Mapping the areas of moorland that are actively managed for grouse and the intensity of current management regimes.

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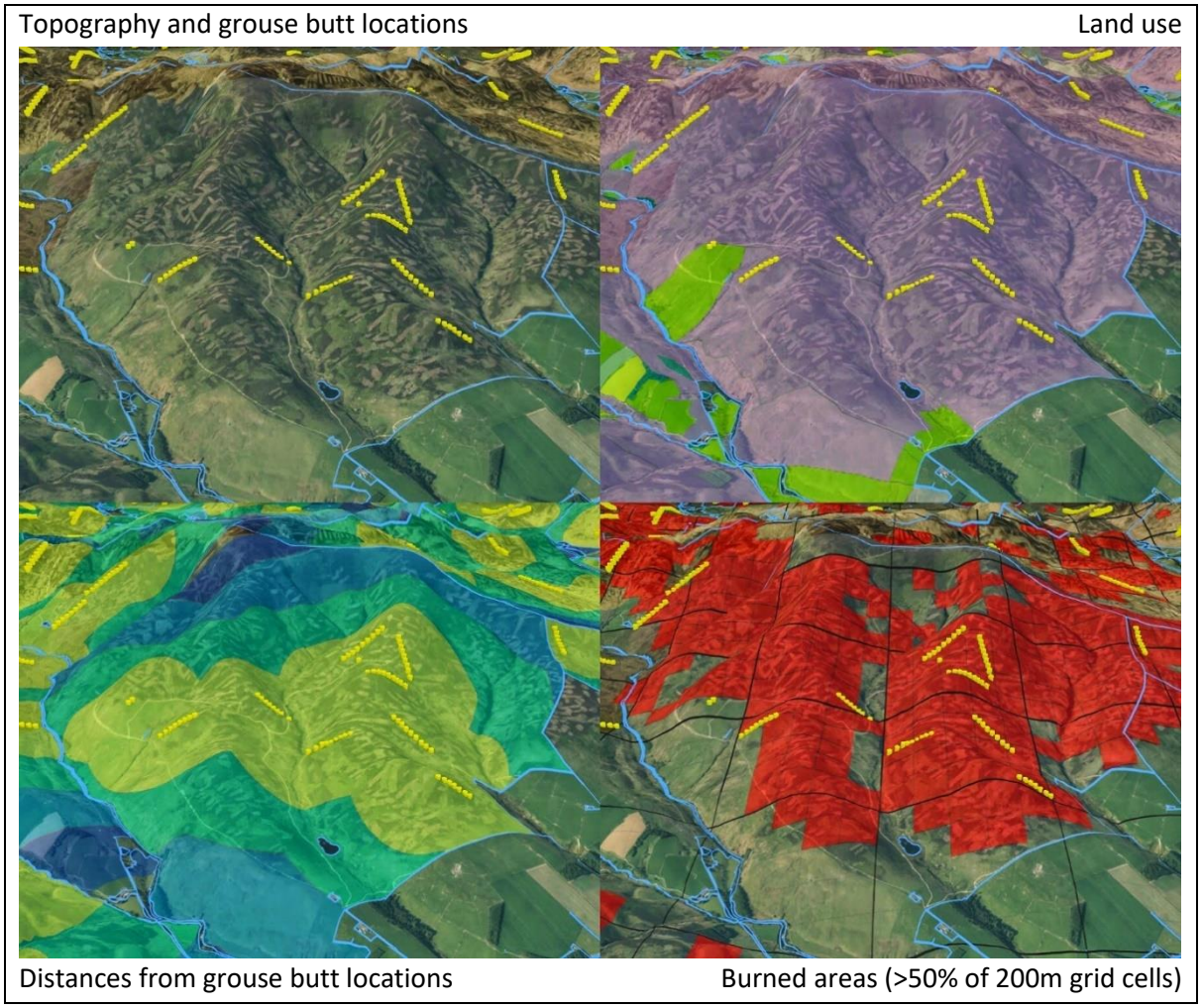
Mapping the areas and management intensity of moorland actively managed for grouse

Part 3: Research to assess socioeconomic and biodiversity impacts of driven grouse moors and to understand the rights of gamekeepers.



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The views expressed in this report are those of the researchers and do not necessarily represent those of the Research Advisory Group, Scottish Government or Scottish Ministers.

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Summary and key findings from the research

Background

The analysis presented in this report updates and enhances that by Matthews et al. (2018) in Phase 1 of this project, where geographical information system and remote sensing methods were used to identify areas of driven grouse moors and assess their potential for alternative land uses. As part of the Phase 1 analysis, assessments were also made of the intensity of moorland management. An assessment of grouse butt density (butts per km2) was made for the first time, but the assessment of strip burning of heather relied on data from 2005-11. This meant that the Phase 1 analysis could provide no insights into changes in strip burning of heather that have occurred in the last decade. The Phase 2 analysis has been conducted to address this limitation by providing updated (to June 2018) and higher resolution mapping of strip burning. The characterisation of grouse butt density has also been enhanced by making an improved assessment of the areas of rough grazing that are close to the locations of grouse butts.

Improvements to the available data and methods

Since the outputs of the analysis are intended to support policy making, and since the topic of driven grouse-moor management is contested, it is essential that data and methods used to generate advice to policy are transparent and seen to be robust, salient and credible. It is also important to assess the limitations of the available data where this has implications for policy making, highlighting where additional data gathering or analysis may be prioritised. This report is thus intended to provide an account both of how the evidence to support policy making was derived and an interpretation of the significance of the project outputs.

The project has collected new data for all agricultural holdings identified in Phase 1 as having grouse butts present and rough grazing, by undertaking the following six steps.

1. **Updating the mapping of strip burning from 2005-11 to June 2018** – interpreting aerial photography or high-resolution satellite data.
2. **Adding a "burned since" date** by comparing 2018 with earlier imagery to quantify the likelihood that strip burning of heather moorland continues to be active rather than being a relict feature.
3. **Improving the spatial resolution of strip burning analysis from a 1km to a 200m grid** allowing the attribution of areas of burning to specific holdings. This attribution means it is now possible for the first time to look at the distribution of burning areas and intensity across all holdings.
4. **Identifying where there may have been a change in intensity of burning** by comparing 2018 data with that from the 2005-11 RSPB analysis. Any comparison needs to be made carefully given the differences in the methods and data used but indicative conclusions can be drawn.
5. **Defining areas more likely to be subjected to management for driven grouse**, by identifying rough grazing within set distances of grouse butts (500m to 2,000m) as being those more likely to be subjected to some form of management for driven grouse. This gives a more robust estimation of the area of driven grouse management with quantified levels of uncertainty. This method eliminates from consideration large areas of rough grazing in holdings that are remote from grouse butts and had in the Phase 1 analysis inflated the overall area associated with driven grouse moors and underestimated the intensity of management being practiced.
6. **Improving the estimation of grouse butt density** (butts per km^2, using data from (5) above) as another indicator of intensity of management.

Taken together the six steps enable the creation of a single unified dataset integrating land cover/use, area and intensity of burning, grouse butt numbers and their density and the other

characterisation data taken from the Phase 1 analysis. From this dataset, deductions about the number and characteristics of holdings, engaged in driven grouse moor management can be made.

Summary Map

The map in Figure 1 below, provides a high-level summary of the analysis of driven grouse moor management within the project. The figure uses a heat map to show the locations, area and intensity of management, in terms of both grouse butt density and percentage of rough grazing area being burned.

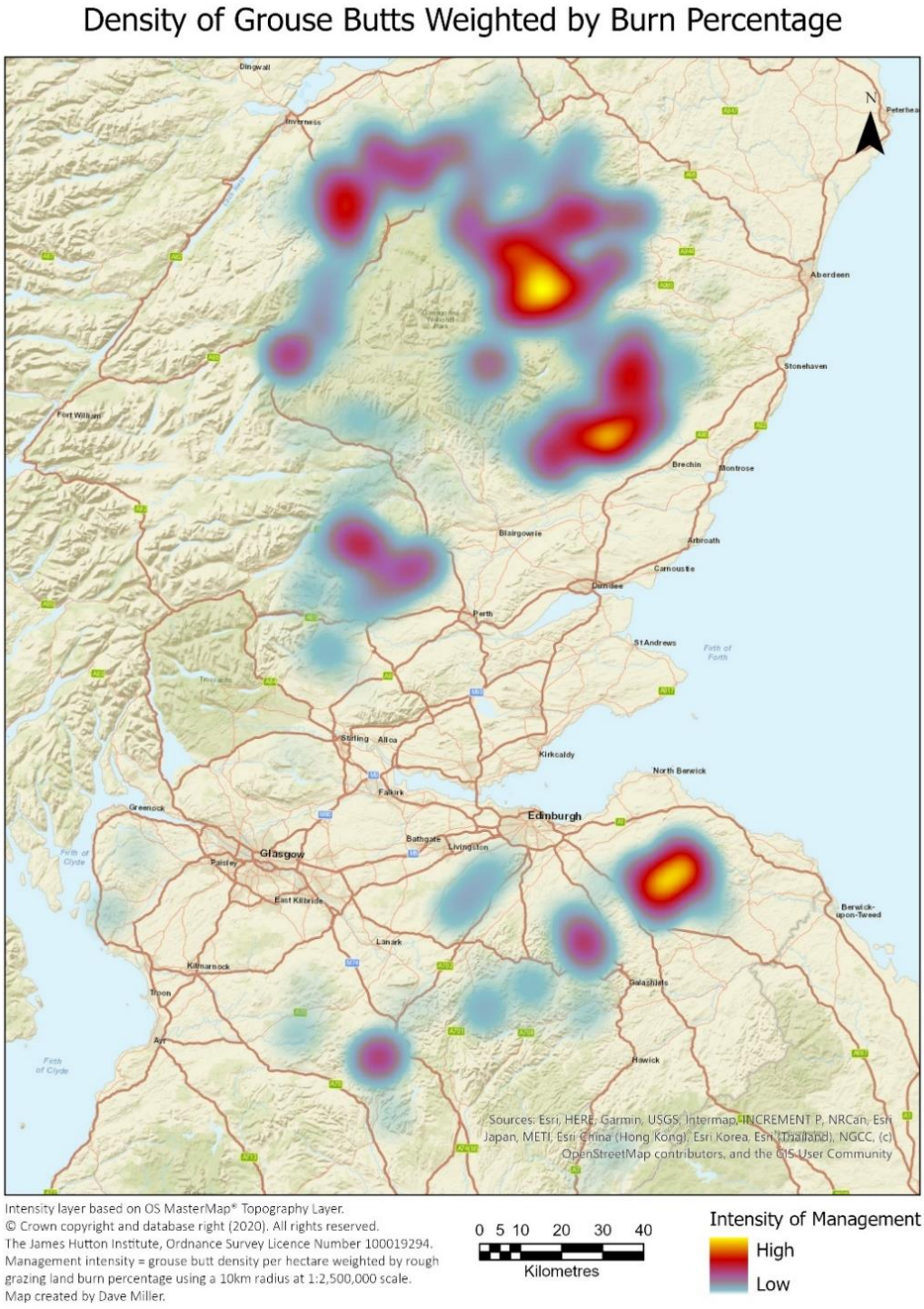


Figure 1: Heat map summary of locations, areas and intensity of driven grouse moor management

The heat map thus highlights relative intensity of management, from low intensity blues to highest intensity yellows. Since the heat map summarises characteristics within a 10km radius circle it provides a form of landscape level summary that is helpful in emphasising where there are concentrations of activity within Scotland in this case highlighting the Cairngorms, Angus Glens and the Lammermuir Hills. The map can also be interpreted as showing the degree of certainty that an area had driven grouse moor management present, with the lower intensity areas potentially no longer being actively managed for driven grouse.

Summary of key findings

1. Holdings with grouse butts mapped on rough grazing – 491 holdings, with about 1 million ha total area, of which about 858,000 ha was rough grazing and about 584,000 ha of this is within 2,000m of grouse butts and around 388,000 ha was within 1,000m. The burned area of rough grazing for these holdings is about 163,000 ha. A substantial share of this rough grazing land is managed by a relatively small number of holdings – 13 holdings, each with more than 10,000 ha of rough grazing, together manage 187,000 ha or 22%.
2. Active burning in 2018 was confirmed as present for 79% of holdings (87% of area), with 10% to be confirmed (out-with the scope of this project) and no strip burning found for only 11% (7% of area). For the holdings without burning, the grouse butts present are likely remaining as a relict feature of previous land management.
3. Where burning is identified as present, this was confirmed as having occurred typically after 2013 and in some cases since 2015, with smaller areas relying on older data.
4. There have been changes in the intensity of management between the period of the RSPB analysis (2005-11) and 2018 with both increases and decreases in intensity apparent with regional variations and clusters of change. There is though a need to be cautious in interpreting local patterns due to differences in data and interpretation methods. Any definitive interpretation of change would require a more detailed analysis of individual holdings data.
5. Areas closer to grouse butts are being burned more intensively (i.e. they have higher ratios of burned to rough grazing area). Any estimation of intensity needs to be explicit on the assumptions about which areas of rough grazing within holdings are being included in the driven grouse moor area. If the whole area of rough grazed land present in the holdings is used, then the burned percentage is 19%. If only the rough grazing within 2,000m of the grouse butts is used then the burned percentage increases to 25% and within 500m the burned percentage is 38%.
6. The distribution of burned percentages across holdings is biased towards lower intensities which may suggest that some of the holdings are largely inactive in terms of driven grouse. The higher intensity holdings, (those above 50% burned), though, make up 11% of the population and have burning intensity values more than twice, and up to four times, the median burn percentage of 19%. The holdings >60% burned have about 34,000 ha or 22% of the burned area on 35 holdings, for an average per holding burned area of about 960 ha.
7. The grouse butt density values have a wide range of values from less than one per square kilometre to over 10 per square kilometre (and in rare cases considerably higher). The range of densities reflect the wide variety of ways in which driven grouse management can take place. There is a bias in the distribution towards lower grouse butt densities but there are 28 holdings with grouse butt densities over 10 per square kilometre and these are managing at total of about 15,000 ha of land. Were environmental harm being generated mainly by holdings with higher densities of grouse butts, then implementation of any monitoring regime could be simplified by prioritising the relatively small numbers of such holdings.
8. The threshold above which the density of grouse butts might be considered excessive, will depend on the circumstances in which it occurs and how the butts are used. It is likely that there

can be a range of management practices associated with holdings having broadly the same density of butts per hectare. Therefore, the utility of the analysis above would seem to be in highlighting cases where it might be prudent to work with holding owners to ensure that any negative impacts can be minimised.

Confirming the Phase 1 analysis

The findings from this research, while having updated and substantially improved on the analysis that was possible in Phase 1, are consistent with the findings of the earlier GIS-based analyses by Matthews et al. (2018) in Phase 1 of this project. Specifically, the analysis reconfirms the diversity of ways in which driven grouse moor management can be conducted. Within holdings, a grouse moor can, in area terms, be a dominant enterprise or near insignificant. In terms of intensity of management, grouse moors are highly variable with large differences even between neighbouring holdings. Overall, the land used for driven grouse has very limited potential for production-oriented agriculture and forestry enterprises, though other uses that do not rely on the biophysical productivity of the land may be viable. Part 1 of this Phase 2 project further considers alternative moorland uses.

Caveats to the analysis

While the analysis conducted has improved on the Phase 1 and earlier analyses there are still limitations on the analysis. Specifically, it was not possible to reinterpret all the potential areas in Scotland where burning could be occurring. Reinterpretation was therefore prioritised in locations where burning was present in both of the previous burning studies by RSPB (Douglas et al., 2015) and James Hutton Institute (McLeod and Newey, 2018). For the areas present in only one of these studies, another supplementary strip-burning analysis project was undertaken funded by the Scottish Government's Strategic Research Programme (SRP) 2016-22, starting in January 2020 and completed in March 2020. A supplementary or updated version of this report will be issued later, and digital datasets supplied to Scottish Government.

Opportunities for further research and stakeholder engagement

The new datasets created here can serve as a baseline against which to assess future change in key aspects of driven grouse moor management. The data also has potential value as training dataset for any computer-based methods being developed to monitor the extent and intensity of moorland strip burning in Scotland. There are several ways in which the analysis could be improved but to move beyond incremental improvements would rely on gaining access to privately held data on land management practices. This could be gained through cooperation with stakeholder and industry associations and/or by augmenting existing Scottish Government data gathering processes such as the June Census/December Survey or the Single Application Form.

Implications for monitoring and other policy making

The analyses within the project have improved the quality and timeliness of the data available on the extent of driven grouse moors and the intensity of their management. What this new data implies for any policy response will though depend on how the data are interpreted by stakeholders. The data can be interpreted to maximise or minimise the overall areal extent and intensity of management of driven grouse moors. Using the data to make estimates that minimise the extent and intensity, it could be concluded that any negative impact is small and there is no need for monitoring or regulation. On the other hand, an interpretation that maximises the area or highlights hotspots of intensive management could imply that there are extensive pressures and locally strongly negative outcomes, and hence the need to monitor and regulate. Research-based analysis does not provide a way to reconcile these differences in perspective, but it does provide a framework within which any deliberation between stakeholders and government could take place.

1. Background

This report is **Part 3: Provide a more up to date assessment of the area of grouse moors in Scotland under management for driven grouse, mapping clearly the areas of moorland that are actively managed for grouse and the intensity of current management regimes** of the Scottish Government's commissioned research project to **Assess Socioeconomic and Biodiversity Impacts of Driven Grouse Moors and to understand the Rights of Gamekeepers (CR/2019/01)**. The research project was led by SRUC and Part 3 was undertaken by an experienced team of interdisciplinary researchers from The James Hutton Institute (JHI). This research builds on the evidence base developed, and evidence gaps identified in 'Phase 1' of this research *Socioeconomic and biodiversity impacts of driven grouse moors in Scotland* (Brooker et al., 2018). A summary for the full project is available as a stand-alone report from the Scottish Government[1] and other technical reports from the project are available from the SEFARI website.

1.1 Policy context

1.1.1 Grouse shooting in Scotland

The sport of shooting red grouse on heather moorlands is unique to the UK and has occurred since the mid-19th century. A ground nesting bird, the red grouse is fast and agile, providing a testing game shooting opportunity. Today, productive grouse moors are mainly found in Scotland and the North of England, where moorlands are actively managed at different intensities by gamekeepers to provide these wild birds with favourable breeding and rearing habitats (see the map in Figure 12). Specific management activities include muirburn, predator control and the use of medicated grit to improve grouse health (Moorland Working Group, 2002).

There are three types of grouse shooting: driven, walked-up, and over pointers. Driven grouse shooting is the most intensive form and accounts for the majority of commercial grouse shooting in Scotland. The grouse shooting season runs from 12th August to 10th December each year. Unlike some other game birds, red grouse cannot be reared in captivity meaning their numbers vary considerably between years, with weather, habitat, disease and predators all having potential impacts on numbers.

1.1.2 Multiple benefits from moorlands

Scotland's Land Use Strategy promotes an integrated approach to land management, with woodland regeneration, biodiversity conservation, carbon sequestration and recreation encouraged in moorland areas alongside traditional sporting activities (Scottish Government, 2016b). Therefore, there is increasing pressure on land managers to deliver multiple benefits from moorlands, including the public benefits that these areas provide.

There have been questions raised about the positive and negative impacts of driven grouse shooting on biodiversity and other public benefits. While grouse moor managers and collaborators are taking active steps to reverse the decline of wading birds in Scotland[2], concerns generally focus on mountain hare culls/management on grouse moors, muirburn and the persecution of raptors. It is

[1] https://www.gov.scot/ISBN/978-1-80004-212-4

[2] For example, through the Working for Waders initiative that began in 2017.

particularly the latter that has generated strong reactions from conservation organisations, campaigners and the press and led to increased pressure on politicians to address the issue[3].

