clear. The data presented subsequently in this section can be used to help assess the likelihood, but we also need to be able to understand likely trends in weather and in deer numbers to make a better judgement.

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[18] All measures were made in plan view, and hence the 3-dimensional nature of bare peat cover on hagg walls etc was not taken into account. In essence, all methods used underestimate the actual surface area (m^2) of bare peat present with the bias being largest where peat depth is greatest and erosion features narrowest and deepest (e.g. at low levels where v-gully erosion is most common but bare peat extent in plan view is lowest).

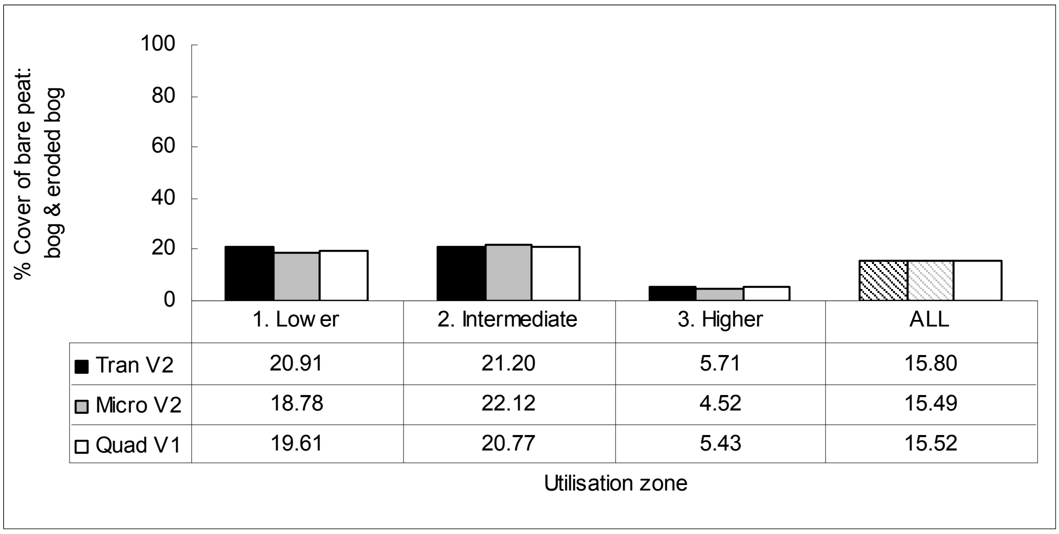


Figure 43. The percentage cover of bare peat on the original bog extent in three analysis zones, measured using three different approaches as described in the main body of text above.

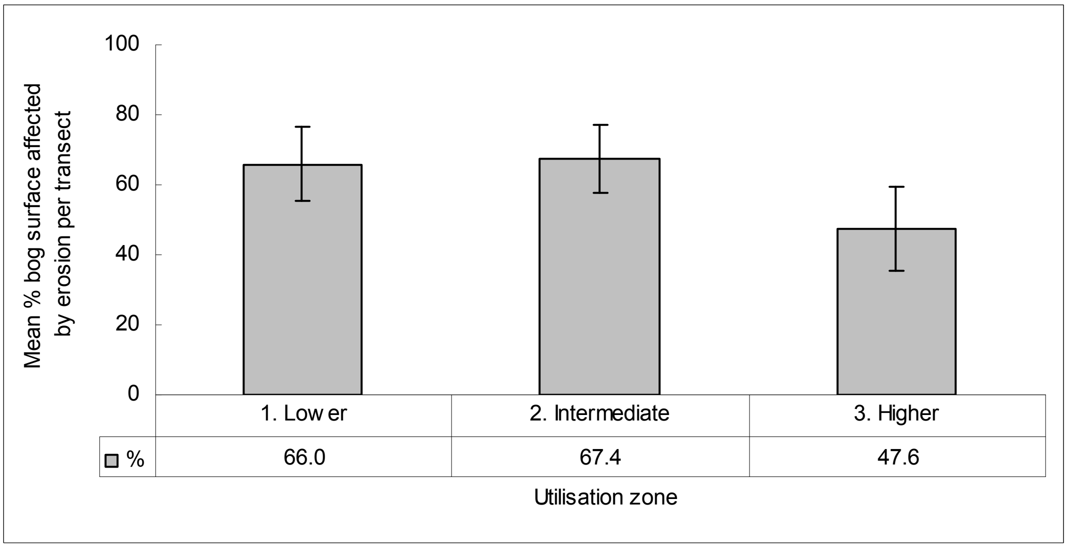


Figure 44. The percentage of the original bog extent that has been affected by major surface erosion.

There are a wide range of possible reasons why the original acrotelm of the blanket bog in the Monadhliath broke down at the onset of the first erosion event on site, as well as during subsequent events. Some of these reasons are discussed later in the Interpretation section. This section focuses on the contribution deer may *currently* be making.

Deer can completely puncture the acrotelm with their hooves, either when walking across intact bog and hagg tops or when they have created paths in the vegetation which, if traversed frequently, results in the complete breakdown or poaching of the vegetation mat and exposure of bare peat beneath. Both processes can expose the underlying peat mass to the effects of the weather, including fluvial, pluvial and aeolian-based erosion processes.

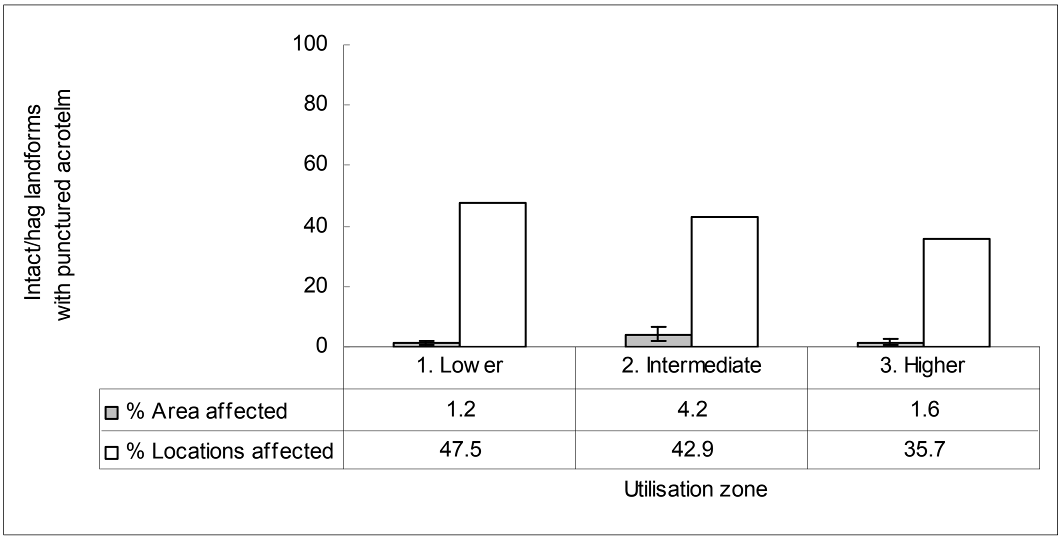
The frequency with which acrotelm puncture features were encountered was fairly high, with c. 35-50% of transects having some signs recorded (Figure 45 upper). The actual area of intact land and hagg tops which displayed signs of being punctured was 1% in Zone 1 but 4% in Zone 2 which is in line with expectations based on deer occupancy levels (Figure 45 upper). The area affected by punctures was only 2% in Zone 3 which might be due to sampling error (small sample size). However, it may represent differences in the bog structure between the zones. In Zone 3, the bog is at lower altitude, has markedly less major surface erosion, less micro-erosion, less bare peat and is generally wetter, with more abundant carpets of *Sphagnum*. These characteristics could make the acrotelm less likely to be punctured / ruptured because the acrotelm is thicker (more robust to being punctured) and wetter for much of the year (less likely to tear than if it is thin and drier; or better able to support the weight of grazing animals due to increased buoyancy).

This is supported by SCL's recent research from another upland site in Scotland where much of the very wet valley bog and blanket bog present appeared resistant to the acrotelm being completely broken by very high levels of sheep and cattle trampling, even though the acrotelm micro-topography and hydrological characteristics were otherwise very badly affected (Appendix 4 has images showing the appearance of heavily trampled areas on this other site). Indeed, small parts had areas where the *Sphagnum* mat had died back (other than on some hummocks) and was being replaced with an algal film – this surface showed significant micro-erosion and grazing animals were implicated through the combined effects of heavy dunging and trampling of the hummock-hollow micro-topography previously present. Possible reasons for the breakdown included the loss of *Sphagnum* exposing the underlying peat (increased nutrient load, which many *Sphagnum* species cannot tolerate) and loss of micro-topography thus exposing the underlying peat mass to more regular freeze-thaw because the insulation provided by the vertical structure of the vegetation mat was lost by trampling.

One could speculate that the process described above may be a potential mechanism for acrotelm breakdown in the Monadhliath. Very large herds of deer, such as those present on the Monadhliath, might at key times and locations produce similar levels of trampling pressure to the sheep and cattle on the other site. Also, the high densities of sheep previously reported to have been on the Monadhliath could have produced similar localised effects. The effect would not necessarily have needed to be widespread to initiate the pattern of erosion seen today; rather, high levels of trampling locally might, with time and as the surface broke down, have led animals to utilise different parts of the site in turn.

The rates of puncture recorded on the Monadhliath may not seem high in absolute terms. However they could, given the severity of the weathering processes which operate on the upper reaches of the sites especially, and given the fact that these sites probably have a thinner acrotelm and less *Sphagnum* present, produce or lead indirectly, to the conditions in which new onset erosion could occur. This may be especially likely where deer activity is focused on paths across intact mire and the acrotelm has ruptured linearly.

The frequency with which over-deepened deer path features were encountered was fairly high in Zone 1 and Zone 2 where much of the bog is present, with c. 30-35% of transects having some signs recorded (Figure 45 lower). The actual percentage of path length affected was low (Figure 45 lower; rates of 1-2% of path linear length were completely ruptured). Nevertheless, localised path rupturing could be a significant factor. In isolation a level of rupture 1-2% might seem low but if it occurs in tandem with more general puncturing (Figure 45 upper) and in areas which are already micro-eroding, either directly due to deer or exacerbated by them, then the combined effect could be significant.



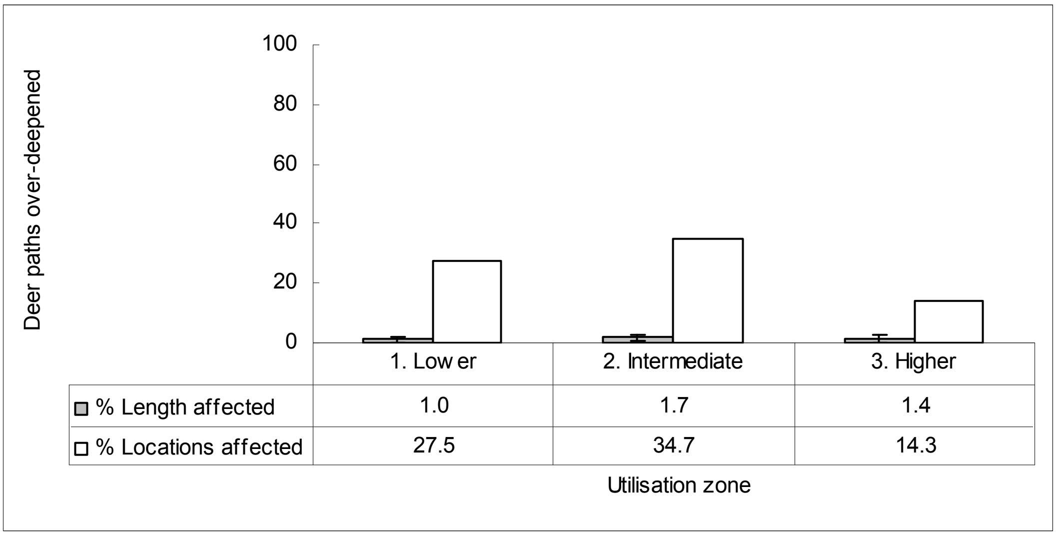
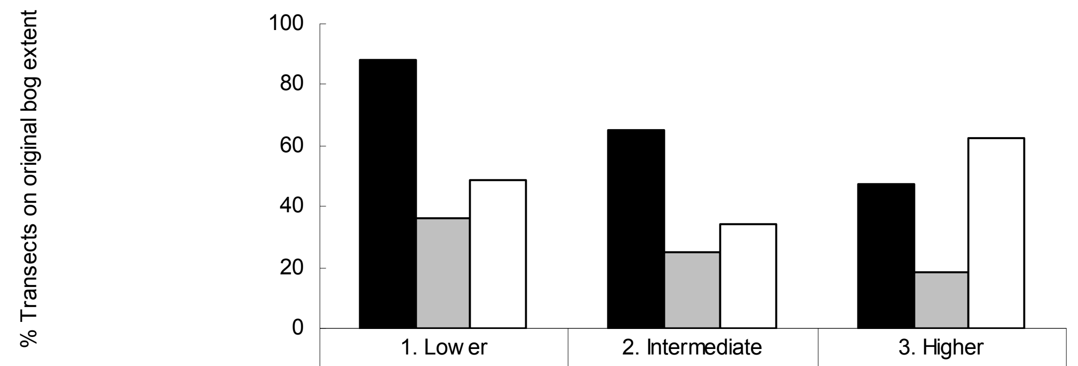


Figure 45. Estimates of the percentage cover of the intact mire / hagg tops that were punctured by deer / sheep hoof prints (upper) and the percentage of the linear length of deer / sheep paths in sampled areas which had been completely ruptured by the pressure of high levels of passage (lower).

The evidence on deer being implicated in the micro-erosion process itself is very limited because (i) it was not anticipated at the outset of the study that micro-erosion would be as frequently seen as it was, (ii) there was limited time to study the intact bog areas in as much detail as would have been required and (iii) the process of micro-erosion is not at all understood by researchers. However, a reasonable amount of data has been obtained from site and when analysed (Figure 44) shows that the percentage of transects with micro-erosion features present is greatest in Zone 1 and smallest in Zone 3. The percentage of the surface affected was also greatest in Zone 1 and smallest in Zone 3, but the percentage of features recolonising was similar across all zones. These trends mirror that of major surface erosion. Therefore micro-erosion may be a precursor, at least in some places, of major surface erosion. Unfortunately it is difficult, without a further detailed study, to prove this categorically. Consequently, it is also difficult to then understand the true impact deer may be having on the condition of the intact bog.

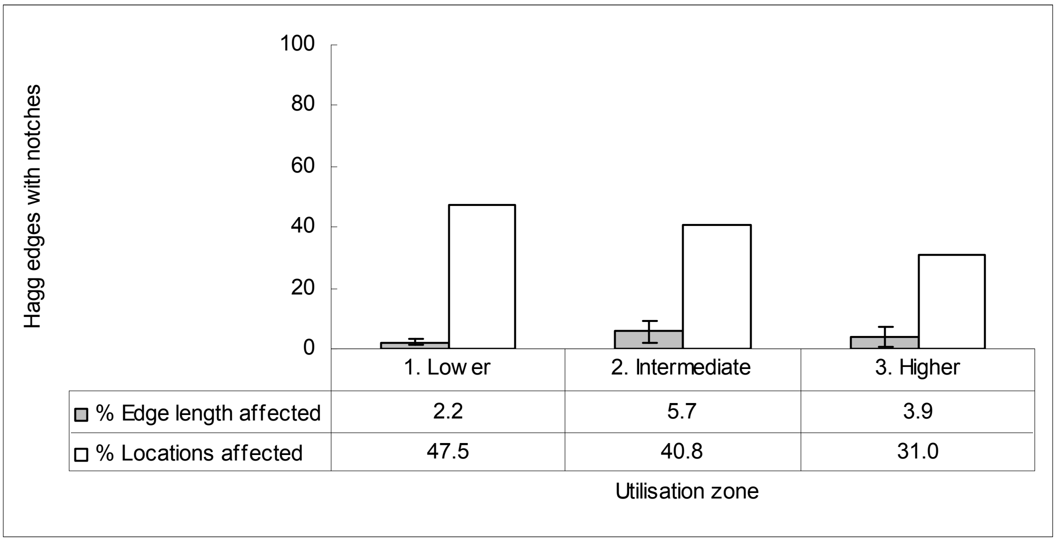


	1. Lower	2. Intermediate	3. Higher
% With micro-erosion	88.1	65.3	47.1
% Surface affected	36.3	25.0	18.2
% Features recovering	48.6	34.4	62.5

Figure 46. The percentage of transects on which intact bog or hagg tops were affected by micro-erosion, the percentage of the surface affected and the percentage of micro-eroded features judged to have some signs of recolonisation or to be fully recolonised.

Once the bog surface has experienced major surface erosion it will, at the stage that linear gullies begin to join into dendritic systems, or when anastomosing systems become established, produce fields of peat haggs. Once these have become established hagg shrinkage occurs, whereby haggs recede laterally by weathering and vertically by de-watering and oxidation of the peat mass. Deer can trample the edges of the haggs and lead to turf being dislodged from their edges and deposited at the toe of the slope. If trampling occurs on the leeward side of haggs which can recolonise by a process of ‘vegetative creep’ onto aoelian deposits, such trampling could be viewed as an adverse impact particularly at higher altitudes where this form of colonisation might be one of the few ways in which deeper peat recolonises. As has been mentioned, most eroding deposits at high altitude seem to become stripped down close to the mineral soil first by weathering before then recolonising.

The frequency with which notched hagg features were encountered was fairly high, with c. 30-50% of transects having some signs recorded (Figure 47). The actual percentage of hagg edges with notches was 2% in Zone 1, 6% in Zone 2 and 4% in Zone 3. The level of notching in Zone 3 did not follow the pattern of occupancy for the zones where one would assume it would have a higher percentage notched haggs. This may be because of sampling error: haggs are clearly sealing up much more often at lower altitudes and it might be that our encounter rate with open-edged haggs which tend to become notched was too small to detect the true rate of notching). Of course, this is the case for any of the phenomena discussed herein, given the lack of *a priori* knowledge of where certain features could be found and the systematic, site-wide approach to sampling employed, and consequently the low frequency of encounter of certain rarer features.



	1. Lower	2. Intermediate	3. Higher
% Edge length affected	2.2	5.7	3.9
% Locations affected	47.5	40.8	31.0

Figure 47. The estimated percentage of hagg edges on which hag notches were recorded as visible.

When deer traverse erosion systems, especially where gullies are present, they often walk along the edge of the gully base on the hagg apron or gully wall. This form of trampling can lead to a marked over-deepening of the peat in this area, and may lead eventually to an accelerated process of hagg undermining. However it could speed up the process by which gullies naturally change from a v-form to a u-form, which could be a positive process as it would result in a marked reduction in the erosive energy of the channel.

The frequency with which terrace path features were encountered was relatively low, with c. 15-25% of transects having some signs recorded (Figure 48). The actual percentage of walls / apron length affected by these was < 1% in Zone 1 but 3% in Zone 2, which is in line with expectations relating to occupancy level (Figure 48). However, Zone 3 was not well correlated with the pattern of occupancy, but there is much more linear gully erosion on the lower reaches of the site and, notably, more gullies of the V-form rather than the 'flat-bottomed' or U-form[19] . Deer would tend not to walk in V-form features especially as they are normally oriented directly downhill.

[19] A V-form gully forms in the early stages of the erosion process, the cross-section being in the shape of a V because fluvial action has no yet acted long enough to incise the gully down to the mineral soil at which point it tends to widen the gully base and hence it develops a U-form or flat bottomed cross-section. Appendix 4 has images of the different forms of gully.

