Biodiversity considerations on grouse moors. Part 4 of Research to assess socioeconomic and biodiversity impacts of driven grouse moors and to understand the rights of gamekeepers:

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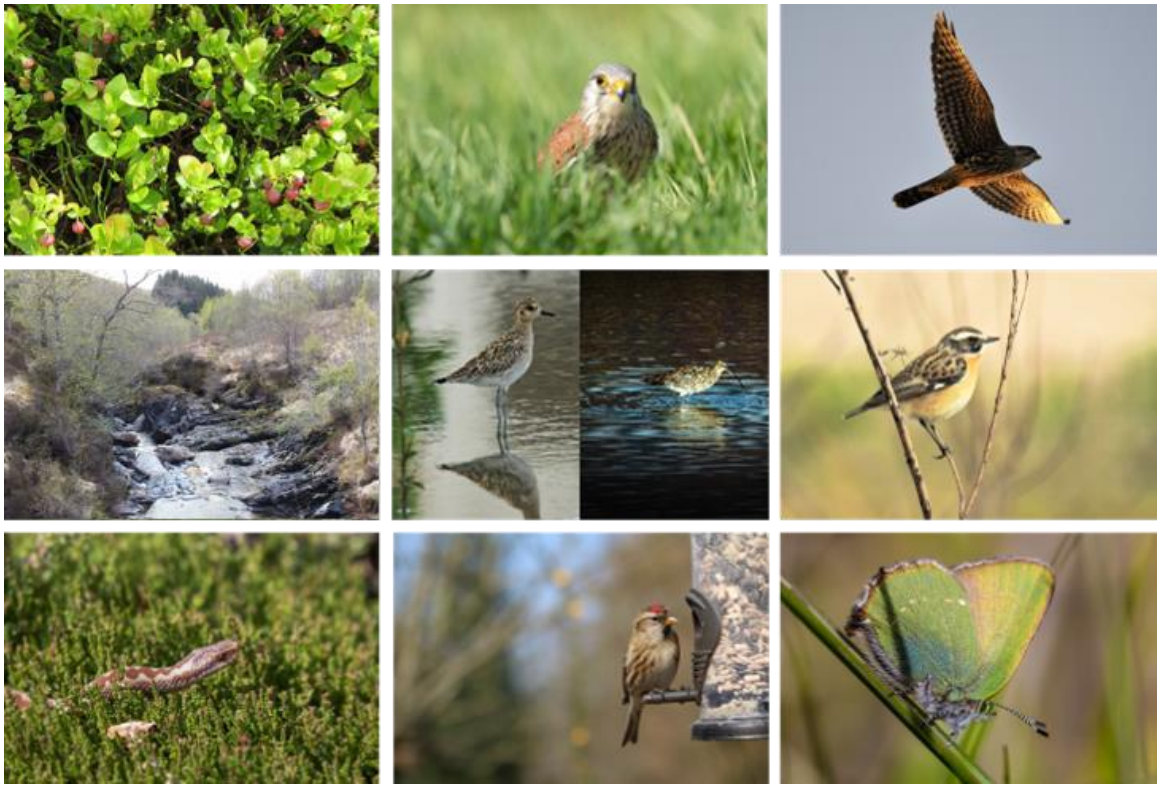
Part 4. Research to assess socioeconomic and biodiversity impacts of driven grouse moors and to understand the rights of gamekeepers.



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

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Summary of the key findings from the research

1. We used aerial photography or satellite imagery to estimate the percentage area of ordnance survey 1 kilometre (km) grid squares that showed signs of muirburn. A total of 3,616 1 km squares that were classified as burned were used for the biodiversity analysis. It was estimated that the proportion of the area classified into different muirburn intensities were:

Muirburn intensity	Proportion of assessed area
less than 5% burnt,	12% of the area
6-20% burnt	24% of the area
21-40% burnt	24% of the area
41-60% burnt	18% of the area
61-80% burnt	13% of the area
81-100% burnt	11% of the area

