Socio-economic and biodiversity impacts of driven grouse moors in Scotland

Part 3. Use of GIS/remote sensing to identify areas of grouse moors, and to assess potential for alternative land uses

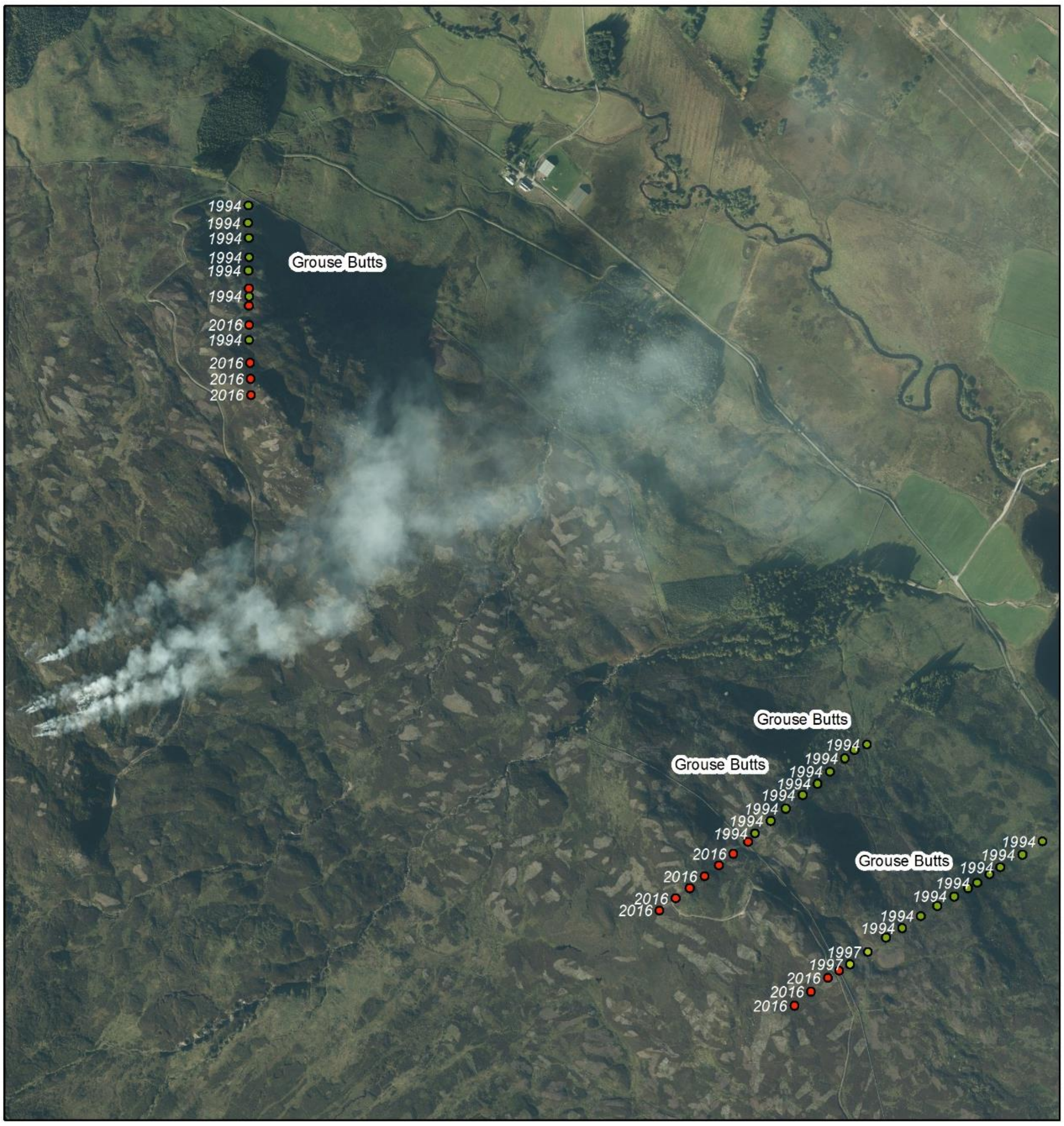

Image displayed at 1:12,500 scale showing characteristic grouse area.
Colour aerial photography © Copyright Getmapping plc.
Point data labelled with date at which feature first appeared in Ordnance Survey MasterMap Topography Layer.

Acknowledgements

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Cover Photo: Excerpt from GIS showing aerial imagery and Ordnance Survey MasterMap Topography Layer® data

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Contents

Summary of the key findings from the research

1. The GIS based analysis has been able to integrate existing spatial data sets to identify a population of holdings that are potentially involved in driven grouse shoots. While the population of holdings identified, using the presence of grouse butts alone, undoubtedly includes false positives, when combined with data such as strip burn proportions, it is certainly possible to have an indication of where regionally more intensive driven grouse activity is being undertaken. Further analysis of the grouse butts' data could provide a time line for changes in their numbers. Updating of the strip burning mapping would highlight where since 2010 there has been change in the intensity of this management practice.
2. Driven grouse enterprises occur at a wide range of scales (more than two orders of magnitude for size). There are holdings that, for land-based industries at least, appear to specialise in little else, others in which driven grouse can be a substantial element in a mix of enterprises and others where it is a minor part of an enterprise mix dominated by other land-based industries. This means the consequences of any policy, regulatory or management prescriptions are likely to vary strongly between businesses, and the *ex-ante* estimation of effects will be non-trivial.
3. There are marked local variations in the intensity of management, with density of butts per hectare varying by over an order of magnitude. Such differences can even occur between neighbouring holdings reflecting not biophysical drivers but historical and current proprietor resources and preferences. There is some evidence to suggest that there may be locations in which, on aggregate, the intensity of management is substantially higher than would be typical elsewhere for the same conditions. If intensity of activity in such regions can be linked to undesirable consequences, then the spatial analysis could provide the start of a framework to guide monitoring or licensing of activity.
4. Typically, the Land Capability for Agriculture of the holdings is low, particularly for the land parcels on which the grouse butts are found, and the recorded land use is rough grazing of unimproved pastures. The presence of rough grazing on land which could, based on land capability alone, be used for improved grassland or even mixed agriculture suggests that either the LCA mapping has been too optimistic, or socio-economic factors mean that the land has not been historically improved or that proprietors have placed a higher value on maintaining the semi-natural pastures for use as grouse moors. While change to an exclusive use of this land as unimproved pastures could be feasible it seems unlikely to be viable given reduction in stocking of hill land since decoupling of CAP payments in 2003. Creation of permanent pastures is likely to be prohibitively costly and may conflict with the desires of the proprietors and with designations.
5. Land Capability for Forestry is also typically low, for the holdings with grouse butts present. Indeed, the areas considered unsuitable for trees with any expectation of delivering harvestable timber are substantially greater than the areas considered as having very little agricultural value. The areas with very limited or even limited flexibility for forestry are substantial but it would be better to make specific analyses of afforestation options where the mix of public and private benefits can be judged. The need to avoid net carbon losses occasioned by current or alternative management practices means the need to integrate more sophisticated assessments of soils into future assessments.
6. There are many options for how the assessments made here could be improved either incrementally or fundamentally, depending on the priority given to any follow up analysis. In the judgement of the research team the most valuable option would be to update the strip burning maps using data from 2016 (to match the grouse butts' data) or for 2018 to reflect most recent practice. There would also be significant value in better integrating the socio-economic perspectives of the SRUC team with the GIS analysis presented here and broadening the range of alternative land uses and land management regimes included within the GIS analysis.

1 Background

In May 2017 the Cabinet Secretary for Environment, Climate Change and Land Reform announced commissioning of "research into the costs and benefits of large shooting estates to Scotland's economy and biodiversity". This was included as a commitment in the Programme for Government (2017-2018) published in September 2017 with research commissioned to "examine the impact of large shooting estates on Scotland's economy and biodiversity." The focus of the Cabinet Secretary's announcement concerns 'driven grouse shooting' estates.

From July to October 2018 analysis was undertaken by James Hutton Institute and Scotland's Rural College (SRUC) on socio-economic and biodiversity impacts of driven grouse moors in Scotland. This report is one of three main documents reporting the findings of this research:

Socio-economic and biodiversity impacts of driven grouse moors in Scotland: Part 1: Socio-economic impacts driven grouse moors in Scotland - an evidence review of the impacts of driven grouse moors on estate employment, wages, capital assets, etc. as well as on the wider rural business base and on local communities. The socio-economics of a selection of alternative land management models is also considered.

Socio-economic and biodiversity impacts of driven grouse moors in Scotland: Part 2: Biodiversity impacts of driven grouse moors in Scotland – an evidence review of impacts from a range of management activities associated with driven grouse moors, including: muirburn; grazing (sheep and deer); legal predator control; mountain hare management; and a review of ecosystem service delivery by driven grouse moors.

Socio-economic and biodiversity impacts of driven grouse moors in Scotland: Part 3: Use of GIS/remote sensing to identify areas of grouse moors, and to assess potential for alternative land uses – using GIS and remote sensing to estimate the extent, intensity and characteristics of grouse moors in Scotland, including opportunities and constraints for alternative uses.

These three documents are summarised with key findings in:

Socio-economic and biodiversity impacts of driven grouse moors in Scotland: Summary Report

2 Objectives of the GIS and remote-sensing based analysis

The intent for the analysis in this report is to provide a context for other parts of the study by giving an impression of the extent and geographical distribution of driven grouse moors and the biophysical characterisations of the holdings involved (without disclosing data that is not already in the public domain). All analyses make use only of those datasets immediately available to the research team and with known provenance and adequate quality.

The outputs from the analysis are maps, charts and tabular data summaries with national or regional coverage with the specific outputs as agreed with the Scottish Government policy lead. The datasets and methodology used are summarised briefly to establish the credibility of the outputs with a more detailed write up available in Appendix A.

The specific objective for the analysis were:

1. To test options for using GIS based methods to identify land areas managed for driven grouse (see Section 3).
2. For those areas identified as possibly under such management to offer a preliminary assessment of alternative land uses (see Section 4).

The analysis concludes by summarising where there are limitations on the analysis and where there are opportunities for improvements in any subsequent work.

3 Identification and characterisation of land areas managed for driven grouse

Driven grouse moors *per se* are not identified in any existing spatial dataset. As a result, the GIS team developed a method to infer their presence using a range of available spatial datasets. The defining feature used within this analysis to identify the land areas managed for driven grouse, is the presence of grouse butts. The presence of butts in a landscape is a strong indicator of current, or past, use of the land for driven shoots. The presence of butts in a landscape is, however, not definitive in identifying a land area as being currently or actively managed. This means that there is an ever-present danger of false positives within the analysis being presented. The analysis therefore draws on and integrates a range of other spatial data (such as land cover and the presence of strip burning) to progressively refine the set of holdings managing land for driven grouse. The next section outlines the main data sources used and then summarises the methods used with more detail provided in Appendix A.

3.1 Data and methods summary

Ordnance Survey MasterMap Topography layer® lists Grouse Butts among the range of identified features in its Real World Object Catalogue[1]. A method to extract these points from the data was derived and this forms the basis of much of what follows. A series of ancillary datasets were used to definitively rule out a subset of extracted points due to their location on land uses or land cover inconsistent with current use for grouse moor management (e.g. around 5% of the points fall within woodland or forestry). Any remaining points were then intersected with a dataset of agricultural holding boundaries. Approximately 95% of points identified fall within the field boundaries held in the Scottish Government's Integrated Administrative and Control System (IACS). This generated a spatial analysis framework of agricultural holdings which was characterised in several different ways with the aim of assessing the current use and flexibility of the land for alternative uses. This included land use data from 2015 Single Application Form returns, land capability datasets for agriculture and forestry, and a combination of designated area layers relevant to onshore wind turbine development and other land management options. A muirburn dataset provided by RSPB and based on data between 2004-2010 was also incorporated providing an assessment of the percentage of strip burn present in 1km grid cells. The resulting data analysis environment has a range of datasets that can be flexibly recombined to address specific questions and has both high granularity (down to individual fields) and national coverage. This capability permits taking an across-Scotland view but can also support closer scrutiny of locales of interest in any future work. A more comprehensive description of datasets and method is provided in Appendix A.

3.2 Characteristics - density of grouse butts

The analysis uses heat-maps to provide an overview of the extent and intensity of driven grouse management in Scotland. These provide a way of summarising the point data (one per grouse butt) as a map that shows the numbers of butts within a user defined radius (in this case 10 km was used). The visualisation converts the point data for the individual grouse butts into a continuous surface to which a colour ramp is applied to allow the interpretation of where there is a higher density of grouse butts (the yellow and red) and where the density is lower (the browns and blues). The specific density values can be interrogated if needed. Testing of alternative radius values shows, as would be expected, that with smaller radii more detail can be discerned, but this can begin to be strongly influenced by single businesses with higher values. Since the intention is not to identify individual businesses but to give an impression of relative intensity of management at a regional level, the larger 10 km radius is preferred here. The 10 km radius eliminates issues of the mapping being disclosive since the radius is twice the size of that of the grid used to anonymise statistical data such as that derived from June Agricultural Census.

[1] https://www.ordnancesurvey.co.uk/docs/legends/os-mastermap-real-world-object-catalogue.pdf

3.2.1 Grouse butts' density maps

The maps presented below show the two main areas of Scotland in which management of land for grouse occurs (referred to here as "grouse regions"). These are presented as two maps one for the northern grouse region and the other for the southern grouse region, see Figure 1 and Figure 2.

The map for the northern grouse region shows the significant variation across the region for the density of grouse butts. The maps highlight the higher densities of butts in parts of the Monadhliath Mountains, the Angus Glens and Deeside.

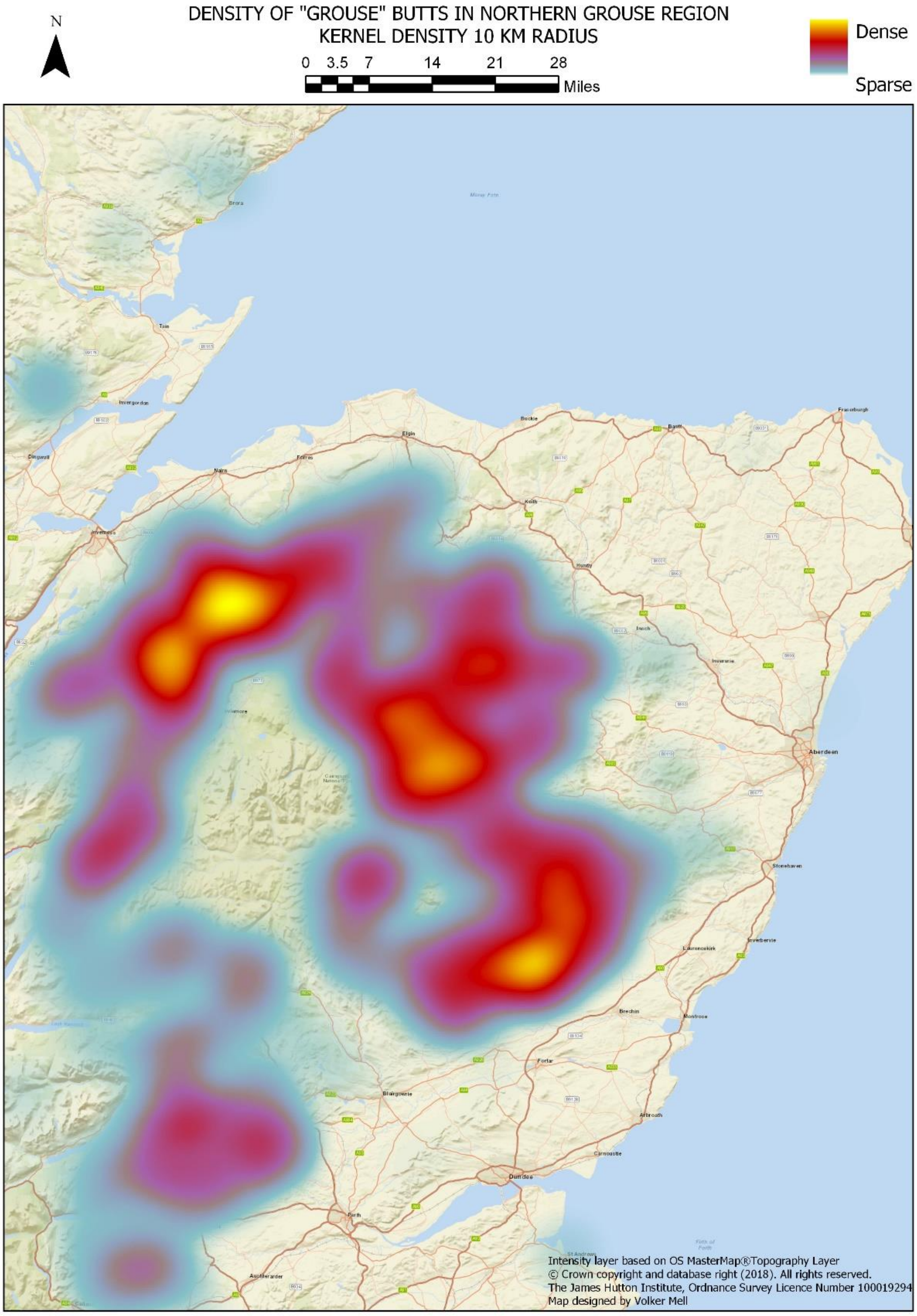

Figure 1

The map for the southern grouse region highlights that in the Borders the densities are lower than the peak values in the northern grouse region. There is still variation across the region with higher values in both the central and eastern areas of the Southern Uplands.