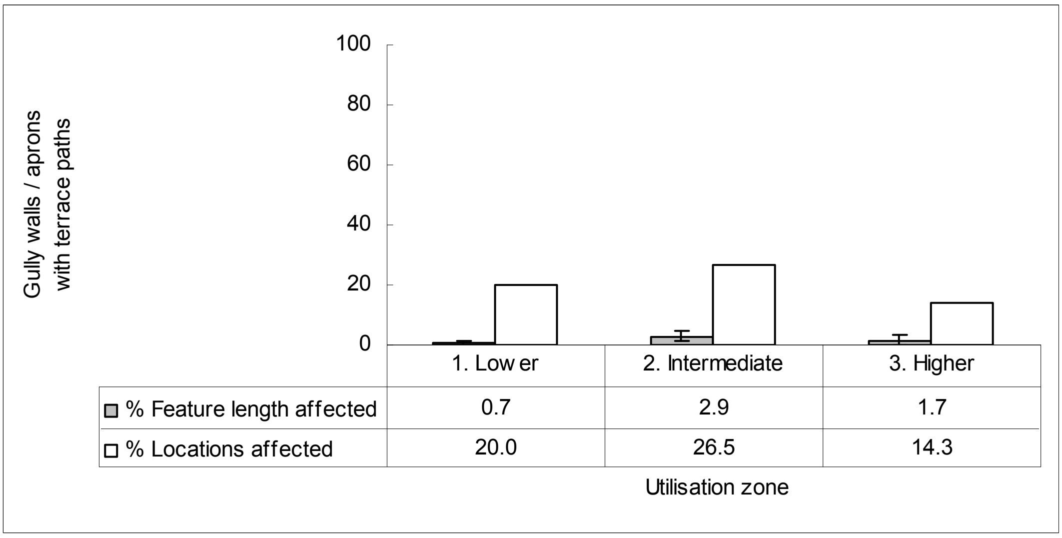


Figure 48. The estimated percentage of gully walls / hagg aprons on which terraced paths were recorded as visible.

As well as traversing erosion complexes through gully lines, deer will also walk across larger peat flats, often to reach other areas to graze but possibly also specifically to graze on recolonising vegetation. Both of these activities might lead to enhanced rates of erosion of bare peat, through (i) dislodging peat directly by hooves so that small area of peat becomes susceptible to erosion from aeolian activity and (ii) facilitating it being dislodged indirectly as a result of plants being killed by deer, hence the reduced level of colonisation will lead to further erosion. Depending on the circumstances, this additional loss of peat could be considered as an impact. It is most likely to be viewed as negative when relatively low rates of erosion of the bare peat would otherwise be expected (e.g. at lower altitudes and on sheltered aspects; also perhaps at times of year when erosion rates are lower due to reduced rates of weathering).

The percentage of quadrats with visible hoof marks rose in line with the level of occupancy by zone, implying that increased deer densities result in a higher percentage of the bare peat surface being trampled (Figure 49). If the trampling is locally heavy then it can manifest itself as an ‘over-deepened’ path across the bare peat surface as opposed simply to superficial hoof imprints. The percentage of quadrats with signs of over-deepening rose in line with the level of deer occupancy by zone, implying that increased densities of deer will act, in key places, to produce higher frequencies of defined channels in the bare peat which will be a focus for fluvial action leading to an enhanced rate of loss of peat from that surface locally and perhaps more widely (Figure 49).

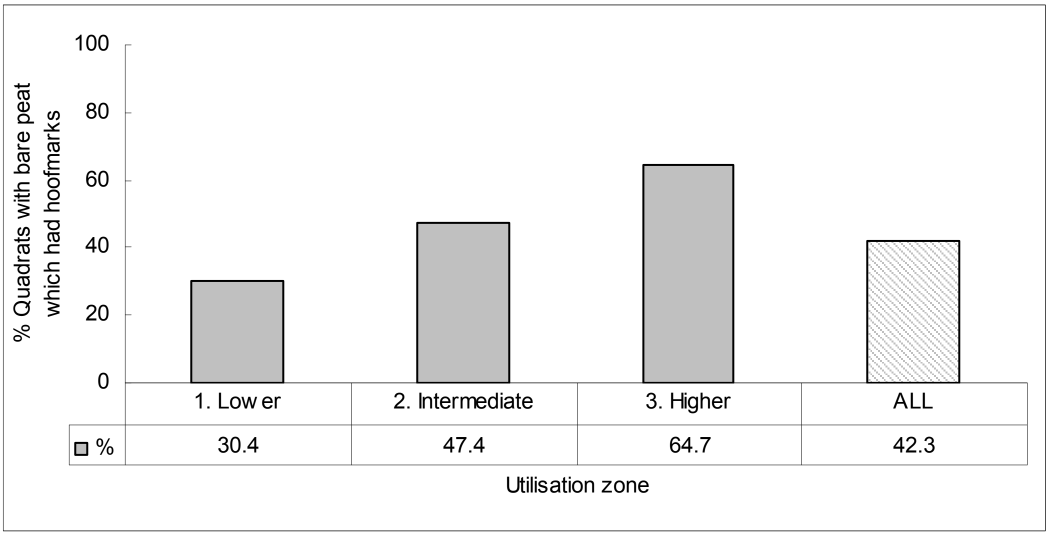


Figure 49. The percentage of quadrats with bare peat on which hoof marks were recorded.

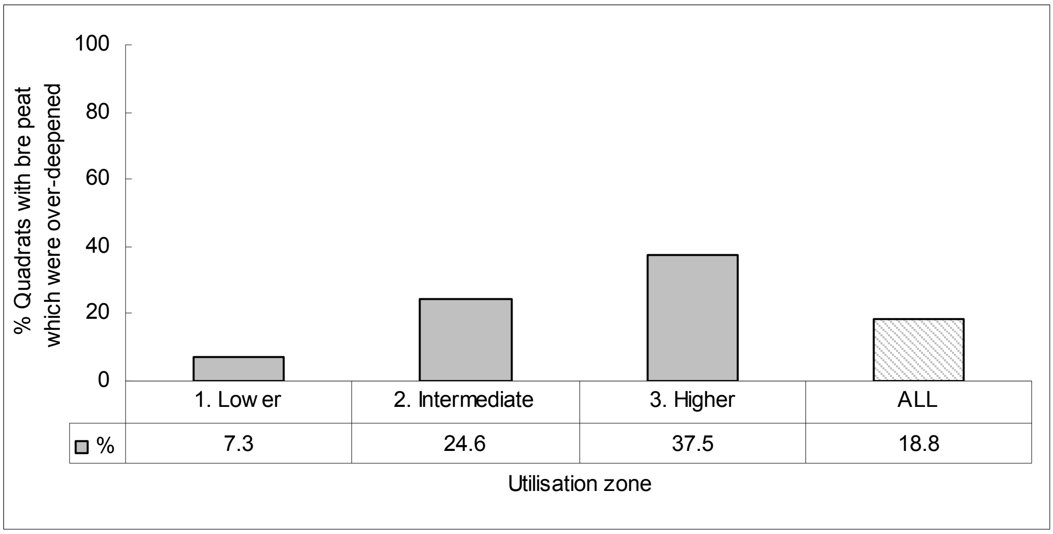


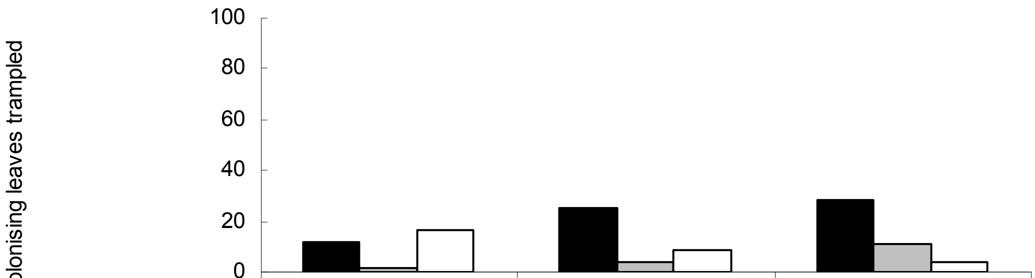
Figure 50. The percentage of quadrats with bare peat on which over-deepened channels (defined paths) were recorded.

One of the reasons why deer might be active on bare peat is because these areas can, in certain circumstances, hold patches of colonising plants which might be a preferred food source. In traversing bare peat patches, and in accessing recolonising areas to graze them, they might also dislodge new plants by trampling.

The average percentage of leaves of new recolonising plants trampled rose in line with the level of deer occupancy, as did the percentage of quadrats on which trampling was detected. This implies that increased deer densities result in a higher proportion of recolonising plants being trampled, which, when young and on potentially loose substrates, might be a negative consequence leading to higher mortality rates (Figure 51). However, the deep-rooting nature of the most common colonising species, which is *Eriophorum angustifolium,* may mean that the long-term significance of any trampling which occurs is limited. Furthermore, the sample size of transects on which colonising plants were available for assessment in Zone 3 was small and so it is not necessarily considered to be a good reflection of the true rate.

The average percentage of leaves of new recolonising plants grazed rose in line with the level of deer occupancy in Zones 1 and 2, as did the percentage of quadrats on which grazing was detected. This implies that increased deer densities might result in a higher proportion of recolonising plants being utilised. If young and on potentially loose substrates, this might adversely affect the plants if it disturbs them or weakens the developing reserves in their roots (Figure 52). The small sample size for Zone 3 means that the percentage level shown, and the percentage of quadrats affected may not be considered a good representation of the situation on the ground.

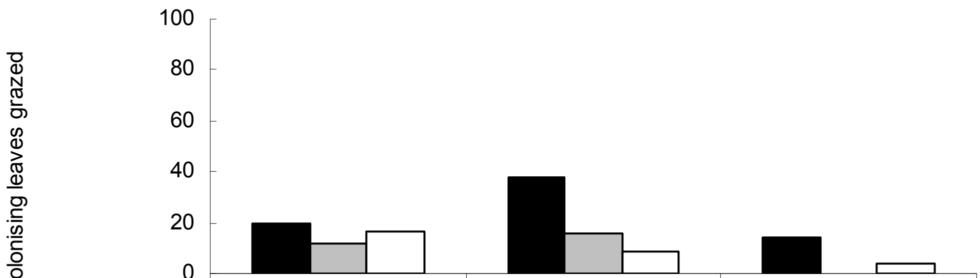
There was a trend towards reduced cover of colonising plants with increasing occupancy (Figure 53). This might be expected given that trampling rose in line with occupancy and new plants, especially at higher altitudes and on potentially loose substrates, might easily be disturbed.



	1. Lower	2. Intermediate	3. Higher
■ % Locations	12.1	25.0	28.6
▨ % Cover trampled	1.8	3.7	10.9
□ % Cover	16.2	8.8	4.2

Utilisation zone

Figure 51. The percentage of locations at which recolonising leaves were trampled by deer / sheep, along with the percentage of leaves trampled (weighted by cover) and the mean percentage cover.



	1. Lower	2. Intermediate	3. Higher
■ % Locations	20.0	37.5	14.3
▨ % Off-take	11.8	16.0	0.0
□ % Cover	16.2	8.8	4.2

Utilisation zone

Figure 52. The percentage of locations at which recolonising leaves were grazed by deer / sheep, along with the percentage of leaves grazed (weighted by cover) and the mean percentage cover.

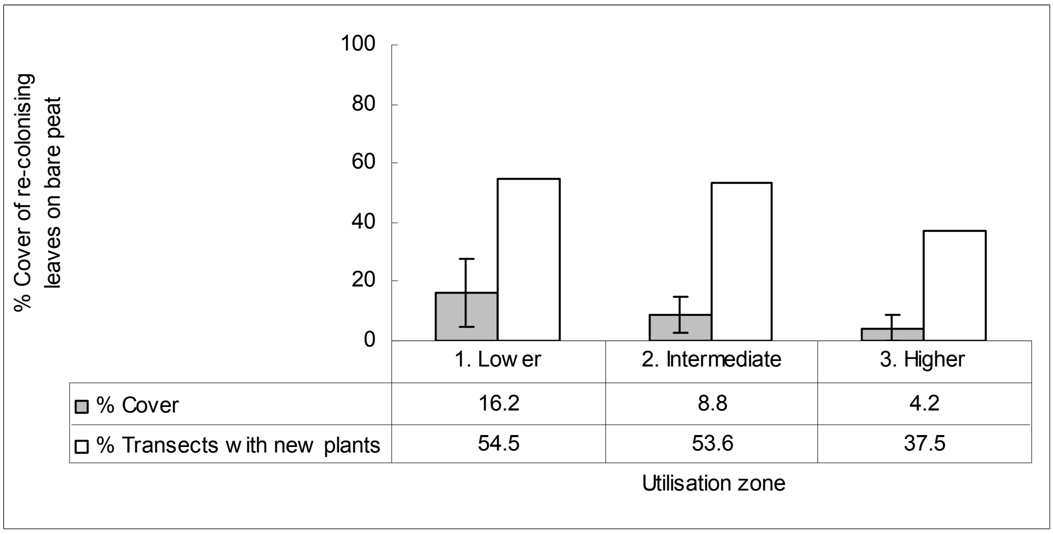


Figure 53. The mean percentage cover of recolonising leaves on bare peat, along with the percentage transect locations at which recolonising plants were recorded.

The frequency with which at least one of the three impact types (trampling, grazing plots, over-deepening) was detected rose in line with occupancy level (Figure 54), implying that the presence of deer in increasing numbers acts to expose a larger percentage of the overall bare peat extent to potentially adverse impacts. However, the sample size for the Higher zone was small (n=11 transects) and a larger data set should ideally be gathered for this area to be able to draw firm conclusions.

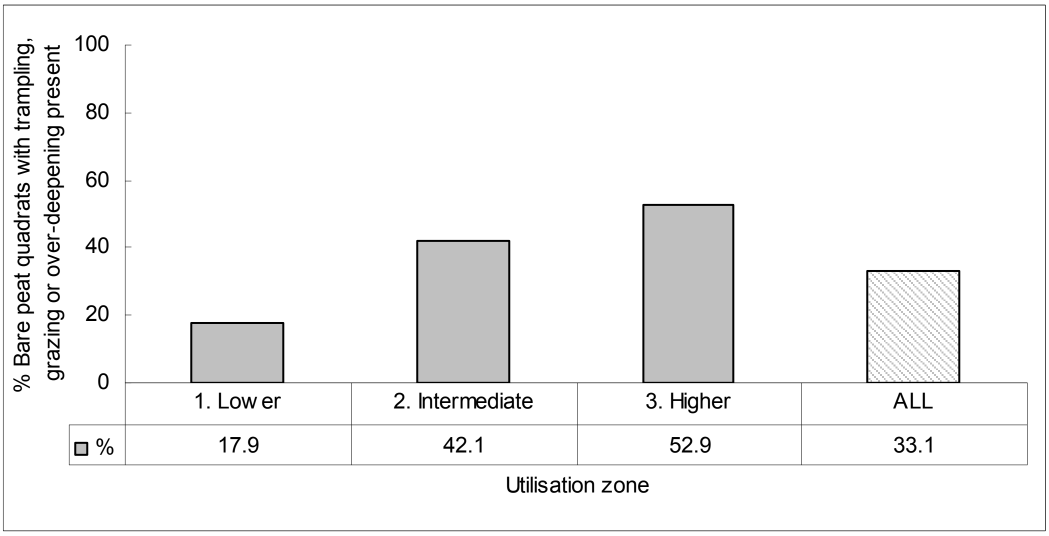


Figure 54. The percentage of quadrats with bare peat present at which at least one of the main impacts on bare peat occurred: over-deepening, trampling of recolonising leaves and/or grazing of recolonising leaves.

4. INTERPRETATION

4.1 The blanket bog

4.1.1 Previous extent

The SAC site and its wider environs clearly once held a blanket bog complex extending over many dozens of square kilometres. During its growth phase this blanket bog would have been actively accumulating peat through annual build-up of partially decomposed plants in waterlogged conditions.

Whilst the bog complex appears to have extended over a large proportion of the site, it was most extensive at higher altitudes and on gentler slope angles. Lower altitude areas also had bog but it was restricted to the valley bottoms and other topographic depressions, whereas at higher elevations true blanket peat was present.

At some time in the past, and perhaps on multiple occasions, the bog surface began to break down. The reason(s) why this happened are not well understood (see Appendix 6 for an overview of relevant scientific literature). However, they may include:

- Increase in overburden pressure caused by continued peat growth, which may lead to general failure of the peat mass by creep and catastrophic slope failure.
- Collapse of peat pipes, possibly for the same reasons as above, leading to focused fluvial action in these areas which, in turn, facilitated wider surface breakdown.
- Micro-erosion of the surface, leading in turn to major surface erosion by fluvial processes. The possible reasons for micro-erosion occurring include: downslope creep of the peat mass; material expelled from peat pipes landing on vegetation and killing it; bog breathing (mooratmung) causing surface cracks to appear; gas expulsion, perhaps related to mooratmung, causing gaps in the vegetation; animal trampling.
- Natural wildfire, leading to loss of the acrotelm which, if followed by severe weather which removed the remaining humus and plant roots prior to recolonisation, would leave the peat mass very susceptible to fluvial action. Related slow-burning peat fires might also have occurred and exacerbated the problem. Older systems of extensive farming probably used fire to produce early growth. Grouse management was more widespread in the past which would have increased the likelihood of planned fires spreading onto the mire.
- Unusual weather events causing stresses in the peat surface which led to breakdown.
- Removal of the original woodland cover from down-slope centuries ago, leading to hydrological instabilities moving up slope over time.
- The sudden introduction of large numbers of sheep to the site some time in the 18th – early 20th century, which would have led to changes in species composition at the same time as increasing rapidly the level of trampling. These effects in combination may have reduced the integrity of the acrotelm surface.
- Rising deer numbers over the past century or more, perhaps happening as a result of reduced grouse management and reduced levels of consumption of venison by local people.

It is quite possible that erosion was initiated by a number of the catalysts above, and that it has occurred in phases with different causes acting at different times or in different places. However, it might be that evidence is available to show that there is one clear cause or one clear time when erosion began. It is therefore important that attempts are made to better understand the reasons why erosion began (see Recommendations).

4.1.2 Current extent & condition

The SAC is now highly eroded across much of its extent. The extent and intensity of erosion increases with altitude, which suggests that weathering has in the past played an increasingly important role with altitude in determining the ultimate extent and intensity of habitat loss from the original bog surface.

Erosion has led to the development over time of a highly complex mixture of large-scale landforms which include intact bog, peat haggs, gully systems and peat flats. The intact parts of this landform assemblage appear to have broadly the same characteristics as might be expected of a typical undisturbed upland mire complex: peat deposits of 0.5-1m or more; a *Sphagnum*-rich acrotelm; fairly abundant *Eriophorum* species; a bog water table close to the surface for most of the year; diffuse surface flow, with much of the input waters leaving the mire as saturation-excess overland flow.

However, the landforms affected by erosion either indirectly (peat haggs) or directly (gully walls, peat flats) appear to be variously modified. Changes on peat haggs include: reduction in the level of bog water table leading to a loss of characteristic species (e.g. *Sphagnum papillosum)*, and cessation of active peat formation; oxidation of the main peat mass due to bog water table reductions. Changes on directly eroded sections include: increased extent of bare peat; direct loss of peat leading to increased influence of mineral soils and consequent modification of plant species composition.