1.1.3 Recent scrutiny

There has been a growing public and political concern relating to the disappearance of golden eagles in Scotland. In 2016, the Cabinet Secretary for Environment, Climate Change and Land Reform asked Scottish Natural Heritage (SNH) to report on the issue. In May 2017, SNH published a commissioned report that studied the movements of 131 young golden eagles over a 12-year period, finding that more than 40 had disappeared in suspicious circumstances. The majority of cases were found to have occurred in or close to areas where land is intensively managed for driven grouse shooting (Whitfield and Fielding, 2017). Indeed, in summer 2019 further, significant, attention was brought to the disappearance of two golden eagles in Perthshire, with more calls being made for political action to regulate grouse moor management.[4]

When the SNH report was published, the Scottish Government specified the intention to establish a group (the Grouse Moor Management Group – GMMG), with a remit to look at "*the environmental impact of grouse moor management practices such as muirburn, the use of medicated grit and mountain hare culls and advise on the option of licensing grouse shooting businesses*" [5]. In the same month, the Cabinet Secretary also announced commissioning of research into the costs and benefits of large shooting estates to Scotland's economy and biodiversity[6]. A related Programme for Government (2017-2018) commitment also confirmed that a research project would be commissioned on the topic, alongside "*work in relation to protecting gamekeepers' employment and other rights*" (Scottish Government, 2017).

These announcements by the Cabinet Secretary focused specifically on driven grouse shooting. The Grouse Moor Management Group (GMMG), chaired by Professor Alan Werritty began its work in November 2017 to "*ensure grouse moor management [driven and walked-up] continues to contribute to the rural economy while being environmentally sustainable and compliant with the law*". During the working life of the GMMG 'Phase 1' of this research into the socio-economic and biodiversity impacts of driven grouse (Brooker et al., 2018) was completed and the GMMG considered the results. The GMMG's final report and recommendations to Scottish Ministers was published in December 2019 (Grouse Moor Management Group, 2019).

This 'Phase 2' of the socioeconomic and biodiversity impacts research, along with the study of gamekeepers' rights, provides new evidence that address some of the knowledge gaps identified during the Phase 1 research and in the evidence collated by the GMMG.

1.2 Aims and tasks across the whole research project

The aim across this commissioned body of research (Phase 2) was to build on the existing research knowledge base regarding grouse moors; and to better understand the rights, attitudes, motivations and behaviours driving the gamekeepers' employment.

[3] For example, the Revive Coalition call for reform of driven grouse moors and a petition submitted to the UK Parliament in 2016 to ban driven grouse shooting. This has been followed by a number of subsequent petitions, and counter petitions from the grouse shooting sector (see here for a full list during the 2017-2019 Conservative Government).

[4] See, for example, coverage in The Guardian (01.07.19).

[5] Grouse Moor Management Group terms of reference.

[6] Scottish Government news: Golden eagle deaths (31.05.2017).

The part of the wider body of research reported here is Task 3 – one of four Tasks in Phase 2. The aims for each of these Tasks are set out below with Task 3 highlighted.

1. Examine the extent and impact of economic connections between grouse shooting estates and surrounding businesses and communities (Task 1a).
2. Evaluate the socioeconomic impacts of alternative land uses for moorland and how they compare against land used for grouse shooting (Task 1b).
3. Understand the employment rights and benefits available to the gamekeepers involved in grouse shooting, as well as their working conditions, attitudes, behaviours and aspirations for the future (Task 2).
4. **Provide a more up to date assessment of the area of grouse moors in Scotland under management for driven grouse, mapping clearly the areas of moorland that are actively managed for grouse and the intensity of current management regimes (Task 3).**
5. Understand further the impacts of driven grouse shooting on biodiversity making use of more up to date estimates of grouse moor management intensity and linking it with the best available biodiversity data. Introduction (Task4).

2. Introduction

Previous analysis by Matthews et al. (2018), (Phase 1 of this project), identified and characterised a population of holdings[7] where there was evidence that driven grouse shooting was being undertaken. This Phase 1 research used the presence of mapped grouse butts[8] and the presence of strip burnt moorland[9] as indicators of grouse shooting activity (Matthews et al., 2018).

The aim of this research was to enhance the Phase 1 outputs improving the assessments of the area and intensity of driven grouse activities. Therefore, for those holdings identified in Phase 1 with grouse butts present there were two Phase 2 objectives:

Objective 1 – Update the mapping of strip burning;

Objective 2 – Improve the estimation of grouse butt density.

The research therefore sought to enhance key indicators so that they could be utilised by Scottish Government and stakeholders to inform the development of policy options.

The rationale for Objective 1 was that by updating the mapping of active strip burning from the 2005-11 data of previous research to 2018 the analysis would:

- more definitively identify the holdings where burning is currently taking place;
- better define both the extent (area) and intensity of burning (percentage of area burned);
- highlight any change in extent or intensity of burning over time.

The rationale for Objective 2 was that by seeking to improve the estimation of grouse butt density two key components of the Phase 1 analysis would be enhanced:

- the estimates of the numbers of mapped grouse butts present on the holdings;
- the areas of land close to grouse butt locations that are more likely to be associated with driven grouse enterprises and management activities.

Together, the two improvements would allow more robust estimations to be made of the areas associated with driven grouse moors and the intensity of management.

The next section elaborates the Methods and Data used to deliver the Objectives.

[7] Holding refers to an area of land recorded as a single entity in the June Agricultural Census. While these entities are agricultural in the sense that they have an agricultural holding number, they are referred to here simply as holdings since they have such a diversity of sporting, agriculture and other enterprises present. The group of holdings with grouse butts present on rough grazing is referred to as the population.

[8] A screened stand for a shooter often made of turf, stone or wood.

[9] Strip burning is conducted on moorland to create a mosaic of heather of different ages as habitat for red grouse.

3. Summary of data and methods

This section sets out the data and methods used in this research to improve on the quantification of the area and intensity of driven grouse moor management. Since the outputs of the analysis are intended to support policy making, and since the topic of driven grouse moor management is contested, it is essential that data and methods used are transparent and seen to be robust, salient and credible. It is also important to assess the limitations of the available data, particularly where this has implications for policy making, and to highlight where additional data gathering or analysis may be prioritised. This section therefore provides a summary of data and methods used, showing how this research builds on that conducted in Phase 1.

Figure 2 summarises the key data used and the analyses undertaken for both Phase 1 and Phase 2, with each of the analyses (the blue boxes in Figure 2) outlined below.

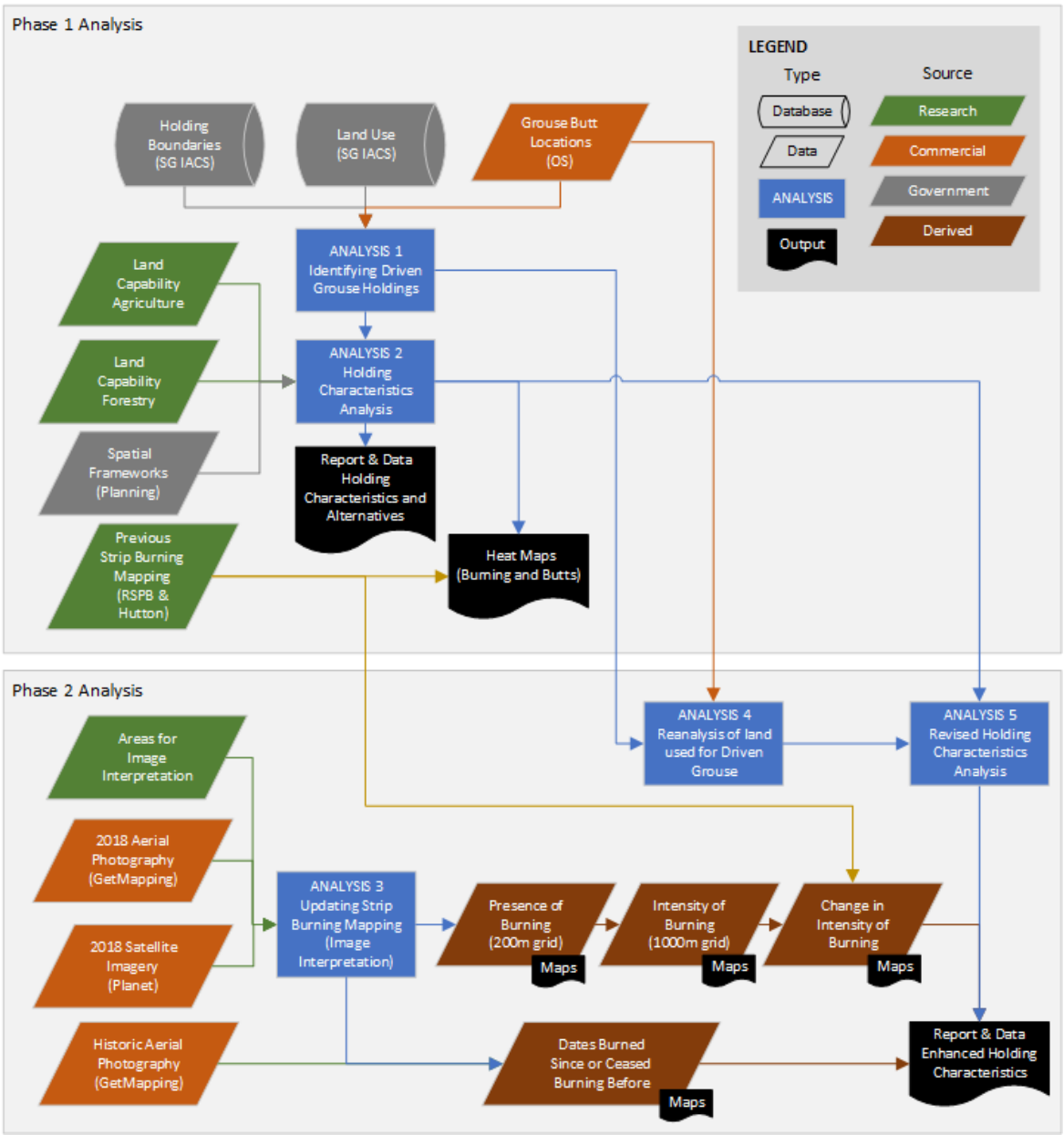


Figure 2: Flow chart of the methods, data and outputs of the two Phases of spatial analysis of driven grouse moors in Scotland

The key analyses and datasets in Phase 1 (the upper part of Figure 2) were fully detailed in Matthews et al. (2018) and are summarised here as:

- Identification of holdings that potentially have driven grouse enterprises present (shown as **Analysis 1** in Figure 2) using data on grouse butt locations from Ordnance Survey and holding boundaries and land use data from Scottish Government.
- Characterisation of the holdings identified in Analysis 1 in terms of location, size and the underlying biophysical land capability characteristics that might limit the range of feasible alternative moorland enterprises (**Analysis 2** in Figure 2). The characterisation also noted how much of the area of the holdings were subject to land use limitations from environmental designations or other planning restrictions (spatial frameworks).

The Phase 1 analysis also generated visualizations of the location, extent and intensity of driven grouse moor management as "heat" maps drawing on previously conducted mapping of strip burning conducted for RSPB by Douglas et al. (2015).

Using expert-based interpretation of aerial photography and high-resolution satellite imagery from 2018, the Phase 2 analysis updated the strip burning mapping that was previously conducted using 2005-11 data (**Analysis 3** in Figure 2). This generated maps of the presence/absence of burning on a grid with 200m cells and from this the intensity of burning (% of area burned) was estimated for each 1km grid. This was compared with the RSPB mapping (Douglas et al., 2015) to generate a map of change in burning[10]. Further analysis, compared the 2018 photography and imagery with earlier (historic) aerial photography to derive dates after which burning visible in the 2018 imagery had occurred – or if there was no new burning visible in the 2018 imagery the date before which no new burning could be observed[11].

The second part of the Phase 2 analysis is a reanalysis of the land used for driven grouse (**Analysis 4** in Figure 2). In this analysis new estimates of the area used for driven grouse and the density of grouse butts within this area were made. The estimates of the numbers of grouse butts present were refined to eliminate a small number (286 of 24,163) from the Phase 1 analysis that had been misidentified. The more substantive reanalysis sought to make a better estimate of the areas of rough grazing in closer proximity to the grouse butts. The Phase 1 analysis had included all rough grazing land in each holding, and while all this land may be subjected to some grouse-related activates such as predator control, there were cases where the estimates of grouse butt density was being reduced substantially by areas of rough grazing very distant from the areas where grouse butts were located.

Two improved estimates of the areas closer to grouse butts were made.

- The first created a series of areas by drawing circles round the grouse butts at between 500m and 2,000m distance, this is the simple buffering method shown in Figure 3A.

[10] The change in intensity maps need to be interpreted cautiously since some of the changes will be due to differences in data sources, interpretation methods and interpreter bias or errors. The overall pattern of change and local changes of the larger magnitudes are more reliably identified.

[11] Since the comparison was made between the 2018 imagery and the most recent historic imagery the "burned since" date is reliable and informative. The date for "no new burning" while reliable is less informative since the time between the 2018 imagery and the historic data used may be less than the period between burns. That no new burning is visible between the historic and 2018 imagery is informative but should not in all cases be interpreted as meaning that burning has ceased.

- The second created a "convex hull"[12] round all the grouse butts and then buffered the convex hull area by between 500m and 2,000m, see Figure 3B.

These alternative estimates of driven grouse moor areas were used to derive both the extents and intensities of driven grouse moor management for individual holdings.

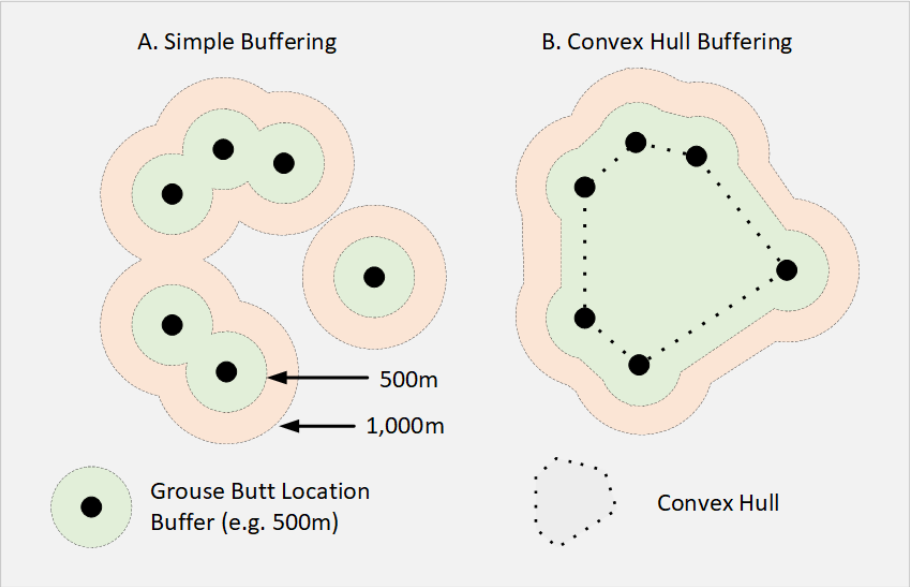


Figure 3: Ways to infer driven grouse moor areas from the locations of grouse butts

These potential driven grouse moor areas can be combined with the mapping of burning (from **Analysis 3** in Figure 2) to provide a more reliable estimation of the areas in which driven grouse moor management may be being practiced[13].

The final part of the Phase 2 analysis (**Analysis 5** in Figure 2) was the integration of data from all the previous components of Phase 2 into a single dataset from which interpretations of the likelihood that holdings are actively engaged in driven grouse moor management can be made. This dataset shaped the presentation of project Outputs (see Section 4) but also has the potential to be further refined using information available only to industry or stakeholder bodies.

The more reliable estimates of intensity of management generated within this research, have been used to underpin assessment of impact, such as on Biodiversity in Task 4 of this project. They are also the best publicly available data on which policy makers can base decisions on the need for moorland monitoring and any geographical locations that may be prioritised.

For more detail on the methods and data used see Section 8 Technical description of data and methods.

The next section presents and discusses the Outputs from the Phase 2 analyses.

[12] A convex hull is the smallest convex polygon that encloses all the points in a set (in this case the set of grouse butts).

[13] It needs to be noted that this analysis will potentially include false positives when there are grouse butts present but not being used and burning that is taking place for habitat, or wildlife, management (e.g. for Capercaillie) and not to support driven grouse. There will also be cases where walked up or over pointer shooting is supported by burning. The decision within this analysis was to be inclusive in terms of the holdings and areas reported anticipating that other sources of data will become available to refine the population of holdings.

4. Outputs

The analysis has generated a substantial body of new data that can be presented and interpreted in a variety of ways. The outputs from the project are organised as follows.

4.1 Coverage – the areas that were prioritised for the image interpretation of burning.
4.2 Mapping of strip burning – presents national coverage maps for the patterns of:

- Percentage of burn – a map of the intensity of burning on a 1km grid;
- Date of burn – maps of dates derived by comparing the 2018 data with earlier imagery;
    - Burnt since – the date since with burning visible in 2018 has occurred,
    - Ceased burning before – the date before which burning may have ceased,
- Change of burn percentage – maps comparing the 2018 burn percentage estimates with the earlier analyses by RSPB from 2005-11.

4.3 Linking burn mapping to holdings – the improved spatial resolution of the data makes it possible to attribute burned areas to specific holdings and calculate areas and percentage of holdings burned. This data is presented as:

- Counts of holdings and overall area of burning, a summary of the maps;
- Distribution of holdings classified by burn percentage – counts and area.

4.4 Better defining the size of driven grouse moors – using buffers around the butt locations to test how this changes the land use mix area "included" within the driven grouse moors.
4.5 Intensity of management – summaries and distributions across holdings of:

- Burn percentages – holdings classified by burn percentage – counts and areas;
- Density of grouse butts – holdings classified by hectares per butt – counts and areas.

Following the presentation of outputs there is further discussion of the outputs in Section 5, Interpretation of the Phase 2 outputs.

4.1 Coverage of area and holdings in this analysis

The geographical references used in the text are shown on the map in Figure 12 in Section 7.1.

In presenting the outputs a key caveat is that within the scope of this project it was not possible to reanalyse area for strip burning for all the rough grazing land in holdings with grouse butts present. Since the degree of coverage achieved has implications for the other outputs present, the coverage achieved and how this was prioritised is set out in this section.

491 holdings were identified in Phase 1 as having grouse butts present on rough grazing. The rough grazing land on these holdings is present in 12,496 cells of the 1km map grid[14]. Within this set of 1km map grid cells 3,827 were prioritised for strip burning interpretation using the 2018 data. This set of grid cells was prioritised since they had been identified as having strip burning present by both RSPB (Douglas et al., 2015) and McLeod and Newey (2018). A further set of 2,251 map grid cells, where burning was reported by either RSPB or McLeod and Newey is being interpreted as part of an additional linked project. In the 6,418 cells of the 1km grid cells, where neither RSPB nor McLeod and Newey previously reported burning, it was assumed that no new burning had occurred[15].

Prioritising the areas previously known to have strip burning present made best use of the resources available to the research team, focusing on increasing the robustness of the estimates of intensity of driven grouse management conducted in 2018. The areas interpreted for strip burning conducted in

[14] Note in many cases the 1km map grid cell isn't 100% occupied by rough grazing land – of the total 1,249,000 ha in the 1km map grid cells only 856,769ha is rough grazing (69%).
[15] Imagery is in hand that could confirm this assumption with further interpretation.

this project are shown in Figure 13 in Section 7 Maps, and the technical issues of coverage are discussed further in Section 8.3, Definitions of areas analysed.