2. Evidence of muirburn was aerial photography or satellite imagery present throughout the area assessed, though the area assessed was prioritised because it was known to include areas where grouse moor management was an important land use. North of the central belt burning intensity (% area burnt) was generally greater in the NE with parts of Strathdon, Deeside, Perthshire hills, and particularly the Angus Glens showing evidence of areas of intensive burning. South of the central belt the Lammermuirs showed the greatest area of intensive burning.
3. The effect of grouse moor management intensity on the distribution of selected upland species was assessed. The species used in this study were chosen through consultation with the project Research Advisory Group and the Scottish Government to reflect a small selection of species that are likely to be negatively or positively affected by grouse moor management, and for which there was suitable occurrence data available for analyses within the time frame and resources available.
4. Some obvious species of interest such as mountain hare *Lepus timidus*, red deer *Cervus elaphus*, and high conservation priority species such as lapwing *Vanellus vanellus,* were not included in the final list of species assessed because there is already a substantial body of evidence indicating that these species benefit from and are positively associated with moorland managed for grouse shooting. Rather the aim of this work was to assess the effects of the intensity of grouse moor management on species where the association between species distribution and grouse moor management is less well understood or unknown. The species assessed were:
    - Birch
    - Green hairstreak butterfly
    - Curlew
    - Merlin
    - Lesser redpoll
    - Bilberry / blaeberry
    - Adder
    - Golden plover
    - Kestrel
    - Whinchat
5. Birch and blaeberry were most prevalent in areas with little to intermediate burning and showed a decline with increasing burning but were also present in squares with high levels of muirburn.
6. Green hairstreak butterfly and adder were both most prevalent at low to moderate levels of burning and showed a general decline in prevalence with very high levels of burning. However, the pattern in change in prevalence with increasing burning is not clear. For these 'semi-cryptic' species it is not clear whether greater detectability in areas with intense burning is a result of greater detectability in burnt areas.
7. Curlew and golden plover prevalence generally increased with intensity of muirburn, though golden plover occurrence peaked in the 41-60% burn category whereas curlew increased with greater percentage muirburn. This was particularly the case for these, and the other bird species

assessed at the hectad (10 x 10 km) scale where sample sizes for squares representing intense muirburn were very small.

8. Merlin prevalence increased with increasing intensity of muirburn up to the 41-60% muirburn, and then declined and was absent from the squares with 81-100% burning, whereas kestrel was present at a consistent level across all muirburn categories up to 81%. Interpretation of prevalence at the 81% plus muirburn category is likely confounded by small sample size.
9. Both lesser redpoll and whinchat showed consistent levels of prevalence at low to moderate levels of muirburn and showed increases in prevalence in the 61% and higher muirburn categories. Lesser redpoll prevalence peaked in the 61-80% burn category and the species was absent in the 81-100% category, while whinchat was most prevalent in the 81-100% category.
10. Birch was the only species assessed here where prevalence appeared to decline with increasing intensity of muirburn, though blaeberry also showed evidence of lower prevalence at the highest category of muirburn. Green hairstreak butterfly, adder, and kestrel showed fairly consistent occurrence across the range of muirburn measured. Whereas golden plover and merlin showed an increased occurrence with greater burning, occurrence for these species peaked at intermediate levels of muirburn. Curlew, whinchat and lesser redpoll appeared to increase in prevalence with increasing percentage of ground classed as burnt.
11. It is difficult to draw any firm conclusions and for all species care is needed in interpreting the relationship between species occurrence and the high levels of muirburn as the sample size of both the number of assessed squares within each burn category, and the number of species records are low for these high intensity burn categories. Species may be responding to aspects of moorland management other than Muirburn and for the bird species occurrence was likely influenced by the wider landscape.
12. In addition, it must be noted that assessment is restricted to the area for which muirburn data was available and that this was largely from areas where grouse moor management was known to be an important land use. The restricted area also had the consequence of reducing the area of intersection between areas assessed for muirburn and species occurrence data.

1 Background

This report is Part 4 of the 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 4 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 provided 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. Specific management activities include muirburn, predator control and the use of medicated grit to improve grouse health. [2]

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, 2016). 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 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[3], concerns generally focus on large-scale culls of mountain hares on grouse moors, muirburn and the persecution of raptors. It is particularly the latter that has generated emotive reactions from the general public, conservation organisations and campaigners, and led to increasing pressure on politicians to address the issue. [4]

1.1.3 Recent scrutiny

There has been a growing public and political concern relating to the disappearance of golden eagles in Scotland in recent years. 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

[1] https://www.gov.scot/ISBN/978-1-80004-212-4
[2] Moorland Working Group (2002). Scotland's Moorland: the nature of change. SNH: Battleby.
[3] For example, through the Working for Waders initiative that began in 2017.
[4] 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.