A major consequence of the erosion is that at present a considerable proportion of the original bog extent does not appear to be able to actively form peat and is in fact losing peat mass. There are two main processes operating; the first is that oxidative losses of remaining peat on haggs are occurring due to a reduction in the level of the bog water table. The second, more significant process, is that direct losses from bare peat surfaces, termed active erosion, are occurring. Based on the evidence presented in the first section of the results, active erosion is occurring across the vast majority of the bare peat surfaces present[20].

The extent of active erosion increases with altitude, to the point where *c*. 20% of the original bog surface on the upper reaches of the site currently comprises bare peat. The evidence presented, and research from other upland areas, also indicates that the *intensity* of active erosion increases with altitude, due to the combination of heavy rain, high winds and frequent snow / ice formation that occur in these locations.

Whilst active erosion is very common, there is also a large amount of land on the site which has eroded but then completely recolonised with plants. Across the site as a whole, *c*. 50% of quadrats located on directly eroded land (walls / aprons and base / flats) were completely recolonised at the time of survey and a further proportion only had very low levels of bare peat cover which may, continue to colonise. Precisely when much of the current recolonisation happened is difficult to establish without further research (see Recommendations) but the characteristics of these presently recolonised sites can certainly help us to better understand the physical process by which recolonisation occurs.

As altitude increases the depth of peat in recolonised areas on average decreases and this implies that it is inherently difficult for plants to colonise bare peat at altitude until such time as the bare peat is thin or absent. This may be because plants can root into the mineral substrate once the peat reaches a key depth (10-30cm depending on the species) and thus further erosion of the peat surface is (i) less likely through consequent stabilising effects and (ii) the rate then reduces rapidly with increasing plant cover (i.e. peat stops eroding directly

[20] Some bare hagg walls, notably at lower altitudes, appear to be fairly stable and producing little if any sediment. However, most bare peat surfaces have the appearance of being actively eroded.

once plant cover has returned). However, at lower altitudes recolonisation of plants on deeper deposits of peat occurs at a much higher frequency and with a higher abundance of specialist bog plant species. At higher altitudes the plant communities recolonising appear, at least in the early stages post-colonisation, to be somewhat modified.

The end result of the various recovery processes is that there are different forms of recolonised bog at different altitudes. At lower altitudes the bog has a higher proportion of original intact surface. The linear or dendritic erosion gullies within these areas often recolonise spontaneously, by processes such as turf collapse from gully edges, with plant assemblages similar to those found on the wetter sections of the mire surface (aquatic microforms such as *Sphagnum* lawns and seasonal pools – see images in Appendix 4). These recolonised areas typically have a high proportion of sealed hagg edges and a gently undulating form. Typically, much of their surface comprises active bog even after erosion because the original bog water table is still present and close to the surface. At the highest altitudes there is relatively little of the original mire surface present, with much having been lost to processes such as sheet erosion. The surface appears ultimately to colonise well, but only after much of the peat has been stripped off and hence the recolonised landforms often appear as smooth and relatively dry, grassy land with remnant dry haggs present in differing extents and spatial configurations depending on how the erosion originally acted (e.g. according to slope angle). Over longer timescales much of this recovered land may well eventually form a mantle of peat again, but this is not guaranteed because we do not know the extent to which the climatic influences which allowed peat formation in previous times will change over the coming decades.

Irrespective of whether and when a return to peat formation occurs on some of these eroded areas, the available evidence indicates that a significant proportion of the remaining peat will be lost in coming years and decades, notably from the higher reaches, before the site as a whole can reach a new equilibrium.

Presently, *c*. 30-40% of the original peat mass (volume) has already been lost by the processes described. Therefore, it should be expected that considerably more peat will be lost in the future, depending on how long the active erosion continues for and where it occurs. The likely volume of future losses could be established by undertaking further research (see Recommendations) but it is difficult to be precise at this stage.

The majority of peat will probably be lost from currently bare areas as described, but the possibility that new erosion of the intact surfaces will occur should not be discounted on the basis of the evidence gathered. Both processes are discussed in detail in the next section of the report, with specific reference to deer given the focus of this particular study.

4.2 The impacts of deer on bog

4.2.1 Intact bog surfaces

The mechanisms by which intact bog surfaces might break down due to deer-related impacts, or by which the breakdown process might be accelerated by deer presence, have been discussed in a preliminary way earlier in this report (see Findings).

The evidence presented suggests that in places, deer are having a measurable impact on the integrity of the intact bog surface, including a proportion of the vegetated surface being punctured by hooves and a proportion of paths becoming over-deepened such that bare peat is exposed. These features may expose enough of the underlying peat mass to catalyse major erosion.

It is possible that some of the deer impacts recorded on the intact bog in the SAC could be trampled micro-erosion features rather than features caused solely by the deer (e.g. over-deepened paths could be micro-eroded features which have then been trampled). However, most of the impacts assessed appeared to occur in addition to any 'underlying' micro-erosion. Some of these micro-erosion features may actually have developed because of earlier 'deer-related' punctures or path 'deepening'.

The level of understanding of micro-erosion is fundamentally limited, and the involvement of deer in the process is even less well understood. This points to a precautionary stance being adopted i.e. that the agencies should assume that deer might be implicated in surface breakdown of intact bog. This view would be supported by the fact that the impacts on intact bog described appear to be somewhat higher where levels of deer occupancy are also higher.

If we accept that measurable deer impacts are occurring, and their intensity tends to increase with increasing deer density, it then becomes important to establish whether the present level of impact on the intact bog is serious enough to warrant concern from the authorities tasked with protecting it.

The site was originally notified because of its blanket bog interest, related at least in part to the interest in the intact 'original' parts of the bog as they existed at that time. The data gathered in this study show that the extent of this intact bog is now very limited, notably so at higher altitudes. Whether it was more extensive in the recent past, for example at the time of SSSI notification or, more recently, SAC designation, needs to be ascertained conclusively through further research (see Recommendations) as the present body of evidence is not robust enough to confirm this.

What we do know is that a significant proportion of the intact bog currently has signs of micro-erosion present which are 'over and above' the deer impacts identified on intact bog in this survey, and whilst signs of recovery were present on some micro-eroded features there are many other areas which were not recolonising at the time of survey. It remains unknown as to whether micro-erosion is a pre-cursor to major surface erosion but it would be wise, based on the precautionary principle, to assume it is, given that it has many of the characteristic patterns associated with early stage fluvial erosion. Certainly, we know from site that any weaknesses in the bog surface are likely to be exploited rapidly by the weather at the higher altitudes, thus underlining the importance of maintaining the integrity of the surface if possible.

Of course, if the micro-erosion is occurring as a result of natural processes, developing into major surface erosion and then recolonising independent of the presence of deer then that would suggest no management actions involving deer would be justified. However, a key difficulty at present is that we do not hold enough long-term data on the dynamics of the site, nor is there enough understanding of micro-erosion, to be sure to what extent deer are implicated. It may be that the directly-observable deer impacts (punctures and path deepening) either lead independently to major erosion, or are a catalyst for some of the micro-erosion we see on site.

That said, the surface of an intact blanket bog is in some ways fairly resistant to trampling impacts by deer in the short-term, as we have seen to be the case on other sites where bog is extensive and highly saturated. This is similar to the conditions on some valley bogs at the lowest altitudes on some parts of the SAC. However, the evidence from other sites is that it is possible, through the trampling and dunging habits of large mammals, to cause physical impacts that in turn could lead to surface breakdown on local areas of intact mire. The process likely involves die-back of *Sphagnum* and localised poaching of the die-back areas, which in turn allows weathering of the main peat mass to begin and fluvial action to become focused. It is likely also that frost is implicated, with high levels of trampling flattening the typical micro-topography of the bog thus reducing the insulating effects of the upper acrotelm which in turn may expose the upper surface to more frequent and intense frost-heave.

A compounding factor is that relatively high densities of animals exist on parts of the SAC which have high levels of bare peat cover of no real value to deer for foraging, and thus their attention must become focused on the remaining areas which are vegetated. Moreover, if the extent of preferred habitat is fundamentally limited and thus bog habitat is used heavily, as seems to be the case in many of the higher parts of the SAC, pressure will consequently be higher on the remaining intact bog. The way deer use intact bog might also be related to 'spillover' effects because the level of occupancy on any better habitat adjacent is very high and hence some deer (e.g. sub-dominants) have to utilise the sub-optimal bog habitat. This is a common feature of the way animal populations behave in the natural world when operating close to their carrying capacity. We do not know how close to carrying capacity the population in the SAC is, but it is certainly important to find out (see Recommendations).

Our view on balance is that deer impacts could be implicated in surface breakdown of intact mire within the SAC now and in the near future, irrespective of whether they were implicated in previous breakdown when the original bog was much more extensive. Therefore, the agencies should seek to understand more about the problem as a matter of urgency.

4.2.2 Bare and recolonising surfaces

A range of mechanisms by which bare peat surfaces appear to recolonise with plants on the Monadhliath have been listed previously (see Findings). So also have the reasons why plants can fail to colonise in the early stages of erosion, and hence a slow cycle of plant germination and mortality occurs which, over time and depending on the situation, eventually results in total and permanent recolonisation. The potential negative and positive impacts that deer may have on the process have also been described and information held on the extent of impacts has been presented (see Findings). We recap the range, extent and intensity of their impacts here, and discuss the implications.

Deer walk across a very high proportion of the bare peat surfaces present in the SAC, which may act to loosen the peat more than it would otherwise be by the weather. Deer also tend to graze and trample a proportion of the new plants colonising bare surfaces, which may otherwise grow unfettered but for some grazing by the mountain hares present. Deer also tend to over-deepen a proportion of the bare peat surfaces by their habit of walking regularly across the same piece of land over a period of time. This may often occur when they are traversing between two preferred patches of land via a bare peat surface. The evidence is that these impacts tend to rise as average occupancy levels increase.

Deer also prefer to forage on grasses in the summer months where possible and, based on the status of these plants inside and outside some of the experimental enclosures located on hagg edges, it is clear that locally they are removing a high proportion of the flowering heads of grasses which is where the seed develops and becomes available later in the year for dispersal. These seeds may well be important in helping highly eroded surfaces to colonise, given that grass species are quick to colonise most types of land. The evidence is that, deer grazing impacts on grass seeding rates will tend to rise as average deer occupancy levels increase (i.e. progressively larger amounts of flowering heads will be removed by increasing numbers of deer).

In utilising eroded bog areas deer can and do tend to trample the edges of some peat haggs as well as creating terraced pathways on hagg aprons and gully walls – these features might not otherwise occur by weathering to the same degree. The hagg top trampling impacts can be viewed in two ways.

They can be viewed negatively in that one of the few mechanisms by which peat haggs seem to seal up at higher altitude is by the gradual creep and eventual expansion of hagg top vegetation (certain species only e.g. *Calluna*) – this is often leeward as a result of the deposition of peat sediment by aeolian processes. Hagg edge trampling, which can also manifest itself as notches on steeper-edged haggs, also occurs on the edges of intact bog. As we have discussed earlier, this is a relatively rare habitat now and should ideally be protected.

On the other hand, these same processes can be viewed positively if we assume that the process of peat erosion from high altitude surfaces is inexorable and will only halt when most of the peat has been lost from flats and gully bases, at which point plants will recolonise. Then, hagg edge trampling and wall / apron terracing potentially become much less important.

In terms of impacts on colonising plants on bare peat, it can also be strongly argued that a proportion of the plants which recolonise do not necessarily end up becoming part of the community of plants which finally colonise. This is because we see signs of new plants being killed by processes including swamping by washed and blown sediment. The wind can also act to isolate new plants on 'pedestals' which can then eventually cause the plant to die of moisture stress etc. Frost heave is also highly likely to be implicated in new plant death. And so a proportion of deer trampling and grazing impacts on recolonising plants might be viewed as unimportant because the plants being damaged would otherwise have died anyway.

In fact, deer trampling may in certain circumstances actually help surfaces to colonise if the pressure of their hooves actually results in new plants germinating on the surface being back pushed into the peat and closer to a good rooting zone, or when they were isolated on pedestals but trampling helps them back into a zone of improved soil moisture. Trampling may also be a mechanism by which fragments of *Sphagnum*, which will probably be present in a lot of the slope wash which occurs in storms, can become re-established in gully bases and peat flats if they are pressed down by hooves.

The trampling of un-colonised bare peat surfaces, which is very widespread, might be considered to matter only if it in the end affects the 'recolonisation outcome'. That is, trampling of bare peat would need to have an additive effect on the rate of loss of peat by weathering. Then this additional rate of loss would need to be proven to affect the ultimate outcome in terms of recolonisation (which, ultimately, leads to renewed protection of the peat mass if there is any left to protect after erosion has acted).

The facts seem to point, at least on the highest reaches of the site, to bare peat surfaces being very heavily eroded by weather before they eventually become ready for colonisation. Furthermore, the widespread signs of preparation of peat surfaces by weathering (e.g. frost fluff) and the ease with which peat sediment can be found locally on peat flats and more widely in channels points towards a system in which the majority of the bare peat surface could disappear whether deer are present or not. This point is also relevant to the process of colonisation as described above, which can involve many failed attempts by plants to establish, but possibly few failed attempts relating to deer trampling and grazing, before colonisation finally occurs. A final and related point is that once the bog has recolonised it appears to be the case that the new habitat is inherently more resistant to impacts by deer, because of the lack of peat, reduced wetness, and increased robustness to trampling and grazing of some of the plant species which finally colonise e.g. *Juncus squarrosus* Heath rush and *Racomtrium lanuginosum*.

To summarise the discussions at this stage, deer undoubtedly have a negative impact on the physical state of bare peat flats and also on the chances of new plants establishing, and this level of impact tends to rise with increasing deer density from the evidence available. Whilst they also have potentially positive effects, it is considered in the circumstances unwise to treat these latter effects as widespread or important processes. Therefore, the debate ideally needs to focus on the extent to which these impacts affect the ultimate outcome on site which is that eroded areas need to recolonise. The simple fact is that the bare peat supply will eventually run out on any given slope (as it is restricted in depth) and hence weathering can only operate for so long.

Our view, and this is tentative pending the results of further research (see Recommendations), is that the likelihood of deer having an adverse impact on the recolonisation process is in many ways inversely related to altitude. That is, at lower altitudes it is less likely that weathering and other related processes will counteract the impacts deer cause; the impacts of deer at the lowest altitudes could be argued as being almost wholly ‘additive’. On the uppermost reaches of the site where exposure is extreme, much of the impact deer are having on the recolonisation process could conceivably be counteracted by the effects of weather and related processes which act to prepare surfaces for recolonisation based on a ‘temporally-dependent sequence’ of physical events. Rising up the altitudinal cline present in between the extremes of elevation, the effects of deer may become less important and the effects of weathering and related processes may become more important in determining site condition.

However, this argument is made in isolation of several other fundamentally important points:

- We do not yet know the reasons for the mire surface breaking down in the first place. If deer or sheep were partly implicated, and it cannot at present be guaranteed they were not, some of the erosion we see on site today might be in part related to large mammal problems in the past. That has two obvious implications. Firstly, it puts a different perspective on the condition of the site today, and the nature of interventions that could be justifiably employed (e.g. bare peat stabilisation might only be justified if human mismanagement of sheep and deer, or other inappropriate land use practices, are implicated). Also, it puts a different perspective on the issue of whether or not present deer densities are compatible with ongoing survival of remaining bog remnants. If deer are implicated then these intact areas are a critically-important vestige of the original habitat to protect whereas if the process of their breakdown and erosion is entirely natural then they are simply the last vestiges of the bog prior to the onset of a natural erosional phase.
- We cannot be sure at present that our understanding of the colonisation process is robust, nor can we be sure that the factors which came together to allow previous recolonisation on the site are still present today. The most obvious is that we do not really know without further research what the size and distribution of the deer population was previously in the SAC and wider area, nor what the level of cull being taken was in each area. Hence we cannot be sure how the deer and sheep populations interacted with the bog during previous phases of colonisation. It may be that some previous colonisation only happened *because* the bare peat was less disturbed? Another possibility is that recolonising areas were more extensive in the past than now, and thus deer impacts were diluted whereas now recolonising areas may be more limited in extent and hence utilised proportionately more often – they are certainly in some senses attractive to deer given that they are a source of potentially palatable new plants in an environment otherwise lacking them. However, we cannot establish this without further and more detailed research.

- The counteracting effects of weather are not relevant when considering deer impacts on the intact bog as described earlier – in fact, weather acts to make any break up of the acrotelm by deer worse. On this point, high densities of deer on bog whether on the upper reaches of the site or the lower reaches cannot be considered ideal from a nature conservation perspective. This is especially the case because an apparently low percentage of surfaces being affected by impacts does not in turn imply a lack of seriousness – the effects may be creeping cyclically (i.e. 5% loss of hagg edges every year means that haggs continue to shrink every year, not simply that 5% of their edges are affected).

4.3 Other deer impacts

The 2011 study also showed that a range of general impacts are occurring on non-bog habitats as a result of deer/sheep grazing, browsing and trampling, albeit that it was not a prime focus of the work. Perhaps the most obvious is that the present level of off-take of dwarf shrubs, notably *Calluna*, is acting in some places to cause contraction of cover as evidenced by the presence of growth forms indicative of chronic browsing and the fact that in many places off-take levels were found to be high locally. A notable feature of the site in this regard is that summer off-take of dwarf shrubs is fairly high – high levels of off-take do not normally occur at this time of year unless animal densities are high.

Other impacts are occurring, including heavy grazing of grasses and local trampling of vegetation surfaces generally. The high level of trampling could conceivably be implicated in the apparently low density of Dotterel present on the site, and the high level of grazing could conceivably be implicated in the ‘disappearance’ of some of the rare plants previously recorded on site. However, neither of these aspects was directly studied precluding further comment at this stage.

Irrespective, evidence from the site confirms that higher levels of occupancy in general equate with higher levels of impacts, albeit that complex interactions occur because of the distribution and relative abundance of bog and non-bog habitats. It follows that decisions on ‘stocking levels’ will to an extent influence the level of impact observed on site, which is why the occupancy data and abundance estimates obtained from site are a very useful source of information to support decision-making.

4.4 Deer population status

It is undoubtedly the case that large mammal densities on the site over the period studied were, from a nature conservation perspective, very high at c. 25-30 per km^2. Interestingly, this estimate mirrors quite closely the density of deer recorded on the last direct count of the site in July 2010 (count of c. 3000 compared to an abundance estimate in 2011 of c. 2900).

What is arguably of greater interest is the pattern of occupancy, which shows that densities over the months studied were locally much higher than those quoted above. The densities in Zone 2 were close to the average (24 per km^2) whereas those in Zone 3 were approximately 50% greater (36 per km^2); the densities in Zone 1 were measured at around half the average (11 per km^2). Densities locally, and notably in parts of Zone 3, were even higher than 36 per km^2.

Critically, the density of animals using the blanket bog was fairly high even in Zone 1 (12 per km^2); it was much higher in Zones 2 and 3 (21 per km^2 and 30 per km^2 respectively). A related point is that the way the large herds behave. Whilst fieldwork was ongoing in summer and autumn 2011 deer were seen to be regularly disturbed on the site by hill walkers high up, and by other activities in the southern section lower down, which often seems to result in large herds moving as one and feeding in a large group wherever they decide to settle. This appears to result in local densities of animals at certain times and in key locations being exceptionally high, which cannot help matters in terms of trampling impacts especially. On average we assume deer tend to be pushed northward by disturbance but we presume their preference at key times of year is to be in the southern zone because of the better feeding and progressively less harsh climate as one descends towards Laggan and Newtonmore. This probably means that there is a regular movement of deer as they are disturbed, moving north but then trying to move south again.