4.2 Mapping of strip burning

From the interpretation of the aerial photography and the satellite imagery a series of maps were derived. These present a national overview of the areas where burning is occurring (extent) and the rate of burning per unit of area (intensity). The intensity values are expressed as burned percentages of the 1km map grid cells, mainly for comparability with earlier studies that use this metric, but also as percentage of area burned can more meaningfully be interpreted as a driver of other outcomes (such as socio-economic and biodiversity impacts assessed in Task 1 and Task 4).

4.2.1 Estimating burned area and percentage from presence absence mapping

The burned area and burned percentage were derived from the presence/absence data recorded for each of the 25, 200m map grid cells within the 1km map grid cell. The way the burned area and burned percentage is derived is illustrated in Figure 4.

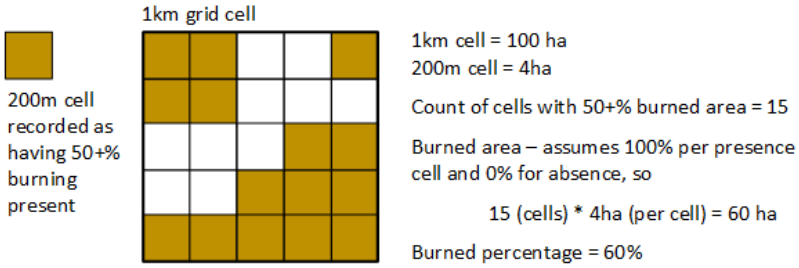


Figure 4: Calculating burned percentage from presence absence of burn data

The calculation of the burned area and percentage burned assumed that each of the 200m map grid cells identified as having burning present was 100% burned even though for a cell to be identified as having burning present required only 50% of the area to be burned. This overestimation of burned area in presence cells was compensated for in cells recorded as burning being absent, since burning can present at up to just below 50% but is assumed to be 0%. The working assumption is that these errors are compensating. In many cases this assumption will be valid, but overestimation of the burned percentage for the 1km map grid cells is more likely when most of the 1km map grid cell has burning present at >50%. (see Section 8.6 *Issues for creating and interpreting burn* percentage maps for a more detailed discussion).

The sections that follow provide explanations and brief commentaries on the maps generated within the project.

4.2.2 Percentage of burn map

An overall visual summary of the locations in which strip burning is being conducted and the intensities of management, using the estimated percentage of the rough grazing area being burned, is provided in the map in Figure 14 in Section 7.3 on p33. The map uses a colour ramp of five classes to present the burn percentage values per 1km map grid cell. The legend for the map also shows the counts of cells with burning present per 1km grid cell as an alternative way of interpreting the colour ramp[16].

[16] The counts of cells burnt more than 50% are a more reliable measure than area or percentage burned for the reasons outlined in Section 4.2.1 but is less easily interpreted or compared with earlier analysis.

By using a map with the whole of Scotland represented, the map in Figure 14 highlights that strip burning in 2018, while an extensive activity, is not practiced universally across the rough grazing areas of Scotland. The intensity of burning is highly variable in space. There are regions with higher concentrations of burning apparent and within these regions there are clusters of locations with the highest rates of burning (darker coloured areas). This reveals that there are core areas (Cairngorms, Angus Glens and Lammermuirs) where strip burning is being actively practiced – in most cases to support driven grouse enterprises. There is also a wider area with low intensity burning (lighter coloured areas) where either less intensive forms of grouse shooting are being practiced (walked -up or over pointer shooting) or the grouse shooting enterprise is now absent, with the grouse butts present and the evidence of burning both being relict features.

Summary statistics for the map in Figure 14 are presented as part of the per-holding level analysis in Section 4.3. Interpretation of strip burning activity or inactivity is enhanced by the "date maps" presented in the next section.

4.2.3 Date of burn map

The date maps present supplementary information that enhances the interpretation of the burn percentage mapping. It does so by quantifying the dates after which burning is known to have occurred (see Section 7.4, Figure 15 – North-East and Figure 16 – South) or before which burning "ceased" (see Section 7.5, Figure 17 – North-East and Figure 18 – South). The closer the "ceased" date is to 2018 there is a higher probability that burning may not have ceased, rather it simply had not occurred between the dates since the intervals between burning events may be larger than the gap between the 2018 and previous historic data (see Section 8.4 Strip burning interpretation for more detail). The maps are split into a North-East and a South region as this allows the detail within the regions to be better represented.

For the "burned since" maps, both show that the new burning being detected has occurred since 2013 (orange and red colours) except for small areas where the previous imagery can be much more dated (back to 2007 – coloured green). For higher intensity areas the typical burnt date was 2015. The need to use multiple dates of historic photography is a limitation on the analysis but at least serves to put a floor under any discussion of how recent any visible burning may be.

For the "ceased burning" or potentially "no new burning since" date maps the typical values are again in the 2013-15 range. The period between 2018 and the next previous imagery are probably too narrow to be definitive on any cessation of burning but may highlight areas where reductions in intensity could be occurring. Where there are areas with dates in the 2007-11 range it is much more likely that driven grouse management has ceased in these areas (the Pentlands and Moorfoot Hills in the central parts of the South map see Figure 16). Further analysis of earlier aerial photography would enhance the reliability of the "ceased burning" maps and is in some cases possible with the mapping available in GetMapping™.

4.2.4 Change of burn percentage map

Maps of the change in the burning intensity comparing this analysis with the previous RSPB mapping are presented in Section 7.6, again with two maps one for the North-East region, Figure 19 and one for the South region, Figure 20. Both maps suggest that there has been a change in intensity of management between the period of the RSPB analysis (2005-11) with both increases (red colours) and decreases in intensity (green colours) apparent, with regional variations and clusters of change. There is, though, the need to be cautious in interpreting local patterns due to differences in data and interpretation methods. Any definitive interpretation of change would though rely on more detailed analysis of individual holdings data.

The distribution of change shown in the maps is presented in Figure 5. The distribution graph highlights that there has been change between 2005-11 and 2018. The degree of change can be substantial, for both increases and decreases, but there is also consistency between the two periods with the largest areas being associated with relatively small changes in intensity. The figure indicates an overall increase in intensity between the periods, but again there is the need for caution in interpreting the magnitudes given the differences in methodology. The value of the analysis is perhaps greatest in highlighting locations where the largest changes are indicated as being those where any monitoring of impact might be prioritised.

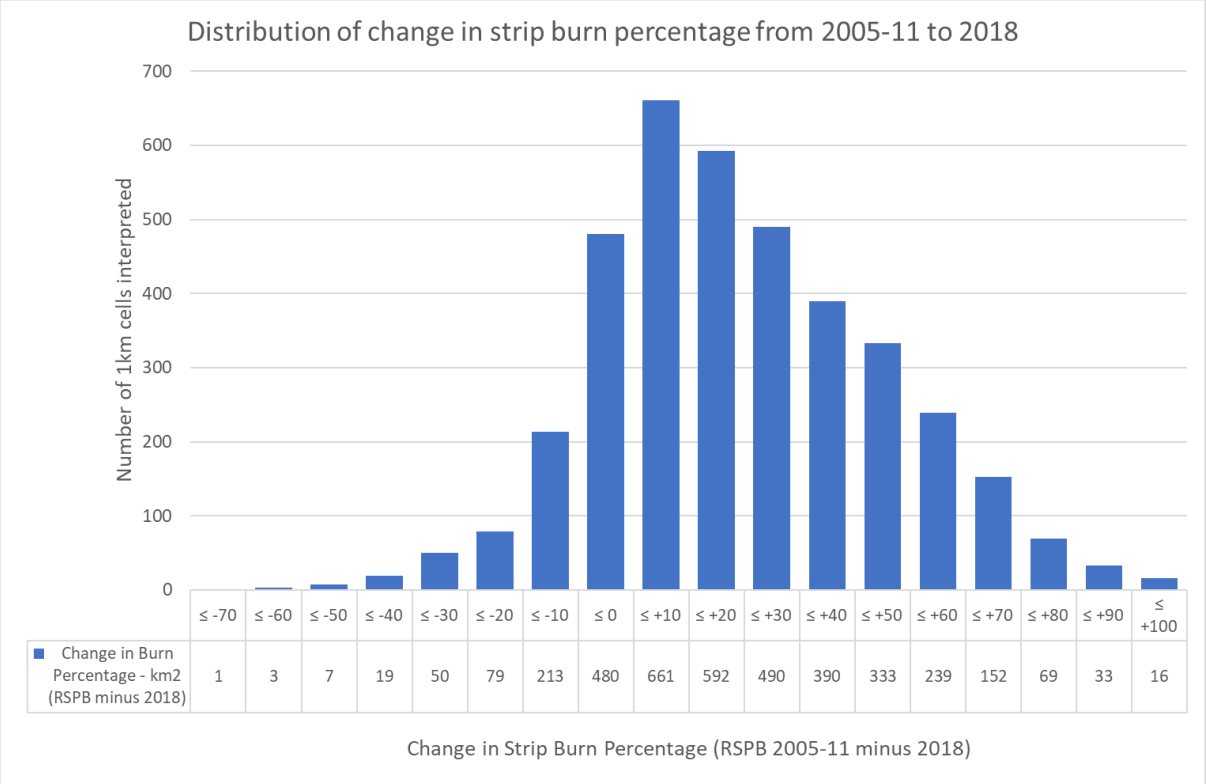


Figure 5: The distribution the change in strip burn percentage comparing the RSPB 2005-11 dataset with the 2018 analysis in this report.

Having provided a national scale overview of the intensity, dates and changes in strip burning the report now examines how this burning data turns to a per holding analysis of the patterns of burning.

4.3 Linking burn mapping to holdings

Previous analyses of strip burning have not sought to link the analysis of patterns of burning to specific holdings or other representations of ownership or management. Partly this may have been due to limitations on access to holding boundary maps, but linkage to holdings was also made very challenging by the granularity of burning interpretations made. The use of 1km map grid cells for interpretation was compatible with landscape scale analysis of biophysical phenomena such as impact on biodiversity but meant that attributing areas of burning to specific holdings was unreliable. With the use of the 200m presence/absence mapping in this project it is possible to characterise better individual holdings and begin to get insights into the distribution of intensity of management. This analysis has potential value for policy makers in identifying the numbers and areas of holdings where intensity of management is higher and where any negative or positive

impacts could be occurring. This kind of characterisation could be used as a starting point for prioritising monitoring.

4.3.1 Burning present within holdings with grouse butts present

This section summarises for the population of holdings with grouse butts present on rough grazing land the area of burning.

Where burning was identified in the 2018 data this was termed the **active burning** area. Where the 2018 cells had no burning present these were termed the **no burning** area. Where the RSPB or Macleod and Newey data was used (2,251 cells of the 1km map grid) then, if burning was present, this was the **assumed burning area** and if absent then the **assumed no burning** area. For the assumed burned area when the burned percentage per 1km cell was not available, such as when only presence of burning and not the degree of burning was recorded, a 15% of area value was assumed. This process was consistent with the overall average for burned area versus moorland coverage values in Douglas et al. (2015) as interpreted by Armstrong (pers. comm and 2019). By including the assumed area, it is possible to get a more complete characterisation of holdings engaged in driven grouse activities[17].

Where appropriate then the analyses that follow refer to sets of holdings as follows:

1. A "focused" set of holdings – only those with active burning identified in 2018.
2. A "relaxed" set of holdings – adding those with assumed burning present.
3. An "inclusive" set of holdings – all those with grouse butts present.

4.3.2 Summary of counts and areas of holdings subjected to burning

Table 1 presents a classification of the inclusive set of holdings with grouse butts present. It identifies those holdings with active burning present (387), the holdings with either active or assumed burning (436) and those with no burning present, in both 2018 and earlier analysis (55). From this classification it is possible to infer that over three-quarters of the holdings had active burning in 2018 (79%), and if assumed burning can be confirmed then the percentage becomes nearly 90%. This implies that even if these holdings are not conducting driven grouse enterprises then moorland management via strip burning is still being actively pursued. In terms of area, Table 1 highlights that while the area of land at the disposal of these holdings is substantial at just over 1 million hectares, the area of rough grazing being subjected to active and assumed burning is much smaller at 162,920 hectares. This implies that any monitoring scheme for strip burning associated with grouse moors would not have to be extensive compared with, for example to inspections regimes for agriculture.

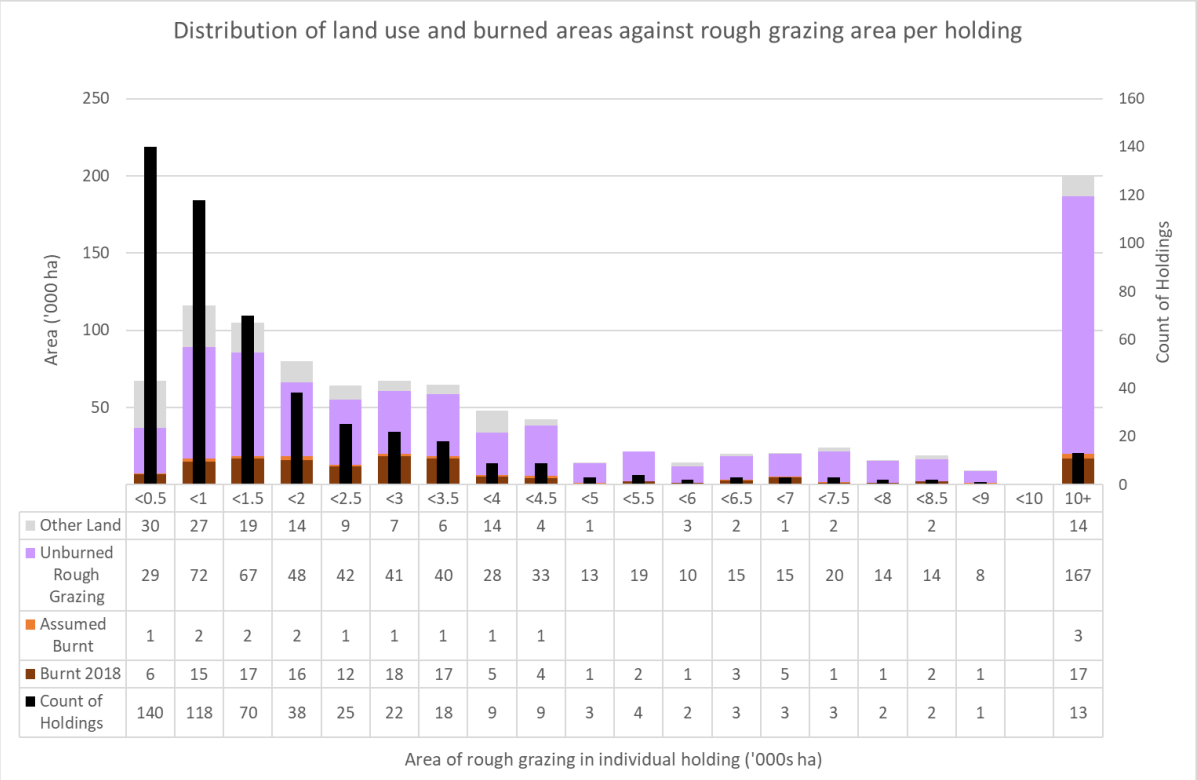
Table 1: Breakdown of characteristics of holdings with active and assumed burning present – inclusive set of all holdings with grouse butts present on rough grazing land

		Holdings			Rough Grazing	Burned
Burning	**Count**	**Count (% of All)**	**Area ('000 ha)**	**Area (% of All)**	**Area ('000 ha)**	**Area ('000 ha)**
Active	387	79%	894	87%	757	144
Active & Assumed	436	89%	956	93%	802	163
None	55	11%	68	7%	55	-
All	**491**	**100%**	**1,023**	**100%**	**857**	**163**

[17] The assumed area is being reinterpreted in a linked project to be completed in March 2020.

4.3.3 Distribution of the rough grazing and burned areas between holdings

Classifying holdings based on their area of rough grazing allows an assessment of the distribution of all land, rough grazing and burned land for the population of holdings. The numbers of holdings for each rough grazing area class can also be visualised and are presented in Figure 6. The figure shows the predominance of rough grazing as the land cover/use (unburnt and burnt), though smaller holdings tend to have a greater proportion of other land uses. The figure also highlights that there is a substantial area of rough grazing land managed by a relatively small number of holdings (13 holdings, each with more than 10,000 ha of rough grazing, together manage 187,000 ha[18] or 22% of all that land).



	<0.5	<1	<1.5	<2	<2.5	<3	<3.5	<4	<4.5	<5	<5.5	<6	<6.5	<7	<7.5	<8	<8.5	<9	<10	10+
Other Land	30	27	19	14	9	7	6	14	4	1		3	2	1	2		2			14
Unburned Rough Grazing	29	72	67	48	42	41	40	28	33	13	19	10	15	15	20	14	14	8		167
Assumed Burnt	1	2	2	2	1	1	1	1	1											3
Burnt 2018	6	15	17	16	12	18	17	5	4	1	2	1	3	5	1	1	2	1		17
Count of Holdings	140	118	70	38	25	22	18	9	9	3	4	2	3	3	3	2	2	1		13

Figure 6: Distribution of land use and burned areas against rough grazing area per holding

While these summaries give a high-level characterisation in terms of extents (areas) it has not addressed in detail the intensity of burning, i.e. the proportion of the rough grazing land that is being burned, a key indicator of the potential for impacts. To make this estimation on intensity though requires care in deciding which rough grazing land should be considered part of the land being managed for driven grouse.

4.4 Better defining the size of driven grouse moors

Using the simple buffering and the convex-hull buffering of grouse butt locations methods outlined in Section 3 it was possible to refine the land cover/use based definitions of the extent of driven grouse moors. By linking the buffered grouse butt locations with the maps of land use created in the Phase 1 analysis it was possible to generate a characterisation of both the holdings as a whole and for the land in closer proximity to the grouse butts. Doing this helps to better understand why there have been widely differing estimates of the driven grouse area based on interpreting land cover/use. The analysis also provides better estimations of the proportions of rough grazing being strip burned.

[18] The combining burned and unburned rough grazing values.

4.4.1 Land use mix in the grouse butt buffers -inclusive set of holdings

The breakdown of land cover/use is presented for the inclusive set of all holdings in Table 2 for the simple buffered butt locations, and Table 3 for the buffered convex hulls. Part A of both tables presents the areas for groupings of the land cover/use classes as reported in the Integrated Administration and Control System (IACS) in 2015[19]. Part B of the tables shows the mix of land uses present in the buffer areas, with each land use area expressed as a percentage of the total area of the whole holding or relevant buffer. The Part B breakdown provides an insight into the nature of the land use in closer proximity to the grouse butts. Part C of the tables shows the areas of land uses in the buffers as percentages of the whole holding area. This gives an insight into the relative share of land within holdings devoted to driven grouse moors depending on the assumptions made on buffer size (these range from 500m to 2,000m and are referred to, for example, as "Simple 2000").