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 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.[5]

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*" (Scottish Government, 2018). 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 to address some of the knowledge gaps identified in Phase 1 and evidence collated by the GMMG.

1.2 Objective of the research

This research set out 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.

The key aims of this research as follows:

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. (Task 4).**

[5] See, for example, coverage in The Guardian (01.07.19).
[6] Scottish Government news: Golden eagle deaths (31.05.2017) .

This report examines the biodiversity impacts of driven grouse moors using species distribution data for selected moorland biodiversity indicator species. This work utilised estimates of moorland management intensity for driven grouse developed in Part 3 of this project.

2 Introduction

Grouse moor management comprises of a range of management practices, including predator control, muirburn, grazing management and disease management (Newey et al. 2016; Thompson et al. 2016; Mustin et al. 2018). These management practices are carried out to maximise red grouse *Lagopus lagopus scotica* numbers for sport shooting. Grouse moor management has been demonstrated to have positive and negative effects on the distribution and abundance of different species and biodiversity (Thompson et al. 2016; Brooker et al. 2018; Mustin et al. 2018).

Predator control, the legal killing of crows *Corvus corone*, foxes *Vulpes vulpes* , stoats *Mustela erminea* and weasels *Mustela nivalis* undertaken as part of grouse moor management to minimise predation of red grouse has been shown to benefit other ground nesting birds (Fletcher et al. 2010; Newey et al. 2016; Littlewood et al. 2019, and see Mustin et al. 2018 for recent review), and mountain hares (Patton et al 2010; Brooker et al. 2018; Hesford et al. 2019). Predator control will suppress the local population of controlled species, however the wider biodiversity impacts of predator control on the controlled species are poorly understood (Brooker et al. 2018).

Muirburn, the burning of vegetation for management purposes, in the context of grouse moor management entails the controlled, rotational burning of heather to maintain open moorland and provide a mosaic of different aged heather stands (Yallop et al. 2006). The biodiversity and environmental effects of muirburn have recently been reviewed by Brooker et al. (2018), Mustin et al. (2018), and Thompson et al. (2016) among others. Muirburn has been shown to benefit some species of ground nesting birds, particularly upland waders (Newey et al. 2016; Thompson et al. 1995; Pearce-Higgins & Grant 2006), and has been shown to negatively affect the abundance of some other species, for example some passerine, corvid and raptor species (Newey et al. 2016; Smith et al. 2001; Thompson et al. 2016). The effects of muirburn on vascular plant richness and diversity are not clear and are dependent on fire severity, intensity and vegetation type (see Brooker et al. 2018 for a recent review). Muirburn essentially arrests moorland succession and suppresses scrub and tree colonisation, preventing the establishment of scrub and woodland communities together with the associated species these would support (Thompson et al. 2016; Brooker et al. 2018).

Overall the effects of grouse moor management practices vary with habitat (e.g. wet or dry heath), species and management type, and in many cases the evidence base is not conclusive on whether specific practices have positive or negative biodiversity effects (Thompson et al. 2016; Brooker et al. 2018; Mustin et al., 2018; Werritty 2019). While there is a clear evidence base that grouse moor management can positively and/or negatively affect different species of wading birds, raptors, and vegetation communities the evidence remains inconclusive for many other taxonomic groups and species (Brooker et al. 2018; Mustin et al. 2018). Indeed, the effects of grouse moor management on the distribution and abundance of the majority of species has not been investigated.