What can be said is that the deer / sheep densities measured on the site generally, and on the bog specifically, and especially the local densities where the large deer herds exist (which can be many hundreds in size e.g. on the Coignafearn-Glen Banchor march), are very high for a site designated for nature conservation and especially one where the key feature of interest is bog habitats. This is a habitat not generally noted for its resilience to the effects of high densities of grazing animals, as reflected in the rates quoted for stock animals by, for example, the Scottish Government. Moreover the SAC is protected by law which makes a decision on 'stocking levels' all the more important to get right.

There are general reasons why the density of deer using the SAC would normally be considered very high as well as the specific reasons relating to blanket bog already discussed. These include deer welfare, and the related implications of holding deer at high density on upland areas over the winter and spring. That said, most parties familiar with the site say that many of the deer present in the summer disperse for the winter – we have no evidence against which to judge whether or not this is the case (see Recommendations). Other reasons commonly quoted for not holding deer at higher densities, most of which are not particularly relevant to the Monadhliath, include: preventing encroachment onto agricultural land to the detriment of the landowner; preventing high densities of animals from congregating at roadside to the detriment of road users; preventing encroachment onto forestry land etc.

What is even more important than the present density, and debates over its appropriateness, is the future trajectory of the deer population around the SAC and how, depending on its dynamics, this will affect occupancy levels within the SAC. This is a critical given the potential role of deer impacts in determining the future condition of the site from a nature conservation perspective.

Unfortunately, we cannot at present predict the future trajectory of the population using the SAC because of a lack of appropriate data - see Recommendations. What we do know is that cull levels vary very dramatically between estates around the site, and they also seem to have varied markedly between years in some places. These differences and changes will likely have effects on the population of deer using the site, but it is difficult to know how these changes affect the trajectory of 'occupancy level' without further research. Of course other factors will also be important in determining population dynamics not least the recent hard winters, the ongoing issue of climate change and the changes in previous years to the culling regime at Coignafearn.

To manage deer objectively in the SAC we need to be able to address with some certainty a range of basic questions such as:

- How close is the site to its maximum carrying capacity presently? Can the deer population naturally increase to a higher level than it is now? To what extent will recent changes in sheep stocking affect deer numbers?
- Are the impacts we see on site today a result of a recent decline in large mammal density, or are they a product of an increasing density? To what extent are impact patterns on site a legacy of the time that sheep numbers were higher?

- How much has the site changed in recent years and why - what does this tell us about the likely direction of change in future years? To what extent will the future ‘condition-trajectory’ of the site be affected by physical processes and by mammal-related impacts? Will a reduction in occupancy on the SAC result in a significant change in the ‘condition-trajectory’ of the site?
- What would happen to occupancy levels on the SAC if an increased cull were implemented in the wider area – would the level of occupancy in the SAC decline and, if so, by how much for a given level of cull? What would happen to the level of occupancy on the bog habitats?

Obtaining answers to these questions is important if we are to understand more fully the potential implications of the impact levels and patterns observed in this study, as well as the potential consequences of managing deer in a range of different ways in the future.

5. CONCLUSIONS

We propose the following conclusions at this stage:

- Much of the blanket bog complex which was originally present on the site has now experienced major surface erosion, with a notably higher proportion of the surface lost as altitude increases. A high proportion of this land has completely recolonised at all altitudes, although spontaneous colonisation of bog on deeper peat seems to occur much more frequently at low altitudes whereas at higher altitudes the peat surface appears to strip down markedly before being able to recolonise; the early-stage plant assemblages in these high-altitude areas tend to have more minerotrophic influences acting upon them which make them appear drier, although signs of bog recovery are also present in places.
- Whilst a large proportion of land has recolonised a considerable proportion is still eroding actively, notably so at higher altitudes. The site will therefore undoubtedly lose considerably more peat mass from these active areas before this current phase of erosion ends. The rate at which this occurs will probably determine to an extent the timing of recolonisation at higher altitudes because of the apparent dependence on peat becoming shallow before recolonising.
- The intact remnants of the original bog also now show signs of new surface erosion being initiated in many places, notably so at higher altitudes. These may also, depending on their response in the near future, contribute to an increased level of erosion and hence habitat loss in the near term. This is potentially serious, given that there is relatively little ‘intact’ mire left on the site.
- The occupancy assessment shows that the density of deer / sheep on the site in summer-autumn 2011 was very high overall at 25-30 per km^2, but that densities actually varied markedly within the SAC boundary; densities were locally high over the period in some parts of the site (average of 36 per km^2) and lower in others (12 per km^2). Whether or not the occupancy level is rising year-on-year in the SAC (which could have potentially serious implications), is stable or is falling is a matter of conjecture at present because the data needed to make this judgement are not available.
- Irrespective, it is clearly the case from the data gathered that many forms of deer impact on the bog and eroded bog areas are present; these tend to increase broadly in line with occupancy level in the analysis zones dominated by blanket bog, which implies that their frequency of occurrence and their intensity will likely decline if deer occupancy levels decline; the corollary is that they may also increase if occupancy levels in increase, although we cannot say at this juncture whether or not the population using the blanket bog specifically, or the wider site more generally, is presently at ‘carrying capacity. The population, and hence impact levels, can only conceivably increase further if the population is presently below carrying capacity on the site.
- In terms of the potential seriousness of the present level of impacts as recorded on site in 2011, which are a product of the present occupancy levels and related deer behaviour apparent, we can conclude the following at this stage:

    - The deer impacts on the intact bog at higher altitudes and in some places at lower altitudes will, if they continue, likely move the site to a less favourable condition especially when it is considered that superficial micro-erosion is also fairly widespread in these areas and may be a precursor to the onset of major surface erosion.
    - The significance of deer impacts on eroding and recolonising bog, including on bare peat and on new colonising plants, is thought in part to depend on the altitude at which they occur. The significance of impacts at the highest altitudes may be over-ridden by weathering processes which seem to

produce more intense effects (i.e. deer impacts on bare peat and colonising plants are not necessarily ‘additive’ at the highest altitudes). With decreasing altitude though, as these weathering effects quickly reduce in severity, the impacts of deer appear to be of increasingly greater significance.

- That said, these are interim conclusions on the significance of impacts and are predicated on several underlying assumptions, including that:

  - Deer were not in any way implicated in the initial or subsequent onset of erosional phases on the site.
  - Deer density on the site in the past, when ‘successful’ recolonisation has occurred, was at a similar level to the present day. A lower density than now might have allowed recolonisation to occur more easily, meaning that colonisation in the face of higher densities could now be less likely to occur.

- Unfortunately there is a lack of applied academic research into erosion processes on blanket bog at high altitudes in the Scottish Highlands, notably so in relation to deer, and this contributes to making it difficult to place the results of this present study into context. That said, we feel it is entirely incumbent on SNH to commission this type of research if it is not otherwise available. On a related point, SNH has been working for a number of years now on the Monadhliath site and a number of studies have been undertaken. It might have been expected that more had been learned from these studies had they involved the gathering of more data generally, and more data on blanket bog condition and deer occupancy patterns specifically. That said, this is easier to argue in hindsight than to have predicted in advance. What is clear is that much more knowledge does now exist after the 2011 study. Nevertheless, SCL believes that the present level of understanding of the processes at work on site remains very poor even after our own study being completed.
- Our concern is that this lack of understanding, unless it is addressed by further and more detailed study, might well lead, albeit perhaps unwittingly, to inappropriate decisions on the future management of the site being made. This could be serious given its status as an SAC and as a significant store of terrestrial carbon, but also because of its status as privately-owned land of significant local socio-economic interest.
- As a consequence, we believe that it would be prudent to spend a period of 3 years studying the site in more detail, as part of SNH’s wider programme of works planned for the site, prior to deciding on the best course of action. The reason we feel this course of action is justified is that the extent of changes to the bog that will occur in this time are unlikely to be large enough to warrant any greater concern than already exists at the time of writing. On a related point, a wider programme of research will help in understanding more about the wider debate over the importance of bogs, including eroding bogs, as terrestrial carbon stores as well as related debates over land use and climate change.
- We make a raft of recommendations to SNH about how to deal with the site over the next three years, with a very strong emphasis on ensuring that a fit-for-purpose package of research and monitoring is developed and implemented as part of SNH’s wider programme of work as planned for the site.

6. RECOMMENDATIONS

A range of technical work on the blanket bog and the deer population in and around the SAC is recommended as a follow up to the 2011 study. It should be undertaken over a three-year period with the aim of trying to better understand the prior history of the bog within the SAC as well as its present dynamics, in order that a robust prognosis for its future prospects under different management regimes can be produced. Our proposals for research are:

1. Deer population assessment in the wider estate area:
    a. the size of the population of deer in the wider estate area is ascertained concurrently with that in the SAC, both in the winter and in the summer, in 2012-13 and again in 2014-15. This could be by pellet group counts or by live counting.
    b. a count of sheep should be incorporated into these assessments.

2. Deer population assessment in the SAC, based on pellet group counts:
    a. the sampling locations set up in summer 2011 are ideally re-visited in early summer 2012, the aims being to:
        i. Ascertain the pattern of over-winter utilisation, thus obtaining an idea of the utilisation over the course of a year.
        ii. Gather extra data on habitat condition and impacts on key local sites, as well as on their geomorphology – see later points in this section.
    b. this study is repeated at least once more over the proposed 3 year study period, in 2014 if not also earlier.

3. Detailed cull records obtained from the estates and analysed in order to:
    a. Establish the likely level of cull in the SAC
    b. Ascertain the level of cull in the wider area, and analyse in conjunction with older count data to try and understand the likely dynamics of the deer population using the SAC in the past 20 years or more.
    c. Use the same data, in tandem with the population assessment data of summer 2011, to model estate and SAC populations into the future under various cull scenarios (current scenario; different future scenarios).
    d. Procedures for standardised recording of the cull in the SAC and wider estates should be implemented, and data made available for analysis.

4. Impact assessments in the SAC:
    a. the suite of data gathered in this study should be subjected to advanced types of spatial-multivariate analysis in order to extract maximum value from it.
    b. additional data should be obtained on the state of the intact blanket mire, and recolonising land, in 2012 from each transect location set up in 2011 which is located on bog or eroded bog.
    c. the impact study should be repeated again in 2014 along with the pellet group counts, in order that a 'condition trajectory' for the site can be established.
    d. the suite of current enclosures is examined to ascertain what further evidence can be obtained from them at the present juncture (e.g. grass flowering status, patterns of colonisation allied to surface geomorphology etc). These enclosures should be modified to reduce the degree to which their design affects the surface processes which would otherwise occur, or not occur, in their absence.
    e. a suite of new enclosures be erected on (i) intact mire and (ii) on bare peat flats (not at hagg – bare peat interfaces as presently) and monitored with due cognisance of geomorphological processes as well as key ecological processes (including e.g. rates of plant germination and mortality; key surface

processes rates of peat sediment accumulation and loss; these measures should be undertaken on the existing enclosures also).

5. A detailed assessment of the previous dynamics of the blanket bog within the SAC should be scoped out and undertaken, to include all aspects of land use change likely to have affected the way the bog was managed:
    a. Historic land use:
        i. Obtain records of sheep stocking from landowners and other public sources
        ii. Obtain data on grouse / deer culls from estate game books, with the aim of understanding the basis for historic changes in deer numbers arising
        iii. Muirburn extent and sheep stocking from historic images; compared with other similar sites nearby where bog is extensive.
    b. Old SSSI reports and images; parish records.
    c. Climate data.
    d. Sediment coring of upland water bodies to ascertain the likely timing of erosion events; checking of peat cores from the site for evidence of fire and its timing; analysis of peat cores to check for the timing of major changes in plant cover; dating of material from the cores to establish a minimum period for the onset of peatland erosion

6. Wide-ranging geomorphological assessments of the site should be undertaken, to include:
    a. Field assessments:
        i. Checks for charcoal in peat stratigraphy (fire as a catalyst for erosion events).
        ii. Micro-erosion research: patterns & processes.
        iii. Check current enclosures for evidence of differences in surface processes between enclosed and un-enclosed sites.
        iv. Measurement of surface erosion rates, to facilitate prediction of future state.
        v. Fixed point photos and possibly videography of bare peat extents, to better understand surface processes.
        vi. Tagging of colonising plants to quantify rates of mortality due to surface process.
        vii. Terrain sensitivity: deer use of sites at a small scale, and implications for future management.
    b. Detailed assessment of aerial photos from the present day and from previous periods (1950s, 1970s, 1980s) with the aim of identifying pattern and process in surface conditions including:
        i. Changes in bare peat extent.
        ii. Hag shrinkage / gully widening rates.
        iii. Changes from intact to eroded states.
    c. Undertake a search for older photographic material (e.g. from local residents/estates) which might also help us to better understand surface processes in past years.
    d. Modelled reconstruction of the original mire, using erosion rate data and peat depth data from the 2011 assessment.

7. A quantitative study to benchmark the condition of the SAC against other local areas of mire (e.g. to the north in Garrogie; at Drumochter etc), in order to ascertain how the Monadhliath site might have looked prior to the onset of major erosion. This is critical in order to assess what ‘recovery’ should look like as well when it might happen if at all.

8. Following completion of this package of work after three years, a formal review of the data held should be undertaken to include:
    a. Consideration of the appropriateness of current condition targets for the site, notably peat-related condition targets.
    b. Proposed management plans, including a scientifically-informed program of culling if required.

7. REFERENCES

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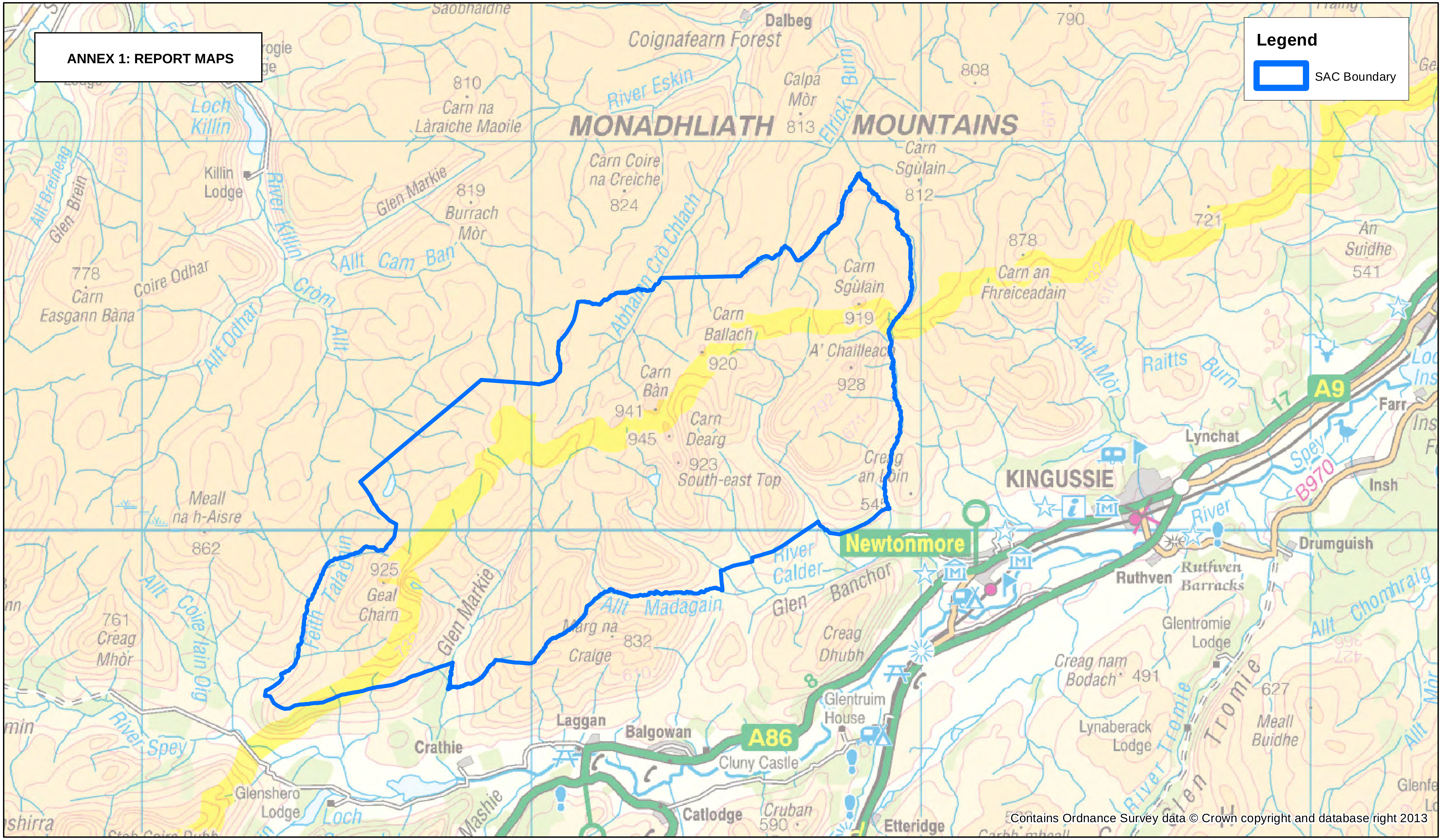
ANNEX 1: REPORT MAPS



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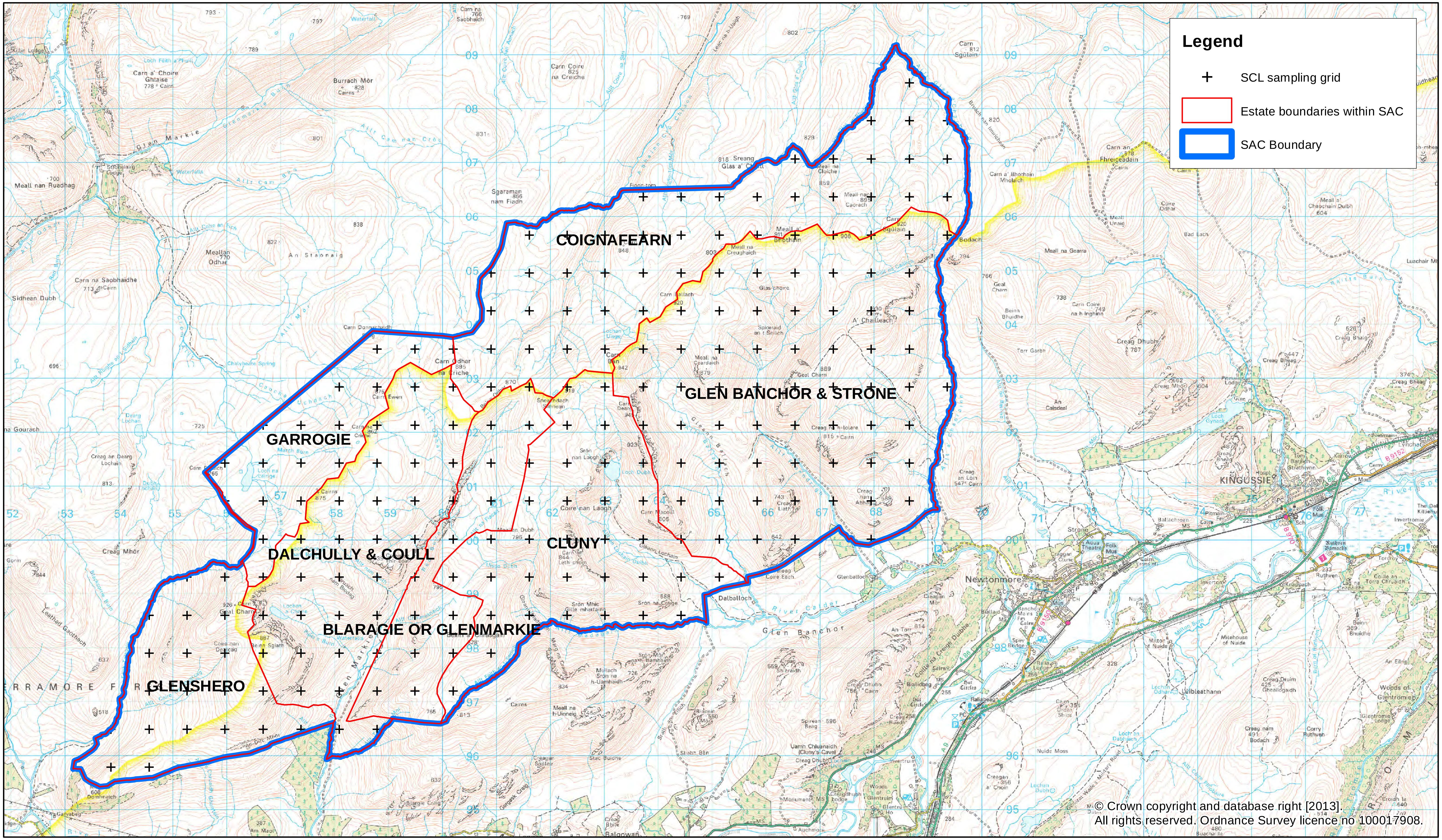