Table 2: Land cover/use mix using simple buffered butt locations, inclusive set of holdings (490) – land use areas (A), as percentages of the buffer areas (B) and as percentages of the whole holding area (C)

A	Area (000's ha)	Rough Grazing	Woodland	Crops	Temp Grass	Perm Grass	Other Land Uses	All Land Uses
	Whole Holding	857	30	8	8	63	58	1,023
	Simple 2000	584	11	2	3	34	20	655
	Simple 1500	510	8	2	2	25	14	562
	Simple 1000	388	5	1	1	14	8	417
	Simple 500	194	2	-	-	4	2	202

B	% of the Buffer	Rough Grazing	Woodland	Crops	Temp Grass	Perm Grass	Other Land Uses
	Whole Holding	84%	3%	1%	1%	6%	6%
	Simple 2000	89%	2%	<1%	<1%	5%	3%
	Simple 1500	91%	1%	<1%	<1%	5%	2%
	Simple 1000	93%	1%	<1%	<1%	3%	2%
	Simple 500	96%	1%	-	-	2%	1%

C	% of the Holding	Rough Grazing	Woodland	Crops	Temp Grass	Perm Grass	Other Land Uses	All Land Uses
	Whole Holding	84%	3%	1%	1%	6%	6%	100%
	Simple 2000	57%	1%	<1%	<1%	3%	2%	64%
	Simple 1500	50%	1%	<1%	<1%	2%	1%	55%
	Simple 1000	38%	<1%	<1%	<1%	1%	1%	41%
	Simple 500	19%	<1%	-	-	<1%	<1%	20%

Part A of both tables highlights that the maximum area that can be associated with the 490 holdings with grouse butts present is just over 1 million hectares. Within this area the mix of land cover/use is dominated by rough grazing – with 857,000 ha or 84% of the whole holding area. If, however, a narrower definition of the area associated with the driven grouse moor enterprises is used then the area is much reduced (e.g. to 202,000 hectares for the Simple 500 definition).

[19] 2015 was most recent date of IACS data available to the research team when the analysis was undertaken. For a small number of holdings IACS data from earlier years was used when none was available in 2015. In an even smaller number of cases the land cover/use for a holding was interpreted from aerial photography.

Part A also shows that for the population of holdings there are limited areas of other land uses present – improved pastures (~71,000 ha), woodlands (~30,000 ha) and cropping (~8,000 ha). Part B shows that these other land cover/use types are, on average, small portions of holdings (improved pastures 7%, woodland 3% and cropland 1%)[20]. These are negligible or near negligible for Scotland as a whole, 5% of grasslands, 3% of woodlands, 1% of cropping, (Scottish Government, 2016a). The other land uses class accounts for inland water, rock/scree, buildings and areas within the dataset for which land use data was not available[21].

Table 3: Land cover/use mix using buffered convex-hulls, inclusive set of holdings (490) – land use areas (A), as percentages of the buffer areas (B) and as percentages of the whole holding area (C)

A	Area (000's ha)	Rough Grazing	Woodland	Crops	Temp Grass	Perm Grass	Other Land Uses	All Land Uses
	Whole Holding	857	30	8	8	63	58	1,023
	Convex 2000	610	13	2	3	35	21	685
	Convex 1500	553	11	2	2	27	16	611
	Convex 1000	468	9	1	1	17	12	508
	Convex 500	350	6			9	7	373

B	% of the Buffer	Rough Grazing	Woodland	Crops	Temp Grass	Perm Grass	Other Land Uses
	Whole Holding	84%	3%	1%	1%	6%	6%
	Convex 2000	89%	2%	0%	0%	5%	3%
	Convex 1500	90%	2%	0%	0%	4%	3%
	Convex 1000	92%	2%	0%	0%	3%	2%
	Convex 500	94%	2%	0%	0%	2%	2%

C	% of the Holding	Rough Grazing	Woodland	Crops	Temp Grass	Perm Grass	Other Land Uses	All Land Uses
	Whole Holding	84%	3%	1%	1%	6%	6%	100%
	Convex 2000	60%	1%	0%	0%	3%	2%	67%
	Convex 1500	54%	1%	0%	0%	3%	2%	60%
	Convex 1000	46%	1%	0%	0%	2%	1%	50%
	Convex 500	34%	1%	0%	0%	1%	1%	36%

The importance of the buffer analysis is emphasised by the reductions in the areas of rough grazing, associated with driven grouse management, by requiring the land to be within a defined distance of the grouse butts themselves. As the restriction is increased (by reducing the buffer distance) the area of rough grazing is cut for both simple and convex-hull based analyses. Using a 2,000m buffer the area is cut to 584,000 ha for the simple buffer or 610,000 ha for the convex hull buffer. For a 500m buffer the area associated with driven grouse moors drops to 194,000 and 350,000 ha

[20] Of course, as was shown in the Phase 1 Report holdings with grouse butts present can have a wide variation in the relative proportions of land cover/use types.

[21] A feature of the 2015 IACS dataset was that in some cases the land use was not recorded if the land was rented out to a business that did not itself submit an IACS single application form. Most of this rented area will be rough grazing. Some areas that are clearly moorland were recorded as exclusions rather than rough grazing reflecting preferences of the holding owner in their interactions with the Scottish Government payments systems. Further refinement of the land cover/use analysis is therefore possible, but the core of the analysis provides an adequate basis from which conclusion may be drawn.

respectively. As the buffer distance is reduced the percentage of rough grazing rises from 84% for the whole holding to 96% for simple buffers or 94% for convex hull buffers (using 500m distances) – Part B of the tables.

Part C of the two tables highlights how much of the holdings' rough grazing area may be being devoted to driven grouse. Again, the contrast is between the whole holding at 84% and 19% for the simple buffers at 500m or 34% for the convex hull buffer at 500m. These smallest percentages, from the 500m buffers, however, exclude a substantial area that is being strip burned. The implications of using alternative buffer distances are discussed further in Section 8.8.

The analysis highlights the importance of moving beyond land cover/use alone as a basis for defining the extent of driven grouse moors. The use of the buffered grouse butt locations potentially provides a better way to estimate the areas of rough grazing associated with driven grouse management, but uncertainty remains in interpreting which of the buffering approaches and distance is more appropriate[22]. Depending on the definitions adopted, the rough grazed area associated with driven grouse management is between 610,000 hectares (Convex 2000) and 193,000 hectares (Simple 500).

Having presented the area and land use mix of the Simple and Convex-hull buffers it is now possible to use these within analyses of the of the intensity of management for the holdings with grouse butts present.

4.5 Intensity of management

Two aspects of intensity of management were analysed within this project, the percentage of rough grazing land strip burned, and the density of grouse butts present in the rough grazed areas of holdings.

4.5.1 Intensity of burning

A high-level summary of the overall intensity of burning associated with driven grouse moors is provided in Table 4. This calculates an overall percentage burned from the rough grazing area and the burned and assumed burned areas.

Table 4: Summary of intensity of burning depending on the area of rough grazing and burning included

	Area (000's ha)		
	Rough Grazing	**Burned & Assumed**	**Overall % Burned**
Whole Holding	857	163	19%
Simple 2000	584	152	26%
Simple 1500	510	145	28%
Simple 1000	388	124	32%
Simple 500	194	73	38%
Convex 2000	610	154	25%
Convex 1500	553	148	27%
Convex 1000	468	163	35%
Convex 500	350	114	33%

If the whole area of rough grazed land present in the holdings is used, then the strip burned percentage is 19%. When the buffered grouse butt locations are used to limit the rough-grazing land

[22] It is highly likely that the most appropriate buffering approach and distance will be a unique combination for each holding so any estimation across the population with a single method will have remaining uncertainty.

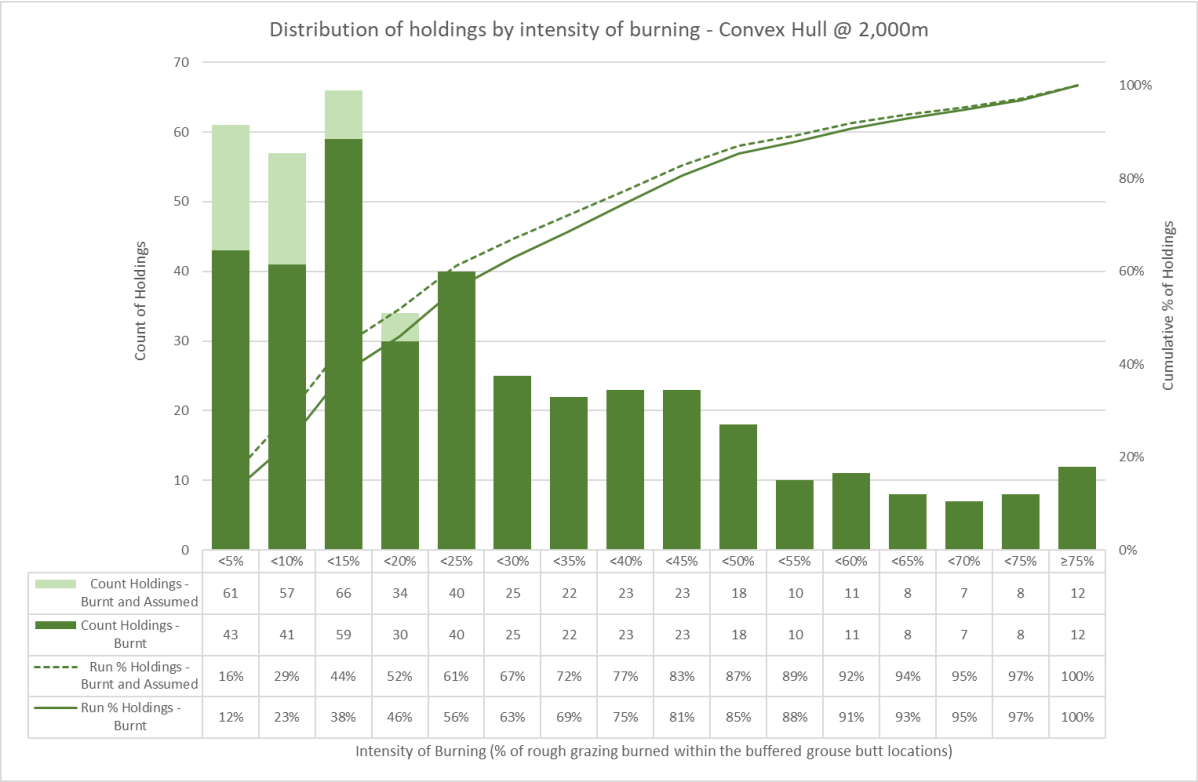
considered part of the active driven grouse moor then both the rough grazing area and the burned and assumed burned are constrained. The rough grazing area is constrained more and thus the overall percentage is higher when the buffered areas are considered. Even with the least restrictive (largest) buffers the burned percentage increases to 25% or more and the burned percentage is highest at 38% for the smallest simple buffered 500m case. The overall implication is that areas closer to grouse butts are being burned more intensively and that any estimation of intensity needs to be explicit on the assumptions on which areas of rough grazing within holdings are being considered.

These overall percentages of burning, of course hide a very wide range of intensities that occur in the population of holdings, so this is quantified in the next section.

4.5.2 Distribution of burning percentages per holding

Taking a holding-oriented view of rates of burning provides a way to look in more detail at the differences in intensity of management being practiced. Given the results in the previous section it is undesirable to use all the rough grazing areas within holdings as a basis for estimating percentage burned. While any of the buffer options could be used to make a holding level estimation only one is presented here, the 2,000m convex hull. This was chosen as it retains the largest area of burned and assumed burned land, while still eliminating a substantial area of rough grazing less likely to be associated with the driven grouse enterprise. Using the 2,000m convex hull means using an inclusive definition of the driven grouse moor area. This can thus be interpreted as a more realistic analysis than one based on all rough grazing areas alone. The distribution of holding level intensities presented in the charts below can thus be interpreted as floor values, i.e. while it is possible the burn intensity values are higher, they are unlikely to be lower.

Figure 7 shows the counts of holdings for a set of burning intensity classes (defined as the percentage of rough grazing within the grouse butt location buffer burned – in 5% intervals).

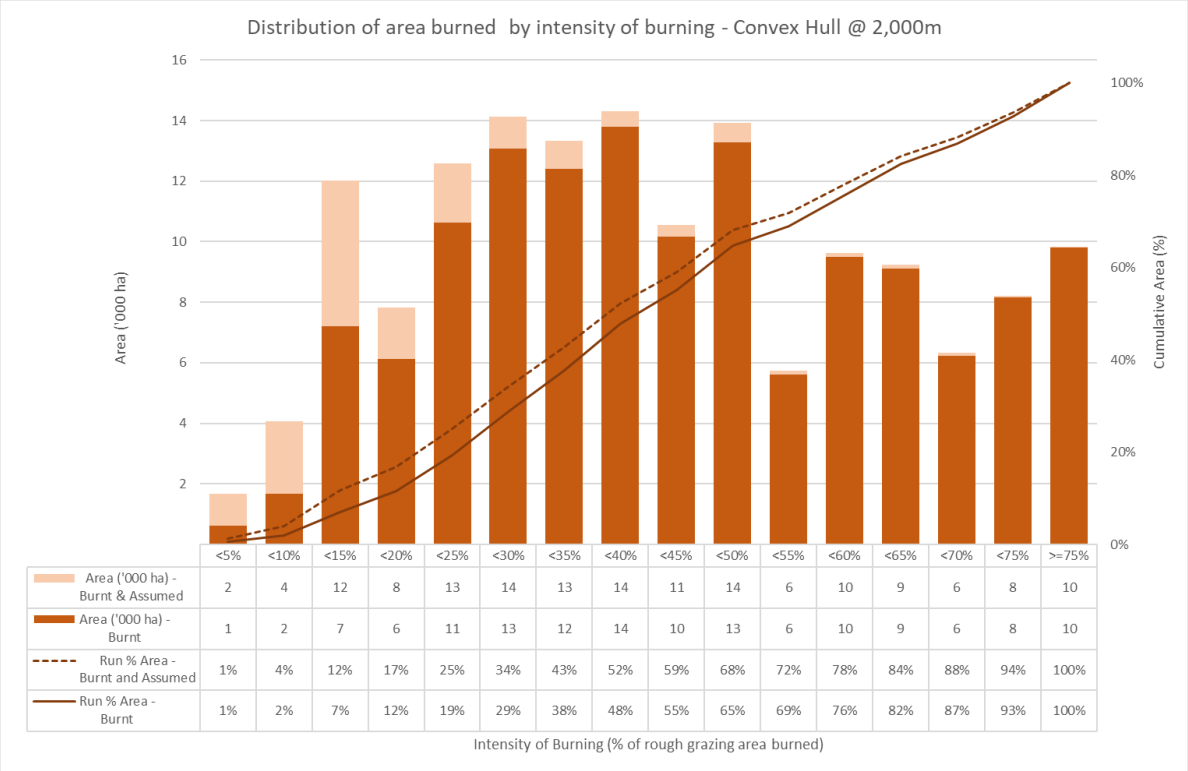


	<5%	<10%	<15%	<20%	<25%	<30%	<35%	<40%	<45%	<50%	<55%	<60%	<65%	<70%	<75%	≥75%
Count Holdings - Burnt and Assumed	61	57	66	34	40	25	22	23	23	18	10	11	8	7	8	12
Count Holdings - Burnt	43	41	59	30	40	25	22	23	23	18	10	11	8	7	8	12
Run % Holdings - Burnt and Assumed	16%	29%	44%	52%	61%	67%	72%	77%	83%	87%	89%	92%	94%	95%	97%	100%
Run % Holdings - Burnt	12%	23%	38%	46%	56%	63%	69%	75%	81%	85%	88%	91%	93%	95%	97%	100%

Figure 7: Numbers of holdings per intensity of burning class

The counts of holdings with burning confirmed in 2018 and those with both confirmed and assumed are presented as are cumulative percentages of the holding population. The figure highlights that there is a wide range of burn intensities across holdings engaged in driven grouse reflecting the different proprietor priorities and enterprise mixes. The distribution is biased towards lower intensities which may suggest that some of the holdings are largely inactive in terms of driven grouse. In interpreting the distribution, it should be borne in mind that even low percentages of very large holdings could be significant (10% of the largest holding would be ~2,000 ha). In this regard knowing the factors that influence the minimum area needed for a viable driven grouse moor would be valuable in refining the population of holdings being used. The higher burn intensity holdings, those above 50% burned, make up 11% of the population and have burning intensity values more than twice, and up to four times, the median burn percentage of 19%.

Figure 8 uses the same classification of holdings but presents the total area of strip burned areas within the 2,000m buffer for each burn intensity class.



	<5%	<10%	<15%	<20%	<25%	<30%	<35%	<40%	<45%	<50%	<55%	<60%	<65%	<70%	<75%	>=75%
Area ('000 ha) - Burnt & Assumed	2	4	12	8	13	14	13	14	11	14	6	10	9	6	8	10
Area ('000 ha) - Burnt	1	2	7	6	11	13	12	14	10	13	6	10	9	6	8	10
Run % Area - Burnt and Assumed	1%	4%	12%	17%	25%	34%	43%	52%	59%	68%	72%	78%	84%	88%	94%	100%
Run % Area - Burnt	1%	2%	7%	12%	19%	29%	38%	48%	55%	65%	69%	76%	82%	87%	93%	100%

Figure 8: Area burned per intensity of burning class

Comparing Figure 7 and Figure 8 highlights that there are numerous holdings with grouse butts present that had low intensity of burning; 218 holdings (51% of the population) have <20% of the rough grazing in the buffer burned. The area burned by these holdings was also relatively small at ~25,000 ha or ~17% of the total burned area within the buffer. This equates to ~117 ha per holding. Conversely the top four intensity classes, with >60% burned have ~34,000 ha or 22% of the burned area on 35 holdings, for an average per holding burned area of ~960 ha. Were there the need to monitor for any negative outcomes of higher intensity strip burning, then the analysis presented here provides a quantified first basis for prioritising and directing the effort.

Having elaborated the analysis of the percentage of burning per holding it is possible to take a similar approach to another potential indicator of intensity of management – the density of grouse butts.

4.5.3 Density of grouse butts

In the Phase 1 analysis estimates were made of intensity using the entire rough grazing area per holding, while noting that using such a denominator may not always be appropriate. Using the new values from the buffered grouse butt locations analysis in this research it was possible to generate a range of more nuanced butt density values.

Table 5 presents a summary of the estimated grouse butt density using the range of buffers to determine the relevant area of rough grazing. The density is expressed as grouse butts per square kilometre. As with intensity of burning, Table 5 highlights that the decisions on which areas of rough grazing are included have profound effects on the grouse butt density values generated. Using the entire holding areas means much lower values for the lowest butt density areas (the 10% percentile in Table 5). The difference between the buffering methods was less substantial except for the smallest buffer distance (500m) and for median and lower densities. Table 5 also emphasises that there are great differences between the density of grouse butts within the population of holdings, again reflecting differences in management of grouse shooting. The difference in grouse butt density between the 10% and 90% is between two- and seven-fold.

Table 5: Summary of butt density estimates (ha per grouse butt) using a range of rough grazing area estimation methods

Density of grouse butts (butts per 1km^2)	Percentile 90%	75%	50% (median)	25%	10%
Whole Holding	8.0	5.3	3.2	1.6	0.7
Simple 2000	8.3	5.8	3.6	2.0	1.2
Simple 1500	8.6	6.1	4.0	2.5	1.5
Simple 1000	9.8	7.2	5.3	3.7	2.6
Simple 500	16.0	13.4	11.0	8.9	6.9
Convex 2000	8.2	5.8	3.6	2.0	1.2
Convex 1500	8.6	6.0	4.0	2.4	1.5
Convex 1000	9.5	6.8	4.9	3.3	2.4
Convex 500	14.3	10.9	8.2	5.9	4.2

4.5.4 Distribution of grouse butt density per holding

As with the intensity of burning analysis it is also possible to look in more detail at the distribution of grouse butt densities using the holding level data. For comparability with the burning percentage analysis, the same grouse butt buffering option is used, the convex hull buffered at 2,000m. Two charts for the distribution of grouse butt density have been generated, Figure 9 for the counts of holdings and Figure 10 for the rough grazing areas associated with these holdings.