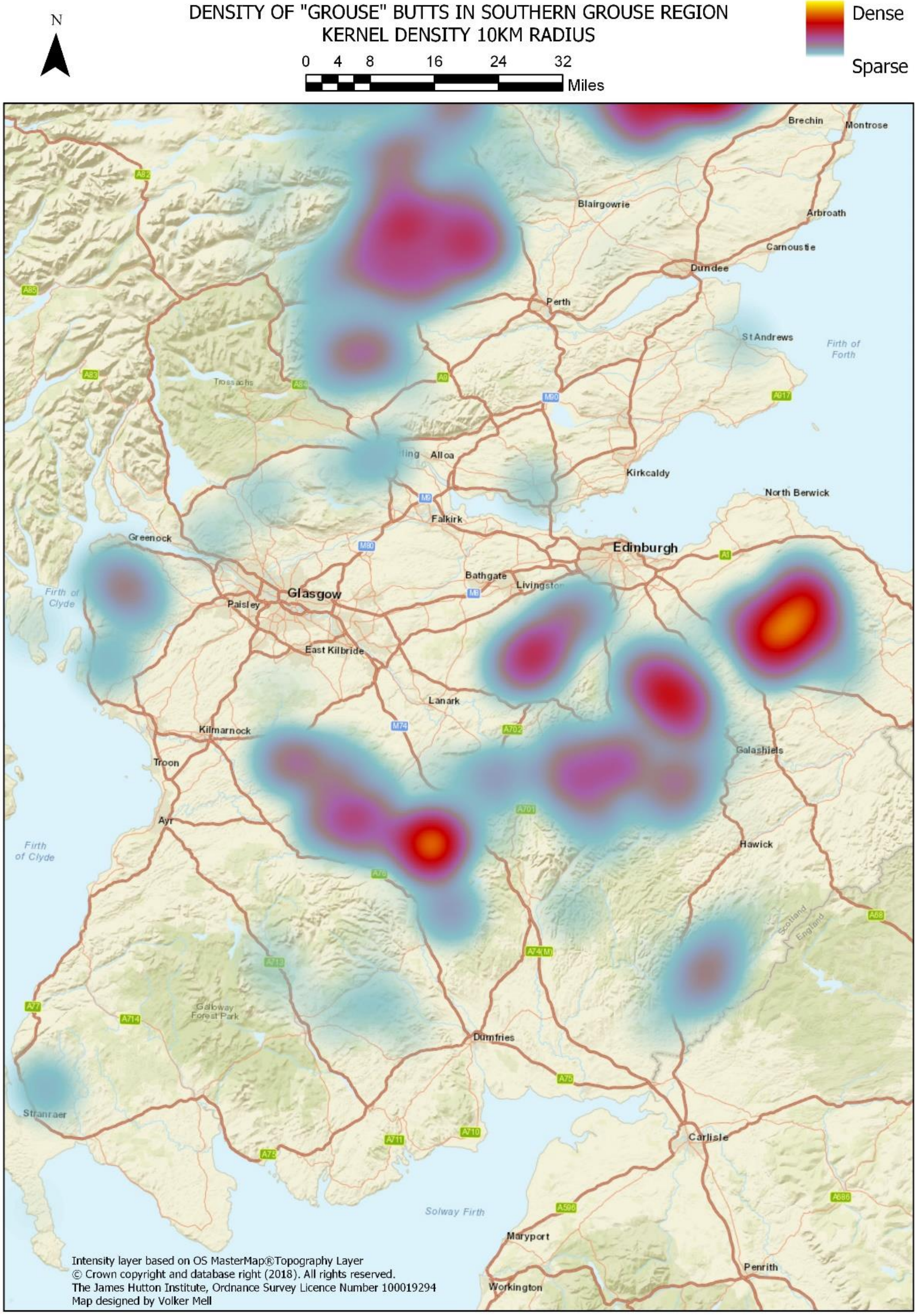

Figure 2

There is a significant limitation in using density maps alone, however, as without other supplementary data sources it is not possible to tell if the grouse butts are still being actively used or are relict features. The best supplementary data set available, in the absence of bag counts per business, is the degree of strip burning present, a proxy for the intensity of management activity.

3.2.2 Grouse butts' density and burning maps

To better characterise intensity of management, each of the grouse butts was classified using the strip burn percentage data from the RSPB strip burn maps for 2005-10 (see Appendix B). A new set of heat maps was generated that weighted the grouse butts using the strip burn percentage and again presents them as a continuous surface using a 10km radius and a relative scale of lower to higher intensity of management, see Figure 3 and Figure 4. Note that for this analysis it was necessary to exclude all the grouse butts recorded as being mapped after 2011. This meant that the burn data and the butts' data were then contemporaneous.

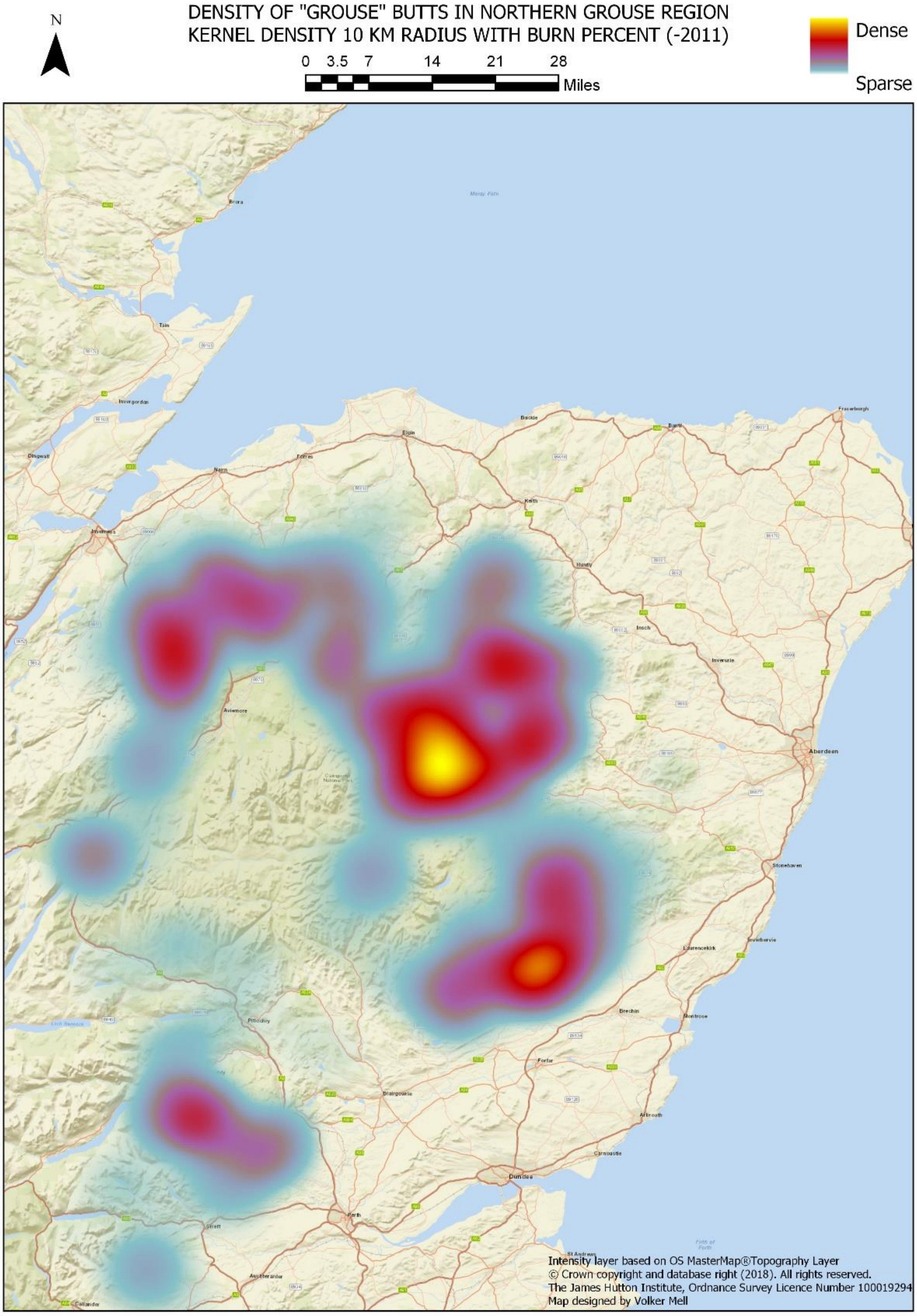

Figure 3

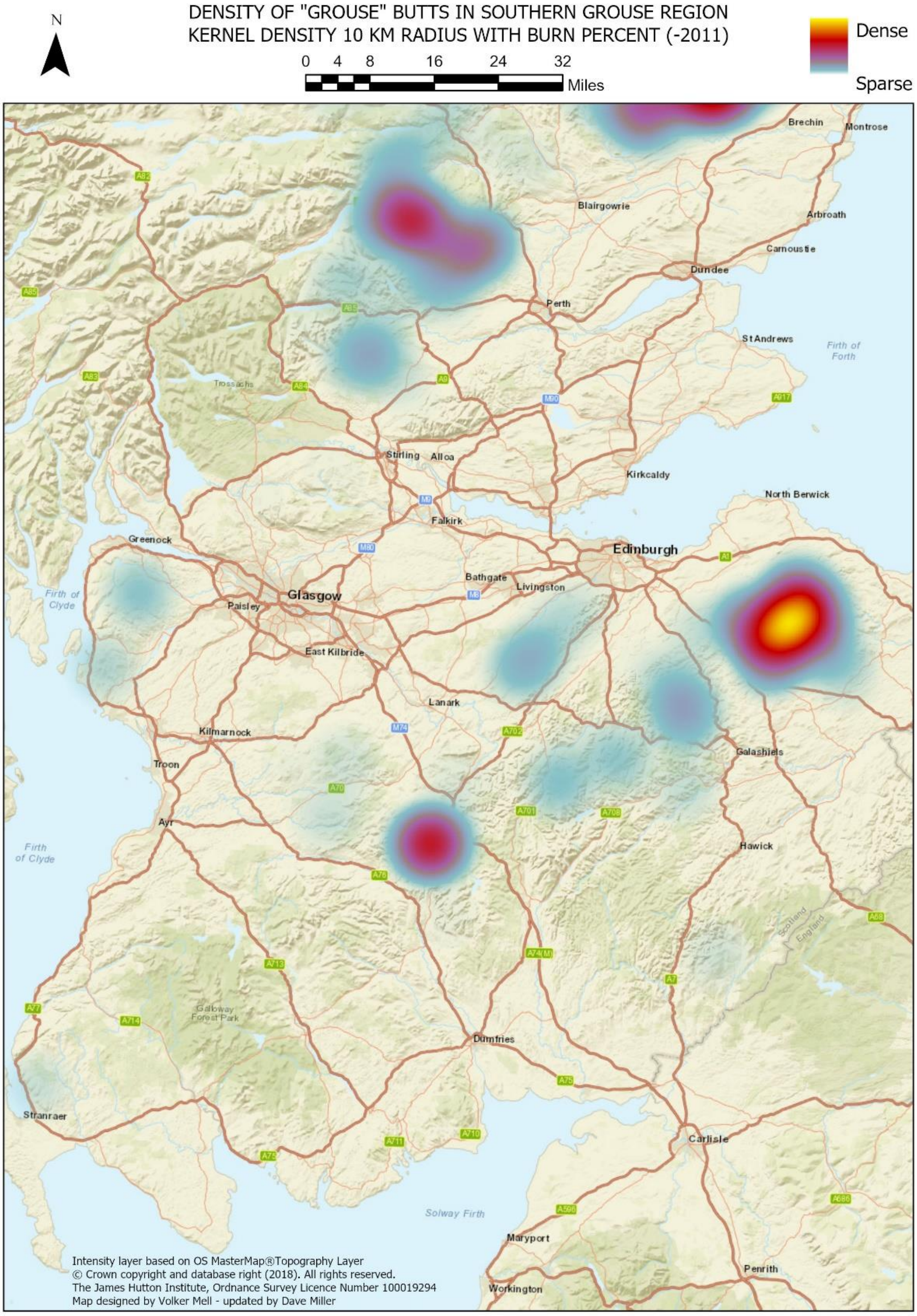

Figure 4[2]

The maps highlight that when burning is included then a different picture of intensity of use is apparent. For the northern grouse region parts of Deeside stand out and in southern Scotland the easternmost areas of grouse moors have the higher intensity of management. The maps may also

[2] This figure is a replacement for the version published in the original report.

give an indication of where driven grouse has ceased to be an enterprise (i.e. those areas with grouse butts present but no evidence of strip burning between 2005 and 2010).

While it is possible to generate heat map for the new butts added to grouse moors (see those in Section 4.1 for the 2013-2016 period), it is clear from the heat maps in this section that butt density needs to be supplemented by burning data if a true picture of intensity of moorland management is to be achieved. With such a dataset available for 2011-18 it would be possible to be more definitive about where intensity has increased, but also where there may have been reductions or even a move away from a driven grouse enterprise.

The need for such an analysis is reinforced if there is evidence for change in burning regimes. While a systematic analysis was beyond the scope of this project, an initial assessment was made for several locations suggested by research team colleagues. Visual comparison was made of the RSPB estimates of strip burning with aerial photography in the GetMapping web mapping service[3] (with photography from 2010 onwards and with most from after 2014) and with Sentinel-2 satellite data from July 2018[4]. This indicated that there has been a considerable change in the intensity of management in several locations. There is thus merit in considering if an updated mapping of strip burning should be undertaken in any follow up to this analysis, to better characterise current intensities of moorland management and change from the 2005-10 period

3.2.3 Grouse butt density charts

It is also possible to present an alternative view of the grouse butts' density in chart form. The charts below and in the supplementary materials in Appendix B3 present histograms classified using grouse butt density per hectare for counts of butts, Figure 5, count of holdings Figure 21 and area of rough grazing Figure 22. Each of these gives an alternative quantification of the extent and intensity of grouse moor management.

[3] http://www.getmapping.com/products/aerial-data-high-resolution-imagery/aerial-data-gb-imagery

[4] Acquired from https://scihub.copernicus.eu/dhus/#/home with other options for access and information on Sentinel-2 from https://www.arcgis.com/home/item.html?id=93ba20b268fb426c9c665a6bcd816da8

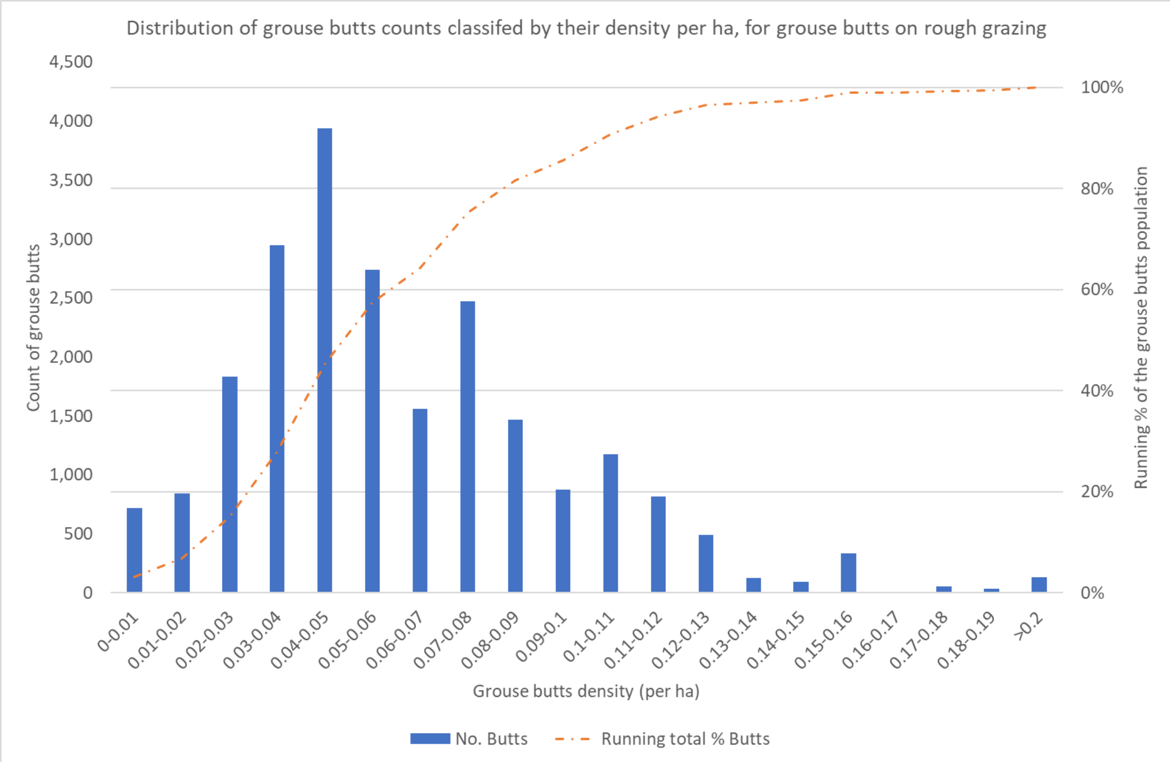

Figure 5

Figure 5 presents a histogram of the frequency of grouse butts classified by their density per ha. The chart highlights that there is a considerable variation in density of grouse butts (over an order of magnitude) even excluding the highest and lowest classes that may be the outcome of limitations in the analysis within the study.

Figure 5 and the other charts are built from a common data set and there are some limitations which should be understood in interpreting the charts. The density figures are only calculated for areas of rough grazing with grouse butts present. This accounts for 91% of the mapped grouse butts, with a further 6.8% having no land use in 2015 (though this could be found in later years of the land use datasets or manually interpreted in any follow up study). The remaining 1.84% are likely to be either grouse butts that are no longer active or land use claims that may need to be reassessed. Note also that the analysis only considers those rough grazing land parcels with grouse butts present as being part of the grouse moor, not others in the holding with the right land use but no grouse butts present. This represents a compromise in which there will be cases when, because of the way land parcels are delimited, parts of a grouse moor are excluded as butts are not present in the land parcel. On the other hand, it can exclude potentially large areas of rough grazing in a holding which are potentially not part of the grouse moor. In any further study it would be possible to experiment with using spatial analysis methods to estimate the area of the grouse moor by creating a buffer round the locations of grouse butts and including any rough grazing that falls within the buffer. With more sophisticated land cover mapping such as that derived from aerial photography or satellite data it may also be possible to better delineate the areas of driven grouse moor, see Appendix C.

3.3 Characteristics - holding size distribution

A key element in understanding the nature of the businesses that underpin the patterns seen above is their size distribution. The presence of grouse butts would perhaps be associated more often with the larger holdings. As Figure 6 makes clear there is a very wide range of holding sizes on which grouse butts occur but, as with many other land-based industries distributions, the degree of inequality of holding size is substantial.

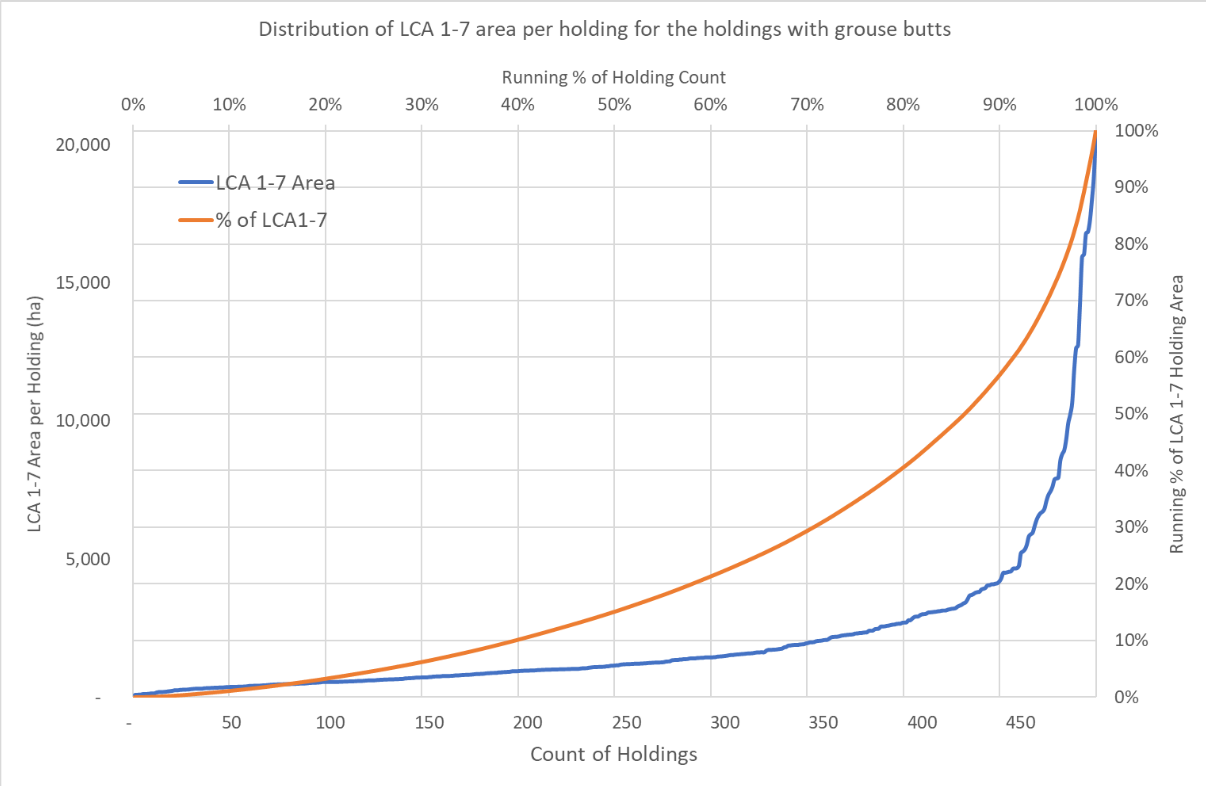

Figure 6

The chart in Figure 6 plots the count and size of holdings (in order of size, using the blue line) and a running total for size and holding count to allow the assessment of shares of land held (using the orange line). The size in this case is the area of Land Capability for Agriculture (LCA) Class 1 to Class 7 land. This is the total area of holdings that could have any use for agriculture (so for example excluding inland water). The chart shows that the largest 10% of the holdings with grouse butts present have at their disposal 58% of the LCA1-7 area. The smallest 50% of holdings have at their disposal 15%. Any consideration of policy or regulation for grouse moor-based activities needs to be able to consider that the enterprise occurs within holdings that vary over more than two orders of magnitude and as such are almost certain to be very different kinds of enterprise.