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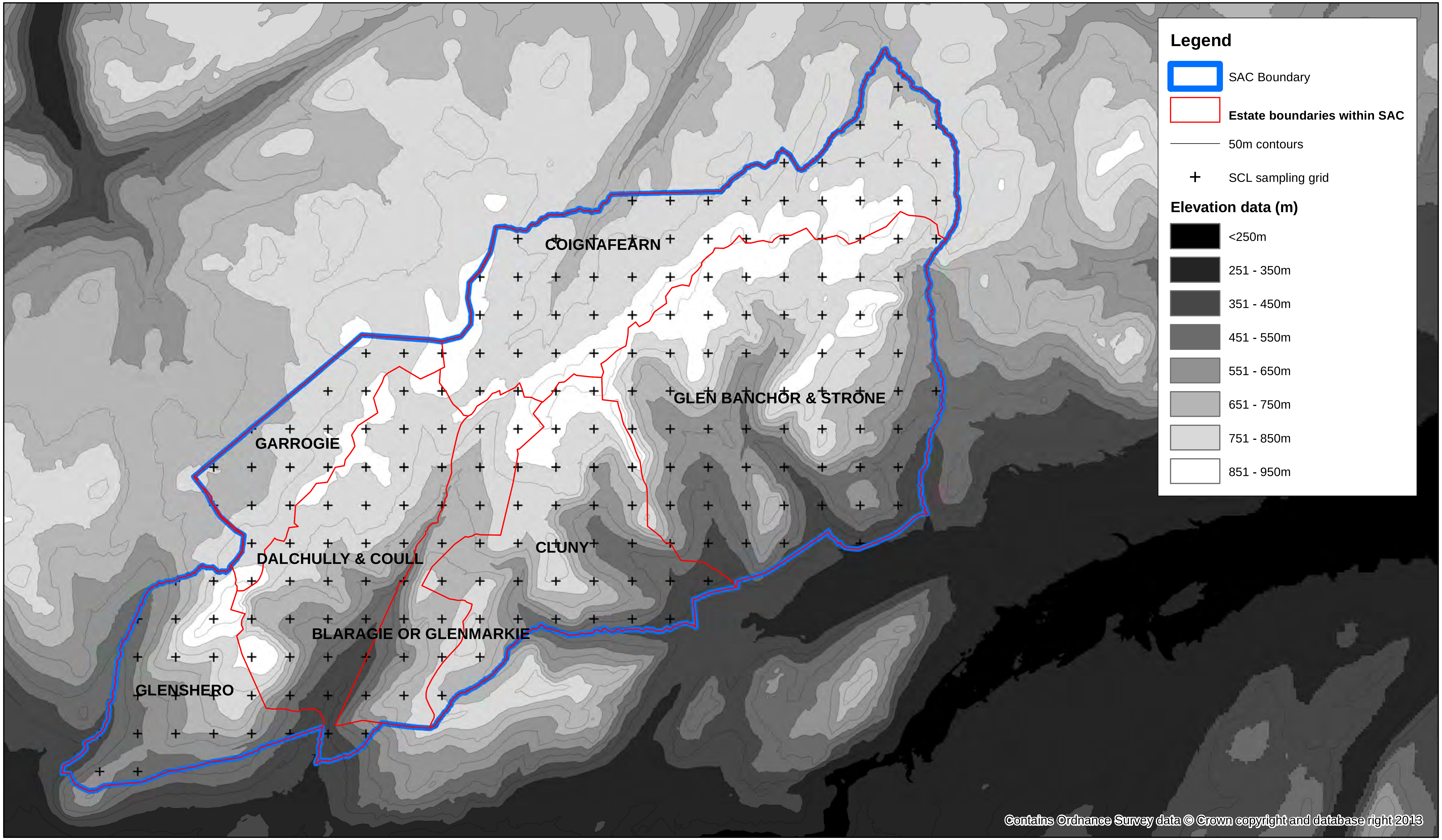

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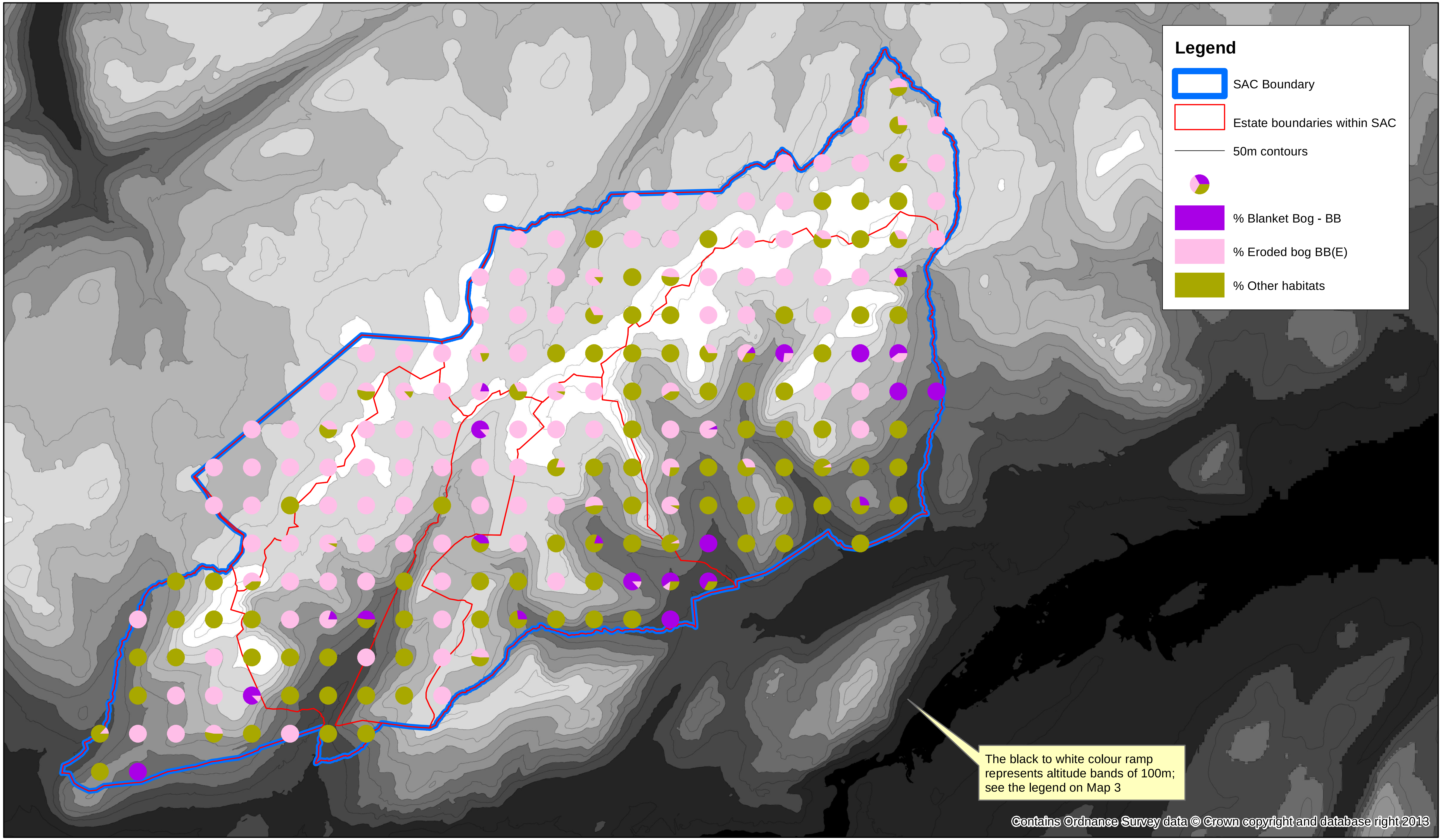

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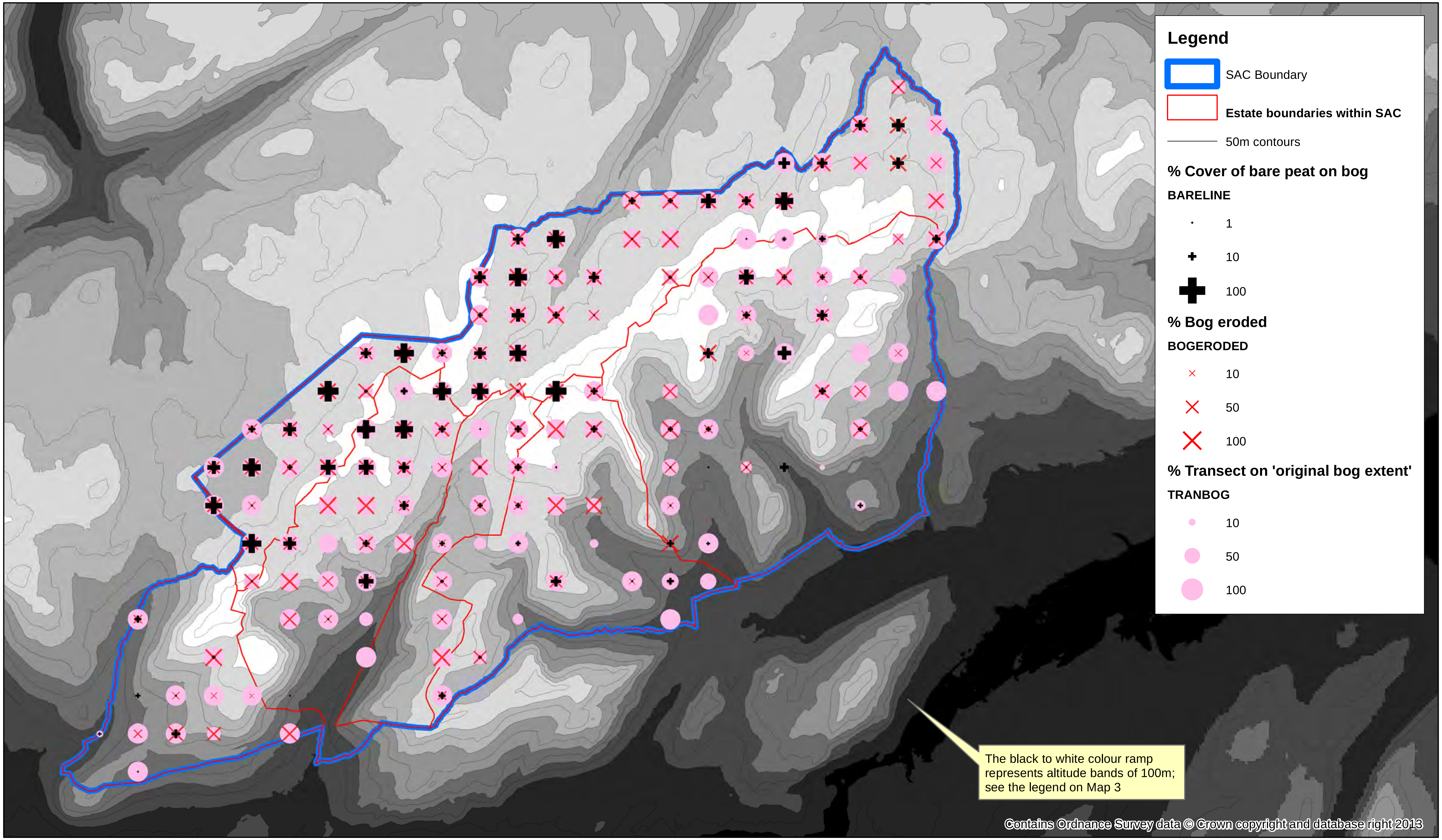

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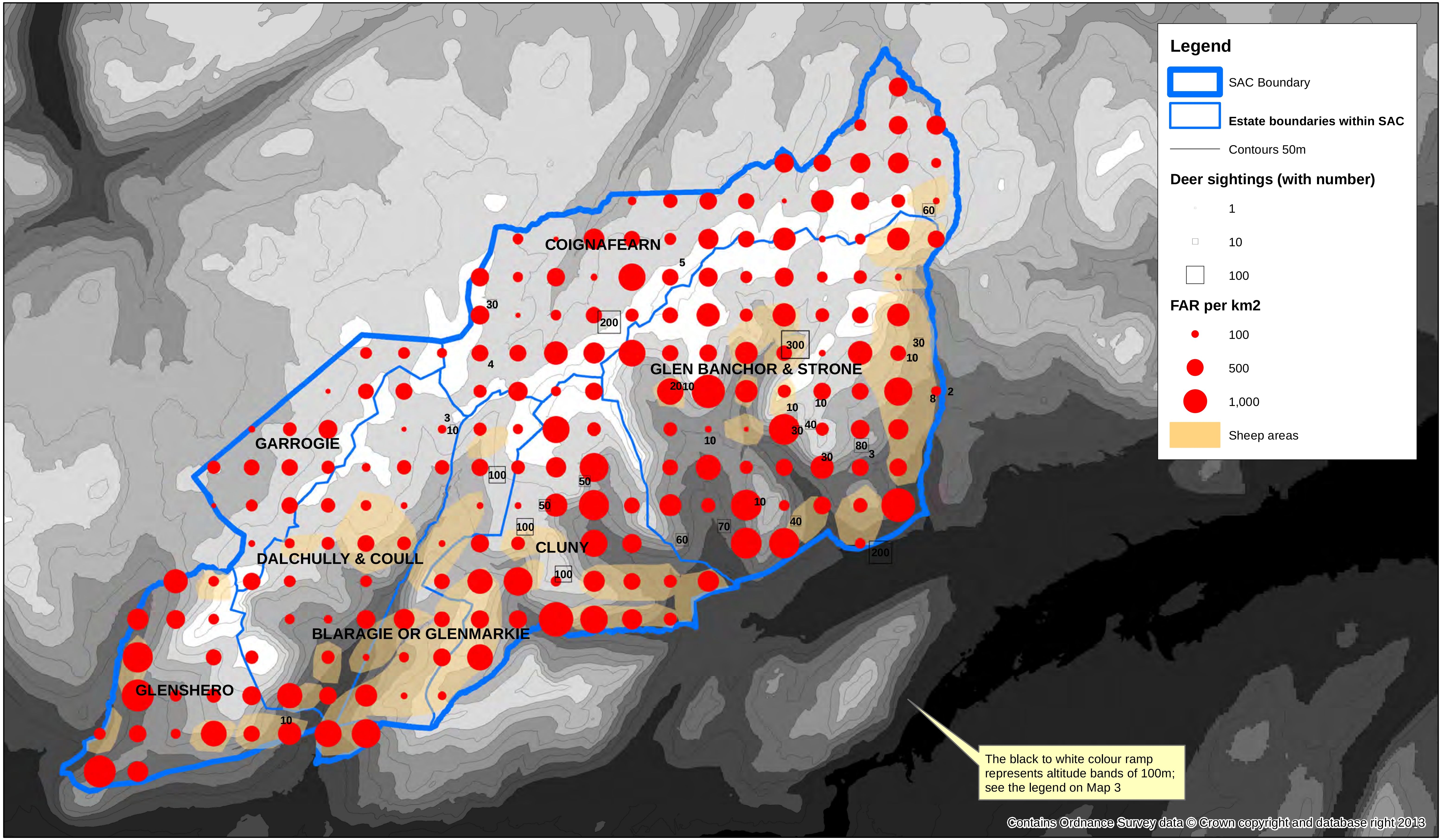

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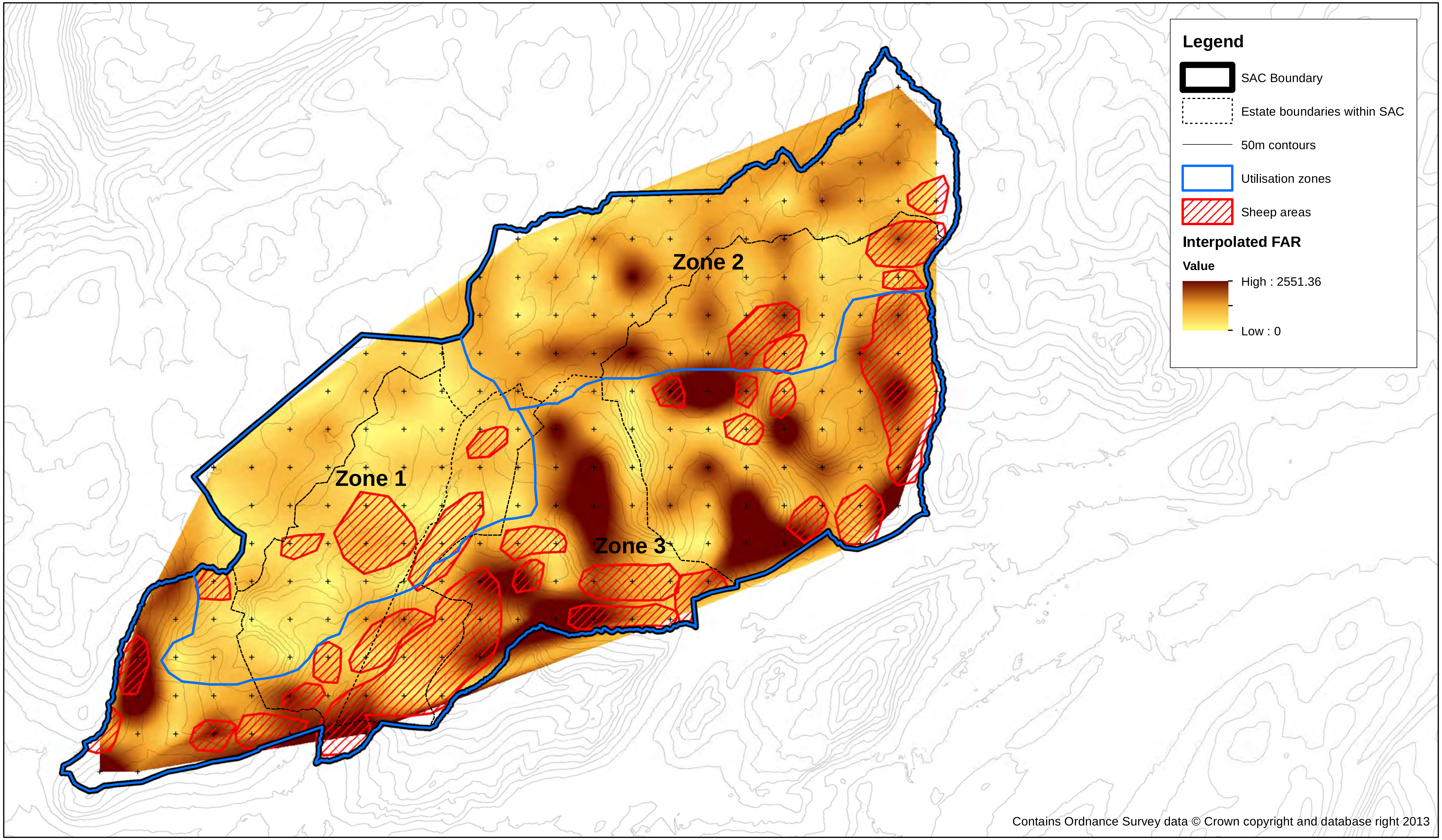