Here we assess the effect of grouse moor management, based on the intensity of muirburn (the estimated percentage of ground burnt), on the distribution of selected upland species (Table 1). The species used in this study were chosen through consultation with the project Research Advisory Group and Scottish Government to reflect a small selection of species that are likely to be negatively or positively affected by grouse moor management, and for which there was suitable occurrence data available for analyses within the time frame and resources available. Some obvious species of interest such as mountain hare *Lepus timidus*, red deer *Cervus elaphus*, and high conservation priority species such as lapwing *Vanellus vanellus* were not included in the final list of species assessed because there is already a good body of evidence indicating that these species benefit from and are positively

associated with moorland managed for grouse shooting (Fletcher at al. 2010; Patton et al. 2010; Newey et al. 2016; Mustin et al. 2018; Littlewood et al. 2019). Rather the aim of this work was to assess the effects of the intensity of grouse moor management on species where the association between species distribution and grouse moor management is less well understood or unknown.

3 Methods

3.1 Intensity of management

Grouse moor management, which itself may be carried out alongside other land uses, can entail a range of management practices that are not necessarily exclusive, and which may be implemented at different intensities and spatial scales depending on management objectives and resources (Werritty et al. 2015; Newey et al 2016; Thompson et al. 2016; Sotherton et al. 2017; Mustin et al. 2018; Werritty 2019). To obtain a measure of management intensity we use the percentage of ground that has been subject to muirburn assessed from aerial photography or satellite imagery as an index of the intensity of grouse moor management (Yallop et al. 2006; Douglas et al. 2015; Newey et al. 2016; Matthews et al. 2020). Estimates of percentage of muirburn used here come from the work carried out in Part 3 of this project and readers are directed to Matthews et al. (2020) for details of the muirburn assessment methodology. In summary; to estimate the percentage of muirburn at the 1 km square scale we summed the number of 200 m x 200 m cells within each 1 km square (25 accessed squares) that had been classified as at least 50% burnt and converted this to a percentage. This estimate of percentage muirburn assumes that each cell classified as burnt is 100% burnt which is not necessarily true as the percentage of burn will range from 51-100% and is therefore an overestimate of actual muirburn (although it is balanced by exclusion of cells in the 0-50% burned range). However, this likely gives a good estimate of the intensity of management and area of land under grouse moor management. For those species where the distribution data was only available at the 10 x 10 km^2 (hectad) scale we calculated the percentage burn at the 1 km square level and then took the median value of the 1 km squares within that 100 km square to represent the overall level of muirburn.

3.2 Species distribution data

Species distribution data were acquired from different sources (Table 1). In Scotland, except for birds and arguably red deer there are no systematic national, monitoring programs of wildlife. For bird species (curlew, golden plover, merlin *Falco columbarius*, kestrel *Falco tinnunculus*, lesser redpoll *Acanthis cabaret*, and whinchat *Saxicola rubetra*) we used the British Trust for Ornithology's (BTO) Breeding Bird Atlas (BBA) data (Gillings et al. 2019). Plant species (birch *Betula sp.*, and blaeberry *Vaccinium mytillus*) distributions are based on data from the Botanical Society of Britain and Ireland (BSBI; Prescott et al. 2018) and the National Plant Monitoring Scheme (NPMS; Walker et al. 2015; Prescott et al. 2015, 2019). Data on the distribution of adder *Vipera berus* and green hairstreak butterfly *Callophrys rubi* were obtained from the National Biodiversity Network (NBN) Scotland (NBN 2020) and data partners (Table 1, Annex 1). For the BBA data we mapped presence in 2010 at the hectad scale, for all other species we restricted our analysis to records from 2000 onwards and then mapped the presence of each species over the entire time range the available data covered at the 1 km square scale. Adder data are shown at the hectad scale for display purposes at the request of data providers to protect sensitive sites. The written permission of data holders was obtained for use of all data sources licenced under "CC-BY-NC" (Attribution – Non-Commercial) licence (see Annex 1 for list of data providers).

Table 1. The list of 10 species and the data sources used in this study, along with details of sizes and the distribution of samples by estimated burn category.