3.4 Land Cover/Use

Land cover/use is included in this part of the analysis since it provides useful insights into the business context for any grouse moor. In particular, it identifies businesses which appear to specialise in grouse (with the main land use being rough grazing), rather than grouse being part of a wider portfolio of land-based enterprises such as forestry and/or agriculture on improved ground. The rough grazing class used here covers a diverse set of habitats including, for example, dwarf shrub heath, unimproved upland grassland, and bogs. Note also that the unit of aggregation used here, and elsewhere in this part of the report, is the holding as registered in the IACS Integrated Administration and Control System. This covers more than 95% of the entities with grouse butts present on rough grazing. It is possible to group these holdings into businesses using holding to business relationships held by Scottish Government for linking to data such as CAP payments, but for the analyses presented here holdings were considered more appropriate as there is greater clarity on some aspects of tenure and use.

The bar chart in Figure 7 provides a high level (across Scotland) summary of the land uses declared for the holdings identified as having grouse butts present on any of their rough grazing land. From this chart the predominance of rough grazing is apparent with ~820,000 ha or 83% of the holding area.

Figure 7

The diversity of enterprise mixes for individual holdings with grouse butts present does, however, mean that even though the areas of other land cover/uses is small in aggregate, there are businesses in which the rough grazing with grouse butts makes up a relatively smaller percentage of the area of the holding (even if the area of rough grazing is in some cases still large). This is illustrated in the chart in Figure 8. In this chart each holding is represented by a single circle with the area of the circle representing the size of the holding (the largest is >20,000 ha). The two axes of the chart present the area of rough grazing in each holding in two ways. First in absolute terms with the area in hectares (x-axis) and second as the share of the holding area (as a percentage on the y-axis). By presenting the rough grazing data in this way it is possible to judge both the *extent* of rough grazing and the relative importance of rough grazing as a land cover/use (even if only in real terms). The percentage of rough grazing is a kind of *intensity* measure, and pairing of extent and intensity measures are used repeatedly in this analysis to illustrate the diversity of circumstances in which driven grouse moor management occurs.

While Figure 8 shows that there is a positive relationship between size of holding and rough grazing area it is also clear that there are a very wide range of percentages of rough grazing that can occur for any given rough grazing area. The chart emphasises that while there are holdings which are made up of 100% rough grazing these are the exception rather than the rule. There are many holdings with more than 80% rough grazing, but these are not restricted to only the largest sizes with examples from 100 ha to over 10,000 ha. Larger holdings are not restricted to having large percentages of rough grazing, but the larger businesses with lower percentages are infrequent.

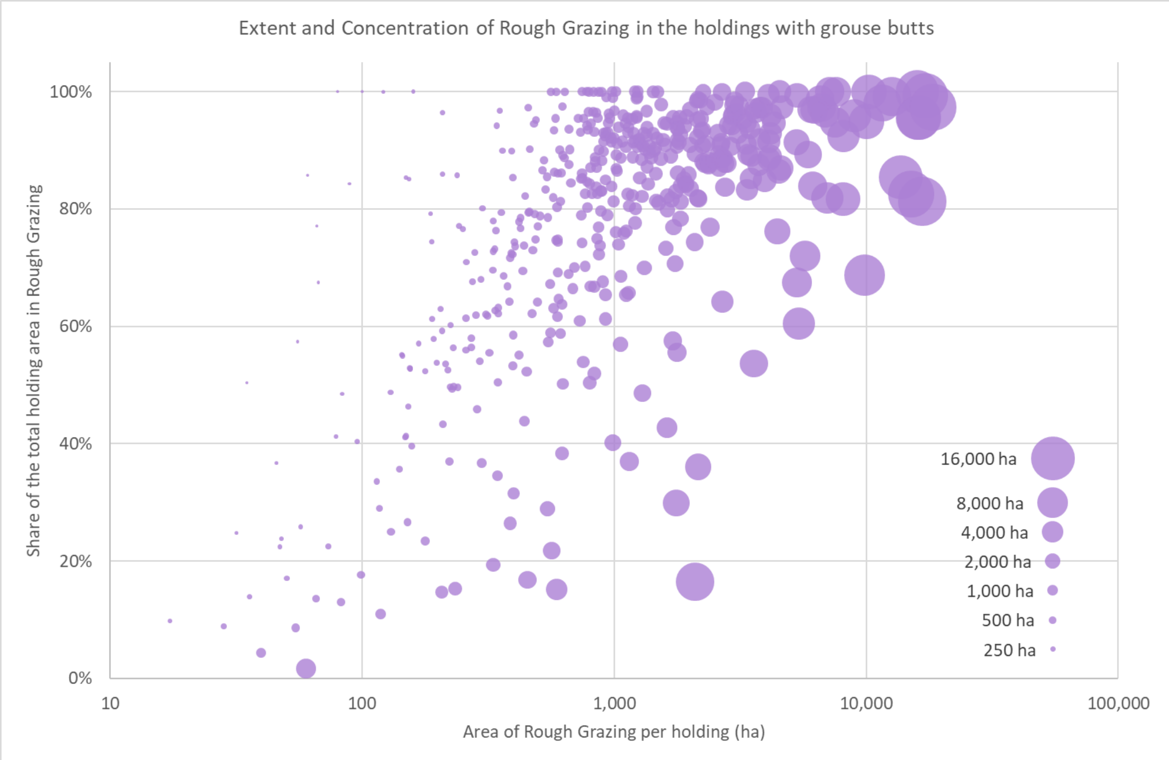

Figure 8

Visualising the diversity of land use combinations per holding is challenging but can provide some insights into combinations that occur more frequently or ones which may merit more detailed analysis in any follow up to this work. These visualisations are included in Appendix B – Supplementary illustrations and materials, with the potential to generate maps of land use mix noted as a future analysis option.

This land cover/use analysis alone cannot speak to the relative importance of the grouse moor versus other enterprises in financial terms (see Part 1: Socio-economic impacts of driven grouse moors in Scotland) but does provide a useful insight into the wide range of circumstances in which a grouse moor enterprise is undertaken. This analysis can be enhanced where it is possible to link to other known characteristics of the holdings such as those provided by the June Agricultural Census, December Survey or the Farm Structure Survey (see Section 0). Integration of these and other socio-economic datasets can provide a more rounded appreciation of the land-based enterprises being undertaken but attribution of benefit can be compromised by lack of clarity on the formal and informal tenure and other business relationships.

4 Characterisation of alternative land uses or management

The intent here is primarily to address the biophysical constraints on alternative land uses for the businesses identified above. It is possible though to characterise changes in the numbers of grouse butts mapped (presented in Section 4.1) and this complements the analysis of potential for change presented Section 4.2.

4.1 New grouse butts 2013-16

A key change considered in the analysis is to map where there has been an increase in the number of new butts. Maps of the density of the new butts established between 2013 and 2016 are presented in Figure 9 for the northern grouse region and Figure 10 for the southern grouse region.

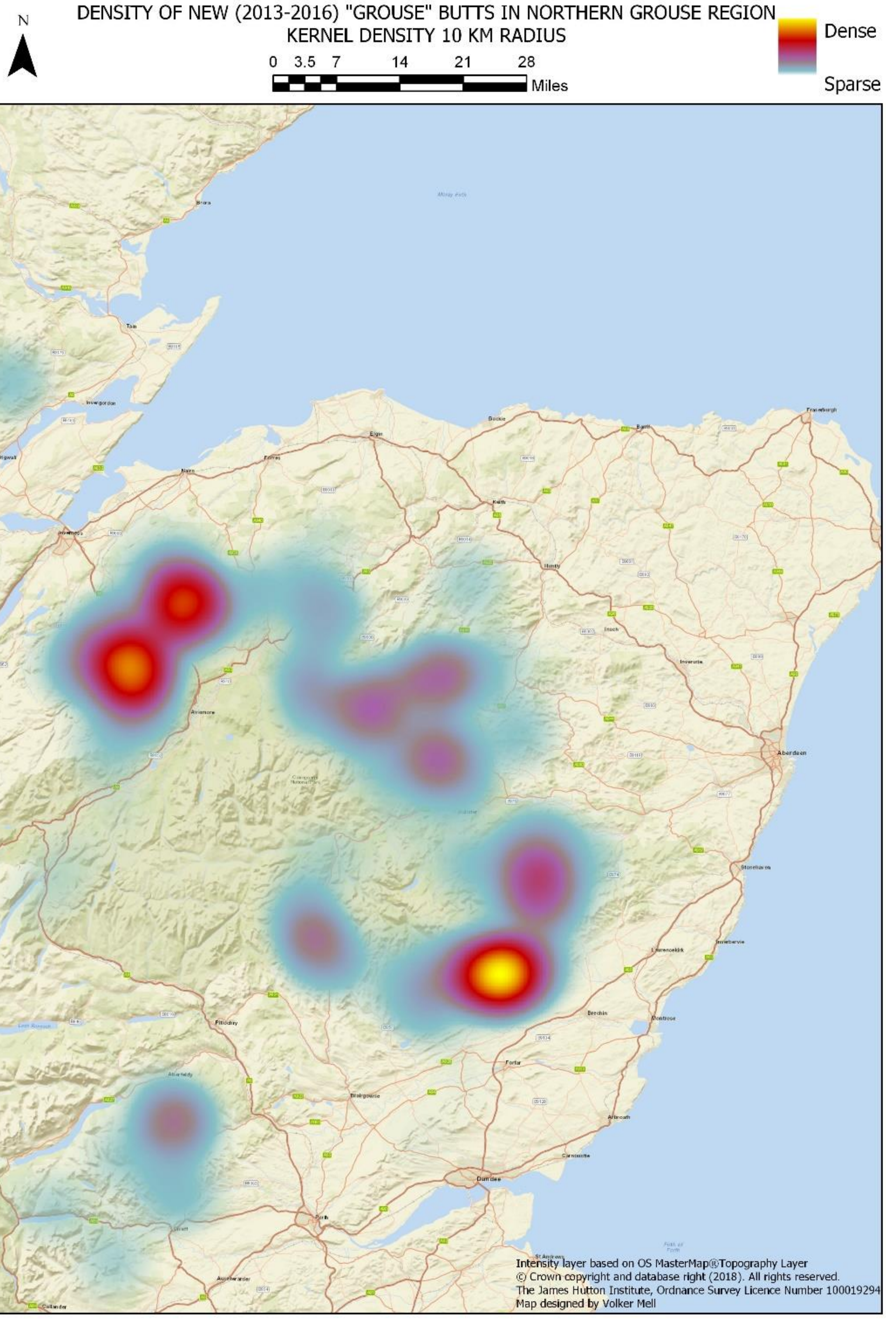

Figure 9

As noted in Section 3.2.1, some care needs to be taken in using grouse butt density data alone as an indicator of change in intensity of management. The narrow time window used here (2013-16) does though make it much less likely that many of these grouse butts are no longer in use.

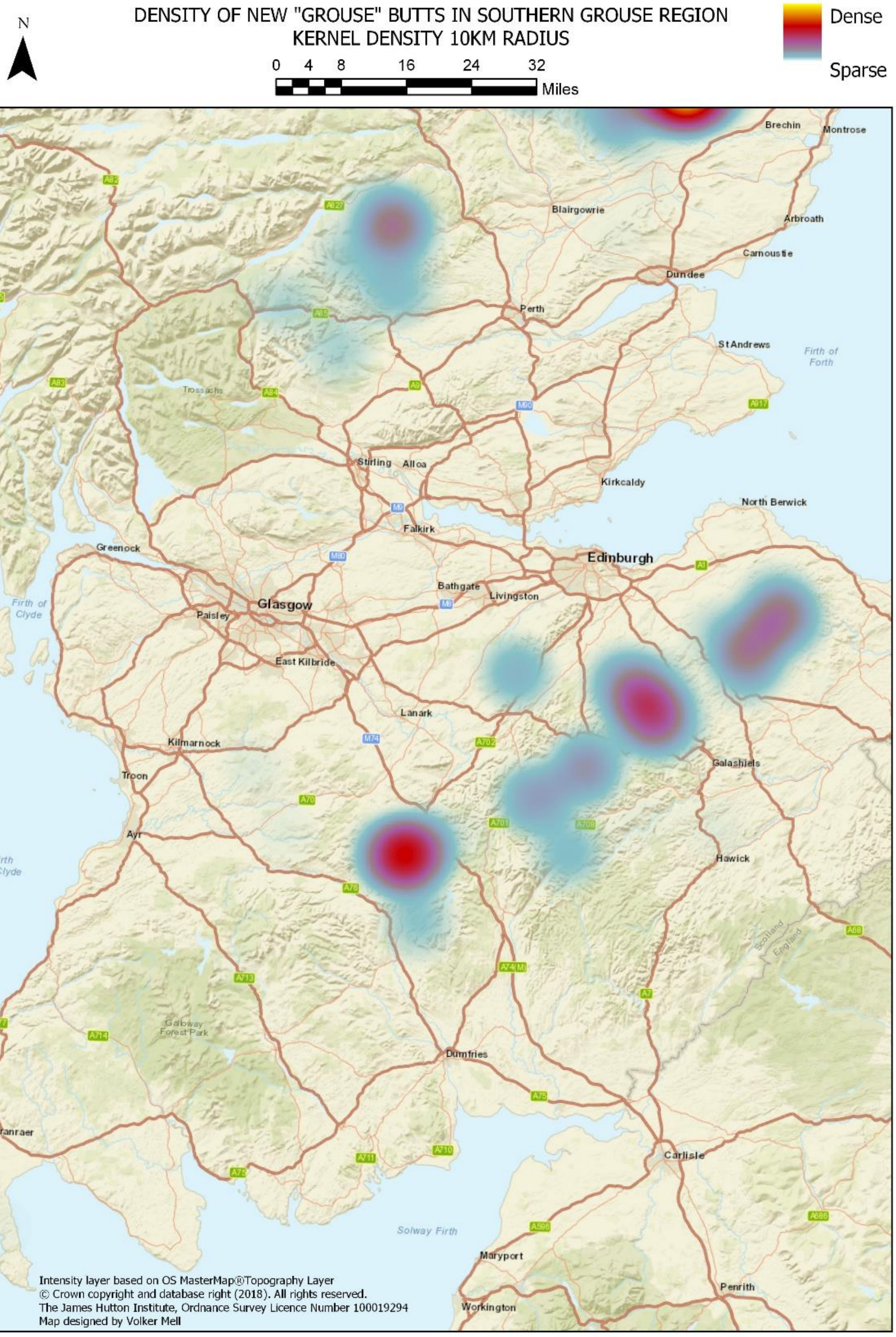

Figure 10

These figures highlight the Monadhliath Mountains, the Angus Glens as being areas where there has been the greatest increase in grouse butt density, but that grouse butt density has increased to a degree in nearly all the regions though not on all holdings. Again, mapping of changes for specific holdings is possible but did not fall within the scope of this analysis.

The date assigned to a grouse butt is when it makes its appearance on OS mapping. It should be noted this means there is certainty that the butts were established before the assigned date (since they can't have been mapped if they didn't exist) but they may have been mapped an unknown period after they were created. Further investigation of the OS mapping protocol is being undertaken to validate the approach and to see if "mapped as new" dates can be found for all the butts.

4.2 Potential for alternative land uses

This section presents for the population of holdings with grouse moors, their potential to undertake other land-based activities. These analyses take a biophysical capability perspective and do not yet consider socio-economic factors such as infrastructure, relative competitiveness in a market, business strategies or owner priorities, all of which will strongly shape the mix of activity undertaken. The analysis thus speaks mainly to feasibility of activities rather than their viability in an economic sense or their desirability either for proprietors or wider publics.

4.2.1 Land Capability for Agriculture

The Macaulay Land Capability for Agriculture (LCA) mapping[5] classifies land into 7 major classes which with subdivisions gives 13 classes. These are numbered from Class 1 with the least restrictions to Class 7 with the most restrictions. For the population of holdings with grouse butts present some will have a wider range of capabilities, particularly if they include lowland and upland ground as well as hill. Businesses with nearly all hill land will tend to have present only Class 7, 6, and 5 land. Class 7 is considered as having very limited agricultural value. Class 6 land is considered capable of supporting only rough grazing as an agricultural use (and is nearly always only lightly stocked with sheep). Class 6 subdivisions represent the likely nutritional value of the plant species present (declining from Class 6.1 to Class 6.3). While Class 5 land can support improved grasslands, the subdivisions from Class 5.1 to Class 5.3 indicate the increasing challenge faced in maintaining a sward. The bar chart in Figure 11 below shows the areas and the running percentage of each of the LCA classes present in the population of businesses with grouse butts. As might well be expected the chart shows that just under 70% of the area of the holdings would be classified as suitable only for rough grazing or as having very limited agricultural value.

As with the land cover/use analysis presented in Section 3.4, as well as considering the land capability for the population, it is useful to consider the mix of LCA classes for individual holdings. A key aspect of this analysis is set out in Figure 12 below, with other components of the LCA analysis in a supplementary analysis in Appendix B4. The figure below again uses the extent and intensity approach to characterise the population of holdings with grouse butts present. In this case the variable used is the area of LCA classes 6 and 7, both as area and share of the total holding area. Again, the circles are used to indicate relative size of the holdings. The chart emphasises that very few holdings are exclusively LCA class 6 and 7 but a substantial number could have over 60% of their area in these classes. Yet even among the largest holdings there are substantial areas of potentially improvable land (at least as defined in biophysical terms by the LCA). The interaction between potential as defined by the LCA and actual use as defined by the land cover/use data available is presented in Section 4.2.3.