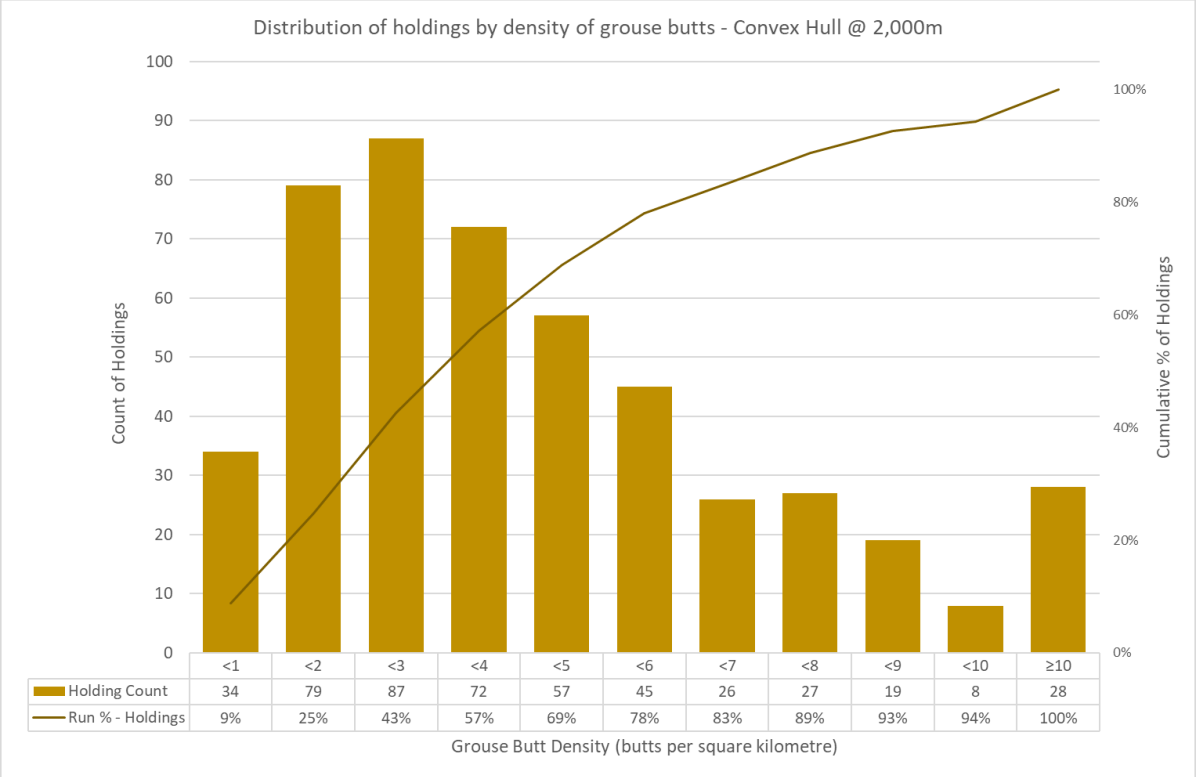


Figure 9: The count of holdings by the density of grouse butts (Convex 2000)

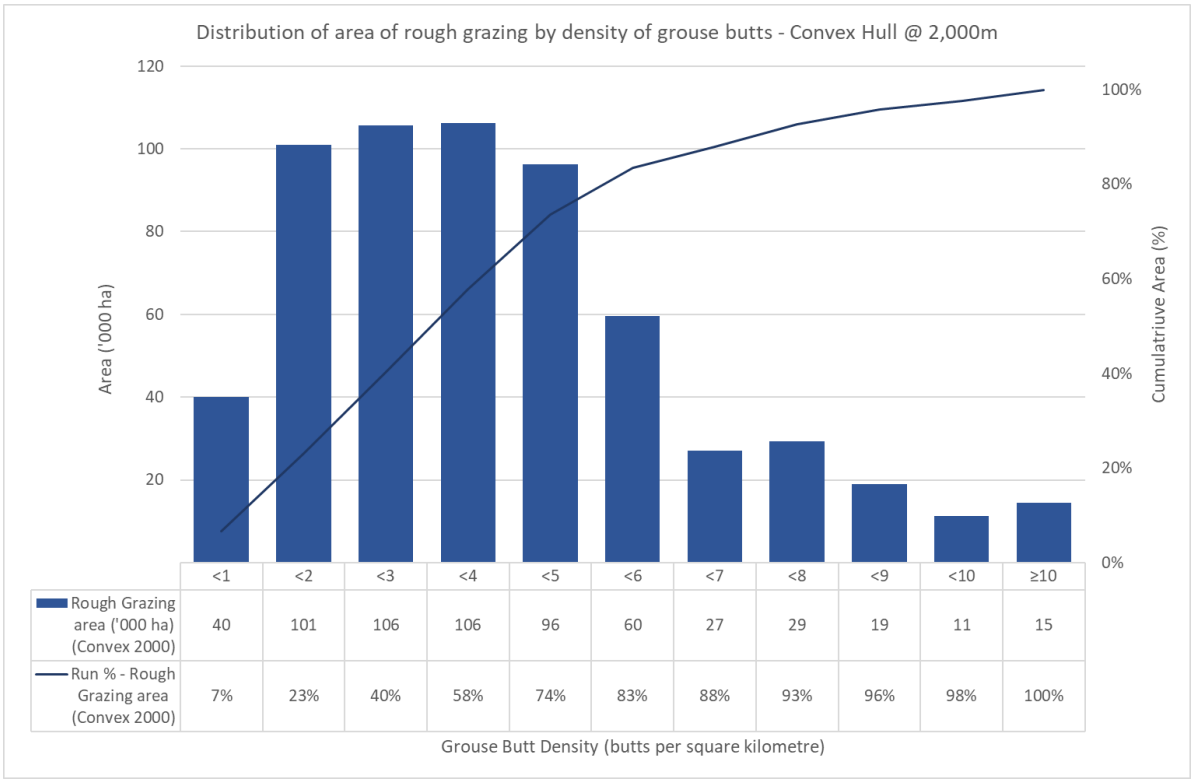


Figure 10: The area of rough grazing in buffer (Convex 2000) by density of grouse butts

As with burning, the grouse butt density values have a wide range of average values from less than one per square kilometre to over 10 per square kilometre (and in rare cases considerably higher). The range of densities reflect the wide variety of ways in which driven grouse shooting can take

place. There is a bias in the distribution towards lower grouse butt densities but there are 28 holdings with grouse butt densities over 10 per square kilometre and these are managing ~15,000 ha of land. Where there are concerns that environmental harm is associated with holdings that have higher densities of grouse butts, then Figure 10 would imply that the issue has a point source rather than a diffuse character, with a few higher intensity locations the likely priority for any monitoring.

The threshold above which the density of grouse butts might be considered excessive, will depend on the circumstances in which it occurs and how the butts are used. It is likely that there can be a range of management practices and environmental outcomes associated with holdings having broadly the same density of grouse butts. Therefore, the utility of the analysis above would seem to be in highlighting cases where it might be prudent to work with holding owners to ensure that any potential negative impacts are avoided.

With the improved baseline data generated in this project, further investigation of the relationships between extent and intensity of grouse moor management and environmental outcomes at a macro level may be informative.

5. Interpretation of the Phase 2 outputs

5.1 Combining strip burning percentage and grouse butt density

In the Phase 1 analysis heat maps were used to provide an overall interpretation of the locations and intensity of driven grouse moor management. Heat maps summarise mapped data within a spatially defined window, in this case the combination of the percentage of rough grazing land burned and the number of grouse butts present within a 10km radius circle. Heat maps thus provide an alternative "landscape" perspective on the project data. This can complement the presentation of data using individual holdings or grid-based mapping and provides an accessible overall summary. This can be helpful in interpreting regional patterns, though with the caveat that the maps are sensitive to cartographic and other analytical choices.

The heat map is presented in Figure 1 within the Summary of this report (see page 2 above). The heat map is helpful in emphasising where there are concentrations of activity within Scotland in this case highlighting the Cairngorms, Angus Glens and the Lammermuir Hills. The map can also be interpreted as showing the degree of certainty that an area had driven grouse moor management present, with the lower intensity areas potentially no longer being actively managed for driven grouse. The heat map in Figure 1 is consistent with those generated within the first Phase of analysis differing only in detail. This means that the updating of burning data to 2018 and the refining of the grouse butt data set has increased the robustness of the analysis and reaffirmed the earlier conclusions.

5.2 How should the driven grouse moor area be defined?

Defining the area and significance of land managed for driven grouse is an important part of debates for or against policy interventions by government. This section reflects on the differences in estimates of driven grouse area and concludes that they are an outcome of issue framing. That is, the area included in driven grouse moors is neither self-evident, nor agreed, and therefore depends on adopting shared definitions, choices, and assumptions.

For example, including all rough grazing (or even all land) in holdings with grouse butts and burning present may be legitimate, as all the land in a holding could potentially be influenced by the management regime needed to support a driven grouse enterprise. Yet there can be areas in holdings very remote from the locations of grouse butts, or in parcels of land that are entirely separated from those where grouse butts are present, and these should in our view be excluded from the driven grouse moor area.

A narrower definition of driven grouse moors could include only those areas subjected to burning. Yet even here, there is a practical and conceptual problem for defining areas of driven grouse moorland. Practically, imagery can allow interpretation only of the area that has been visibly burned not the area that has fully regenerated or may be burned in the future. Conceptually this is significant as the area of driven grouse moor is not only the visibly burned patches themselves, but also the mosaic of moorland vegetation within which the burned patches sit. This still means the need to decide how much of the yet unburned moorland vegetation should be associated with the practice of driven grouse moor management, using approaches such as the buffering of grouse butt locations.

Using new methods this analysis has provided a range of updated estimates on the amount of land managed for driven grouse in Scotland. Given the potential for widely differing definitions of the area of driven grouse moors, the analysis has created a framework within which these definitions can be tested, compared, and reconciled in deliberation between stakeholders

5.3 Reconfirming the conclusions of the Phase 1 analysis

The analysis in this second Phase reconfirms the findings of Phase 1 as the population and extents while refined have not been fundamentally changed. Specifically, the analysis reconfirms the following:

1. Driven grouse enterprises occur at a wide range of scales (two orders of magnitude for area). The enterprise occurs in holdings where there are no other land-based enterprises apparent and as part of highly diversified holdings with a wide range of land-based enterprises. The grouse moor can be dominant in area terms or near insignificant. This makes any generalisation about driven grouse moor enterprises or any *ex ante* policy impact assessment challenging.
2. Intensity of management (burning and grouse butt density) is highly variable and appears to depend more on the proprietors' preferences and resources than on any biophysical characteristics (intensity differences between neighbouring holdings can be substantial). The regions where aggregate intensity is higher could be prioritised if there were to be monitoring of any benefits or negative impacts.

The variation in extent and intensity of management is summarised graphically in Figure 11.

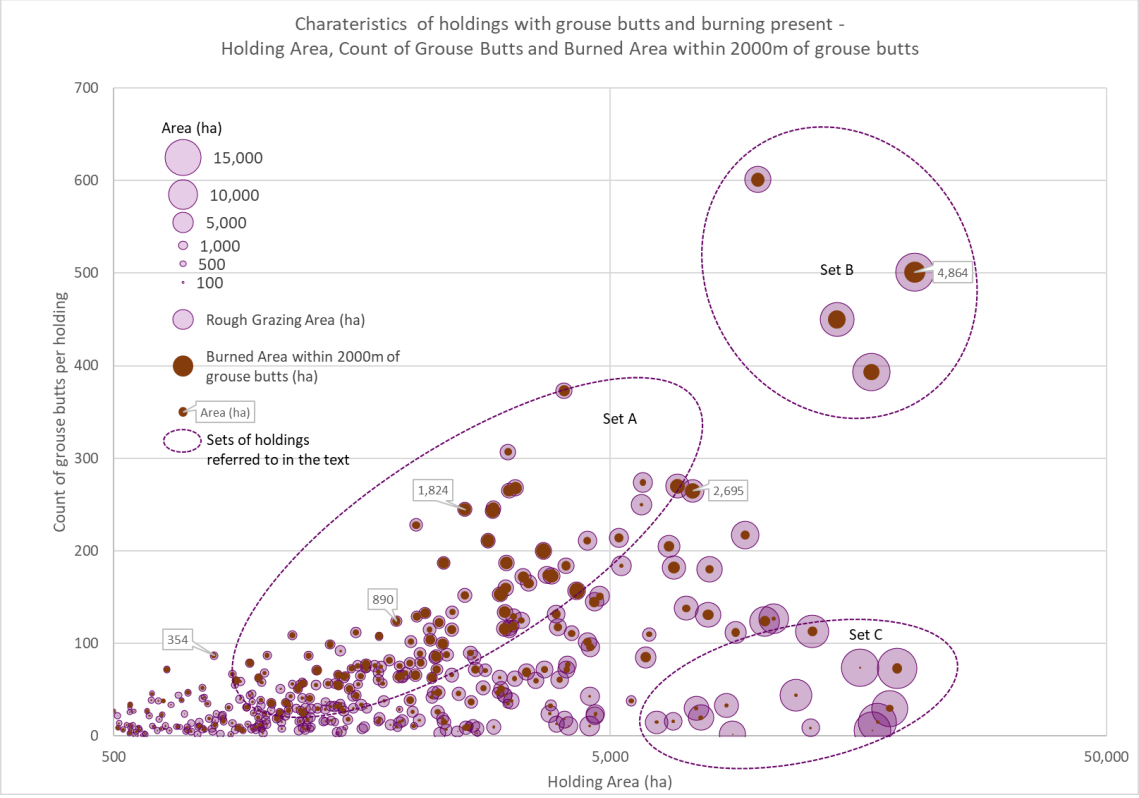


Figure 11: Graphical summary of the characteristics of holdings with grouse butts present.

In the figure each circle is a holding. The location of the holding in the figure is determined by the size of the holding (all land uses) on the x-axis[23]and the number of grouse butts present on rough grazing on the y-axis. Larger holdings are thus located to the right-hand side of the graph and holdings with more grouse butts present towards the top. Note that for any size of holding there are a range of grouse butt numbers that occur and the larger the holding size the wider the range of

[23] Note the use of a log scale on the x-axis for clarity and the 500-ha minimum value for holding area.

grouse butt numbers. Given the maximum number of grouse butts is limited by the available area there is an upper limit to the numbers of grouse butts present (no combinations in the top left part of the graph). Below this limit there are more densely and more sparsely populated areas of the graph and some clustering. Since there are many more smaller holdings (but each is still >500 ha) the left-hand part of the graph is more densely populated.

The graph also provides insights for the holdings into both their rough grazing and burning areas[24]. This is done by using two sets of marker circles, with circle size set by two area measures. The first (in purple) is the total rough grazing area, the second is the burned area within 2000m of the grouse butt locations (in brown). Holdings where the burned area is equal to nearly the whole rough grazing area occur across the range of sizes and numbers of grouse butts but are more common towards the upper edge of the distribution, that is on holdings with larger numbers of grouse butts than is typical for their size (Set A in Figure 11). For the largest holdings the area of burning can be very extensive, and the butt numbers the highest present, but typically in these cases there are remaining rough grazing areas managed in a different way (Set B in Figure 11). By contrast for similar sized holdings there are examples with large areas of rough grazing and low numbers of butts for their size (Set C in Figure 11). Some of these also have low areas of burning and these can be presumed not to have any significant driven grouse enterprises. In other cases where larger scale burning is present with low grouse butt numbers it may be that limited driven grouse shooting is conducted, other forms of grouse shooting are preferred or that burning is conducted mainly for another purpose such as habitat restoration.

From the Phase 1 reporting it was demonstrated that, in biophysical terms, the areas used for driven grouse moors typically have very low potential for other conventional production-oriented land-based enterprises (agriculture or forestry). While there was some evidence that there are areas of land that have the biophysical potential for improvement these are limited in extent and costs of such improvements do not make them an investment that is likely to take place. Establishment of woodland via natural regeneration has potential in terms of habitat creation and possible net carbon storage. The potential in this regard needs to be carefully considered though since changes on higher carbon soils can partially or wholly offset the carbon stored in vegetation depending on the species, management regime and bio-climatic circumstances (Matthews et al., 2020 in press). The compatibility of such activities with driven grouse or other sporting use (e.g. deer stalking) requires more specific regional or business-based assessments.

5.4 Caveats to the analysis

While the analysis conducted has improved on the Phase 1 and earlier analyses there are still limitations on the analysis. Specifically, it was not possible to reinterpret all the potential areas in Scotland where burning could be occurring. Reinterpretation was prioritised in locations where burning was present in both of the previous burning studies by RSPB (Douglas et al., 2015) and James Hutton Institute (McLeod and Newey, 2018). For the areas present in only one of these studies another supplementary strip-burning analysis project was undertaken funded by the Scottish Government's Strategic Research Programme (SRP) 2016-22, starting in January 2020 and completed in March 2020. The outputs from this supplementary SRP analysis will be integrated with the data

[24] Note that while comparing the two areas is valid interpretation of intensity this tends to underestimate the intensity of burning located within the area closer to the grouse butts. The whole rough grazed area was used here to highlight when driven grouse moors are a dominant use of the rough grazed area and when they may be combined with others uses.

from this report. A supplement to this report will be issued later, and digital datasets supplied to Scottish Government.

5.5 Implications for monitoring and other policy making

The analyses within the project have improved the quality and timeliness of the data available on the extent of driven grouse moors and the intensity of management being practiced, but how these data are interpreted will depend on the perspective(s) of the interpreter(s). Definitions that minimise the overall extent and intensity of management could be interpreted as meaning that any negative impact is small and there is no need for monitoring or regulation. On the other hand, definitions that maximise the size and highlight hotspots of intensive management could be interpreted as implying extensive pressures and locally strongly negative outcomes, hence the need to monitor and regulate. As it stands the analysis to date does not provide a way to resolve the differences, but it does provide a framework within which deliberations could take place.

Supporting such a process means the need to further refine how data are combined on ownership/usership (property boundaries), land cover/use (rough grazing), the presence of grouse butts and the presence of burning. A variety of options are available for how these component datasets could be combined but a more in-depth exploration of these options was beyond the scope of this project. Ideally the analysis would be supplemented by data on actual management practices from the holdings themselves or from stakeholder associations. Even if this data were not available for all holdings, it would be useful to start to test the robustness of the definitions used within the analysis.

6. Further analysis options

This section summarises the further analysis options, as identified in earlier sections, and classifies them in terms of priority. The section also notes, for each option, their likely resource implications and how risky they are (from known solution simply needing implementation to cases where new data or methods are required). Where appropriate the section also indicates possible sources of funding differentiating between improvements that have a mainly scientific basis and those that have a more stakeholder or policy-led character. Note also that there remain a range of options for enhanced analysis as set out in the Phase 1 analysis – Section 5, (Matthews et al., 2018).

To move beyond these incremental improvements would rely on gaining access to privately held data on land management practices. This could be gained through cooperation with stakeholder and industry associations and/or by augmenting existing Scottish Government data gathering processes such as the June Census/December Survey or the Single Application Form.