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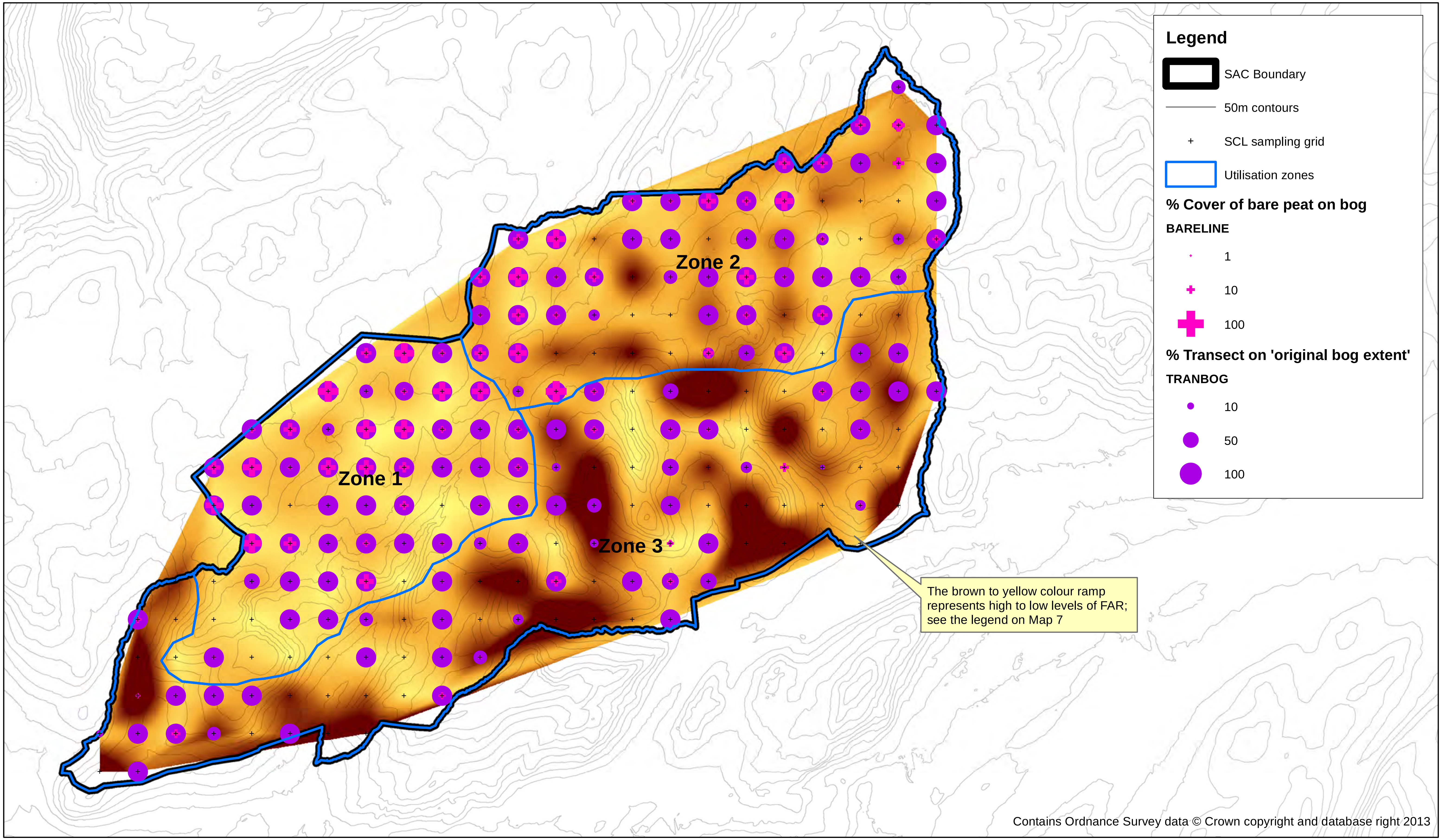

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ANNEX 2: PELLET GROUP COUNT METHODS

Woodland deer numbers are normally assessed indirectly using faecal pellet group counts. Open range areas can also be assessed using the technique. The method exploits the fact that deer deposit faecal pellet groups at relatively regular intervals over time due to their pattern of feeding and rumination. This fact enables estimation of deer numbers by counting pellet groups, under the assumption that the number of pellet groups will increase in an approximately linear manner with the amount of time deer spend in the area being surveyed. Pellet group count data can be 'transformed' into a measure of deer abundance if we know (a) the rate at which deer defecate faecal pellet groups and (b) the period over which counted pellet groups accumulated.

There are two basic approaches to counting pellet groups - the Faecal Standing Crop (FSC) technique and the Faecal Accumulation Rate (FAR) or 'clearance plot' technique. FSC count data are collected by counting all the pellet groups present on a single visit to the study site. Clearance plot data measure the rate of pellet group accumulation between two or more points in time. Both types of data are gathered on sample plots because survey areas are always too large to census in their entirety.

The faecal standing crop is a reflection of the balance between gains of new pellet groups (i.e. deer defecation) and the disappearance of older pellet groups from the system (i.e. complete decomposition). The size of the 'standing crop' in the northern UK changes seasonally. In winter, decomposition rates are slow, often zero, and the standing crop of pellet groups generally increases in size from around October to May in the uplands. In summer, decomposition rates are considerably higher and the standing crop gradually reduces in size during this time and until the onset of winter.

Standing crop counts provide a measure of deer utilisation over a period equal to how long pellet groups last in each habitat type present. Clearance plot data provide a measure of deer utilisation over a period equal to the time between visits to sample plots.

To transform standing crop data into a measure of deer abundance, you need to know the average amount of time that pellet groups counted during the survey have been present. This is complex and time-consuming to work out accurately. Often, people estimate this value to reduce costs. To transform clearance data into a measure of deer abundance, you only need to know the period of time between visits. However, the method assumes that no pellet groups defecated after plots are laid out decompose fully before you complete the second visit to count them.

Transformed pellet group count data actually quantify 'average deer abundance' over the study period as it is common for deer to move in and out of a study area during the survey period. As a result, the total number of deer present on any one day may not equal the average number of deer measured over the period. We normally term transformed pellet count data 'Effective Deer Utilisation' or EDU to acknowledge the fact that the data represent the number of deer that were effectively present and not actually present. EDU cannot, in principle, be used to separate '1 deer for 25 days from '25 deer for 1 day' unless movement of deer across the boundaries of the survey area is negligible.

ANNEX 3: INTERPOLATION

This appendix supplies some technical background to interpolation methods for interested readers. The text has been compiled using the contents of the help menu in ArcMap 9.2© but has been adapted slightly for the purposes of this report.

Interpolation predicts values for cells in a raster from a limited number of sample data points. It can be used to predict unknown values for any geographic point data, such as elevation, rainfall etc.

The assumption that makes interpolation a viable option is that spatially distributed objects are spatially correlated; in other words, things that are close together tend to have similar characteristics. For instance, if it is raining on one side of the street, you can predict with a high level of confidence that it is raining on the other side of the street. You would be less certain if it was raining across town and less confident still about the state of the weather in the next region.

Using the above analogy, it is easy to see that the values of points close to sampled points are more likely to be similar than those that are farther apart. This is the basis of interpolation. A typical use for point interpolation is to create an elevation surface from a set of sample measurements. In this report, interpolation is used to create a surface from a set of sampled measurements of faecal pellet group accumulation rate.

There is a variety of ways to derive a prediction for each location; each method is referred to as a model. With each model, there are different assumptions made of the data, and certain models are more applicable for specific data—for example, one model may account for local variation better than another. Each model produces predictions using different calculations. The simplest interpolation tools available in ArcGIS 9.2© estimate surface values for each cell using the value and distance of nearby points. The interpolated values for surfaces are a weighted average of the values of a set of nearby points, weighted so the influence of nearby points is greater than that of distant points.

The Natural Neighbours interpolation method used in this report finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas of overlap in order to interpolate a value. Its basic properties are that it uses only a subset of samples surrounding a query point, and that interpolated values are guaranteed to be within the range of the samples used. It does not infer trends and will not produce peaks, pits, ridges or valleys that are not already represented by the input samples. The surface passes through the input samples and is smooth everywhere except at locations of the input samples. It adapts locally to the structure of the input data, requiring no input from the user pertaining to search radius, sample count, or shape.

ANNEX 4: IMAGES

In this section we present a range of images which provide the reader with a better understanding of some of the features and processes we refer to within the main body of the report.

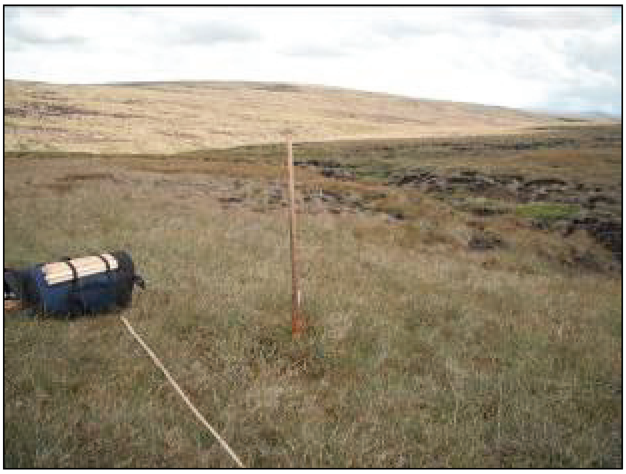

Image 1. Intact, un-eroded mire in the foreground of the image, a relatively rare sight on the upper plateau.

Image 2. A very early stage erosion gully (late stage micro-erosion), which may continue to incise through the peat until it hits the mineral soil below, maintaining a 'v-shaped' cross section during this time, at which point it will widen and lose much of its erosive energy (lower image; in this case the gully is now migrating from left to right because the gully lies on a slope and a stream has formed on its lower edge).

Image 3. A system of linear erosion gullies (not on the Monadhliath) showing the narrow incisions made into the bog surface due to the dominance of fluvial action.

Image 4. An area of sheet erosion on the hill slope above the peat flat in the foreground, showing widespread loss of peat from the surface (upper) and a transition zone between the summit heath (green coloured land) and the original mire surface (orange and yellow mottled surface), now made complicated by a very extensive but recolonised erosion complex on the slope below, with active erosion (black bare peat) clearly apparent in the lower lying valley where the peat is deeper (lower).

Image 5. A large peat hagg, to the right of the erosion gully, on the lower slopes which still retains a bog water table although only in the very centre and probably only temporarily (ongoing horizontal weathering may eventually cause the hagg to be so narrow that the bog water table cannot persist inside the peat).

Image 6. A very small peat hagg within an erosion complex on the upper slopes, now de-watered and almost completely collapsed - it has lost its bog water table, as evidenced by the nature of the vegetation present.

Image 7. A gully wall (the area of bare peat) on the side of a linear gully system on the lower slopes.

Image 8. A 'hagg apron' to the right of the darker, flat area of bare peat. The apron comprises the angled slope running up to the edge of the hagg top.

Image 9. The base of a very large erosion gully, showing removal of almost all of the peat and appearance of stones. The gully wall, albeit a very shallow-angled example, lies to its left and then left again lies a narrow band of intact mire.

Image 10. A peat flat on the plateau, showing a surface typically devoid of major haggs.

Image 11. A sequence of images showing the process by which 'frost fluff' forms: close up of peat having been removed by upwards development of needle ice (upper image); the appearance of the surface when needle ice is present (middle image); the appearance of the surface afterwards (the area of rough peat in the upper right hand side of lower image).

Image 12. A sequence of images showing various forms of aeolian deposition: close up of a re-deposited surface (upper image; with wet deposition by wind-driven rain); general view of an area where aeolian processes are operating (middle image); pedestal created at least in part by aeolian processes (lower image).

Image 13. A sequence of images showing fluvial processes on site leading to re-deposition of eroded peat: transport of peat sediment in a wide channel at a col (upper image); swamping of vegetation by sediment (middle image) and a collapsed peat pipe system showing sediment having been ejected out of the pipe roof during a storm (lower image).

Image 14. A view of typical shallow micro-erosion features on a flat area of otherwise intact mire (upper image) and a view of micro-erosion on the edge of an intact section of mire (foreground) with more heavily eroded mire in the background (lower image; the perspective makes this difficult to see, but beyond the obvious band of orange vegetation in the middle of the image).

Image 15. The spontaneous re-development of aquatic nanotopes in the base of a low-altitude erosion complex (upper) and the re-development of a small locus of Sphagnum in the base of a high altitude peat flat which has experienced major sheet-type erosion (lower).

Image 16. A hagg edge which is partly-sealed, the process involving collapse of the hag edge and undermining of the hag apron until such times as the vegetation overhangs the apron and fuses with it. The left hand side of the hag shows an area where deer have trampled the edge as it tries to seal.

Image 17. The surface of a Sphagnum-rich blanket mire which has experienced extreme levels of trampling and has entirely lost its typical surface micro-topography (upper), a close-up shot showing a heavily trampled and dunged surface and the lack of Sphagnum moss species characteristic of these areas (middle) and well -developed surface micro-erosion on a site in Dumfries & Galloway on which high levels of trampling by sheep are thought to have catalysed, or otherwise sped up, the process of surface breakdown (lower).

Image 18. Images relating to the process of plant recolonisation: plants recolonise the edges of eroded peat flats (upper image) but peat flats frequently experience slope-wash (middle image) which can result in new plants becoming swamped with sediment (lower image).

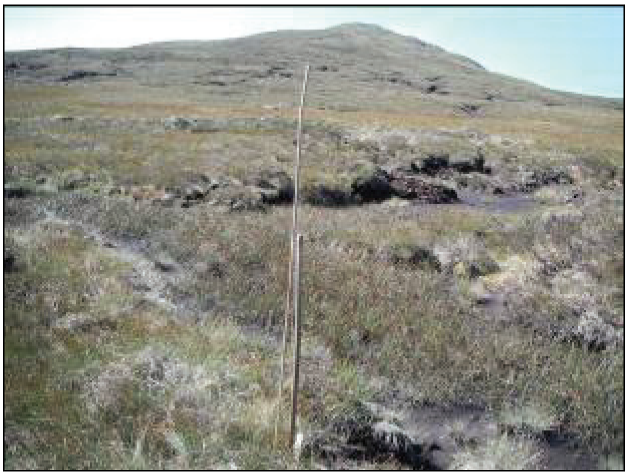

Image 19. Images relating to the process of plant recolonisation: the process of sediment re-deposition can cause vegetation to be swamped (upper image) but with time recolonising plants can gain the upper hand (middle image) often after much peat has been lost, and so eventually areas will become well colonised like this old peat flat on Coignafearn (lower image).

Image 20. Colonising plants being undermined by wind erosion, ending up sitting on little pedestals and hence prone to drought stresses and desiccation.

Image 21. Up-rooting of Sphagnum mosses by deer on the Monadhliath plateau.

Image 22. An over-deepened path lying on the edge of a recolonised gully base.

Image 23. A ‘terrace path’ formed along the base of a gully wall by deer trampling – this is not a particularly well-developed example but gives a general impression.

Image 24. The edge of a hagg after a small number of deer have jumped down it, showing the typical ‘notch’, albeit a small example, where the turf overhang has been dislodged and the peat disturbed below it.

Image 25. Two images of acrotelm puncture, with the top image taken in well-developed vegetation and the lower image in vegetation that is dying back within an area of onset micro-erosion.

Image 26. Colonising plants being grazed by deer.

ANNEX 5: BLANKET MIRES & PEATLAND EROSION

Introduction

This appendix provides a brief review of the scientific literature on peat erosion, especially the types, causes and consequences of erosion. Prior to discussing erosion, a brief overview of mire formation and functioning is provided.

Mire formation

Mires are best classified by the nature of their water inputs. A distinction is often made between bogs (ombrotrophic mires) and fens (minerotrophic mires) where the former are rainwater-fed systems and the latter groundwater-fed.

Hughs and Heathwaite (1995) classify UK mires on a morphological basis into soligenous (sloping) mires, basin mires, valley mires, floodplain mires, raised mires and blanket mires.

The most widespread upland peat type is blanket mire (Milne and Brown, 1997) and it typically occurs in areas with high rainfall and low levels of evapotranspiration, allowing peat to develop over large areas of undulating ground, over slopes up to 25°-30° (Evans and Warburton, 2007). Linsday (1995) suggests the following conditions are necessary for blanket bog formation:

- Minimum of 1000mm rainfall
- Minimum of 160 wet days (>1mm rain)
- Mean temperature of <15°C for the warmest month
- Minor seasonal fluctuation in temperature

Blanket mire is extensive and may therefore incorporate other mire types as it expands, forming blanket mire complexes (Lindsay, 1995).

Blanket mires can be further sub-divided based on scale (Ivanov, 1981); nanotope, microtope, mesotope and macrotope, the characteristics of which are reviewed by Evans and Warburton (2007).

The values of mires

In Scotland alone, blanket mire accounts for some 13% of the land area (JNCC 1999), making it a significant proportion of the UK land resource. Many areas of blanket mire straddle catchment boundaries and contribute to discharge in more than one river system. Consequently, their modification through different management regimes often has implications for several catchments (Bragg, 2002).

Aside from their function in catchment hydrology and carbon storage, there is also considerable ecological value in blanket bog habitat, which is demonstrated by its inclusion in lists of priority habitats requiring protection under national[21] and international[22] mechanisms. Blanket bog provides important breeding and feeding grounds for globally rare and nationally important species such as dunlin, golden eagle and greenshank (Ratcliffe and Oswald, 1987), and a wide range of terrestrial and aquatic invertebrates are exclusively associated with the range of niches that exist in the vegetation mosaic (Coulson *et al,* 1995).