[5] http://soils.environment.gov.scot/maps/capability-maps/national-scale-land-capability-for-agriculture/

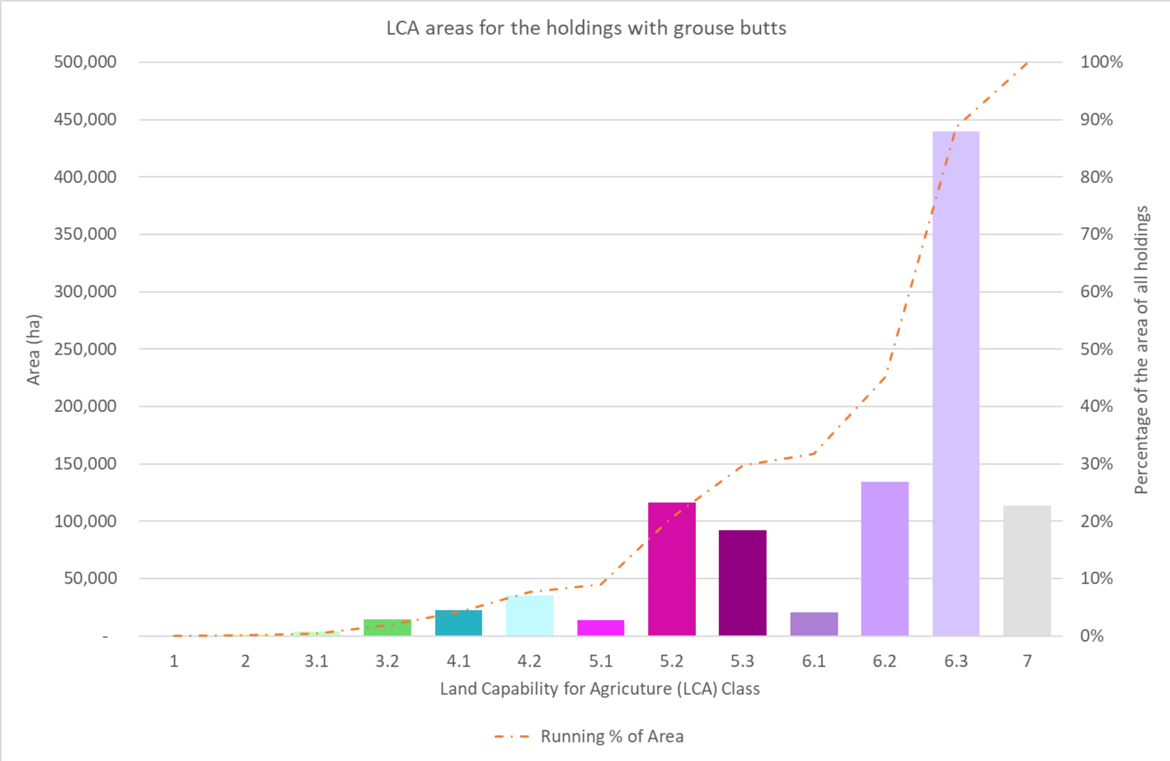

Figure 11

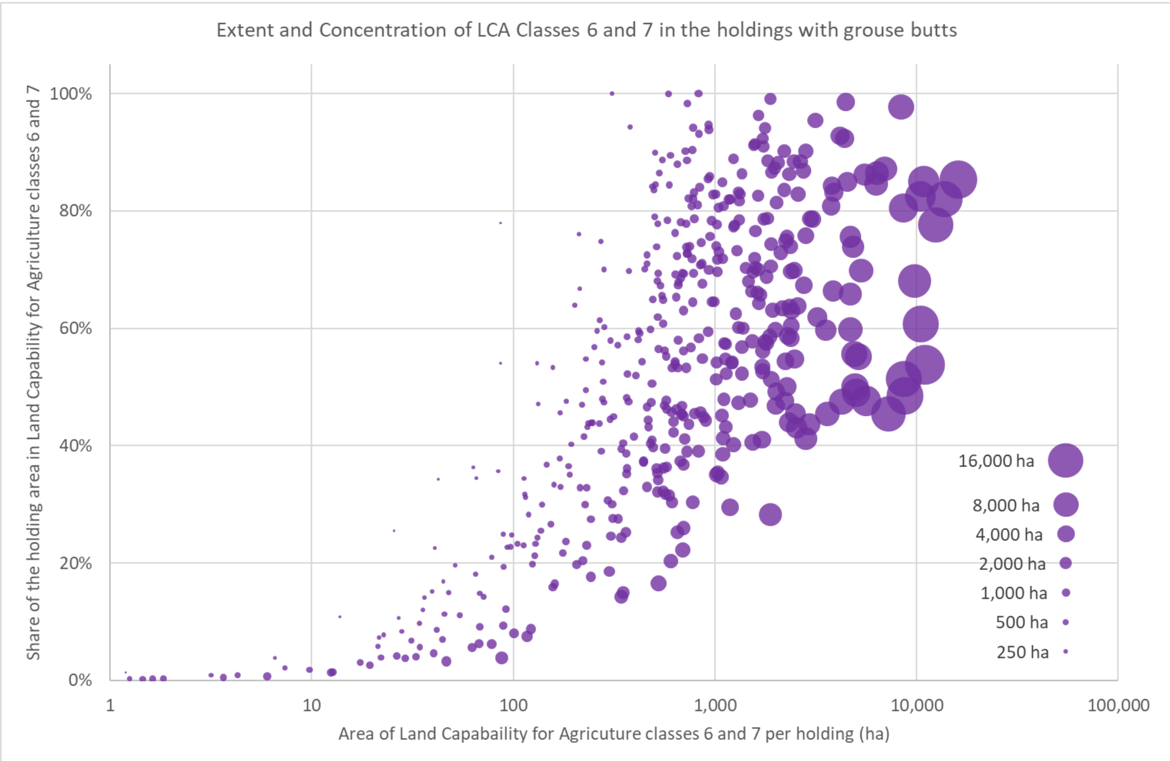

Figure 12

4.2.2 Land Capability for Forestry

For forestry options a conceptually similar analysis was also undertaken. The Land Capability for Forestry[6] (LCF) provides a high-level indication of the kinds of limitations there may be on the establishment and management of new woodlands. There is some evidence of past establishment of woodlands on former grouse moors (butts now appearing in woodlands). This has not always been without controversy, especially where the such establishment has been argued to be detrimental to landscape character, habitats or to result in net losses of carbon from highly organic soils. Presenting the LCF classes for the holdings with grouse butts highlights the proportions of the land where woodland establishment is considered impossible for conventional forestry (Class F7), or where the soils and climate or topography mean there is very limited (Class F6) or limited (Class F5) flexibility for the growth and management of trees and a narrow range of possible species.

As for the LCA analysis it is possible to summarise for the population of holdings with grouse butts the mix of LCF classes present, see Figure 13. This highlights that across the population of holdings over 40% of the area is unsuitable and over 80% has limited or very limited flexibility. This level of limitations means that forestry perhaps faces more severe limitations than agriculture, though accepting that the returns from the type of agriculture that could be practiced would be limited.

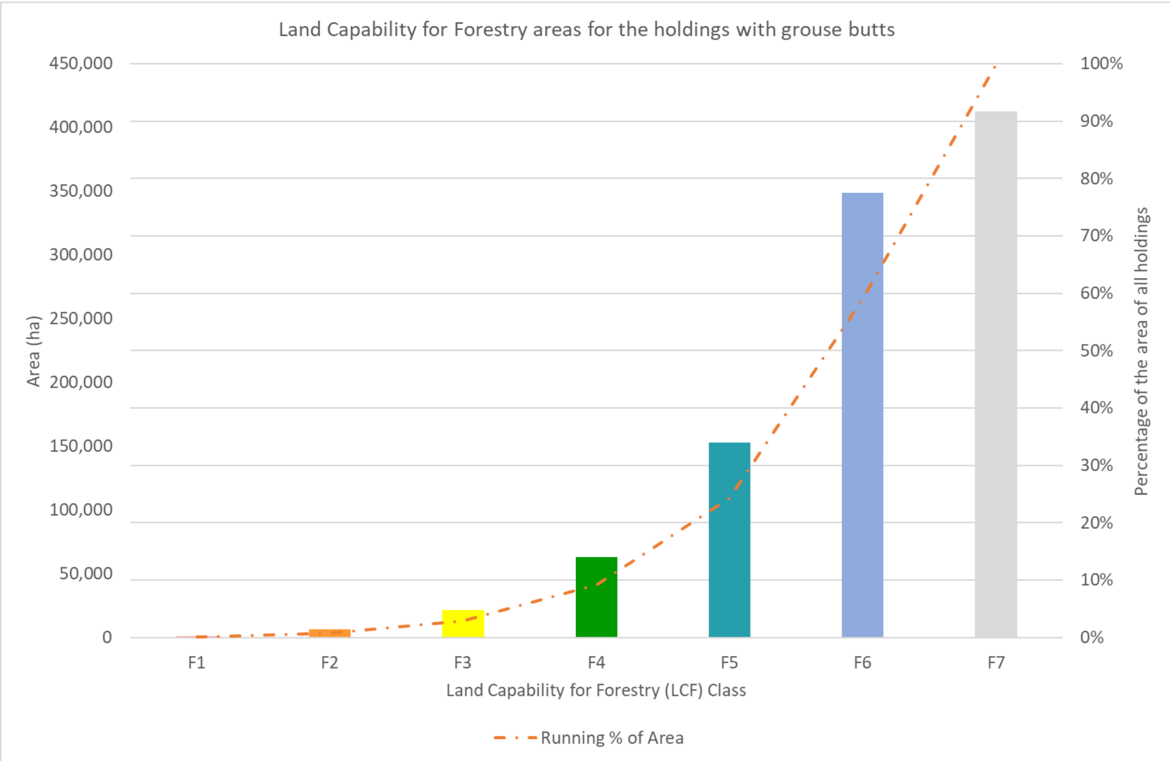

Figure 13

As with LCA there is a significant degree of variation in the area and proportions of the holdings which have more severe limitations; Figure 14 summarises the extent and proportion of LCF classes F5 to F7.

[6] https://www.hutton.ac.uk/learning/natural-resource-datasets/landcover/land-capability-forestry

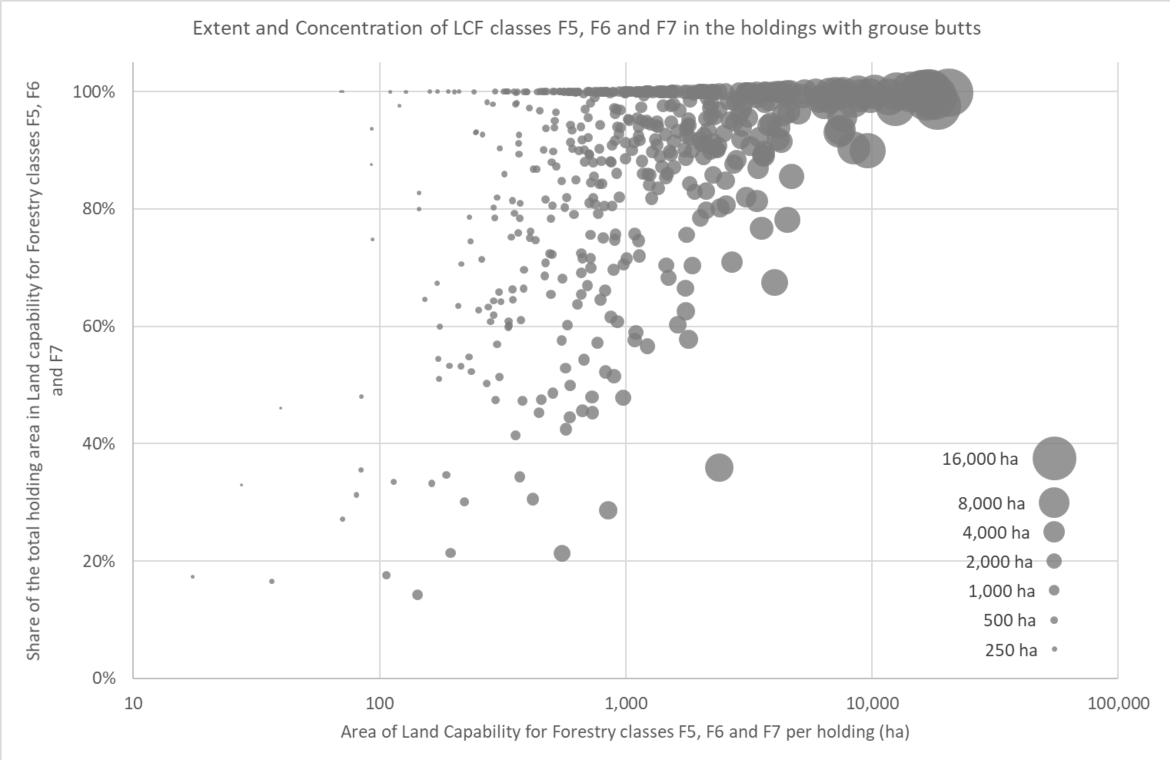

Figure 14

What is immediately apparent is the much greater number of holdings which have only land in LCF classes F5 to F7 and the number where over 80% has this capability. While it is possible to argue that including class F5 is too restrictive compared with the use of LCA class 6 in the earlier LCA analysis, several of the types of soils included within class F5 would now have a presumption against planting because of their carbon content. The mix of LCF class for the holdings is also visualised in supplementary figures in Appendix B5.

More specific analyses of the potential for forestry could be undertaken by incorporating the mapping of Forestry Management Alternatives (FMA's). The FMAs define 11 combinations of tree species and management regimen with a gradient on intensity of management from unmanaged forestry nature reserve to wood biomass production. The maps of areas where the FMA's can be undertaken could be used to derive FMA-specific characterisations of businesses with grouse moors present which would have the benefit of tying through to better defined benefits in terms of both financial returns and the delivery of public goods (e.g. carbon storage).

4.2.3 Land cover and LCA combined

Following on from the land cover/use and LCA analyses it is useful to cross check how the potential as defined by LCA is being exploited (accepting the limitations of the land cover/use data mean that use often has to be inferred). For the population of holdings, the land cover/use mix is summarised for each of the land capability classes. This is summarised by area for each of the LCA classes in Figure 15 and by proportion for each LCA class in Figure 16. From the area-based figure it is apparent that rough grazing is the dominant land cover/use and that it is dominant even where the LCA would indicate that other uses are possible. This is particularly apparent in the LCA 5.1-5.2 classes (land suitable only for permanent pastures) but can also be seen to a degree in the LCA 4.1 and 4.2 (land suitable for mixed agriculture). The small areas for LCA classes 1 to 5.1 mean that the proportions chart in Figure 16 is easier to interpret but it should always be borne in mind that for LCA classes 1 to 3.1 these are in aggregate relatively smaller areas of the holdings with grouse butts present, so any interpretations will be vulnerable to deficiencies in the spatial data.

Figure 15

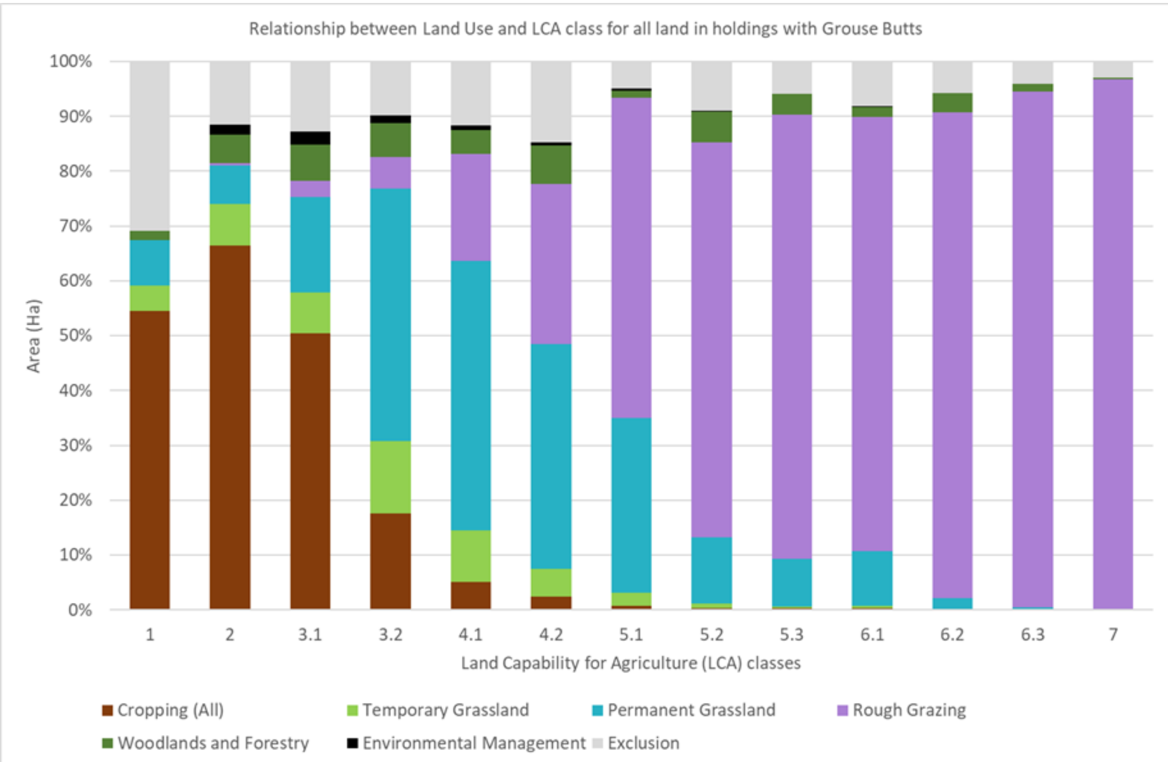

Figure 16

The pattern of proportions of use per LCA class was further analysed by comparing it with the pattern seen in all the other holdings in Scotland without grouse butts present. The differences in the percentage of land cover/uses for each LCA class are presented in Table 1. This highlights the greater amount of unimproved rough grassland than would be typical for LCA class 4.1 and above land and the relative absence of improved (permanent) pastures. The table also highlights smaller than typical areas of cropping, but the areas included in these classes are very small, so this outcome should be treated with some caution. The combined LCA and land use/cover analysis would seem to imply that decisions to not undertake agricultural improvement of at least some of the LCA 4.1 to 5.3 area were driven by historic socio-economic factors or proprietor preferences rather any biophysical limitation. How viable any improvement of such lands would now be, or how desirable this would be in terms of the balance of public and private benefits is clearly a significant area of research and public debate and would depend on how the various factors are weighted.

Table 1

LCA Class	Cropping	Temporary Grassland	Permanent Grassland	Rough Grazing	Woodlands and Forestry
1	-30%	5%	-1%	0%	5%
2	-30%	3%	8%	3%	6%
3.1	-16%	-2%	1%	3%	6%
3.2	-21%	-1%	9%	5%	4%
4.1	-5%	-2%	-12%	14%	1%
4.2	-5%	-3%	-18%	18%	3%
5.1	-2%	-2%	-26%	35%	-1%
5.2	-1%	-1%	-25%	34%	1%
5.3	0%	0%	-9%	21%	-1%
6.1	0%	0%	-6%	18%	-2%
6.2	0%	0%	-4%	14%	-1%
6.3	0%	0%	-2%	10%	-1%
7	0%	0%	-1%	5%	0%

4.2.4 Spatial Frameworks

The set of spatial frameworks included within the scope of this analysis are those that relate to decision making on new wind farms as set out in Scottish Planning Policy[7] (p39). These spatial frameworks represent a significant influence on a potentially viable but also highly visible alternative income source for the population of holdings with grouse butts present. The spatial frameworks relating to wind farms, however, include a broad range of bio-physical and socio-cultural concerns and this also give an impression of the range of planning and related instruments that the holdings interact with.