Table 6: Options for further analysis

Option	Notes	Priority	Resources	Risk	Funding
Analysing the assumed burned area	Adding 2,251 1km cells[25]	☑☑☑☑[26]	☑☑	☑	SRP-UC[27]
Analysing the assumed no burn area	Adding 6,418 1km cells[28]	☑☑☑	☑☑	☑	SRP-UC
Improving the ceased burning before data	Only where earlier imagery exists in GetMapping™[29]	☑	☑☑☑	☑	-
Improve how percentage burn estimates are made	Investigate statistical methods to limit over and underestimation of burned percentage	☑☑	☑	☑☑☑	SRP
Characterise the landscape driven grouse moors influences	Spatial analysis of the land use mix bordering driven grouse moors	☑	☑	☑	-
Interpreting the integrated grouse moor dataset with policy and other stakeholders	Scottish Government – *ex ante* policy analysis	☑☑☑☑	☑☑	☑	SRP-UC
	Agencies – interpreting the Phase 2 data by linking it with other data[30]	☑☑☑	☑☑	☑	SRP-UC
	Industry and eNGO's - enhancing the data with region or holding specific knowledge[31]	☑☑☑	☑☑	☑	-

[25] The image interpretation was completed in March 2020 and analysis was ongoing, April 2020.
[26] It may be valuable to repeat the biodiversity impacts analysis (Task 4 of this project) with the larger area.
[27] SRP is the strategic research programme of Scottish Government (2016-22) and UC is underpinning capacity
[28] Where no burning is present the image analysis can be undertaken much faster.
[29] If data from other sources were to be considered the resource requirements and risk would increase.
[30] Potential instances include suggestions by SNH of linking the analysis with habitat and habitat condition mapping.
[31] This analysis would refine the numbers of holdings undertaking driven grouse moor management, assess the other purposes for burning e.g. wildlife management and generate heuristics for the minimum areas and intensities needed to support driven grouse enterprise. Where industry or eNGO data can be shared then the robustness of the research-based analysis can be assessed.

7. Maps

7.1 Geographical references

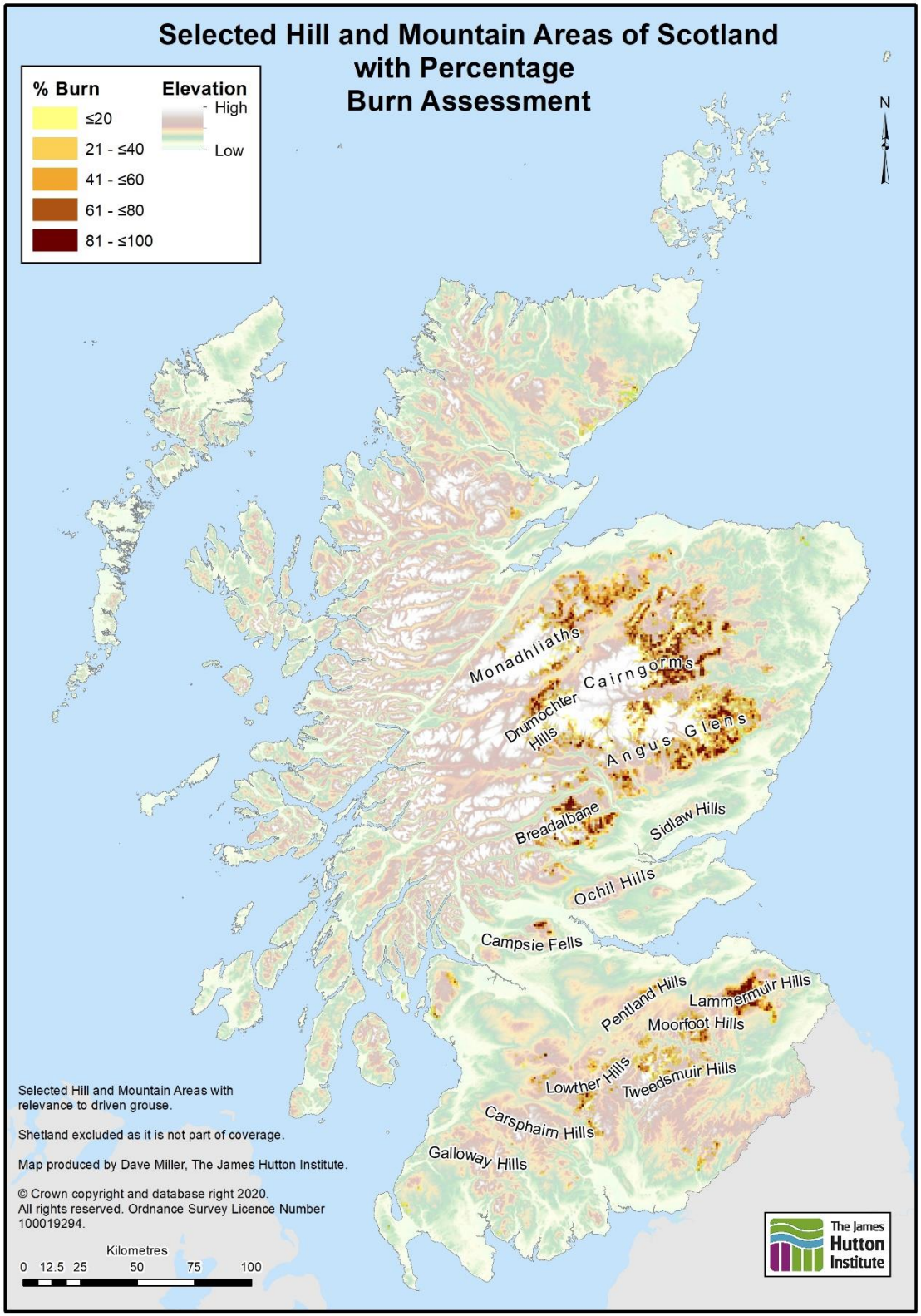


Figure 12: Geographical references used within the report – with topography and the 2018 percentage burned assessment.

7.2 Areas reinterpreted for extent of strip burning

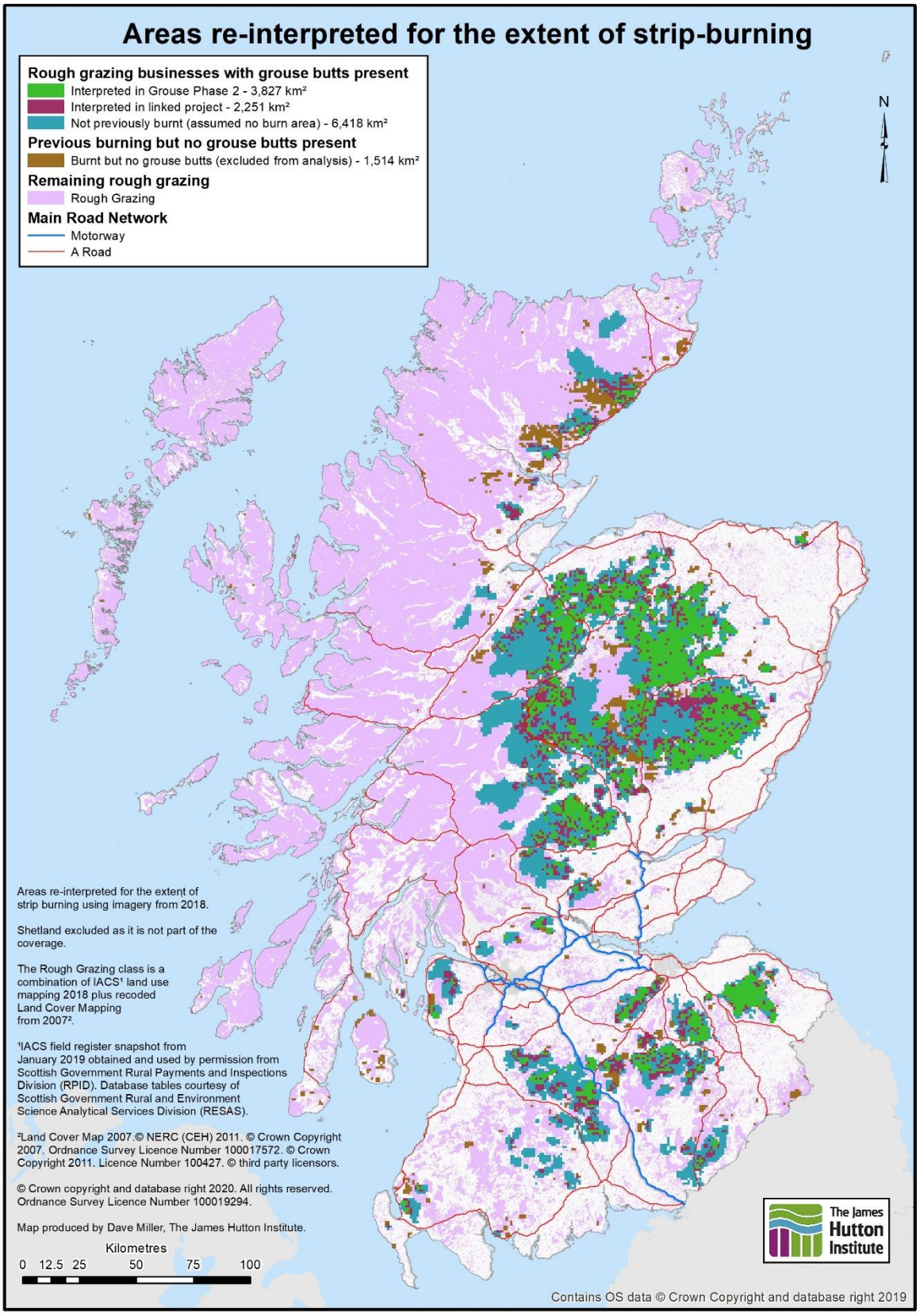


Figure 13: Map of the areas of land re-interpreted for the extent of strip burning

7.3 Percentage of rough grazing land burnt

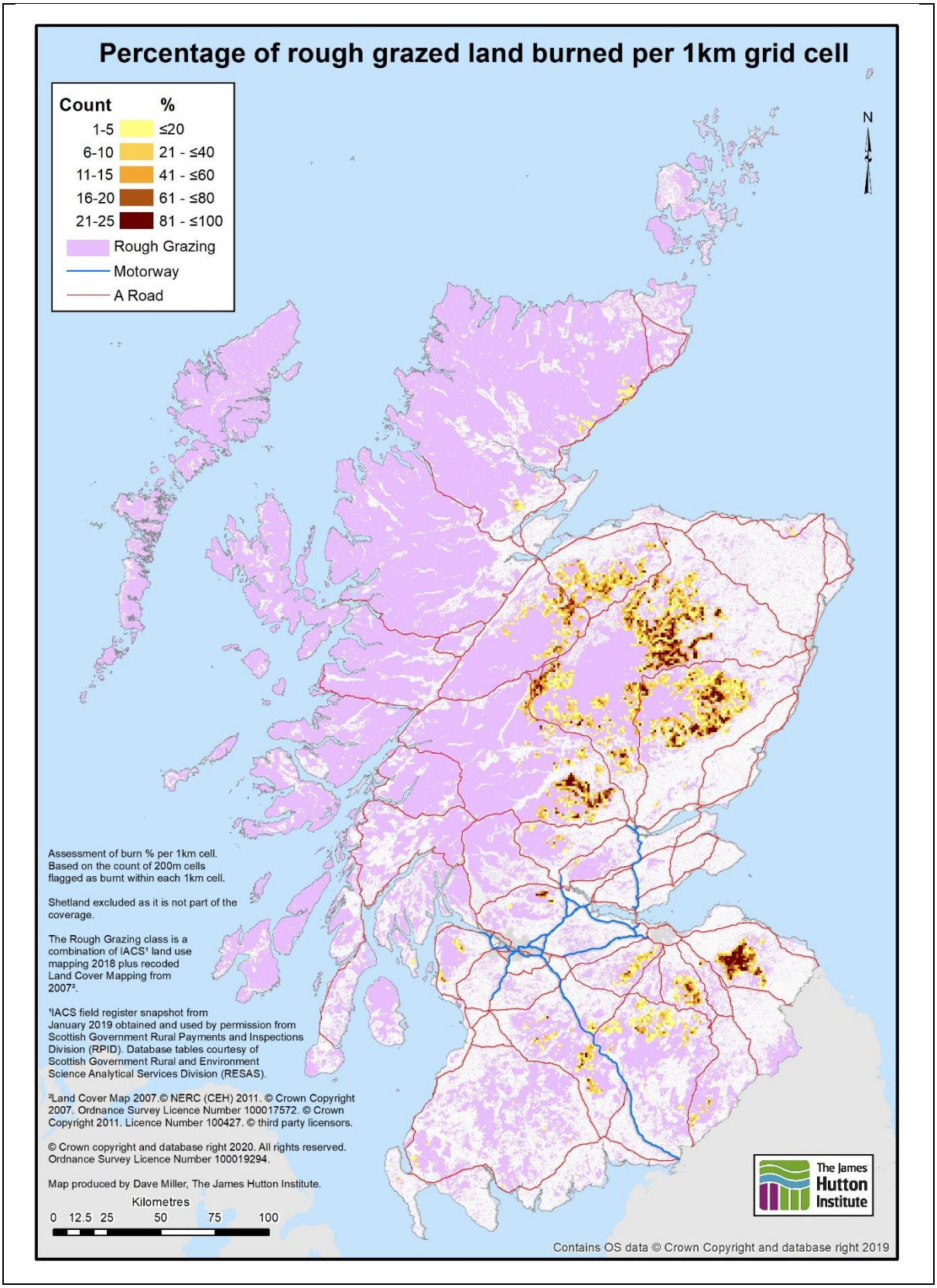


Figure 14: Map of percentage of rough grazing land burned per 1km map grid cell

See Section 8.6 for notes on the issues associated with interpreting this map.

7.4 Burned since dates

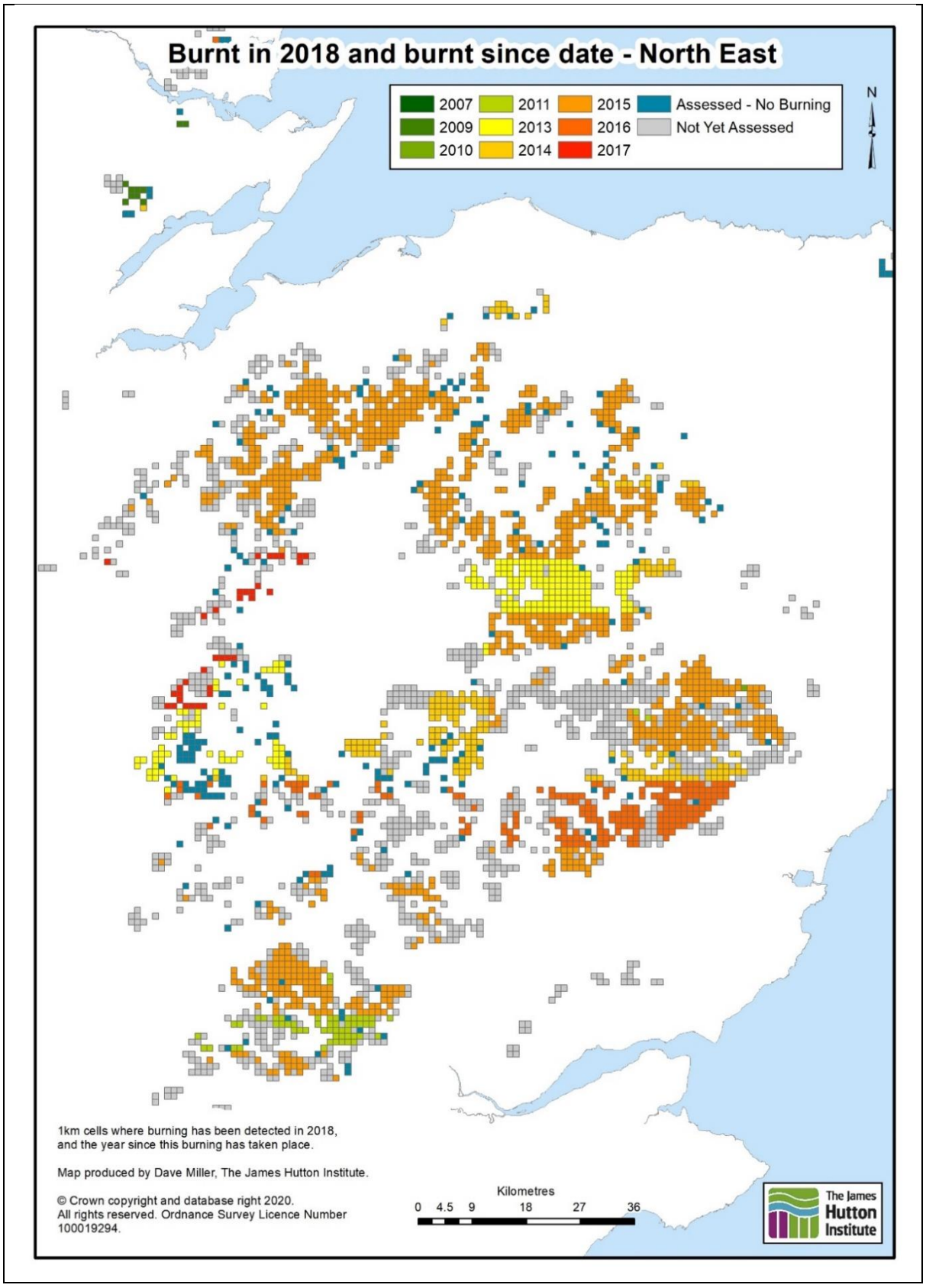


Figure 15: Map of burnt in 2018 and burned since date – North East

Note the map does not show when burning occurred but the date of earlier aerial photography after which burning could be seen in the 2018 aerial photography of satellite imagery.