[21] Conservation (Natural Habitats & c) Regulations 1994
[22] Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora

Peat soils comprise a high percentage of water (85-97%), having formed through the accumulation of dead plant material under low-oxygen, waterlogged conditions (Clymo, 1991). Peat accumulation occurs where the input of material (nutrients and carbon) exceeds the output, with rates fluctuating over time in response to environmental conditions (Worrall *et al* 2003). In this way, mires remove and store carbon from the atmosphere, acting as an important carbon 'sink'. Indeed, on a global scale peatlands account for c. approximately 30% of terrestrial carbon storage, despite occupying only 3% of the Earth's land surface (Hilbert *et al* 2000). However these processes can be halted or reversed due to natural phenomena such as climate change, or through anthropogenic-induced disturbance, such as peat mining and drainage. The desiccation of peatlands can result in increased peat respiration of CO2, thus resulting in the peatland becoming a net source of CO2 (Chapman and Thurlow 1996; Silvola *et al* 1996)

Peat physical properties and mire hydrology

The bog peat matrix consists of an upper, loose layer ("acrotelm") through which water moves rapidly, and a lower, less permeable layer ("catotelm") as defined by Ingram (1978). These zones are also defined by the biological activity that occurs within. The acrotelm is known as the 'active' layer, in which the majority of growth and decay occurs and most soil organisms exist (Charman, 2002). Within the catotelm, rates of decomposition and change occur at slower rates, being permanently saturated and anaerobic. These layers may be visually distinguished by a transition from loose, pale peat to solid, saturated peat, however in some cases the boundary definition may not be as obvious (ibid.). A rapid change in bulk density can also be used to estimate the transition between layers (Rowell, 1994).

Acrotelm depth fluctuates in response to climatic wetness; for example, during dry periods, the acrotelm deepens, producing well-decomposed layers of peat. The structure of the acrotelm resulting from these growth and decay processes gives it special hydraulic properties that tend to stabilise the fluctuations of the water table (Bragg and Tallis 2001). As the water table rises in response to rainfall, it enters layers of material which are increasingly permeable so that lateral subsurface runoff increases. Further rise in water table level is therefore limited, so erosive overland flow seldom occurs. Conversely, when water table levels drop down into the deeper, more decomposed peats, lateral runoff is impeded because permeability decreases with increasing humification of the matrix, limiting the amount of further water table lowering (Ingram and Bragg 1984). The result is that the water table spends most of the year within a layer approximately 100mm thick with occasional drawdown to around 0.5m below the mire surface (Bragg and Tallis 2001).

Disturbance to mires

Long-term changes in peatlands arise from multiple external forcing factors (allogenic factors) as well as from a variety of internal processes (autogenic factors). Climate change, occurring over medium- to long-term time scales, is the single most important factor in the initiation and termination of peat formation. Significant impacts to peatland form and function can also occur over much shorter time scales, such as those arising from human activities (Charman, 2002). In recent decades, greater attention has been paid toward understanding peatland processes in relation to catchment hydrology (Bragg, 2002), carbon storage (Worrall *et al,* 2003; Silvola *et al,* 1996; Hogg *et al,* 1992; Chapman and Thurlow, 1998), and various issues related to conservation and restoration of peatland biodiversity. The impacts of short-term disturbances have also featured prominently in many peatland research agendas, particularly in relation to commercial peat extraction, deliberate drainage for forestry and agriculture, the effects of burning, and, increasingly, the impacts of wind farm installation.

Mires have been shown to be particularly sensitive to human impacts, especially in hydrology (Bragg and Tallis, 2001). Removal of peat and peatland vegetation cover has been demonstrated to lead to peat desiccation, gully formation and increased erosion (Tallis, 1973; Birnie, 1993), while simultaneously changing the chemistry of the surface peats, affecting nutrient availability to plants (Magnusson and Stewart, 1987) and water quality runoff (Evans *et al,* 2006). Alterations to peatland hydrological regimes can have wide-reaching implications; studies suggest that disturbance-induced increase in sediment loads in runoff can adversely affect water quality downriver of upland catchments (Archer and Newson, 2002; Prévost et al, 1999) and adversely affect aquatic organisms, including important salmonid populations (Greig *et al,* 2005). Disturbed areas of peat are at further risk from erosion from wind and rain, which can accelerate its degradation (Foulds and Warburton, 2007).

Peatland erosion

The upland peatlands of the UK are severely eroded with large areas affected by gully erosion, which is the primary removal of particulate carbon from peatland systems. Consequently there is a need to understand the causes of erosion, the nature and rate of erosion and ways to minimise further erosion.

The eroding upland blanket mires of the UK and Ireland support considerable depths of peat, typically in excess of 1m and locally up to 6m or more. It is clear, therefore that long-term character of these mires has been as sites of peat accumulation, but that at some stage in their history the nature of the mire system has switched from peat accumulation to erosion. The initiation of peat erosion is a complex process which may be triggered by a variety of different impacts. Evans and Warburton (2007) consider the onset of peat erosion as a threshold process. At the threshold the mire system switches from an intact system state to an erosional state. The initiation of erosion is controlled by the balance of the forces of mechanical and physiological stress and the ability of the vegetation layer to resist those stresses. Shifts between the two states can therefore be produced by increases in the mechanical and physiological stresses or the reduction in the resistance of the vegetation to these stresses.

In the UK, evidence points to peat erosion being a phenomenon largely of the last millennium. But with numerous contemporary factors operating to perpetuate the erosion processes, it is often difficult to identify with certainty what actually are the initial and subsequent drivers of erosion.

Tallis (1997a and b) identifies in the Southern Pennines two phases of gully erosion; the first starting between 1250 and 1450 AD is associated with dendritic gully development; and the second post 1750 is associated with headward extension of gully systems. In a further study by Tallis (1995), results suggest that some erosion of blanket peat in the English Peak District has been triggered by marginal mass movements which he attributes to peat instability due to natural peat accumulation beyond a critical depth.

Rhodes and Stevenson (1997) identify rapid peatland erosion in Ireland and the west of Scotland, from lake sediment, occurring in the period 1500-1850 AD, which coincides with the Little Ice Age.

The onset or acceleration of peat erosion identified from several regions over the last 250 years is coincident with intensification of upland agriculture, particularly sheep grazing, harsher climatic conditions in the Little Ice Age and impacts of atmospheric pollution on upland vegetation (Evans and Warburton, 2007).

Yeloff *et al*. (2005) investigates the causes of erosion and degradation of March Haigh, a blanket mire in the southern Pennines (UK), over a period of 160 years starting in 1840 AD. Three major vegetation changes were identified to have occurred on the moorland since 1840, namely: 1) the disappearance of *Sphagnum* spp. in the mid 19th century; 2) the replacement of *Calluna vulgaris* by *Poaceae* as the dominant vegetation type ca. 1918; and 3) a reduction in vegetation cover and consequent erosion ca. 1959. The results concur with the findings of other investigations of ecological change in the southern Pennines insofar as degradation of vegetation prior to the mid 20th century appears to have been caused by air pollution, climate change and fire. Following the removal of vegetation by a severe fire during the summer of 1959, unprecedented sheep stocking levels maintained the bare peat surface and thus precipitated extensive erosion.

Aalders *et al.* (2011) demonstrate how Bayesian Belief Networks (BBN) can be used to combine quantitative data from the National Soils Inventory of Scotland (NSIS) with qualitative expert knowledge to estimate risk of peat erosion in Scotland. It was shown that climatic variables (increased temperature, decreased precipitation) are the most important risk factors for perpetuating peatland erosion. However, the BBN approach also indicated that maintaining good vegetation cover is a significant mitigating factor. It would follow that land management practices that impact negatively on vegetation cover would also exacerbate peatland erosion.

House *et al.* (2010) used climate envelope models to suggest as much as 50% of British Uplands and peatlands will be exposed to climate stress by the end of the 21st century under low and high emissions scenarios. However, process-based models of the response of organic soils to this climate stress do not give a consistent indication of what this will mean for soil carbon: results range from a very slight increase in uptake, through a clear decline, to a net carbon loss.

Maltby (2010) concludes that the relative importance of climate as opposed to human activities in both peat formation and subsequent development remains a tantalising question, the resolution of which is highly relevant to the maintenance of existing peat and possibilities for ecosystem restoration, given changes in the climate envelope. Setting policy priorities requires a strong interdisciplinary evidence base. It also demands greater understanding of the effects of both direct and indirect human activities, as well as climate change, on the ability of upland peat ecosystems to deliver societal benefits, which previously may have been undetected, undervalued or simply taken for granted.

Lilly *et al*. (2009) conclude that once upland peat erosion is initiated, in many instances, there is an inexorable tendency towards almost complete loss of the accumulated peat over time. They emphasise that what can be currently observed in the landscape may not be related to present-day but rather to historical conditions. This is supported both by data from sediment cores and measurements of contemporary erosion rates. The measurements show that erosional processes are of the order of millimetres per annum, indicating that the processes may have endured for several centuries. So a geographical coincidence between erosion and present day conditions cannot be assumed, necessarily, to reflect a causal relationship.

Erosion processes

Physical erosion of peat in unforested upland areas can be caused by many factors including wind, fluvial, mammalian or anthropogenic factors and slope movements. Here we briefly review the actions of wind, water and mammals.

Wind

Strong winds are a characteristic feature of UK upland areas. Despite this, understanding of aeolian processes in upland environments of the UK is limited (Foulds and Warburton, 2007) and especially in relation to peat. Wind erosion on bare peat flats and summit areas is an important dynamic process which produces a distinct suite of small-scale landforms. Maximum erosion occurs on SSW to WNW aspects and this is related to the mechanics of erosion by wind-driven rain (Evans and Warburton, 2007). Wind erosion only becomes the dominant process on flatter ground where fluvial processes do not dominate, such as on the high plateaux of the Scottish Highlands.

Foulds and Warburton (2007) present direct measurements and observations of blanket peat erosion by wind action during a two week period of desiccation in the North Pennines, Northern England. Their analysis revealed that surface desiccation led to peat crust erosion and dust deflation. During short (≤1 hour) periods of precipitation, wind-driven rainfall also caused erosion. Typically, dust flux rates were up to two orders of magnitude lower than recorded during periods of sustained wet weather. Measurements demonstrate the hitherto unreported rapid switch in process regime between wind-driven rainfall and dry blow deflation in blanket peat environments. Dry blow processes of blanket peat erosion may become more important in UK upland areas if climate change promotes more frequent surface desiccation and bare areas of peat increase in area.

Water

Upland mires are highly susceptible to erosion by fluvial processes, both through overland flow and sub-surface flow (piping). Large dendritic and anastomosing networks are common features on upland peatlands. Gully erosion is a dominant control for physically removing peat from a hill slope. Much of this erosion occurs in ephemeral channels though erosion in perennial stream channels also occurs. Undercutting of peat can lead to peat blocks falling into the channel, where they can be transported downstream in high flows.

Gully erosion impacts on the carbon balance of peatlands in three ways 1) direct erosional loss of carbon, 2) Enhanced near gully decomposition due to reduced water tables, and 3) Loss of primary productivity in gullies. Representative impacts of the first two mechanisms can be derived from detailed mapping of gully extent, the third requires direct measurement of carbon sequestration. Evans et al. (2010) compare rates of sequestration at both gully edge and intact sites based on multiple approaches to peat core dating (timescales of circa 30 years) , and compared with equivalent data at millennial scales estimated from published peat growth rate data. The results indicate that there is a clearly demonstrable reduction in carbon sequestration due to gully erosion. However, at the landscape scale the direct impact of gullying through particulate organic carbon (POC) loss and reduced productivity is of greater importance.

Results from Evans and Lindsay, (2010) indicate that gully erosion during the last millennium has shifted the Bleaklow Plateau from being a net sink of carbon (–20.3 gC m^{-2} yr^{-1}) to a net source (29.4 gC m^{-2} yr^{-1}). The relative importance of gullying impacts can be expressed as follows: POC flux > change in gully net ecosystem exchange >> loss of gully margin carbon sequestration. The implication of these findings is that the magnitude of the potentially reversible impacts of gully erosion (reduced carbon fixation due to vegetation loss and ongoing erosional loss of POC far exceed the effects associated with irreversible morphological change (enhanced peat decomposition in gully margin locations).

Mammals

Lilly *et al*. (2009) identify that the risk of erosion of organic and organo-mineral soils is considered to be greatest within actively eroding peatland systems with existing and extensive areas of bare peat exposed to the on-going effects of the range of drivers of erosion. Those areas considered to be most at-risk are where sheep are present, combined with moderate to high numbers of red deer (>15 deer per km^2) and coincide with areas where eroded peatlands are a notable feature of the topography, either as extensive areas or in mosaic with other vegetation types. Given the range of herbivore impacts and sheep and deer numbers that currently exist across Scotland, they conclude that it would appear that there is some scope for reducing the risk of erosion by making recommendations in relation to grazing. They identify that possible methods for reducing the risk of erosion in these areas include confining sheep grazing to the growing season (i.e. avoid year-round grazing or winter stocking of these sites) and where necessary reduce deer numbers to at or below overall density of 15 deer per km^2. The numbers of mountain hares could also be controlled within reasonable limits.

Cummins *et al*. (2011) aimed to evaluate the role of different factors known to influence erosion and recovery on upland peatlands in Scotland, including (but not confined to) the impacts of grazing and trampling by herbivores. They developed field, desk-based and remote-sensing methodologies for assessing erosion rates and spatial distribution. They used data for the whole of Scotland to examine the relationships between eroded peatland vegetation and various parameters of potential drivers, including climate, geography and the densities of sheep (Agricultural Parish returns, 1986-2006) and red deer (counts by Deer Commission Scotland, 1987-2002). After allowing for spatial autocorrelation, regression analyses indicate that mean monthly rainfall, altitude, latitude and exposure were identified as the most important explanatory variables of eroded blanket bog vegetation. The data used also demonstrated no significant relationships between the area of eroded peatland vegetation and the densities of large herbivores across Scotland as a whole.

Cummins *et al*. (2011) also concluded that there was no clear evidence to indicate that densities of large herbivores were associated with the incidence, severity or type of erosion, either in the sample squares they studied (which included the Monadhliath) as a whole or in individual patches of erosion, where numbers of animal paths were used as an indicator of usage. The routes of paths indicated that animals tended to avoid crossing deeply eroded systems. Wide and apparently heavily-used animal paths had developed between pools in some systems in the Knockfin Heights site. Recolonisation was rarely detected either in the imagery or during field validations in the Ladder Hills study area. It was commonly associated with areas where severe erosion had exposed mineral surfaces, suggesting that most bare peat is currently unsuitable for recolonising seedlings. They, therefore, conclude that climate appeared to be the principal driver of erosion. The likelihood is that multiple drivers of erosion are operating in concert and some of the current areas of bare peat may be related as much to historical conditions as to more recent impacts.

Rates of erosion

Evans and Warburton (2007) review the available body of work on rates of sediment production from bare peat surfaces, most of it derived from erosion pin studies. The measured surface retreat rates are rapid, ranging from 5-74 mma-1. The available evidence suggests deflation and oxidation may account for a significant part of the total retreat and that needle ice is the main weathering agent of the peat surface.

As part of ongoing research into the benefit of restoring damaged peatlands, Worrall *et al.* (2009) monitored grids of erosion pins annually across 8 sites for the last 3 years. At the same site measures of gaseous exchange were monitored monthly. The survey of erosion

pins has found significant differences between sites with some sites showing significant surface loss and others surface accumulation. The study has shown that it is possible to separate out contributions to the gaseous exchange and thus estimate the actual soil respiration for any site, and thus explain how much of the surface loss is due to erosion.
Worrall presents a detailed organic sediment budget for a blanket peat catchment in the north Pennines and comparative data from a catchment in the southern Pennines. They represent two extremes of a spectrum of eroded peat catchments. It is demonstrated that the lower sediment yields in the north Pennines are associated with extensive natural re-vegetation of the catchment and consequent reductions in slope-channel linkage. Construction of a carbon budget for the north Pennine catchment demonstrates that particulate carbon losses associated with the fluvial suspended sediment load are the largest single carbon loss from the system. The sediment budget data here suggest that in gullied peatlands re-vegetation of gully floors is an effective control on sediment flux so that techniques such as gully blocking are likely to be effective approaches to erosion control.

Yeloff *et al.* (2004) investigate temporal variations in fluxes of peat and other sediment in the catchment of March Haigh Reservoir, West Yorkshire. Organic sediment yields suggest low catchment erosion rates between 1838 and 1963. Blanket peat erosion increased significantly after 1963, and peaked between 1976 and 1984.

The Holocene diatom and pollen records from Kelly's Lough have been analysed to determine the timing and extent of the acidification in this upland lake. At around 1,450 cal year BP, loss-on-ignition (LOI) values, *Calluna* pollen and microscopic charcoal all increase suggesting the initiation of a major phase of peat erosion and an increased inwash of organic matter to the lake.

Martilla and Klove, (2010) studied erosion and suspended sediment transport dynamics in the open water season (April–November) of three consecutive years in a drained peatland forest. The discharge patterns in the study catchment were dominated by peak runoff events resulting from snowmelt and intensive rainfall. Fluctuations in suspended sediment concentrations (SSC) were associated with discharge fluctuations. Sediment transport varied markedly during the study months and years, with organic sediment playing an important role. Results demonstrate inter-storm sediment storage, bank collapse and the role of peak runoff rate on erosion in peak flow events. Sediment availability in drainage network channels also played a major role in erosion and SSC. The results indicate that summer runoff peaks can be a dominant element controlling annual sediment yield.

Impact of erosion on hydrology

Grayson *et al.* (2010) test the hypothesis that peak flows are significantly higher and lag times shorter at the catchment scale when blanket peat vegetation cover is reduced. Using hydrological data back to the 1950s and comparing it to vegetation change demonstrates that hydrographs were significantly peakier and narrower during the more eroded periods in the catchment and less so as the site has re-vegetated. Mean peak storm discharge was also significantly higher during the most eroded period.

Daniels *et al.* (2008) through hydrological monitoring in an eroded South Pennine peatland show that persistent and frequent water table drawdowns occur at gully edge locations, defining a deeper and thicker acrotelm than is observed in intact peatlands (an erosional acrotelm). Antecedent water table elevation is a key control on the hydrological response to precipitation events, in particular runoff percent, the timing of peak discharges and maximum water table elevations. Significant discharge is generated whilst water table elevations are relatively low at gully edge locations, and this has a strong influence on flow pathways. Four characteristics of runoff response are recognised: (i) the rapid development of macropore/pipe flow at the start of the storm; (ii) peat rewetting, water table elevation increase and continued macropore/pipe flow; (iii) maximum water table elevations and peak stream discharge with throughflow occurring within the erosional acrotelm and rapid flow through the subsurface macropore/pipe network; (iv) rapidly declining water table elevations and stream flow following the cessation of rainfall. Gully edge peats provide a key linkage between the hill slope hydrological system and channel flow so that their influence on the hydrological functioning of the peatlands is disproportionate to their aerial extent within the catchment. Future climate change may lead to further degradation of the bogs and a reinforcement of the importance of erosion gullies to runoff generation and water quality.

Allott *et al.* (2007; 2010) present research to (i) evaluate water table conditions and behaviour in blanket peat systems in the Peak District, (ii) develop a model describing water table conditions at the landscape scale, and (iii) provide a preliminary assessment of the impacts of moorland restoration on local peatland water tables. Water tables at intact sites with no erosion gullies at or proximate to the site are consistently close to the ground surface (median site water table depth typically < 100 mm). However, sites with dense erosion gullies are associated with lower water table conditions (median site water table depths > 300 mm). Gully erosion causes water table drawdown through two distinct processes. The first is local water table drawdown immediately adjacent to erosion gullies. This effect is restricted to a zone within 2 m of gully edges, and water tables within the gully edge drawdown zone are approximately 200 mm lower than in the adjacent peatland. The second effect is a more general water table lowering at eroded sites, with median water table depths at heavily eroded sites up to 300 mm lower than intact sites. At intact locations water tables are predominantly close to the ground surface, except during periods of dry weather when a pattern of gradual water table drawdown occurs. Water tables rise rapidly following rainfall. Water table behaviour at heavily eroded locations is characterised by predominantly low water table conditions with 'wet-up' responses to rainfall, i.e. very rapid rises in water table followed immediately by rapid drain-down after the cessation of rainfall. Comparison of water tables at bare peat and restored (re-vegetated) sites indicate higher water tables at the restored sites. This suggests that water tables can be raised by re-vegetation of bare peat.