While it was beyond the scope of this analysis to determine the degree of impact for any individual spatial framework there is arguably value in providing an assessment of the extent of exposure by area and the intensity in terms of the number that apply.

For the holdings identified as having grouse butts present, 62% of the total areas of these holdings is included within at least one spatial framework (and likely a larger percentage for the rough grazing areas of such holdings), see Table 2. This table also sets out for each spatial framework, the area occurring within the holdings (in blue) to highlight which spatial frameworks are most likely to be influential. The top five are the National Parks, Peatwind[8], Wildland, SSSI and National Scenic Areas. These represent a diverse set of spatial frameworks with a wide range of possible implications for land management.

[7] https://www.gov.scot/Resource/0045/00453827.pdf

[8] Classes 1 and 2 of the Carbon and Peatland Map 2016 that occurs within the boundaries of all IACS-registered holdings This is the whole population of holdings considered within this analysis.

Table 2

All holding area (ha)	1,009,436			
Holding area in a spatial framework (ha)	620,880			
% of holding area in a spatial framework	62%			
Spatial Framework	Area of each spatial framework within the grouse butt holdings (ha)	% of the holding area included in a spatial framework	% national area of the spatial framework in the grouse butt holdings	Area of each spatial framework within Scotland (ha)*
National Parks	299,668	48%	54%	553,374
PEATWIND	266,747	43%	15%	1,726,051
WILDLAND	262,669	42%	19%	1,389,813
SSSI	175,492	28%	22%	803,674
National Scenic Areas	82,302	13%	10%	827,523
NNR	12,566	2%	10%	128,900
RAMSAR	11,362	2%	5%	217,983
Gardens and Designed Landscapes	6,032	1%	10%	60,019
Battlefields Inventory	1,092	0.2%	6%	18,283
World Heritage Sites	12	0.0%	0.03%	44,036

*This area is the extent of the spatial framework included within IACS-registered holdings rather than their full extent.

The table also shows these areas as percentages (in orange) of total area of the holdings included within any spatial framework (in yellow). This emphasises relative importance of each spatial framework within the holdings with grouse butts present. National Parks, Peatwind and Wildlands each have more than 40%.

Lastly the table highlights the importance of the population of holdings with grouse butts present for the spatial frameworks nationally. It does this by presenting the area included in each spatial planning framework nationally (dark green) and the percentage of that area that occurs within the holdings with grouse butts present (light green). Here the key figure is the 54% of the National Parks area, so any change in land management that has implications for landscape character is likely to be highly sensitive. The second largest value is 22% of SSSI's so these holdings also have a potentially significant role in management of habitats and species.

The area of holdings with overlapping spatial frameworks was calculated and is presented in Figure 17.

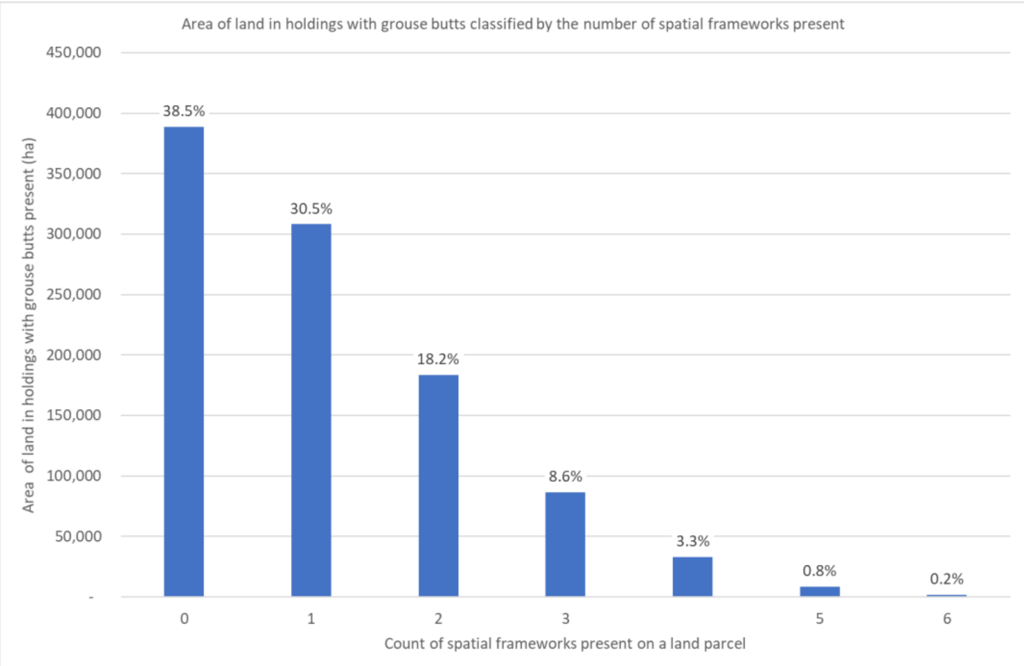

Figure 17

This shows the area and the percentage of area of the holdings with grouse butts with between zero and six overlapping spatial frameworks (calculated at the individual field level). While overlapping spatial frameworks are not the norm there are substantial areas where two or three overlap. The significance of the overlap will to a degree depend on the nature of the spatial frameworks concerned. The top 15 spatial frameworks by area (with 4 single and 11 overlapping) are tabulated in Appendix B6 which highlights the importance of overlaps between National Parks, Wildlands and Peatwind spatial frameworks.

As with the other factors influencing the alternative land use options, an extent and intensity chart was also prepared using the spatial framework areas as the variable. The chart in Figure 18 emphasises that there are many businesses that operate wholly within one or more spatial frameworks. While there are relatively few holdings with grouse butts present that have no spatial framework areas, there is wide range of percentage values for an equally wide range of extents and no strong relationship between holding size and share of spatial framework area.

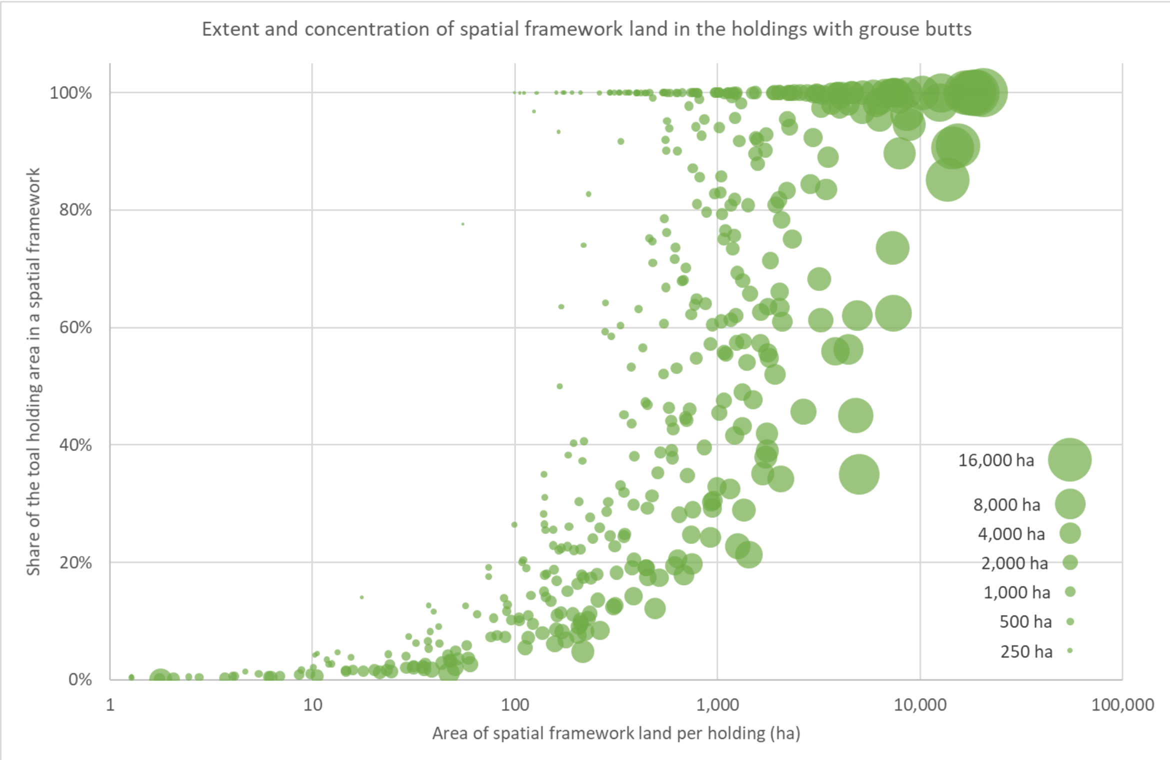

Figure 18

The spatial frameworks also have potential to act as a basis for further analysis of the potential for alternative land management regimes such as rewilding, nature-based tourism or management conducted more specifically to enhance the provision of ecosystem services (e.g. water flow regulation). Such alternatives were beyond the scope of the GIS-based analysis reported here and are likely less well supported by existing spatial datasets. Their inclusion within any further analysis would have potential merit even if only to highlighted where quantification is challenging.

4.2.5 Peatlands and high organic matter soils

There are specific limitations or presumptions against activities that can be undertaken on deep peats (defined as peats with >50 cm depth) since disturbance of such soils can lead to substantial and long-term losses of soil carbon. Beyond these deep peats are other peat soils or higher organic matter soils whose management may need to be carefully considered if there is any intensification of management interventions. Specific soils-based criteria could be developed and applied using maps such as percentages of deep peat (see Appendix B7)

5 Opportunities for further GIS based analysis

Several limitations to the analysis have been set out in the previous sections and suggestions made on how these may be overcome. This section tabulates the opportunities for further analysis and indicates the proposed approach, the degree of effort required and the likelihood of success (risk). The table also provides a priority rating from the perspective of the research team. The options are ordered by priority and effort and linked back to the sections in this report to which they refer.

In addition to these incremental improvements it is possible to suggest enhanced or complementary analyses. Some of these analyses begin to integrate the GIS based analysis more strongly with the socio-economic analyses (see Part 1: Socio-economic impacts of driven grouse moors in Scotland). The options that have not been elaborated on in earlier sections, appear below the double line in Table 3 and are briefly described in the text below the table.

Table 3

Opportunity	Approach	Effort	Risk	Priority	Sec
Map the intensity of current management regimes and changes from 2005-10 RSPB mapping	Update the mapping of strip-burning using post 2010 photography or satellite imagery. Assess changes in intensity.	****	***	*****	3.2.2
Better differentiate the grouse moor areas within holdings to refine estimates of butts per ha (Simple)	Create a buffer around grouse butt locations or a minimum bounding geometry (convex hull) based on butts	**	*	*****	3.2.3
Better differentiate the grouse moor areas within holdings to refine estimates of butts per ha (more Complex)	Generate and interpret remote-sensed strip burn data	****	****	****	3.2.3
Improve the representation of soil factors in the restrictions on management options for grouse moors	Integrate relevant soil properties mapping into the characterisation of holdings with grouse butts (e.g. soil organic carbon percentage, or peat depth)	*	*	***	4.2.5
Better understand the forestry options that are feasible for the holdings with grouse butts	Use the Forest Management Alternative maps to characterise options	**	*	***	4.2.2
Understand the timeline of new grouse butt establishment	Generate a time series of grouse butt from OS data (toid histories)	**	**	***	4.1
Understand the spatial distributions of the mix of land uses and the degree of dependence on rough-grazing based enterprises.	Map the shares of land use per holding	***	*	***	3.4
Understand the spatial relationship between grouse moors and wind farms	Integrate wind farm mapping with grouse moors data	**	*	**	4

Opportunity	Approach	Effort	Risk	Priority	Sec
Understand when grouse butts have ceased to be used	Map where grouse butts are now in woodland or are in areas where strip burning has ceased using either the 2005-10 RSPB data for historical change or an updated strip burn map if available.	*	*	*	4
Improve the understanding of the viability of alternative land management options for the holdings identified in the GIS analysis	Add socio-economic characteristics of businesses and link the GIS analysis with the Socio-Economic analyses conducted by SRUC	****	****	*****	5.1
Understand the relationship between hill path creation or upgrading and intensity of grouse moor management	Assess if it is possible to use OS MasterMap data to date the creation of new paths or their upgrading e.g. from footpaths to off-road vehicle tracks.	**	*	***	5.2
Understand where AECS measures for moorland management are occurring on grouse moors	Integrate AECS payments data for 2009-13 with holding and field level data	**	*	**	5.3
Put the analysis of holding options into a wider socio-economic context	Integrate the mapping of holdings with grouse butts present with the Socio-Economic Performance mapping	**	**	**	5.4
Provide a more integrated assessment of the feasible options	Combining the individual analysis into a single index of limits	***	***	*	5.5

5.1 Socio-economic characteristics

Any biophysical interpretation of options can mainly address the feasibility of options, rather than their viability in the context of existing socio-economic and technical systems (supply chains, markets and infrastructures). Assessment of viability could be enhanced by characterising the holdings identified in the GIS analysis using Scottish Government socio-economic datasets. Sources and variables that are likely to be relevant are tabulated below. Opportunities to integrate administrative data with that available from other stakeholders should also be explored.

Table 4

Source	Metric	Value
June Agricultural Census and December Survey	Stocking rates	The intensity of any agricultural land uses
	Standard Outputs (from agriculture)	The degree of dependence of the holding on income from grouse

Source	Metric	Value
	Labour	The balance of employment provided between grouse and agriculture
Farm Structure Surveys	% of income from farming, other activities identified	The diversity and significance of the various income streams for the holding
Rural Payments and Inspections Directorate	CAP payments – Pillar 1 and 2	The nature and degree of public funds being provide to the holding

5.2 Hill paths and their relationships with land use

Hill paths and their relationship with land use on grouse moors was highlighted in discussion of this report with stakeholders. A variety of narratives are advanced on the nature of the relationships and whether the relationship with driven grouse is direct, indirect or coincidental. If, for holdings with grouse butts present, it was possible to generate time lines for path development in recent years (as with the grouse butt data) then some of these narratives could be analysed.

5.3 Agri-Environmental Climate-Change Scheme (AECS) measures

Annual recurrent payments for agri-environment measures in the 2009-13 period can be linked to land parcels (but note that for moorland management these can be very large, so the specific locations activities can still be to a degree uncertain). Capital payments for the same schemes can also be linked but only to businesses so here the uncertainty on where activities take place is greater. Both data sources could provide further insight on the spatial distribution of management activities and the likely degree of synergy between measures undertaken by individual businesses i.e. the potential for cooperation or coordination or their spatial contiguity. It would also allow reflection on the amount of public money devoted to supporting such activities relative to other payments and the nature of the businesses receiving support.

5.4 Socio-economic performance maps

The mapping of socio-economic performance (SEP) for rural areas and small towns by the James Hutton Institute[9] provides a wider context within which the grouse moors sit. Comparison can be made of the mapping of holdings with grouse butts present as identified in this analysis with the SEP index maps. See Appendix B8 for an example of a SEP map for overall socio-economic performance. While grouse moors are often in remote areas and can have severe limits on alternative uses the regions within which they exist are not those identified as more deprived for the Overall SEP index (i.e. in the lower two performance quartiles). The performance of these regions is less strong for the indices of Wealthier and Fairer but are consistently in the top two quartiles for Healthier, Safer and Stronger and Smarter.

5.5 Defining the decision space for holdings

The analyses above have presented the characterisations of individual opportunities and limitations. They could be combined to generate an overall assessment of the degree of constraints faced.

[9] https://www.hutton.ac.uk/research/groups/social-economic-and-geographical-sciences/mapping-rural-socio-economic-performance

Appendix A. – Data sources and methods

The Ordnance Survey MasterMap Real World Object Catalogue[10] lists "Grouse Butt" as a feature in three scales of mapping in the OS MasterMap Topography Layer®[11]. (1:10,000, 1:2,500 and 1:1,250). These features are not explicitly referenced in the data layers available – the labelling (annotation) layer contains the text description while the point layer contains the location of the butts. The team have implemented a method to identify point features within a set distance of the labels (750m). The result is a 'long list' of possible grouse butts from which false positives can be progressively eliminated through association with other data layers. Any remaining points not excluded by these steps were taken forward and used to identify businesses on whose ground these potential grouse butts exist.

Land Cover of Scotland 1988

The following land classes mapped in the Land Cover of Scotland 1988 dataset were first excluded:

- Recreational Land
- Factories & Urban
- Duneland
- Quarries

Woodland and Forestry

A series of woodland and forestry datasets were used to exclude a further set of points from the analysis. This list is not exhaustive and while other spatial datasets describing woodland could also be included it is expected that the majority of established woodland is captured in the following data layers.

- National Forest Estate Subcompartment Database 2016
  - This gives details of species and planting date for stands of woodland owned and managed by the forestry commission
- Woodland Grant Scheme boundaries
  - Scheme boundaries for WGS1 (1988-1991), WGS2 (1991-1994) and WGS3 (1994-2003) indicated zones where tree establishment was subsidised.
- Scottish Forestry Grant Scheme boundaries (2003-2006)
  - Successor to WGS, the Scottish Forestry Grant Scheme boundaries were also used.
- National Forest Inventory 2016
  - This is 2016 Forestry Commission National Forest Inventory (NFI) Map for Great Britain. The NFI programme monitors woodland and trees across Great Britain.
- Land Cover of Scotland 1988
  - Any remaining areas of land managed for woodland or forestry not already excluded from the previous datasets were captured from the LCS88 data layer.

While the intention of this process was to definitively exclude those areas no longer under grouse moor management, this method makes it possible to quantify the degree to which land formerly managed as grouse moors has switched to woodland. Around 5% of identified points intersected land currently mapped as woodland. If there is interest in exploring this aspect this could be taken further in any follow up analysis.

[10] https://www.ordnancesurvey.co.uk/docs/legends/os-mastermap-real-world-object-catalogue.pdf
[11] https://www.ordnancesurvey.co.uk/business-and-government/products/topography-layer.html

Ordnance Survey Mapping

The final phase of filtering involved the manual exclusion of a number of points through interpretation from 1:25,000 scale Ordnance Survey mapping:

- OS 1:25,000 Scale Colour Raster[12]
  - Manual removal of features identified in the OS 1:25k mapping including cairns, transmitter masts, wind turbines and other features.