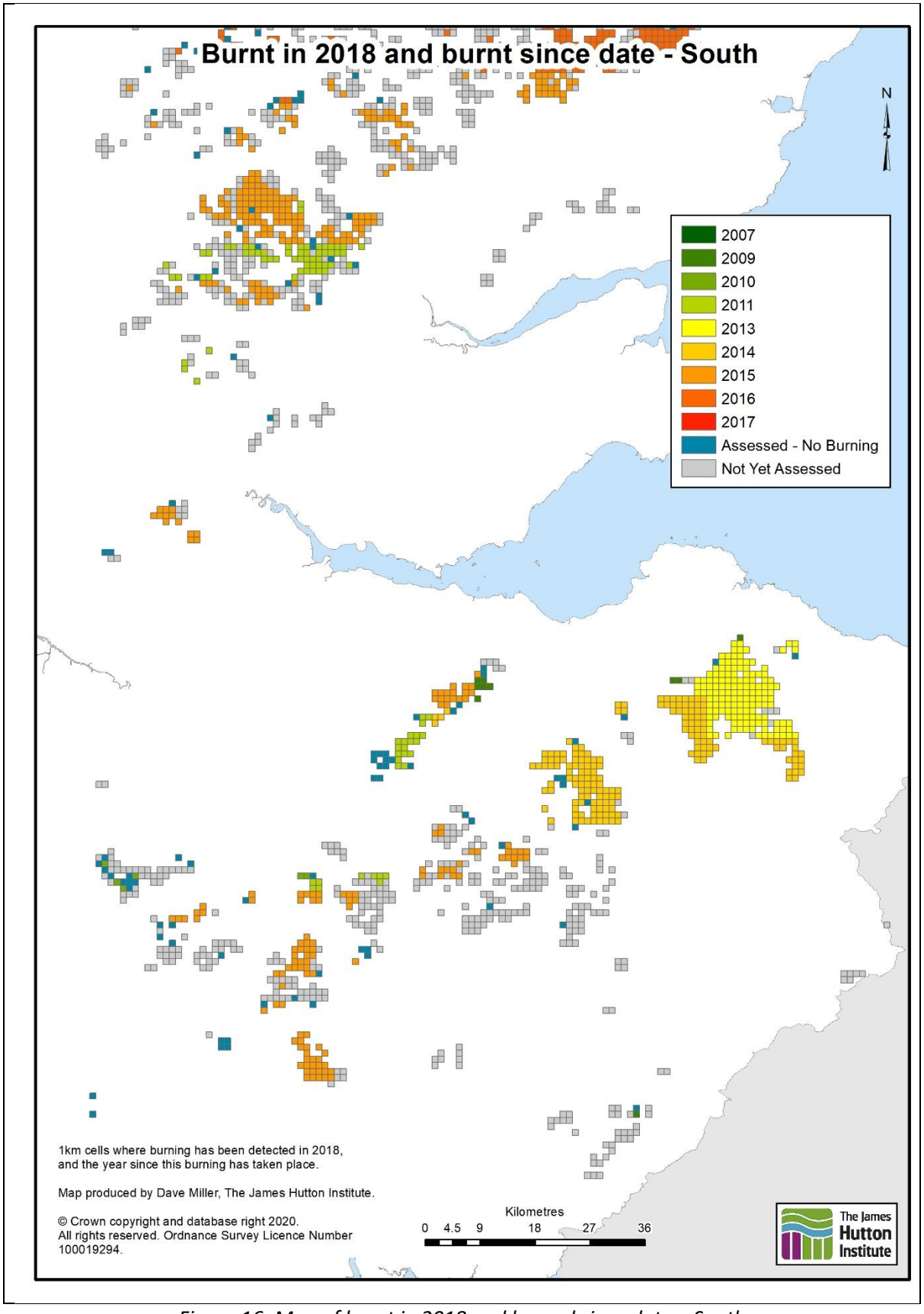


Figure 16: Map of burnt in 2018 and burned since date – South

7.5 "Ceased" burning before dates

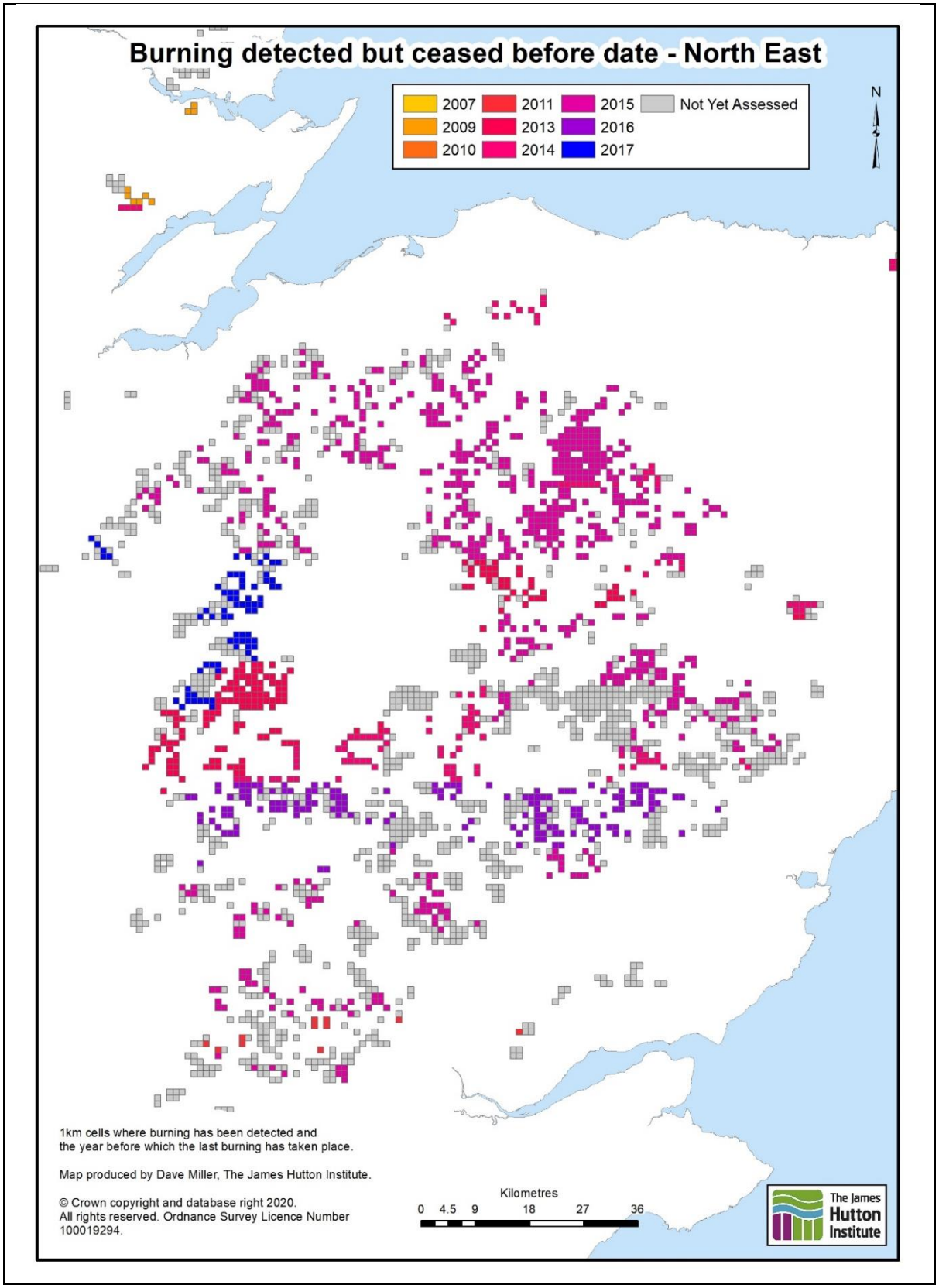


Figure 17: Map of burning detected but ceased before date – North East

Note the map cannot show when burning ceased just that there has been no burning visible in 2018 since the date of the earlier aerial photography, see Section 8.4 for more detailed discussion.

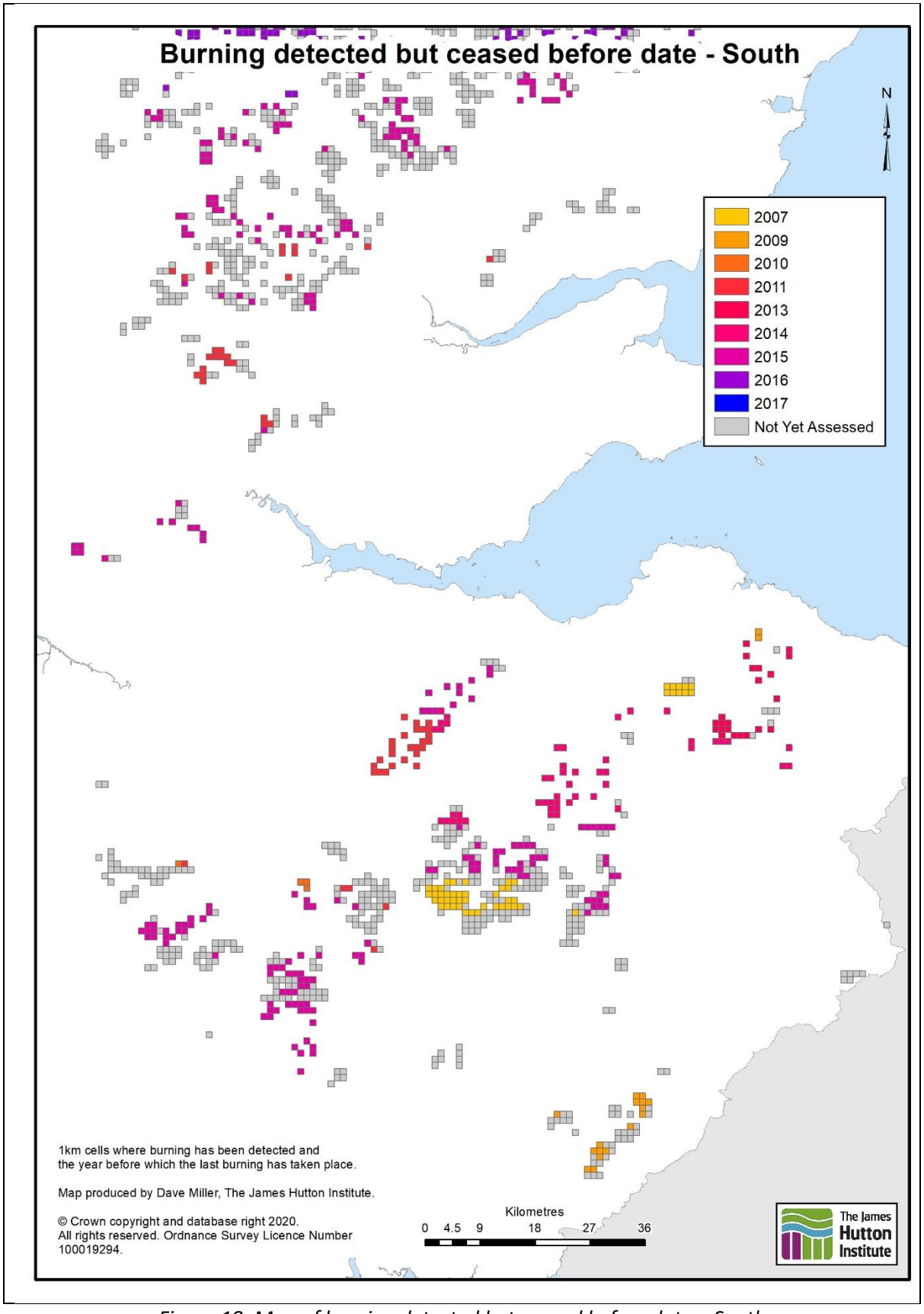


Figure 18: Map of burning detected but ceased before date – South

7.6 Change in burning intensity relative to previous RSPB assessment

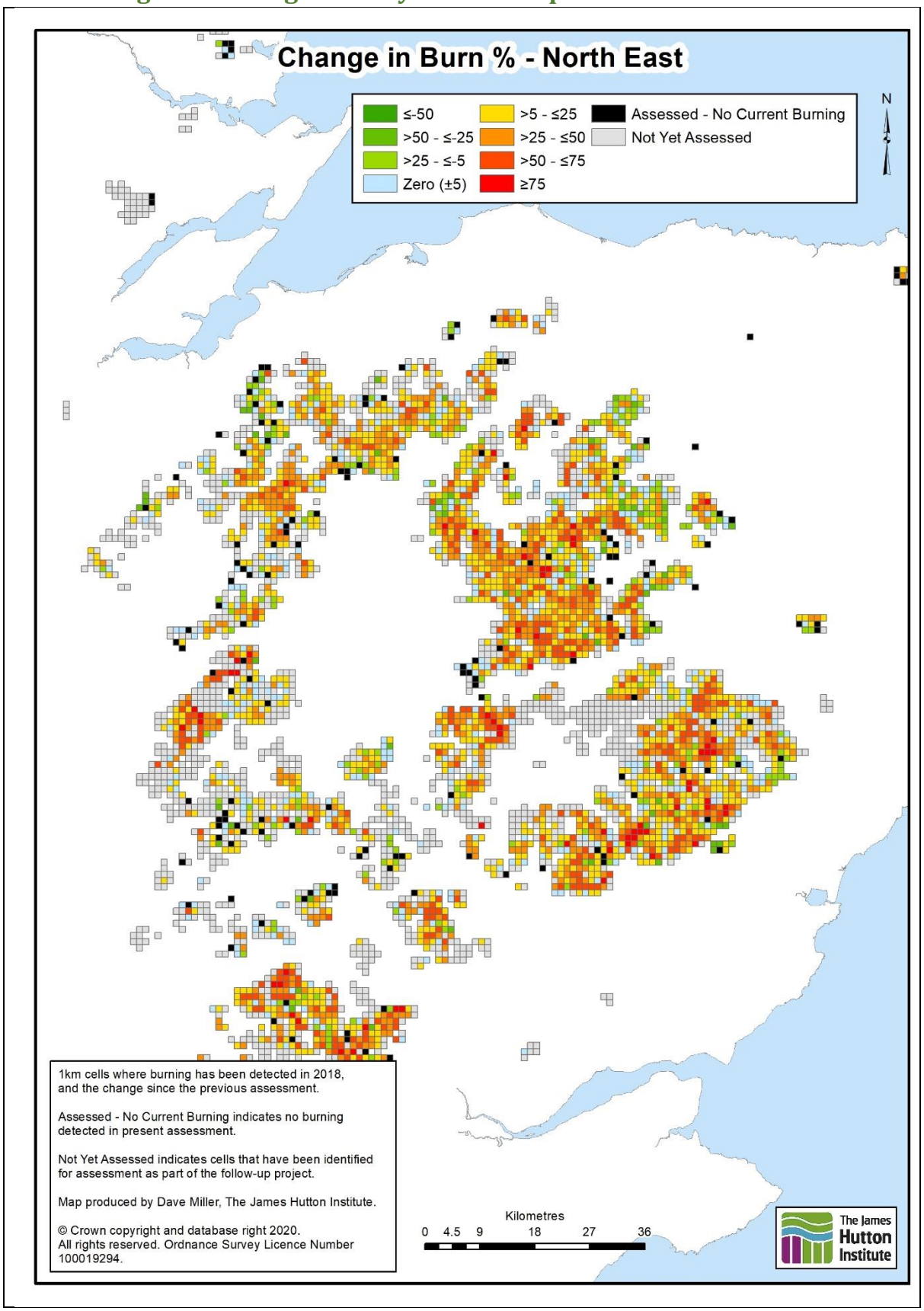


Figure 19: Map of change in burning intensity – North-East

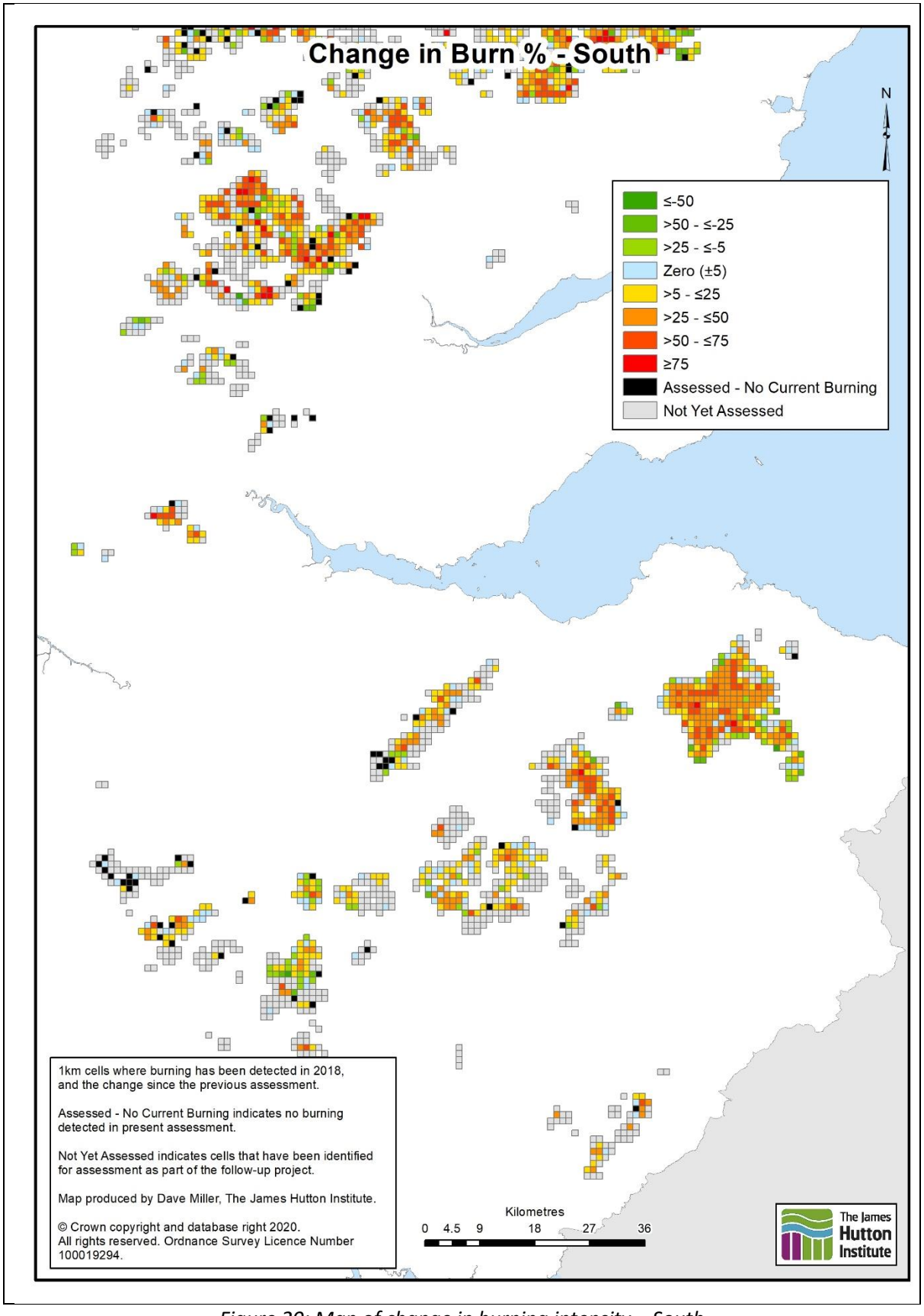


Figure 20: Map of change in burning intensity – South

8. Technical description of data and methods

This section provides a more in-depth discussion on key aspects of the methods used in the analyses. It is included to record the detail needed were the analysis to be repeated or build on later.

8.1 Holdings and land use data

The management units used in the analysis are holdings as defined in the June Agricultural Census. Holdings were preferred over businesses (as defined in the Integrated Administration and Control System – IACS) as this meant that if only one holding in a multi-holding business had grouse butts present then then area of rough grazing in other holdings did not need to be considered. The land parcels to holding relationship and the boundaries of each land parcel are provided from IACS, the latter from the Land Parcel Identification System. The land use and land usership data from IACS was for May 2015, the most recent data available to the team. It is worth noting that there can be complex combinations of ownership, tenure and use rights in play on areas of land and the holdings-based approach is a simplification, albeit one necessary to make the analysis tenable.

8.2 Previous strip burning data

The two existing sources of strip burning data both had limitations. RSPB (Douglas et al., 2015) mapped intensity of burning but the most recent data was 2010 and some data was older, as far back as 2004. The mapping by McLeod and Newey (McLeod and Newey, 2018) was more recent using imagery from between 2008 and 2017[32], covered all of Scotland, but recorded presence or absence of burning rather than percentage. In neither case was it possible to be certain of the date after which visible burning had taken place, since the RSPB analysis did not compare the imagery being used for interpretation with earlier imagery and the McLeod and Newey analysis did not record the date after which visible burning had occurred.

In this project, the cap on budget meant it was not possible to reassess the burning present on all the rough grazing areas within the population of holdings. The analysis focused on those areas of land previously identified by both RSPB (Douglas et al., 2015) and Hutton researchers (McLeod and Newey, 2018). Further analysis beyond the scope of this report will focus exclusively on interpreting areas where there is evidence of increase or decrease in extent of burning as elaborated in the next Section (8.3).

8.3 Definitions of areas analysed.

Table 7 sets out the definitions of the areas for which the project had data and the areas reinterpreted in the analysis. The area interpreted for strip burning within this project was 3,827 cells of the 1km grid (row A in Table 7). This is 63% of the area where burning had been reported by either RSPB or McLeod and Newey and 100% of the areas where both had reported burning present.