Data sources	Spatial scale (number of squares assessed) \Species	Number of squares			Number (%) of squares in each burn category					
		Total No. Records	Spatially unique records	Assessed squares with records (%)	0-4%	5-20%	21-40%	41-60%	61-80%	81-100%
1 * 1 km squares (n = 3,616)					**418 (11.5%)**	**858 (23.7%)**	**856 (23.6%)**	**635 (17.5%)**	**463 (12.8%)**	**386 (10.6%)**
BSBI[1], NPMS[2,3,4]	Birch	14,944	5,406	225 (6.2%)	36 (8.65)	60 (7.0%)	55 (2.9%)	33 (5.1%)	31 (6.7%)	10 (2.6%)
	Bilberry / blaeberry	8,674	4,979	314 (8.7%)	43 (10.2%)	81 (9.4%)	76 (8.9%)	49 (7.7%)	45 (9.7%)	20 (5.2%)
NBN[5 - 21, *]	Green hairstreak butterfly	5,475	1,475	83 (2.3%)	14 (3.3%)	16 (1.9%)	25 (2.9%)	9 (1.4%)	9 (1.95)	10 (2.5%)
	Adder	1,428	810	77 (2.1%)	4 (1.0%)	24 (2.8%)	14 (1.6%)	13 (2.0%)	10 (2.2%)	12 (3.1%)
10 x 10 km squares (n = 179)					**17 (9.5%)**	**60 (33.5%)**	**71 (39.6%)**	**22 (12.2%)**	**8 (4.5%)**	**1 (0.6%)**
BBA[22]	Curlew	337	337	120 (67%)	8 (47.1%)	33 (55.0%)	53 (74.6%)	18 (81.8%)	4 (87.5%)	1 (100%)
	Golden plover	240	240	68 (38%)	2 (11.8%)	18 (30.0%)	29 (40.1%)	15 (68.2%)	4 (0.50%)	0 (0%)
	Merlin	246	246	102 (57%)	7 (41.2%)	26 (43.3%)	45 (63.4%)	18 (81.8%)	6 (75.0%)	0 (0%)
	Kestrel	399	399	116 (65%)	10 (58.8%)	39 (65.0%)	44 (62.0%)	16 (72.7%)	6 (75.0%)	1 (100%)
	Lesser redpoll	368	368	85 (48%)	9 (52.9%)	25 (41.7%)	35 (49.3%)	8 (36.4%)	8 (100%)	0 (0%)
	Whinchat	308	308	80 (45%)	9 (52.9%)	21 (35.0%)	34 (47.9%)	9 (40.9%)	6 (75.0%)	1 (0%)

Data sources; BSBI – Botanical Society of Britain and Ireland, NMPS – National Plant Monitoring Survey, BBA – Breeding Bird Atlas. Total Number of Records; the total number of verified species occurrences within data set. Spatially Unique Records; either the number of 1 km^2 or 100 km^2 squares that have one or more verified records. Assessed Squares with Records; the number and percentage† of squares with verified records. Number of squares in each burn category – the number and percentage‡ of squares with records that occur within each burn category. 1. Prescott et al. (2018), 2. Walker et al. (2015), 3. Prescott et al. (2015), 4. Prescott et al. (2019), 5. NBN (2020). 6. Amphibian and Reptile Groups of the UK (2019), 7. Biological Records Centre (2017), 8. Buglife (2017), 9. Butterfly Conservation (2018) - Data were provided from the Butterflies for the New Millennium recording scheme, courtesy of Butterfly Conservation, 10. Caledonian Conservation (2017), 11. Dumfries and Galloway Environmental Resources Centre (2017), 12. Froglife (2018), 13. Highland Biological Recording Group (2018a,b,c,d), 14. John Muir Trust (2017a,b), 15. Lorn Natural History Group (2018), 16. National Trust for Scotland (2018), 17. North East Scotland Biological Records Centre (2017a,b), 18. Scottish Wildlife Trust (2018a,b,c), 19. The Wildlife Information Centre (2017), 20. The Wildlife Information Centre (2018a,b,c), 21. UK Butterfly Monitoring Scheme (2017), 22. Gillings et al. (2019). * Appendix 1 for list and citations for data providers. † = (assessed squares / total number of squares assessed) x 100, ‡ = (number of squares with records within burn category / number of assessed squares within category) x 100.