The end result of these operations is a point dataset with 24,843 points. With this 'short list' of grouse butts established, the next phase of the analysis sought to identify and characterise those businesses on whose ground these points exist. To this end a further series of datasets were integrated into the analysis framework:

- IACS (Integrated Administration and Control System) field boundaries 2015
  - This dataset contains individual field boundaries and is linked to land use claims made via the Single Application Form for 2015. This provided the spatial framework for intersection with other data layers. The shortlist of points intersected with ~500 holdings.
- Land Capability for Agriculture[13]
  - Identified holdings were intersected with the land capability for agriculture data layer to generate a mix of land capability classes for each holding.
- Land Capability for Forestry[14]
  - Identified holdings were intersected with the land capability for forestry data layer to generate a mix of land capability classes for each holding.
- Muirburn Data – RSPB/Macaulay Institute
  - A dataset obtained from RSPB[15] and incorporating 5,245 1km squares each of which contained an estimate of the % of each square identified as heather moorland and the % of that moorland comprising strip burning. Dates of imagery used for this interpretation range from 2004-2010. Together with the shortlisted points, this dataset was used to generate the heat maps seen in the previous sections.
- GetMapping digital aerial photography imagery[16]
  - High resolution 25cm resolution vertical imagery for the whole of Scotland. The date for the imagery in most of the area concerned is from 2013-onwards. This dataset provided a backdrop which could be used to identify any change in burning intensity from that in the previous assessment.
- Designated Areas
  - In order to assess the degree to which planning designations impose restrictions on the possible establishment of wind turbine developments as an alternative land use, the relevant data layers referenced in the Scottish Planning Policy Spatial

[12] https://www.ordnancesurvey.co.uk/business-and-government/products/25k-raster.html
[13] https://www.hutton.ac.uk/learning/natural-resource-datasets/landcover/land-capability-agriculture
[14] https://www.hutton.ac.uk/learning/natural-resource-datasets/landcover/land-capability-forestry
[15] Dataset courtesy of David Douglas, Principal Conservation Scientist, RSPB.

[16] http://www.getmapping.com/products/aerial-data-high-resolution-imagery/aerial-data-gb-imagery

Framework[17] for onshore wind development were obtained from a number of sources[18] and combined into a single layer. This included the following datasets:

  - National Parks
  - National Scenic Areas
  - World Heritage Sites
  - Natura 2000 and RAMSAR sites
  - SSSI
  - NNR
  - Inventory of Gardens and Landscapes
  - Inventory of Historic Battlefields
  - SNH Wild Land 2014
  - Carbon rich soils, deep peat and priority peatland habitat

- Sentinel 2 Imagery[19]
  - A series of recent scenes (June 2018) from the Sentinel 2 satellite (10m spatial resolution) were obtained and merged into a continuous data layer. This provides a test surface which could be used in any follow up analysis to explore automated image classification methods of detecting muirburn.
- Onshore Windfarm Proposals
  - Sites for onshore windfarm proposals at different stages of the application process are also available for download from the SNH Natural Spaces portal. The existence of such sites does not necessarily preclude grouse moor management but is an indication that diversification into other activities has already taken place. Our estimation is that approximately 4.5% of the points identified intersect a windfarm proposal at either of the Scoping, Application, Approved, or Installed stages of development. If there is interest in exploring this further, then this could be taken forward in any subsequent analysis.

[17] https://www.gov.scot/Publications/2014/06/5823/6

[18] Including Scottish Spatial Data Infrastructure Portal, Scottish Natural Heritage Portal, Historic Environment Scotland Portal

[19] https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi

Appendix B. – Supplementary illustrations and materials

B1. Muirburn maps for 2004-10 from RSPB

A file was provided by RSPB containing burn data for 5,245 1km cells across Scotland. This data was based on aerial photography provided by GetMapping[20] covering a range of dates from 2004-2010. For each 1km cell the percentage moorland area was estimated along with the percentage of that moorland area comprised of strip burning. Further details of the methodology and an image of the coverage of this data may be found in Douglas et al. 2015[21].

While evaluation of the data set was not part of the remit of this analysis, where comparisons were made with imagery from the period the results look to have been effective in distinguishing strip burns from larger areas more likely to have been burned to provide grazing for domestic livestock.

The RSPB analysis looks to have been comprehensive in its spatial coverage, and to have extended beyond areas where it has been possible to identify grouse butts as being present. This data would therefore have value in identifying areas in which there this active management but not necessarily driven grouse shoots using butts.

B2. Visualising the land cover/use mix

The charts below plot for all the holdings the mix of land uses present. Figure 19 shows these in absolute terms (area in hectares) and Figure 20 shows the relative share for each business (percentages). The holdings are ordered by size. The first chart shows the predominance of rough grazing but that there are substantial areas of other land uses present. The percentage chart shows that relationships between size and land cover/use mix these are indicative only (more rough grazing for larger holdings). Substantial (>30%) shares of permanent grassland occur across the size range but less often for larger holdings. Holdings with larger woodland percentages also occur across the size range but are uncommon perhaps indicating woodlands and grouse moors synergise less well.

[20] https://www.getmapping.com/

[21] NB the original version of this report contained two maps showing the extent of muirburn based on imagery between 2004-2010. These were included in error and have been removed. For an image of the extent of the dataset on which these maps were based please see Figure 1a in the Douglas *et al* 2015 reference above.

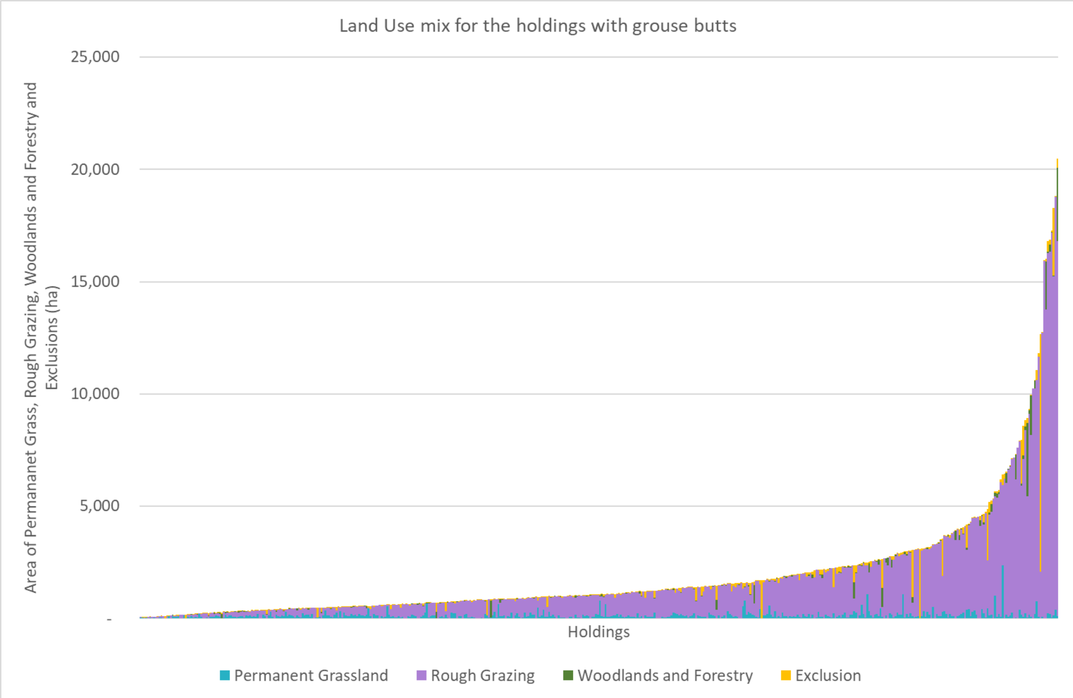

Figure 19

Figure 20

B3. Histograms using grouse butt density

Figure 21 uses the same grouse butt density per hectare data as used in Section 3.2.3 but the count of butts is replaced by the count of holdings and in Figure 22 by area of rough grazing. What is apparent is that there are substantial numbers of holdings with lower densities per hectare. This perhaps needs further investigation as this may be an artefact of the size of the land parcels within which butts are included rather than reflecting the area under active grouse moor management. The amount of land falling within the lowest density class (in Figure 22) would seem to indicate that the nearly 50 holdings in this class may bear further scrutiny in defining the area under active grouse moor management.

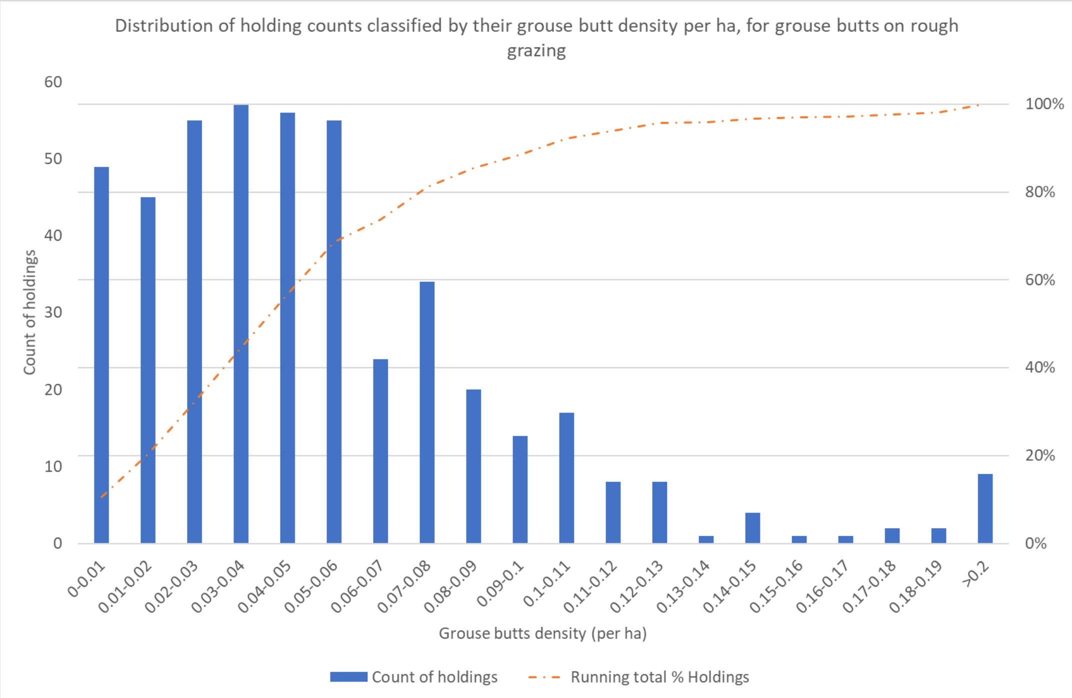

Figure 21

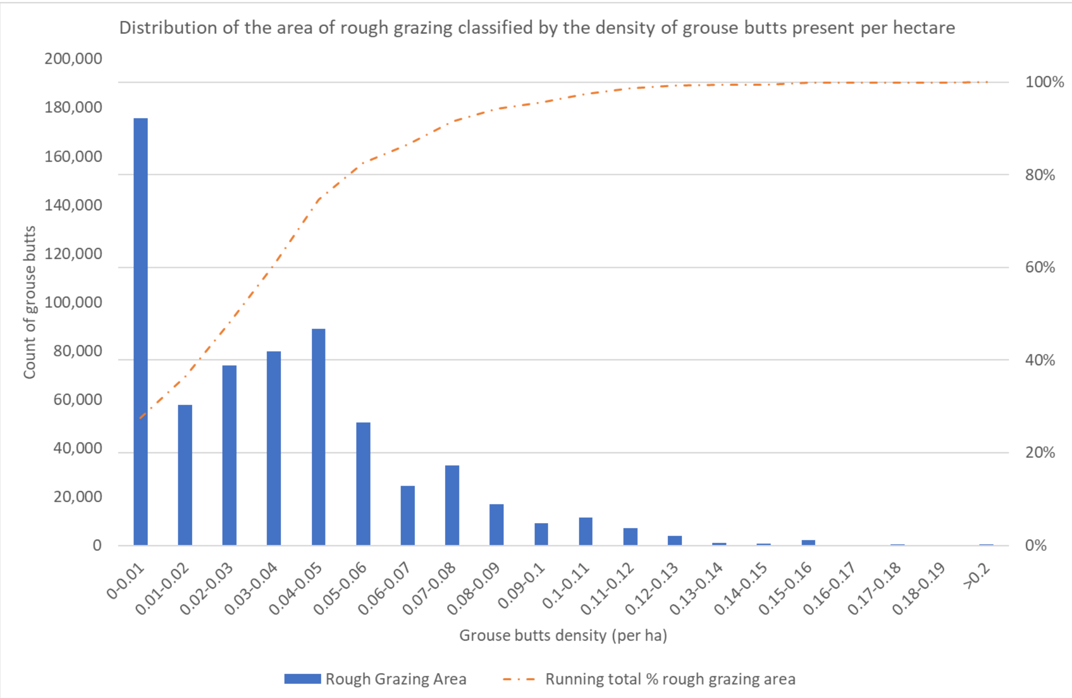

Figure 22

B4. Land Capability for Agriculture components and mix for individual holdings

The following four charts present the area of grouped LCA classes for all holdings in which they are present. The intent here is to show that some holdings vary very significantly form the overall pattern of LCA seen for the population of holdings. Since there are holdings with substantial areas of higher quality land this may need to be considered in any assessment of the impact that any change in the management of grouse moors would have on the holding. The four charts show LCA classes 1 to 3.1 (often referred to as prime land) (Figure 23), LCA classes 3.2 to 4.3 (mixed farming) (Figure 24), LCA classes 5.1 to 5.3 (improved grassland) (Figure 25) and LCA classes 6.1 to 6.3 (rough grazing) (Figure

26). In all cases in addition to the areas a running percentage of the grouped LCA class is presented to allow some assessment of the distribution of the resource between holdings.

The figures show that there can be considerable areas of better-quality land in holdings with grouse butts. The numbers of holdings with prime land though are very small (46 total or and only 9 with more than 100 ha). The numbers of holdings with substantial areas capable of supporting mixed agriculture are greater with 226 having more than 100 ha and 22 more than 500 ha from a population of 488 holdings. The numbers and areas of holdings with land capable of supporting improved pastures are more substantial again (with 52 having more than 1000 ha of land at their disposal). Yet the real potential of such large areas may be severely limited if it has not already been improved. Any interpretation of impact of alternative land management options therefore needs to consider both capability, previous land use practice and current economic circumstances.