Holden *et al.* (2011) investigate water table dynamics on intact, drained and restored peatland slopes in a blanket peat in northern England using transects of automated water table recorders. The results show that restoration of drained blanket peat is difficult and the water table dynamics may not function in the same way as those in undisturbed blanket peat even many years after management intervention. Further measurement of hydrological processes and water table responses to peatland restoration are required to inform land managers of the hydrological success of those projects.

Recolonisation

Crowe *et al.* (2008) describes the natural re-vegetation of eroded blanket peat gullies in the Dark Peak National Park, Southern Pennines (UK). Sequences derived from the plant macrofossil records of nine peat cores indicate a two-phase process of re-vegetation consisting of (a) a primary (pioneer) phase of colonisation by *Eriophorum angustifolium* (common cottongrass), and (b) a secondary phase involving colonisation by up to six species, establishing to either wet bog or dry heath vegetation. The locations where re-vegetation begins are hypothesised to be determined by local geomorphological controls that create zones of re-deposited peat offering favourable conditions for colonisation.

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ANNEX 6: GEOMORPHOLOGICAL PILOT STUDY

A short duration geomorphological pilot study, not part of the Scope of Works, was undertaken by SCL. The aim was to identify the range of physical processes other than deer which were likely to be influencing erosion of the bog surface, in order to help ensure that the recommendations we made to SNH took account of all relevant aspects of peatland geomorphology.

Peat erosion

Introduction

The physical processes operating to cause peat erosion on the Monadhliath are numerous, complex and spatially and temporally variable. Today, physical processes appear to be responsible for the cause of much of the present erosion of peat in the Monadhliath. However, the processes originally responsible for the initial break-up of the vegetation mat are not readily identifiable from the initial inspections we undertook.

The distribution of bare peat

On the steeper slopes below c. 750 m most of the current erosion of peat is caused by fluvial action which tends to create systems of narrow gullies in the bog surface. On flatter surfaces above 750 m, but not on the summits, there are larger areas of bare peat present, which suggests that aeolian and wind-splash processes are dominating. There is a greater propensity for bare peat to be located on western facing slopes although it is present on other aspects also.

The large bare areas of peat tend to form in the hollows (shallow valley bottoms) on the plateau surface above 750 m and on changes of slope (from steep to shallow angles) often in concave areas. Both these areas are likely to be where the deepest peat forms. In these high-altitude valleys there is a noticeable trend for peat to be thick in the centre of the valleys and thin further upslope. The thinner areas are bare and appear to be more heavily influenced by aeolian processes, while the centre sections appear to be more influenced by fluvial processes. Peat depth thins with distance upslope and there is a 50 m zone where solifluction lobes and peat interface at the upper limit of the peat. Peat has formed in small pockets in topographic hollows behind the solifluction lobe fronts.

Slope movements

Slope movement in the form of creep and mass failure is one of the physical processes operating within the study area. The slow down-slope movement of peat (creep) results in the formation of tension cracks where there are differential rates of movement between areas of peat. The creep causes the vegetation mat to rupture exposing bare peat to the action of the processes described below, which ultimately result in the expansion of the area of bare peat. During the site visit there was evidence of peat creep and very small slippages on some of the steeper slopes. The creep was creating cracks and areas of tension in the vegetation that, on the steeper slopes, had failed and resulted in 1-2 m of down-slope peat movement, exposing equally sized areas of bare peat.

Peat failure is visible from aerial photography and field visit photographs in certain locations within the study area, on both gentle plateau slopes and steeper slopes on the lower valley sides. Failure exposes bare areas of peat in the headscarp and results in bare peat being spread across intact and vegetated peat in the deposition zone, which, through time, kills the underlying vegetation and creates larger areas of bare peat if vegetation recolonisation does not occur.

Aeolian processes

Aeolian erosion appears to be a dominant process, when bare peat is exposed, above about 650-700 m altitude. It is much less common on slopes below this altitude and on steep valley side slopes. Aeolian erosion first requires other processes to produce areas of bare peat. However, once bare peat is formed, wind seems to accelerate peat erosion resulting in the formation of large bare peat flats. Rainsplash is likely to be a dominant process in these areas. However, little is known about aeolian processes in this environment, how wind passes over mountains and how it contributes to erosion of the surface.

Evidence of the influence of aeolian (wind-splash) erosion was present on the peat flats and on some gully walls during the site visit. Wave-like features within the peat occurred on the peat flats. These had a smooth, gently sloping, aerodynamic profile on the windward side and a steeper, jagged face on the lee side. These features suggest that the wind is shaping the surface topography of the peat flats, but it was not possible to tell the rate of change in surface topography caused by aeolian processes. There was evidence of wind-deposited peat on the lee sides of gullies, suggesting peat is eroded from the gully face and is then transported along its length until a gap appears which it blows through and is deposited in the lee of the gully walls.

On the snow patches, there was also evidence of wind-blown peat being deposited on the snow surface. This process is referred to as niveo-aeolian deposition. The wind appears, therefore, able to transport peat particles considerable distances in this environment.

Fluvial processes

Fluvial erosion processes are equally dominant on the upper slopes of the Monadhliath, but become the dominant erosive process as altitude decreases. Gullying is an important process. The specific cause(s) of gully formation were not investigated, but erosion systems were noted as being either single thread channels, dendritic or anastomosing. Single thread and dendritic channels appear to occur on steeper slopes, while anastomosing systems are found on shallower slopes. They tend to be found at both convex and concave changes in slope where mechanical and hydrological stresses are highest. Anastomosing systems are most associated with bare peat-flat growth and development. Anastomosing systems also appear to form along the length of a hill slope at the same altitudinal limit, suggesting that spring lines may have an influence on gully formation and bare peat exposure. However, nothing is known of the influence of spring line hydrology on peat stability and erosion.

Collapsed peat pipes are another cause of gully formation and bare peat exposure. Large pipes are associated with deep peat and when these collapse they create linear gullies. These pipes appear to have formed at the peat and minerogenic interface. On thinner or eroded peat, pipe density increases, although the pipes are smaller, and when these collapse they create dendritic or anastomosing systems. These pipes form within the peat mass and at the peat-minerogenic interface. These are actively collapsing and intercept the surface more frequently than the larger pipes. During the visit, there was evidence of a mixture of water and eroded peat having erupted from the pipes at the surface, with eroded peat being spread onto vegetation over a c. 10-20 m2 area.

Peat debris fans have been identified at the foot of several linear gullies on steeper slopes. Bare peat is spread widely across the vegetated surface killing the underlying vegetation and creating large bare areas of peat exposed to erosive processes. Furthermore, during the site visit peat material from the eroding areas of peat had been washed into the main watercourses during a recent flood and had been deposited on the channel banks and narrow floodplains. Some areas of the floodplain were covered in a thick film of peat where it was not possible to see the underlying vegetation.

The large eroding peat flats displayed evidence of fluvial action. There were large peat fans (with very high moisture contents and low bulk density) deposited across the peat flats having been washed down from upslope. The fans were often smothering recolonising vegetation. They had a smooth surficial appearance, which distinguished them from intact peat that had a rougher appearance. On the large peat flats there were lobate features, which either represent fluvial or aeolian erosion. However it was not possible to distinguish the cause of their formation from visual observation alone.

Even on intact areas of bog there was evidence of the influence of water affecting the surface vegetation. There were frequent small pools and evidence of surface wash, both of which cause physiological stress to the underlying vegetation.

Nivation and frost

Nival processes appear to be important on the upper plateau surfaces of the Monadhliath. Down slope of snow patches there is evidence of fluvial erosion of the peat. On bare peat flats, melt from the snow patches will contribute to fluvial erosion and deposition of peat. Vegetation that is able to survive under snow patches may be more sensitive to other forms of erosion, such as wind erosion. Factors such as duration and extent of cover and rate of melt are likely to have a significant influence on peatland erosion on these high surfaces.

Frost and desiccation processes will also be operating to cause the peat to be more susceptible to erosion. These processes were highly visible on the first main field visit but not generally at the time of the second visit to site.

Discussion

The processes described above will not be operating in isolation. Different combinations of the processes will be operating across the site and at different temporal scales to instigate and cause peat erosion. Therefore, there is a need to understand where erosion is occurring and where it is not occurring, where recovery is taking place and where it is not taking place, the rate and direction of erosion, and the variables associated with these different areas to create a peat erosion susceptibility map for the site.

Other geomorphological features of interest

On the lower slopes there is evidence of glacial deposition in the form of either moraines or kame terraces. Deep glacial deposits (till) have been incised by fluvial action creating a sequence of terraces in the valley bottoms. At the transition from low gradient upper slopes to steeper lower slopes the thick glacial deposits have been eroded by glacial and snow melt to form interfluves.

There are very good examples of deflation scars on the upper slopes and plateau surfaces of the Monadhliath Mountains. It is unclear whether disruption by frost heave, needle ice and strong winds is responsible for initiating as well as extending deflation scars, or whether this requires some other agency, such as grazing animals. Deflation scars have coalesced and formed wind stripes on some of the more exposed summits.

Large solifluction sheets and lobes are visible on steeper upper slopes not blanketed in peat. These landforms are likely to be relict, but smaller lobes may still be active. There is evidence of ploughing boulders, which suggests some degree of active soil creep on the upper slopes of the Monadhliath. Some of the upper plateau surfaces and slopes are blanketed in boulder fields, which are likely to be in situ and represent frost shattering during intense cold periods during the last glacial period when the summits were ice and snow free. There are also what appear to be earth hummocks on some of the plateau surfaces. These are relict features indicative of deep frost penetration and thermal sorting of the upper substrate.

ANNEX 7: MONITORING AND MODELLING USING PELLET GROUP COUNT DATA

A case study is employed in this section of the report to demonstrate the application of pellet group count baseline data in a monitoring context, as well as to demonstrate the power of using pellet group counts in combination with population modelling.

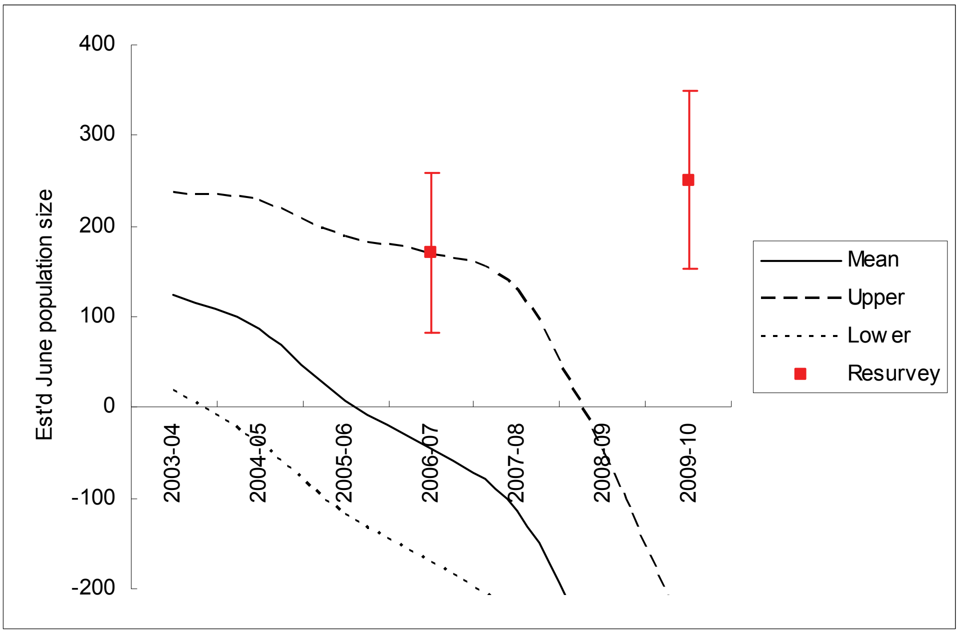
"SCL has been involved with a native woodland restoration site for the past 7 years. SCL undertook deer population assessments on the woodland restoration site three times over the period, with the first two visits (baseline in 2003-04, monitoring in 2006-07) being prior to a strategic fence being removed and the last being after fence removal (monitoring in 2009-10).

Red deer densities were relatively low at the outset of monitoring, with a mean EDU[23] of c. 125 animals present (Figure 1 upper). The client assumed that the removal of the fence would not greatly impact upon the Red deer densities in the woodland but instead found that the population did not behave as expected – the dung counts showed that the Red deer density was rising. At the same time, the population models based on culls taken (Figure 1 upper, Figure 2 upper) indicated that Red deer should have become extinct. That is, neither a model run with mean EDU or a model run with EDU + 95% CL suggested that Red deer should be present in the woodland based on culls taken. The implication is that wholesale movement of Red deer into the Pinewood site occurred – even the very large increase in the cull failed to stop Red deer densities increasing in the Pinewoods (Figure 2 upper).

Interestingly, over the same period the Red deer culls in the neighbouring open range population declined by an amount roughly equal to the rise in Red deer culls in the woodland (Figure 2 upper). This further supports the hypothesis of net inward migration.

Moreover, over the same period the Roe / Sika deer population in the woodland behaved very differently to the Red deer (Figure 1 lower). With culling effort applied equally to each species group (the stalkers generally shoot on sight), the Roe / Sika population declined gradually over a period when woodland culls increased (Figure 2 lower). The implication is that the Roe / Sika deer population acted as an 'enclosed population', providing further evidence for Red deer movement into the woodland.

[23] EDU – definition supplied in Appendix 2.



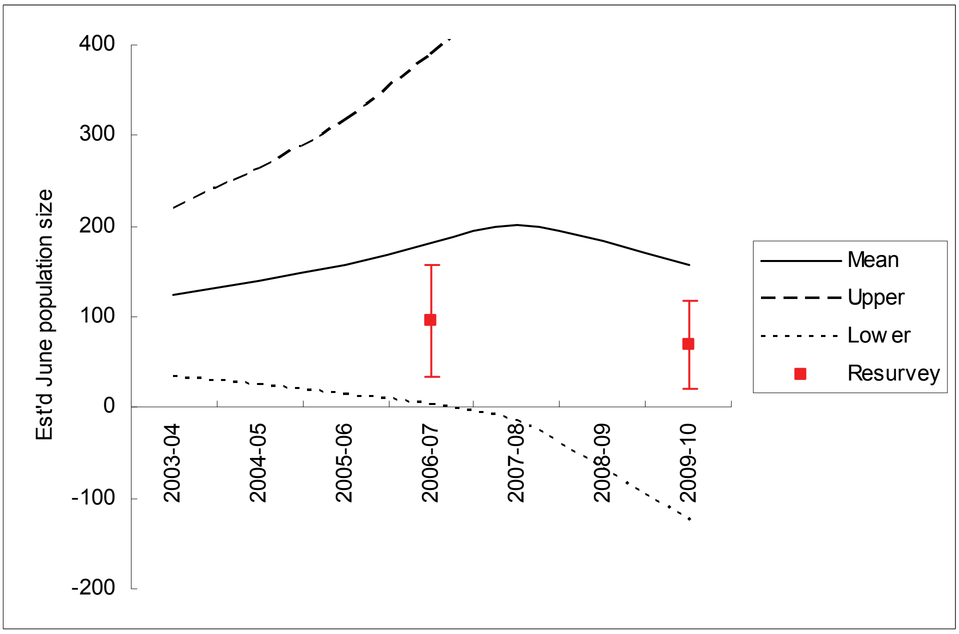
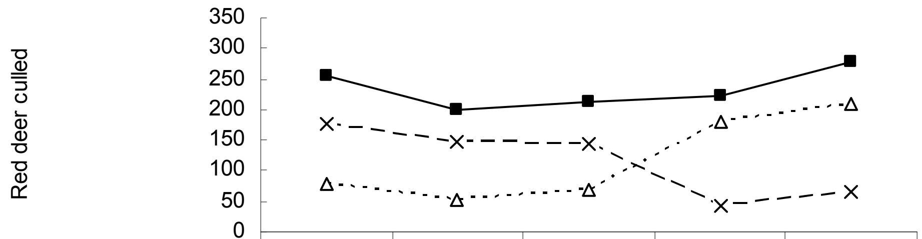
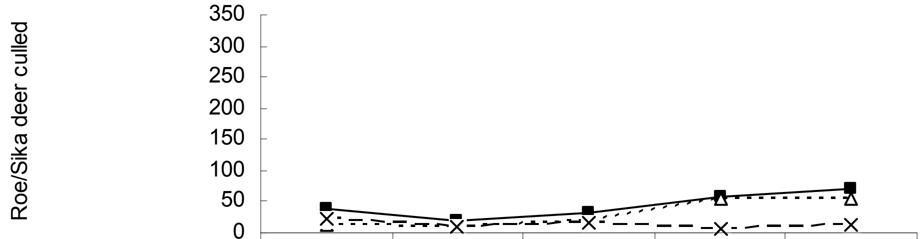


Figure 1. Predicted and actual trends in the population of Red deer (upper) and Roe / Sika deer (lower) in a pinewood population that was enclosed until midway through the study period when a strategic deer fence was removed and the adjacent open range population was free to move in.



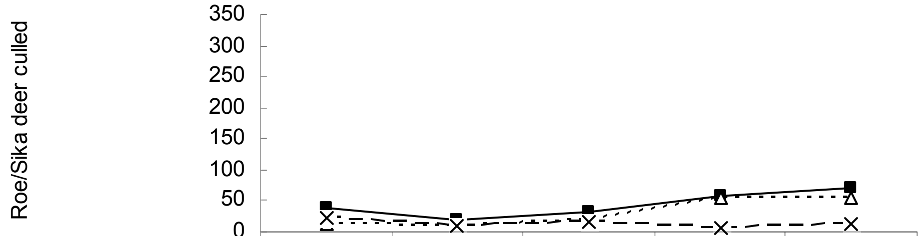
	2004-05	2005-06	2006-07	2007-08	2008-09
ALL	256	201	213	223	277
Pinew oods	79	53	68	179	210
Open range	177	148	145	44	67

Cull Season



	2004-05	2005-06	2006-07	2007-08	2008-09
ALL	37	20	33	59	70
Pinew oods	14	11	18	53	56
Open range	23	9	15	6	14

Cull Season



	2004-05	2005-06	2006-07	2007-08	2008-09
ALL	37	20	33	59	70
Pinew oods	14	11	18	53	56
Open range	23	9	15	6	14

Cull Season

Figure 2. Red deer culls (upper) and Roe / Sika deer culls (lower) taken in the pinewoods area and the adjacent open range area before and after fence removal.

It is of interest to note that the 95% CLs for the starting population in the model are wide, and yet with repeat monitoring plus population modelling the trend in deer density can still be reliably quantified. The reason the starting limits are wide in this particular example is that an allowance for variation in recruitment rate (+/-10%) ha has also been incorporated in the 'upper' and 'lower' model runs; also, because the survey used a smaller sample size than at the Monadhliath (n=70 as opposed to n=215). It is also of interest to note that statistical testing for changes in deer density employ the pellet group density data (PGD) as opposed to the EDU data. The PGD data are always more precise than the EDU data because the precision of the EDU estimate is calculated by 'pooling' the variances of the PGD and the defecation rate estimates."

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