Of the areas where burning was previously mapped, but have not been further analysed in this project, there are two subsets (Rows B and C in Table 7). In Row B, the McLeod and Newey + IACS areas (1,648 cells of the 1km grid) are potentially areas where the extent of burning has increased (with burning detected since the RSPB analysis). In Row C, the RSPB + IACS area (603 cells of the 1km grid) may indicate areas where burning has ceased between the RSPB date of interpretation

[32] The McLeod and Newey analysis used all the dates of imagery in the GetMapping® aerial photography webservice and recorded brining as present if visible at any date. The GetMapping ®service has complete coverage for Scotland but that coverage is a composite from multiple dates. The GetMapping® service continues to be updated and the most recent imagery used in this project was a substantial area of imagery for 2018 (1,130 cells of the 1km grid).

and that of the later McLeod and Newey analysis. Imagery is in hand to interpret these potential changes in extent and is being interpreted as part of an associated project.

Table 7 – Interpretation area coverage definitions.

Row	Combination Name	Definition	Total Area (1km grid cells)
A	McLeod & Newey + IACS + RSPB	These are the core areas where grouse butts are mapped as present in holdings and data from both RSPB and McLeod and Newey indicate the presence of burning – this has been interpreted for **intensity of burning.**	**3,827**
B	McLeod & Newey + IACS	These are areas where RSPB did not identify burning as being present, but the later McLeod and Newey did report burning – this is the potential **increase in extent of burning**. Image data in hand – will be interpreted in another project and the data	1,648
C	RSPB + IACS	These areas are the reverse of the above – where RSPB found burning but McLeod and Newey did not – **so potentially a decrease in the extent of burning**. Image data in hand – not interpreted.	603
Total A+B+C		Count of 1km cells where burning has been previously reported and that intersect the rough grazing fields in holdings with grouse butts mapped. Percentage of burned cells reinterpreted.	**6,078** **63%**
D	IACS only	This large area has no burning previously reported but is rough grazing within the boundaries of holdings with grouse butts present. Analysis would be to **confirm no burning is present** for 2018. Image data in hand – not interpreted.	6,418
Total A+B+C+D		Count of all 1km squares intersecting the rough grazing fields in holdings with grouse butts mapped. Percentage of all cells interpreted.	**12,496** **31%**

Other areas of burning beyond holdings with grouse butts mapped

E	McLeod & Newey + RSPB	Areas where burning has been identified previously but which lie beyond the boundaries of holdings with grouse butts mapped. **In a small number of cases it was possible to add in holdings for which there were IACS polygons but no land use data. This moved some 1km squares from E, F or G to A, B, or C.**	389
F	McLeod & Newey		699
G	RSPB		426
Total E+F+G		Count of 1km squares with burning present that are not in holdings with grouse butts mapped Percentage of 1km squares with burning present not in holdings with grouse butts mapped	**1,514** **11%**

The image interpretation did not reanalyse the extensive area of the holdings (6,418 cells of the 1km grid) where no burning has been identified by any previous analysis (including the McLeod and

Newey whose analysis was Scotland wide). While it is possible that there is new burning present within this region it was judged unlikely to be extensive and reinterpretation was not prioritised.

In summarising the existing datasets (RSPB and McLeod and Newey) in combination with the IACS coverage, it was also possible to highlight that, of the 1km cells identified as having burnt areas present, only 1,514 or 11% occurred beyond the boundaries of holdings with grouse butts mapped (total for Rows E, F & G in Table 7).

8.4 Strip burning interpretation process

For this project the areas in which burning was being conducted were interpreted from aerial photography or satellite imagery (see the example in Figure 21). The burning present in the 2018 imagery was interpreted on a 200m grid (25 cells per 1km cell). Each 200m sub-cell as assigned presence/absence of burning on a majority basis, generating an estimate for the 1km cell as whole and a higher-resolution presence-absence mapping. The approach here was intended to reduce the challenge of interpreting the percentage burned across the 1km cell and to create a finer grained mapping of burned areas that would be more compatible with the granularity of the other GIS data sets being used in the analyses.

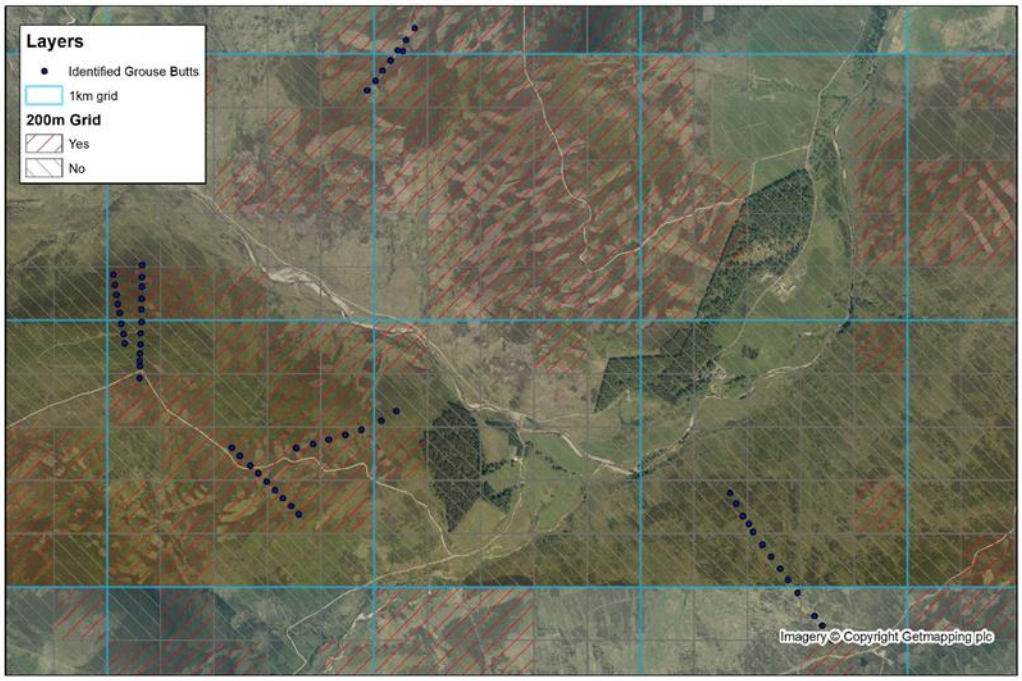


Figure 21: Interpretation of an example area with grouse butts, 1km and 200m cells shown

For each 1km map grid cell it was also recorded if new burning could be seen when comparing between the 2018 imagery with the most recent previous imagery[33]. This presence/absence data, when combined with information on the date of capture for the previous imagery, enables the creation of two maps. The first records the date since which the burning visible in 2018 has occurred. The second records the date since which there has been no burning visible in the 2018 imagery[34]. The two maps serve to classify the interpreted area as active or inactive for burning and put bounds on the dates. Note that neither date map is always definitive on the exact year in which,

[33] GetMapping® hosts both the most recent photography and all previous dates of photography.
[34] Burning may have ceased but may also just not have occurred in the window between dates of imagery. The wider the difference in dates the more likely that when no new burning is observed then burning has ceased.

either the visible burning in the 2018 imagery was conducted, or on the year after which burning ceased. This is because the gaps between 2018 and next most recent imagery can be up to 12 years. This largest gap occurs for only 2% of the area interpreted to date and in 93% of the area the gap between image dates is five years of less (2013 imagery) and 69% is three or less (2015 imagery). Burning may have ceased at a date before the most recent previous imagery. While it may be possible in some cases to look back to even earlier imagery to be more definitive on when burning ceased that option lay beyond the scope of this project.

8.5 Holding level analysis of burning – false positives

Since the presence, absence or degree of burning is interpreted on a grid basis, 200m for the active burned area or 1km for the assumed burn areas, it is possible that a single grid cell can span more than one holding. Since it is not recorded where within the grid cell the burning occurs then it is possible that a holding may have an area of burning attributed to it when no burning is present. The grid to holding attribution is more positive the smaller the grid cells used so the active burning analysis is more reliable than the assumed burn data. Quantifying the number of false positives is not trivial but it is possible to identify cases where only small areas of burning occur, these are more likely to be false positives (literal edge cases). For example, using a threshold of >4 ha (one 200m cell) would eliminate 24 holdings from the active burning set. The larger 1km cells of the assumed burning set are more likely to be causing cells-to-holding attribution issues and thresholding isn't a practical option for these areas. The issue of 1km cells will though be eliminated once the 2018 interpretation of the imagery is completed.

8.6 Issues for creating and interpreting burn percentage maps

As set out in Section 4.2, the estimation of 1km burned percentage values from the 200m map grid cells recording presence and absence of burning means the need to make an assumption of compensating errors. The compensating error assumption is most valid where there is an equal mix of burned and unburned 200m map grid cells. There is potentially an over estimation of the burned percentage in areas where there are more burned than unburned cells and an underestimation where there are small numbers of burned cells.

The worst cases for underestimation occur when all cells have burning present but all at <50%, with the assumed percentage being 0%, and the potential error being up to -50%. This worst case for underestimation is, though, very unlikely to occur given the size of the map grid cells (200m) and the patchiness of strip burning combining to trigger the condition to have presence recorded.

The worst case for over estimation is when all cells have burning present at 50% but with the assumed percentage per cell being 100% so a potential error of +50%. Again, the size of the interpretation grid relative to the burnt patches means that worst case scenario is less likely to occur. While this maximum overestimation is unlikely to occur, some overestimation is likely in the 1 km map grid cells having most cells with burning recorded as present. This means the need for some caution in interpreting the highest burn percentage values in the burn percentage mapping.

Any quantification of the uncertainty in the burn percentage would require a more in-depth statistical analysis of any interpretation and representation biases in the 2018 burning dataset. Options for such analysis were discussed with staff from BioSS (pers comm), for example using comparison with image-segmentation based estimates but implementing these was beyond the scope of this project. What can be presented is the distribution of the numbers per 1km grid cell of 200m grid cells in which burning was estimated as more than 50% of the area. The distribution is presented in Figure 22, with the most reliable data for estimating percentages for the 1km grid being in the centre of the distribution. The figure highlights both that there are large areas of Scotland in

which nearly all cells were interpreted as having over 50% of their area burned but also that for these areas there is the potential that the estimates of burn percentage at 1km grid cell level are too high.

Despite the potential for bias and uncertainty the benefits of the approach were in the simplification of the interpretation tasks and thus on the robustness of the presence/absence interpretations.

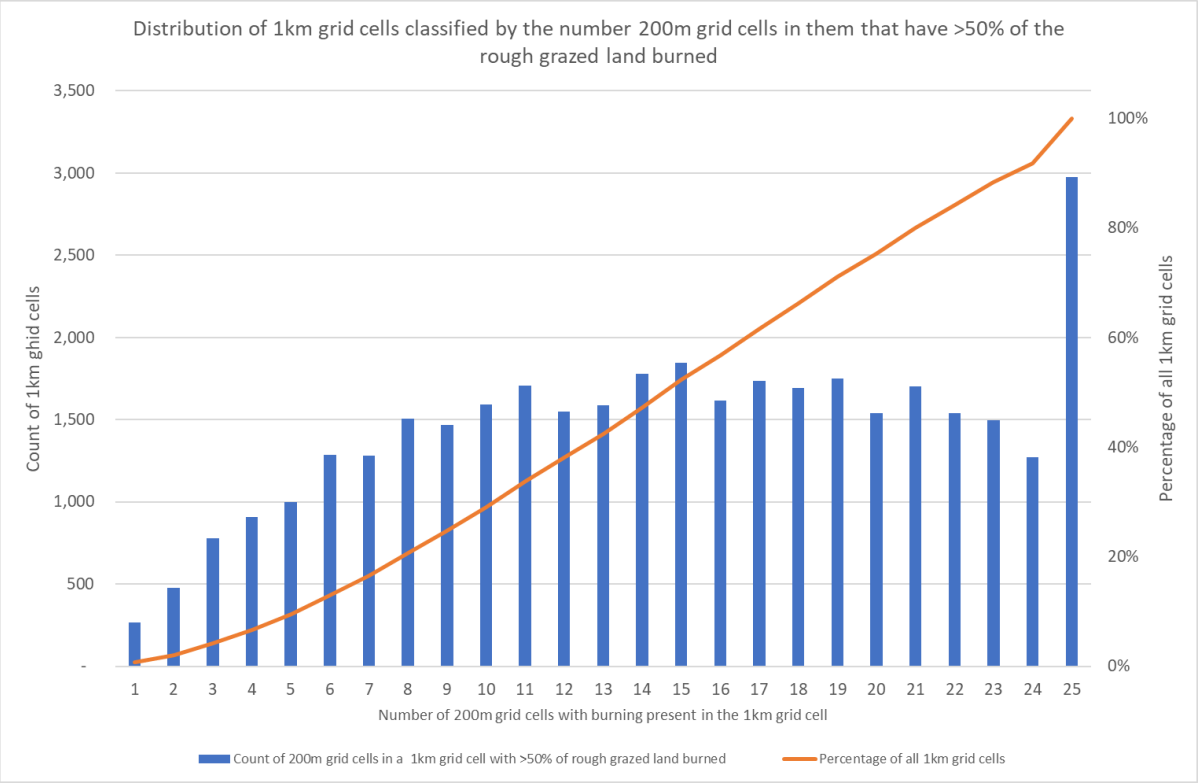


Figure 22: Distribution in the population of 1km grid cells of the count of 200m grid cells with burning present

8.7 Nature of change in burning percentages

In addition to the change mapping and the summaries of change presented in Section 4.2.4 it is possible to get further insights into the nature of change in burning between 2005-11 and 2018 by cross tabulating the “From” and “To” burning percentages. By this mechanism it possible to get a better understanding of for example: the overall balance of change; how intensely new areas are managed; the previous intensity of management for areas where burning is now no longer apparent and how the degree of change in burning is influenced by the 2005-11 management regimes.

The cross tabulation is presented in Table 8, with rows (2 to 12) being the burned percentage in 2006-11 and the columns (B to L) being the burn percentage in 2018. The counts in the grid are the number of 1km cells. The grey diagonal is where the burn percentages (rounded to 10’s) match – and there are 725 of 3827 cells or 19%. Above the diagonal (highlighted in orange) are cases where the burn percentage has increased, in some cases marginally and in other cases potentially substantially (cells farther to the right). Increase in burning percentage occurs for all the 2005-11 rates but occurs more often on lower intensity 2005-11 percentages (e.g. row 2-4) and with smaller increases (columns C-F). The count of all 1km cells where the burning percentage has increased is 2534 or 66% (N1) but bear in mind that interpretation differences mean that this may be an overestimate. Below the diagonal (highlighted in green) are the cases where burning intensity has decreased since 2005-11. Again, most of the possible combinations of reductions occur though it is

worth noting that the 2005-11 data set rarely records cases of over 70% burning. Again, there are larger numbers of cases on combinations of lower rates of 2005-11 and 20187 burning (rows 3-6 and column B-C). Reductions occur for 568 cases (15%) - (B14). From the table it is also possible to highlight the special cases of change from zero burning (row 2) and to zero burning (column B). There are 864 cases of new burning (M2) and 310 cases of burning no longer being visible (B13). What is apparent from the complexity of the cross tabulation is that not only are driven grouse moor enterprises conduced with a wide variety of intensities but that in the period between 2005-11 and 20187 there have been a great variety of changes. The majority are of small magnitudes but in some cases there have been fairly radical changes in intensity, with both substantial increase and decreases in burning percentages occurring. Policy making for the driven grouse industry needs to recognise that such dynamics may need to be monitored.

Table 8 Change in burn intensity by 1km cells from 2005/2011 to 2018

Row Id	Column Id - A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Count of 1km cells	To - 2018 burned % 0	10	20	30	40	50	60	70	80	90	100	Increased for each "From" line	All Inceased
2	From - 2005-11 burned % 0	414	232	254	106	103	55	52	22	21	7	12	864	2534
3	10	195	141	195	133	139	84	100	41	34	12	15	753	
4	20	54	42	67	40	83	36	46	36	39	15	14	309	
5	30	27	32	37	41	59	33	72	33	52	24	26	299	
6	40	19	24	29	18	37	23	40	29	43	28	20	183	
7	50	10	12	8	11	14	12	8	11	26	15	14	74	
8	60	4	2	6	1	6	5	5	9	4	10	5	28	
9	70	1	1	1	1	2	1	1	4	6	1	8	15	
10	80							2	1	2	4	3	7	
11	90									1	2	2	2	
12	100													
13	Decreased for each "From" line	310	113	81	31	22	6	3	1	1	0	0	725	
14	All Decreased	568												Stays Same

8.8 Combining mapping of burned areas with buffered grouse butt locations

Combining the maps of presence of burning with buffered grouse butt locations provides another interpretation of the data that highlights the challenges of precisely defining the area of driven grouse moor management. Figure 23 shows the areas and share of the areas burned (2018 data) and assumed burned (2005-11 data) that fall within the buffered grouse butt areas using the convex hull implementation.

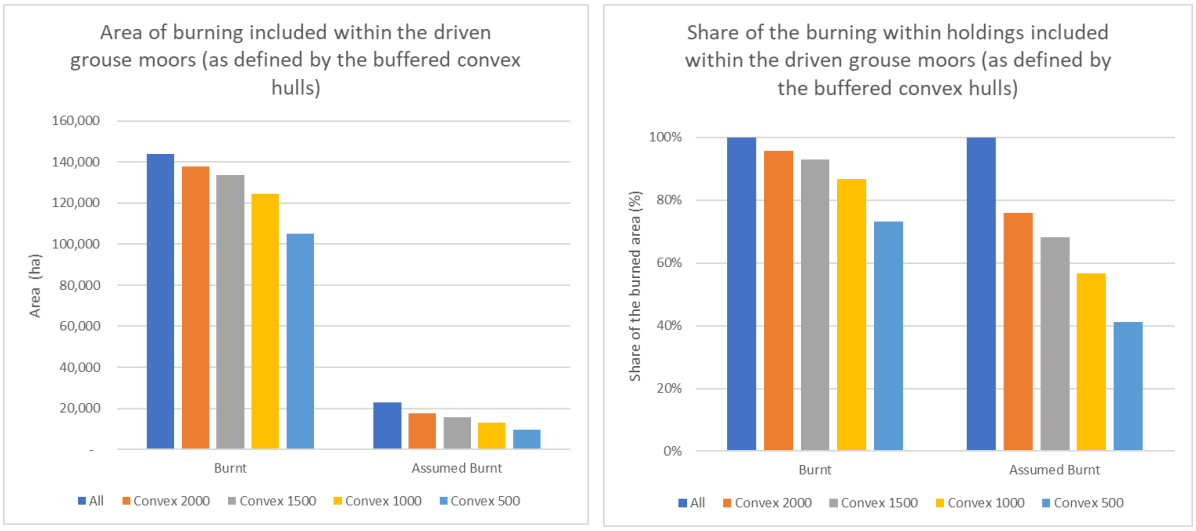


Figure 23: Areas and proportions of burnt and assumed burnt areas within the grouse butt buffered convex hulls.

For both the burned and assumed burned areas the use of buffers excludes some of the burned areas from the area defined as driven grouse moor. The proportion excluded is low for larger buffer distances (4% for 2000m) but becomes more substantial as buffer distances decrease (to 27% for 500m). For the same buffer distance, burned areas have lower proportions excluded compared with assumed burned, (27% vs 59% for 500m distance) reflecting that in general the assumed burned areas in the more marginal areas of moorland. The implication of this analysis is that while it is possible to make improved estimations of burned areas there remains the need to decide which of these burned areas can reasonably be associated with driven grouse management[35].

[35] Exclusive use for driven grouse is in any case unlikely as walked up or over pointer shooting may also be conducted on the same ground especially when grouse numbers in a season are low.

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