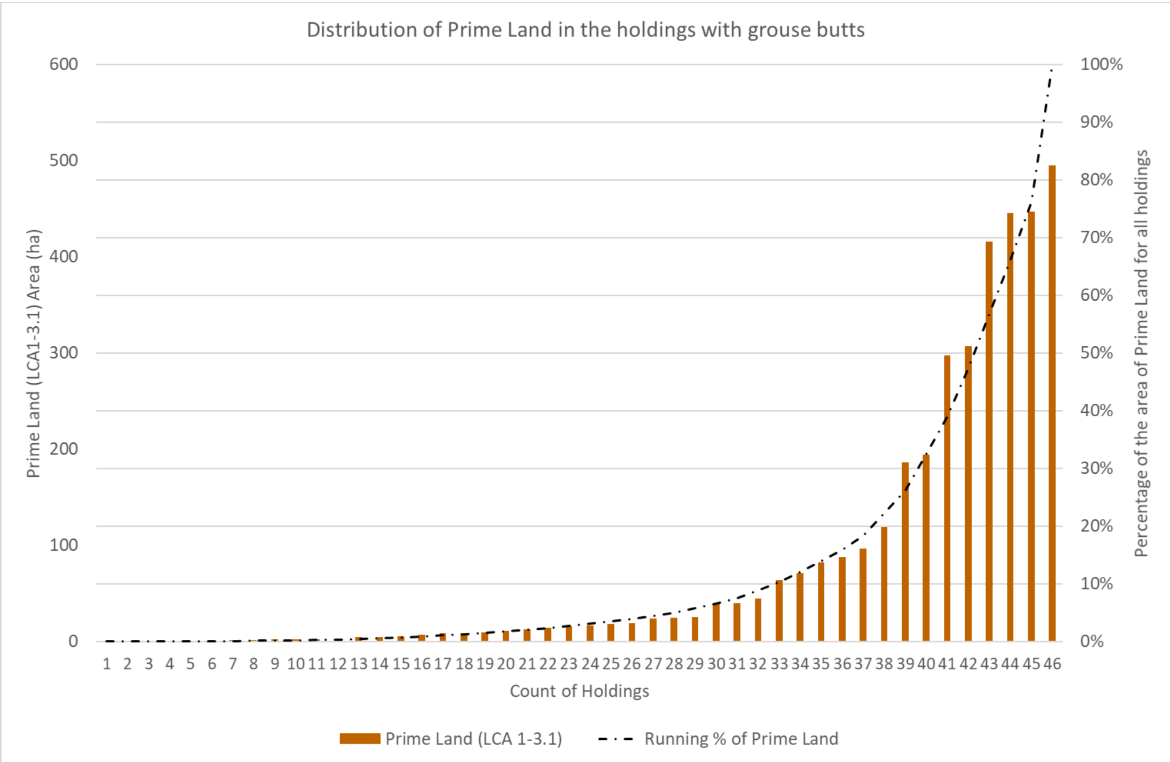

Figure 23

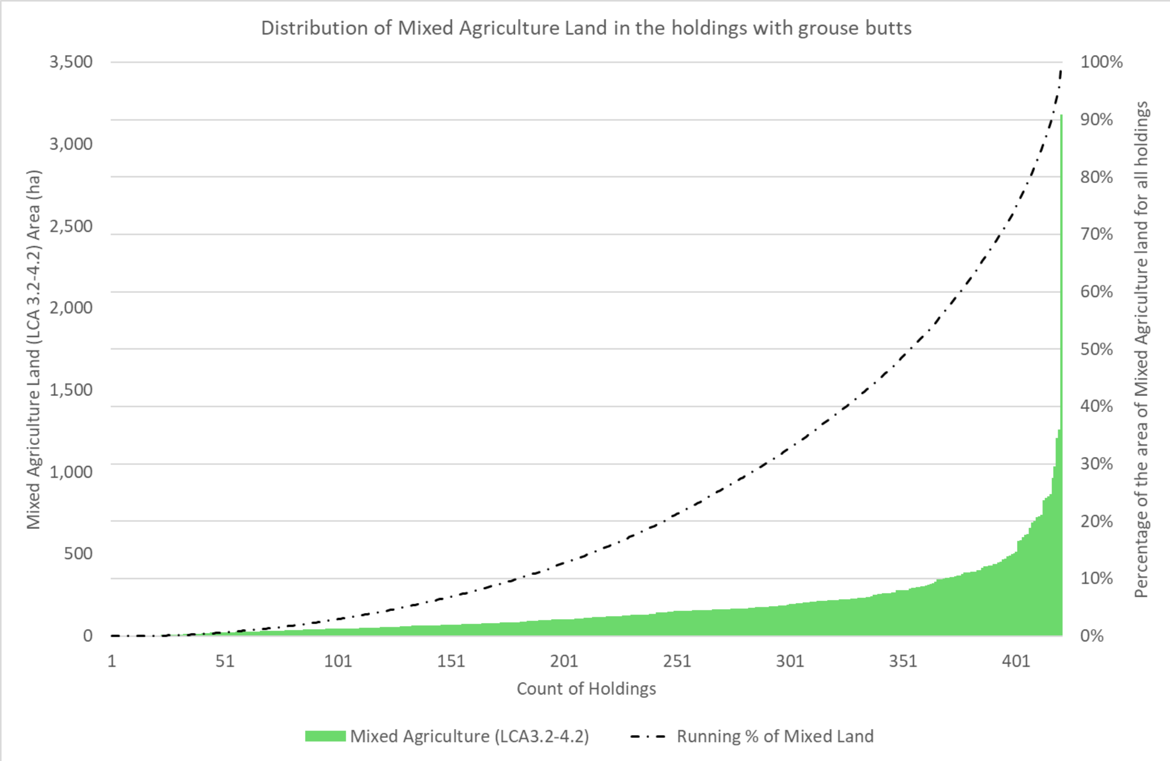

Figure 24

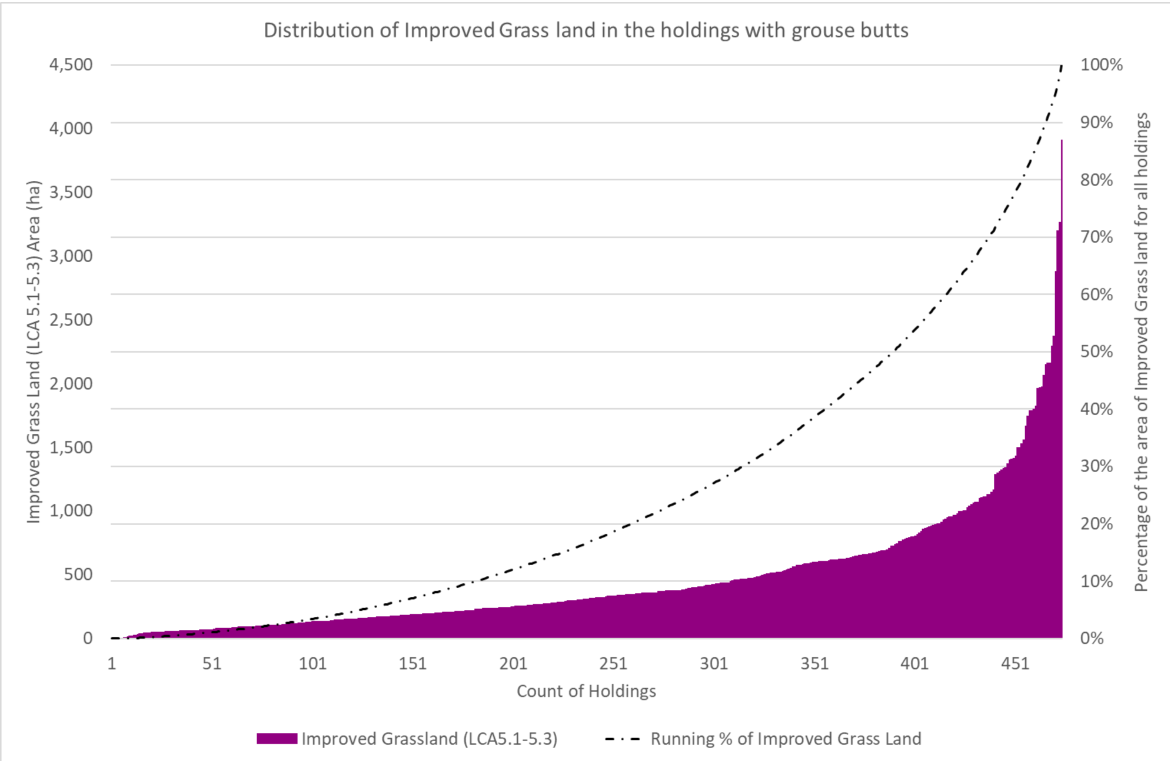

Figure 25

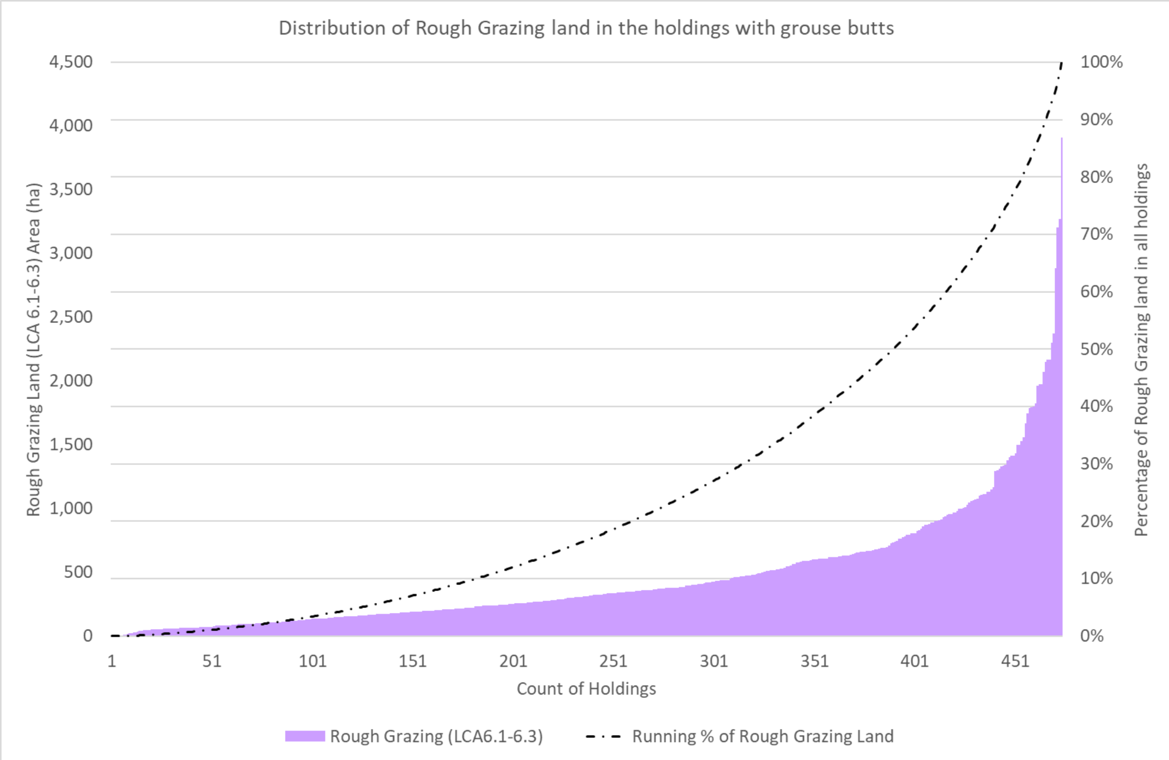

Figure 26

When the individual LCA grouping areas for each holding are put together it is possible to make some limited visualisations of how these combine together for the population of holdings, see Figure 27 and Figure 28. These visualisations give some sense of the relative balance of the LCA class groupings as size of holding increases but as can be seen there is considerable variation in the mix of LCA classes present even for holdings of roughly similar size. This diversity of LCA classes is perhaps even more evident in the chart that shows the LCA components as percentages of the holding area (Figure 28). This chart is better in showing the relationship between size of holding and the less extensive LCA classes (LCA 4.2 and below), with these being more extensive in the smaller holdings. There is some indication that LCA class 7 is more prevalent in the largest holdings but only a very weak relationship between size and portions of LCA classes between 5.1 and 6.3.

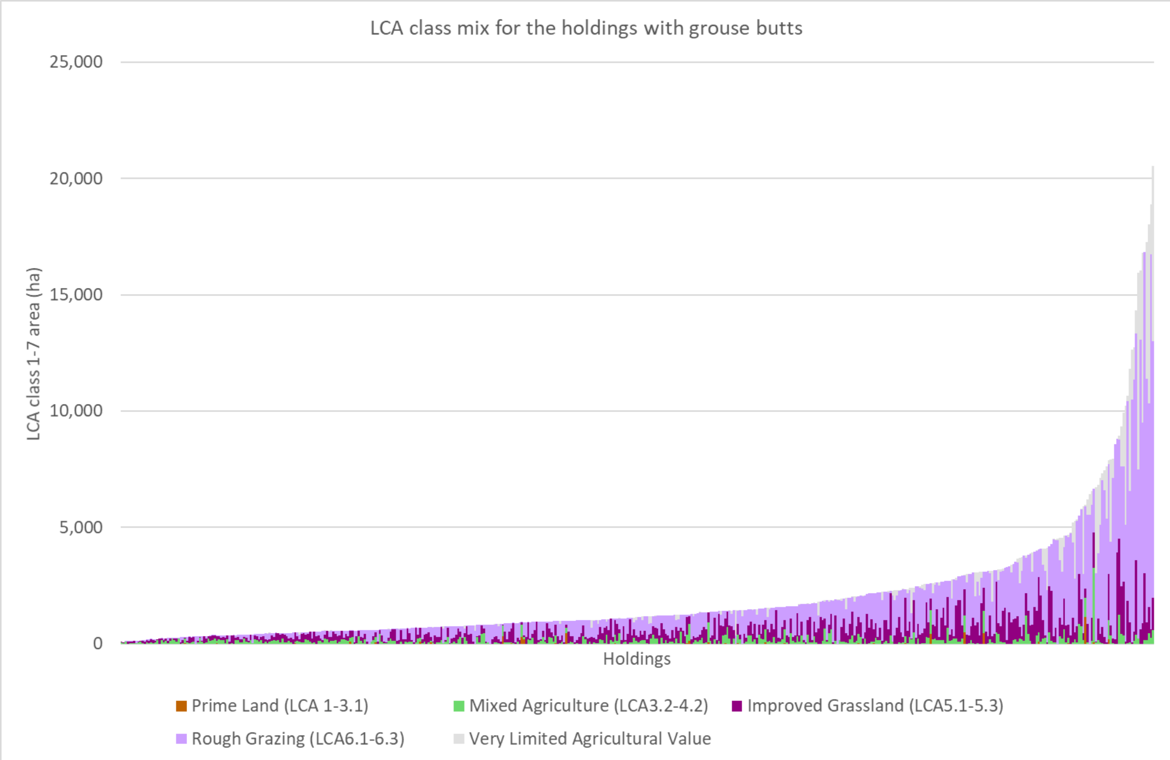

Figure 27

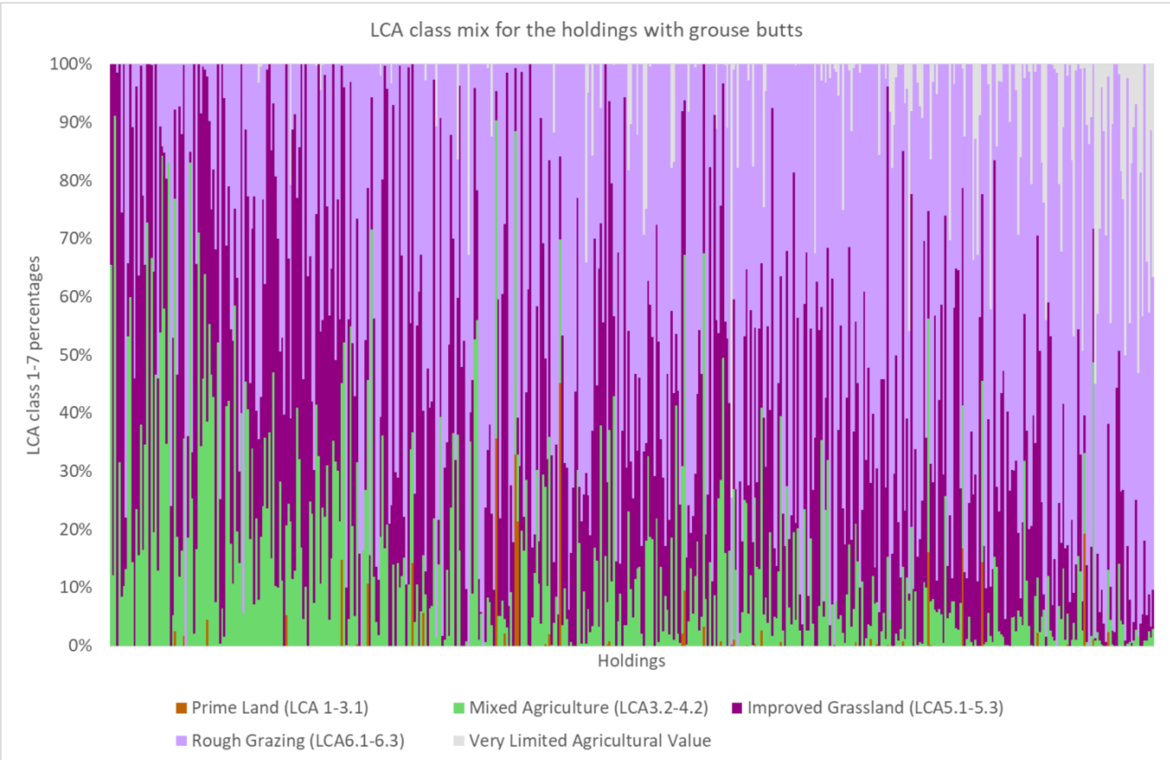

Figure 28

B5. Land Capability for Forestry – mix of classes across holdings

As for the LCA analysis, it is also possible to make charts of the area of LCF classes per holding (Figure 29) and the shares of LCF classes per holding (Figure 30). They can give an impression of how the LCF classes are combined in holdings and any relationship there may be between size of holding and LCF.

As with LCA relationships between size of holding and LCF mix are present, with larger holdings very broadly having larger areas that are unsuitable for forestry or with very limited flexibility. The relationships are overall weaker than for LCA perhaps reflecting the relative lack of woodlands within holdings having grouse moor management as one of their significant enterprises.

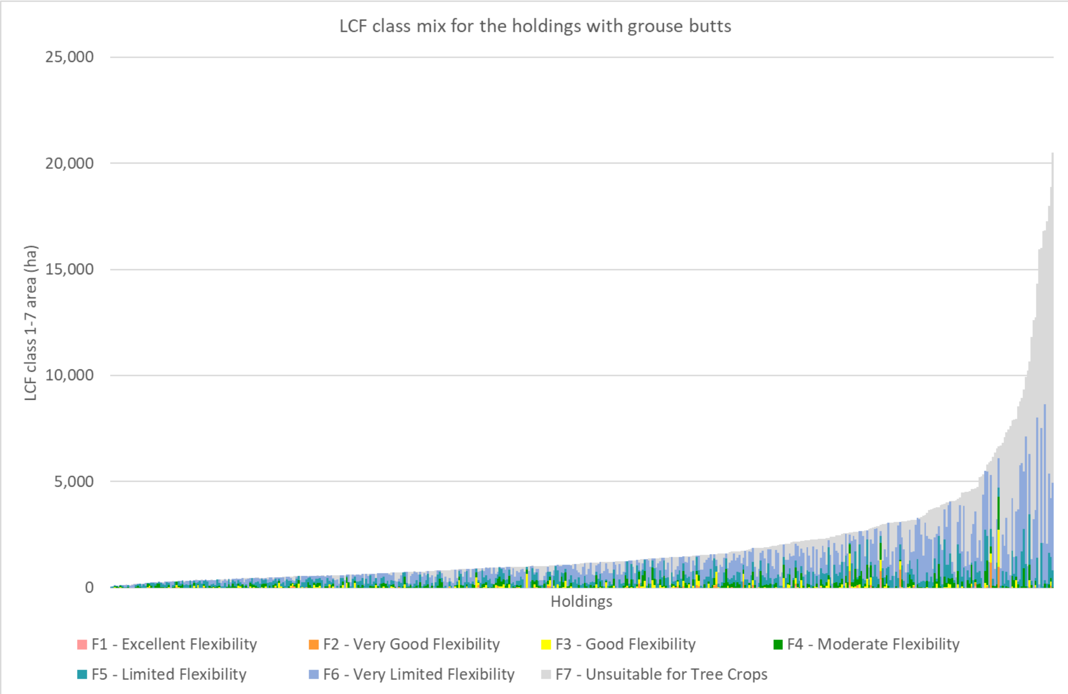

Figure 29

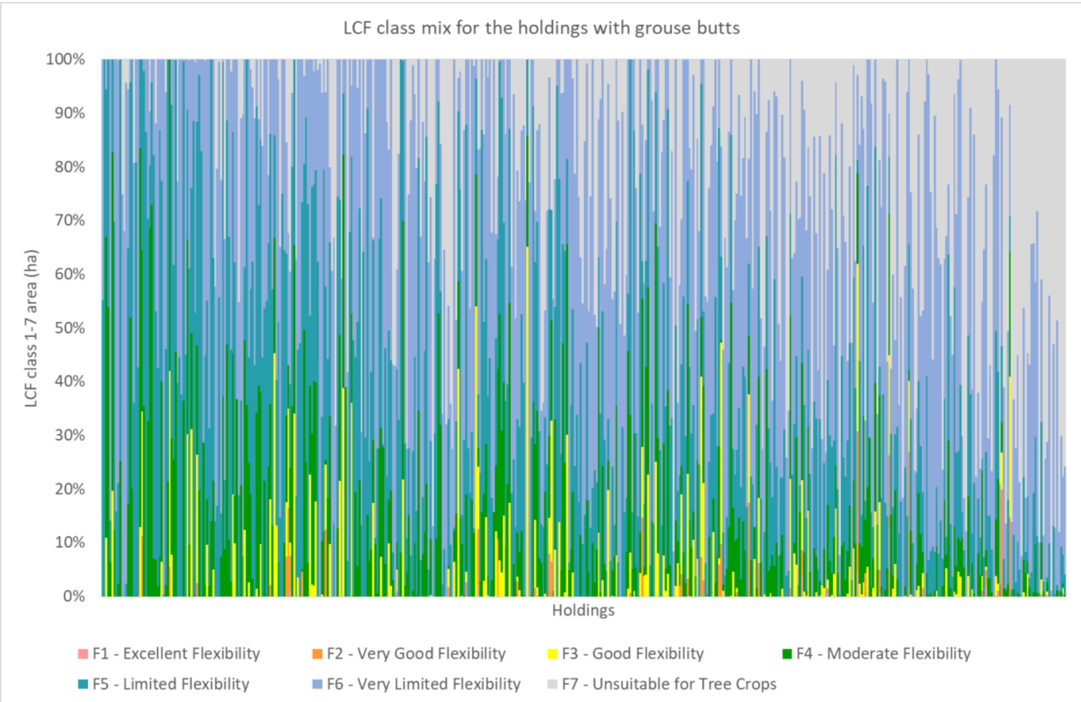

Figure 30

B6. Areas for the largest individual and overlapping spatial frameworks

There are 95 individual and unique combinations of spatial frameworks that occur for the holdings with grouse butts present. Table 5 sets out the top 15 spatial frameworks or their combinations (chosen by limiting the set to only those with more than 10,000 ha of area).

Table 5

	Holdings with grouse butts		
Spatial Framework(s)	**Area (ha)**	**% of total holding area**	**% of the spatial framework area of holdings**
National_Parks	100,249	10%	16%
PEATWIND	98,018	10%	16%
SSSI	57,391	6%	9%
National_Parks, WILDLAND	51,592	5%	8%
PEATWIND, WILDLAND	42,159	4%	7%
National_Parks PEATWIND, WILDLAND	40,429	4%	7%
WILDLAND	33,332	3%	5%
SSSI, PEATWIND	23,831	2%	4%
National_Parks, PEATWIND	20,837	2%	3%
National_Scenic_Areas	14,652	1%	2%
National_Parks, SSSI	13,051	1%	2%
National_Scenic_Areas, National_Parks, SSSI, WILDLAND	12,365	1%	2%
National_Scenic_Areas, National_Parks, WILDLAND	12,358	1%	2%
SSSI, WILDLAND	11,529	1%	2%
National_Parks, SSSI, WILDLAND	11,394	1%	2%
Holding area for all holdings with grouse butts		1,009,436	0%
Area of spatial frameworks in all holdings with grouse butts			620,880

B7. Percentage of deep peats in soil map units

The mapping of deep peats or soil carbon percentages would enhance the characterisation of the management limitations of grouse moors. Figure 31 illustrates the extent of deep peats.

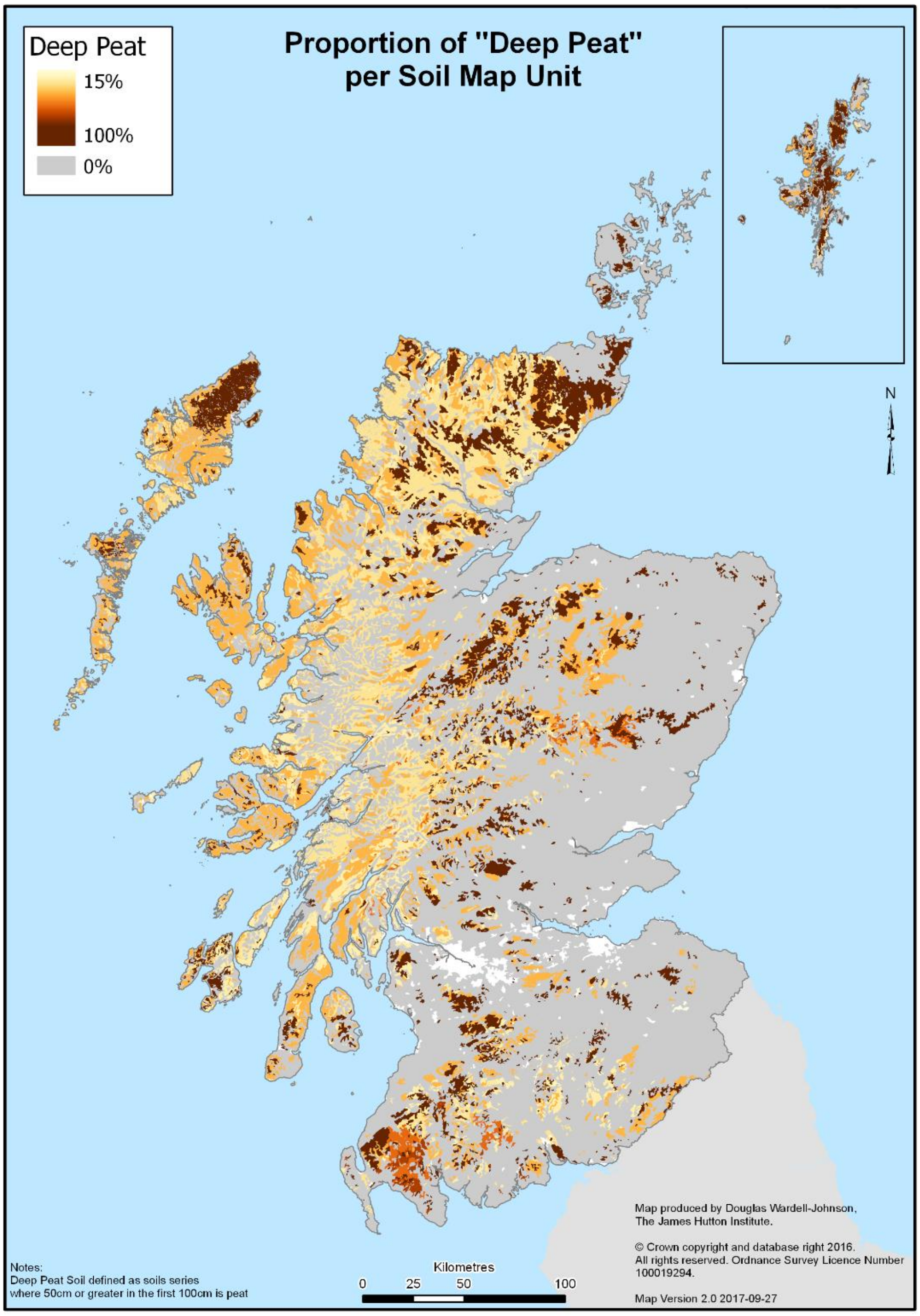

Figure 31

B8. Example of a Socio-Economic Performance (SEP) map

The map in Figure 32 is the aggregate outcome for four axes of socio-economic performance (Wealthier and Fairer, Healthier, Safer and Stronger and Smarter) each of which is itself the product of several individual performance metrics.

Infographic produced by Jonathan Hopkins. SEP Index created and developed by Andrew Copus.

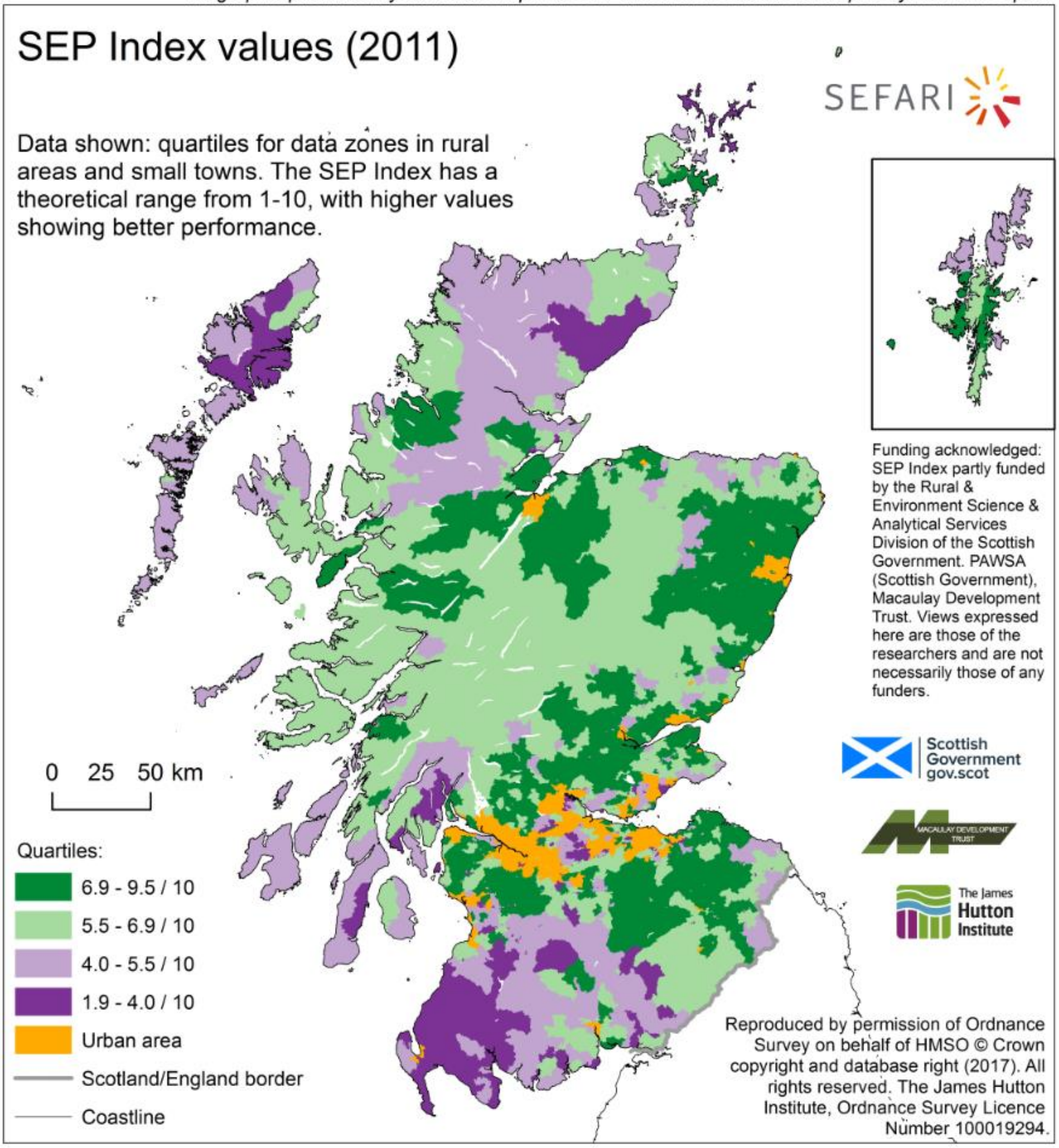

Figure 32

Appendix C. Use of remote sensing to identify areas managed for driven grouse.

C1. Introduction

The upland moorlands are distinctive landscapes of international conservation importance, comprising mosaics of heathland, acid grassland, blanket bog and bracken, which are managed for game, e.g. grouse, by rotational burning. Identifying and monitoring the impact of intensively manage grouse moorland is challenging given the scale of the uplands and accessibility. Here we review the potential for using remote sensing techniques to address these challenges.

C2. In general: What is remote sensing?

Remote sensing is earth observation through passive or active sensors mounted on satellite and airborne platforms. Passive multi-spectral or hyper-spectral sensors capture a range of bands along the sunlight spectrum including visible, near-infrared and infrared light. The exact range of light captured is sensor dependent. There are range of different satellites sensors, which vary in technical aspects (number of spectral bands and band-width, spatial resolution and extent, and observation (fly-over) frequency and orbital paths, mission period) and accessibility (readily available, on demand, or commercial). Data are readily available from the LANDSAT, MODIS and SENTINEL2 satellite sensors, and so these are commonly used. Active sensors send a signal to earth and record the way that signal is returned to the sensor; examples are Sentinel 1 and LiDAR.

Multi-spectral satellite remote sensing data are most commonly used to monitor land cover and land cover change (Morton et al. 2011), because they can distinguish vegetation based on the amount of visible and infra-red light it reflects. The visible light and near-infrared data are commonly used to calculate the Normalised Difference Vegetation Index (NDVI), which measures the density of greenness per area of land. The NDVI can identify healthy growth and (seasonal) biomass productivity (Lees et al. 2018). A range of methods have been developed to assess the soil moisture content using both passive and active sensors (Petropoulos, Ireland and Barrett 2015). Active sensors are able to measure height differences and vegetation structure (Schmidt et al. 2017a).

Application of RS multi-spectral satellite data for land cover mapping involves a range of challenges which can affect their effective use for detecting and monitoring areas of land managed for driven grouse shooting. These include:

- Cloud cover – multi-spectral satellites are optical and unable to penetrate clouds. Weather conditions in Scotland mean that cloud cover significantly constrains the amount of multi-spectral RS data available for analysis, although active sensors are not affected by cloud cover.
- Spatial resolution - the commonly used satellite data (Sentinel and Landsat) have spatial resolution of 20 to 30 m while MODIS has a spatial resolution of 500 m, which means that detailed patterns maybe obscured. High resolution RS satellite data exist but these tend to be available only through commercial sources, e.g. SPOT, WorldView, Pleaides).
- Temporal resolution – satellites follow a particular path pattern and return to the same geo-location in a time that is dependent on their orbit (Landsat -16 days, Sentinel-2 – 5 days, MODIS 2 days). The recent improvements to 5day return times mean that the chances of capturing cloud-free images for Scotland have increased.
- Costs - commercial RS data are expensive, hence the reliance on products like LANDSAT and SENTINEL which are freely available.

Airborne remote sensing data, which are available through project specific data acquisition (i.e. flights on demand), can avoid cloud cover and have a higher spatial resolution which in part depends on the flight height of the aircraft. Therefore, flights are generally restricted to specific and limited case studies rather than national monitoring (Allen et al. 2016, Chapman et al. 2010, Delalieux et al. 2012, Schepers et al. 2014).

Having considered the general characteristics of remote sensing systems and the types of data they can provide, we now examine the use of both airborne and satellite RS platforms for identifying areas managed for driven grouse shooting. Inevitably this focuses on identifying patches of rotational heather burning (i.e. muirburn) that are commonly associated with management for driven grouse.

C3. Air-borne Remote Sensing data

With respect to assessing the conservation status of heathland ecosystems, Airborne Hyperspectral line-Scanner radiometer data (AHS-160) have been used to develop a method for an assessment of conservation status of heathlands and sub-pixel modelling, a tool to aid management and conservation of natural heathlands (Delalieux et al. 2012). AHS data have also been used to map and assess the conservation status of NATURA 2000 heathland habitat (Haest et al. 2017, Schmidt et al. 2017b). These studies consider RS-based assessment of conservation status for heathland in the context of Natura 2000 assessment criteria (*Calluna* coverage, structural diversity and species index) illustrating the potential of airborne hyperspectral imaging spectroscopy for detailed heathland habitat characterization. The methods used in these studies are an encouraging example for monitoring moorland and have a potential for the application in identifying rotational burning, as this management will create differences in *Calluna* coverage, structural diversity and species index.

With respect specifically to the use of air-borne RS data for detecting areas of heather burning, a study in the Peak District National Park on prescribed burning practices from 1988 to 2009 using management maps and aerial photography shows that vegetation mapping and colour aerial photography are an effective method for monitoring prescribed burning practice on moorlands (Allen et al. 2016). In the same study area, Chapman et al. (2010) have demonstrated that a classification of colour and infra-red aerial photographs is able to create high-resolution maps of dominant vegetation cover including burns of managed grouse moors. They conclude that “classification of aerial imagery is an efficient method for producing high-resolution maps of upland vegetation. These may be used to monitor long-term changes in vegetation and management burning and infer species-environment relationships and can therefore provide an important tool for effective conservation at the landscape scale”.

The results of a study considering the use of different spectral bands and indices for the assessment of burned and unburned areas in heathland has identified that the Normalised Burn Ratio (NBR), which uses near infrared and shortwave-infrared data to highlight burned areas and estimate fire severity, is superior in discriminating between burned and unburned areas. However for the assessment of burn severity the study suggests that, in heathlands, a stratification per vegetation type should be considered to produce more reliable burn severity maps (Schepers et al. 2014).

C4. Satellite-based Remote Sensing data

With respect to using satellite-derived data for monitoring moorland health and mapping the production of heather biomass (Robertson et al. 2001), a study into moorland mapping using a classification of Landsat 7 data from point samples has concluded that the results are less accurate than a fieldwork-based classification, which is in line with other identified challenges (see above). However, it also concluded that at relatively large scales, and with robust bird abundance-habitat association models, satellite-based RS can facilitate the mapping of moorland bird abundance over large areas (Buchanan et al. 2005, Sim et al. 2007), indicating the potential for using these data to develop indices of moorland health.

Integration of Sentinel-2 multispectral and Sentinel-1 SAR data has been used for a remote sensing-based habitat quality assessment of dwarf shrub heathland, in line with nature conservation field guidelines from Natura 2000. Sentinel-1 SAR data provide additional information on vegetation structure that is complimentary to optical data. The results of this remote sensing-based mapping of heathland conservation status had an overall agreement of 76% with field data and suggest that, although rule-based approaches for quality assessments offer potential, they still need further development of robust and transferable methods (Schmidt et al. 2017a). This is encouraging because Sentinel-1 is not cloud sensitive and grouse moor management could lead to vegetation structure differences, in particular between burned and unburned areas, indicating the potential use of these data for identifying areas of moorland burning.

Another example of the use of satellite-derived RS data for examining the conservation status of moorlands are studies linking land cover data with moorland management practices. In the UK, land cover is mapped and monitored using satellite RS data (Morton et al. 2011). Using these Land Cover Map (LCM) data, Amar et al (2004) were able to predict red grouse losses to individual hen harriers based on the amount of heather cover around hen harrier nests, and which pairs of harriers would predate most grouse within a population. Their analysis is based on a relationship between heather cover and grouse delivery rates (Amar et al. 2004). Vegetation composition maps (Meirik et al. 2010, Johansen 2004, Buchanan et al. 2005) and land cover maps like the LCM are generated infrequently (in the case of LCM approximately every 10 years), but more frequent updates can be created using RS data.

With respect specifically to identifying areas of moorland undergoing cyclic burning, Douglas et al. (2015) used the Thermal Anomalies Data derived from MODIS to assess burning frequency over a period of 10 years (2001 to 2011) for the UK. MODIS data are derived from a multispectral sensor and are able to deliver a similar type of information to that derived from the LANDSAT and Sentinel-2 systems. However, the minimum spatial resolution of these data is 500 m, which is more coarse, but on the other hand MODIS has a much higher return time, i.e. every 1 or 2 days. Douglas et al. acknowledge that this data can only identify those areas that are still sufficiently hot from burning, but they show that the data can be used for the assessment of trends in moorland burning within 1 km squares. Given the results of NBR in relation to the identification of burning and non-burning areas, it may be valuable to include the Normalised Burning Ratio data in analyses. The NBR is affected by cloud cover, so their inclusion may need to consider the use of MODIS derived NBR when the availability of LANDSAT or Sentinel derived NBR data is constrained.

A retrospective analysis using Landsat data to develop estimates of fire history for sclerophyll woodland and heath ecosystems using a NBR, has shown that the accuracy of the NBR is minimally affected by post burn vegetation growth for Landsat images within ~30 days after fire events (Parker, Lewis and Srivastava 2015). These results suggest that the identification of new burns is limited to about 30 days after which post burn vegetation may make this ratio less effective. For the Scottish circumstances this means that the NBR on its own may not be sufficient to identify burning in moorland, as the likelihood of cloud-free images shortly after burning events is relatively low.

C5. Conclusion

Existing research shows that there is scope for application of RS for monitoring the status and management of grouse moorland, in particular burning events. It also demonstrates a range of different modelling techniques to link field observations to satellite and airborne imagery.

Airborne hyperspectral imagery is most commonly used for monitoring heather moorland. Airborne hyperspectral RS and aerial photography have been applied to characterise vegetation and management burning (Chapman et al. 2010), heathland conservation status and (footpath) erosion (Delalieux et al. 2012, Schmidt et al. 2017b), and monitoring of habitat quality (Neumann et al. 2015, Haest et al. 2017) and burning (Allen et al. 2016, Fernandez et al. 2016, Schepers et al. 2014). . Overall this approach has a high resolution but may not be necessary for the identification of muirburn, as there will be a clear difference between biomass productivity and vegetation structure between burned and non-burned areas which could be picked up by satellite-based systems. However, it may provide additional information about broader biodiversity health and conservation status.

Satellite based data are commonly used for mapping vegetation composition (Meirik et al. 2010, Johansen 2004, Buchanan et al. 2005), habitat prediction through land cover (Amar et al. 2004), and also for mapping the production of heather biomass (Robertson et al. 2001) and assessing multi-decadal fire severity patterns (Parker et al. 2015, Douglas et al. 2015). These examples show that there is clear potential for the application of multi-spectral data in the identification of managed grouse moors when that management includes rotational burning, but this depends on the desired frequency of monitoring in relation to the availability of cloud-free data. To overcome the issue of cloud cover, it is possible to consider the use of MODIS data which, although having a coarser resolution than Landsat or Sentinel data, have a higher return frequency and thus greater probability of cloud-free images. In addition, the integration of Sentinel-1 and Sentinel-2 may help to provide some information even for clouded periods (Schmidt et al. 2017a).

Finally, several studies note that the results from RS don't always match the level of detail and accuracy that can be achieve through intense fieldwork, but the benefit of RS is that it can be used to monitor larger areas. Most of the methods presented in this review have used a type of supervised classification process or modelling process for the assessment of moorland based on extensive field observation data.

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