4 Findings

A total of 3,616 (ordnance survey) 1 km squares were assessed and the percentage of muirburn estimated, covering 179 (Ordnance Survey) 10 km by 10 km squares (Fig. 1a). Though it is important to note that the assessment of muirburn was limited to areas where driven grouse moor management was known to be an important land use the distribution of muirburn reveals that the eastern Monadhliath Mountains, Strathspey, Deeside, Strathdon, the Perthshire hills, the Angus Glens and the Lammermuirs are the most intensely burnt areas which corresponds to both those areas where driven grouse shooting is a dominant land use and where grouse moor management is most intensely carried out (Fig. 1a). For both the 1 km squares and hectads most squares show no or little (<20%) burning and the number of squares showing evidence of muirburn decline with increasing percentage of muirburn present (Fig. 1b,c). The steep decline in the number of hectads with increasing percentage of muirburn recorded suggests that areas of intense muirburn are highly localised (Fig. 1c). The smaller number of squares and hectads associated with higher percentages of burnt ground means care is needed in interpreting the relationship between species occurrence and the high levels of muirburn as the sample size of assessed squares within each burn category is small. This is most notable for the bird occurrence data where there is only one hectad in the 81-100% burn category which needs to be kept in mind when interpreting the results.

For birch species there were a total of 5,406 spatially unique records (at the 1 km^2 scale) of which 225 intersected the areas assessed for muirburn, and birch occurred on 6.2% of the 1 km squares assessed (Table 1, Fig. 2a). Birch records are associated with Scotland's large river valleys; the Dee, Spey and Findhorn (Fig. 2a). The occurrence of birch records showed an overall negative distribution with increasing muirburn, and were most prevalent in squares with little to moderate levels of muirburn (Table 1, Figs. 2a,b).

There were 4,979 1 km squares across Scotland with blaeberry records and 314 of these intersected the assessed area (Table 1, Fig. 3a). Overall, blaeberry occurred in 8.7% of assessed squares (Table 1). Blaeberry records throughout Scotland but more frequent in the north-east, Black Isle, and the North West Highlands than elsewhere in Scotland. Blaeberry records are most numerous in squares with low to moderate (<20%) burning, though overall there is a small decline in proportion of occurrence with increasing burning the species was present in 7-9% of squares with up to 80% burning, but occurrence drops steeply in the 81-100% burn category to around 2% (Table 1, Fig. 3b,c).

There were 5,475 records of green hairstreak butterfly from 1,475 1 km squares of which 83 (2.3%) overlapped assessed squares (Table 1, Fig. 4a). Most records occur within squares with less than 40% burning (Fig. 4b). The proportion of squares within each burn category with records also shows that most records are associated with squares with less than 40% burning, however, the pattern for higher levels of burning is less clear with a decline at 41-60% before increasing with a greater percentage of burning (Fig. 4c).

The majority of the 1,428 adder records from 810 1 km squares are largely concentrated to the south-west of Scotland and Southern Uplands, though there are also records from the south east Cairngorms (Table 1, Fig. 5a). Only 77 (2.1%) of squares with adder records overlap with the areas assessed for muirburn (Table 1, Fig. 5a). Adder records occur at all levels of burning, though most records are from squares with less than 20% burning (Fig. 4b). However, the proportion of squares with adder records is reasonably constant (2-3%) across all burn categories (Fig. 4c).

Curlew occurred in 120 (67%) of hectads in our assessment (Table 1). The species is widespread throughout the Southern Uplands, central and eastern areas of the Central Uplands, and western areas of the North West Highlands (Fig. 6a). Though the majority of records are from squares with little or moderate burning (<40%) within burn categories the proportion of squares with curlew increases with increasing percentage burning (Fig. 6b,c). However, as with all of the bird species which

are assessed at the hectad scale the apparently high proportion of highly burnt squares occupied by curlew may be a consequence of the fact that only one hectad is categorised as being 81-100% burnt (Table 1).

Squares with golden plover are largely found in the north and east of the Central Uplands and throughout much of North West Highlands, but with a notable presence in the eastern Southern Uplands particularly the Lammermuirs (Fig. 7a). Of the 240 hectads with golden plover they are present in 68 (38%) of the squares assessed for muirburn (Table 1). Most records within the area assessed are from areas with low to moderate burning with the highest number of records associated with the squares with a median percentage burn of 21-40% (Table 1, Fig. 7b). However, within burn category the proportion of squares occupied increases with increasing burning up to the mid-range of 41-60% before declining to zero at the highest burn category of 81-100% (Table 1, Fig. 7c).

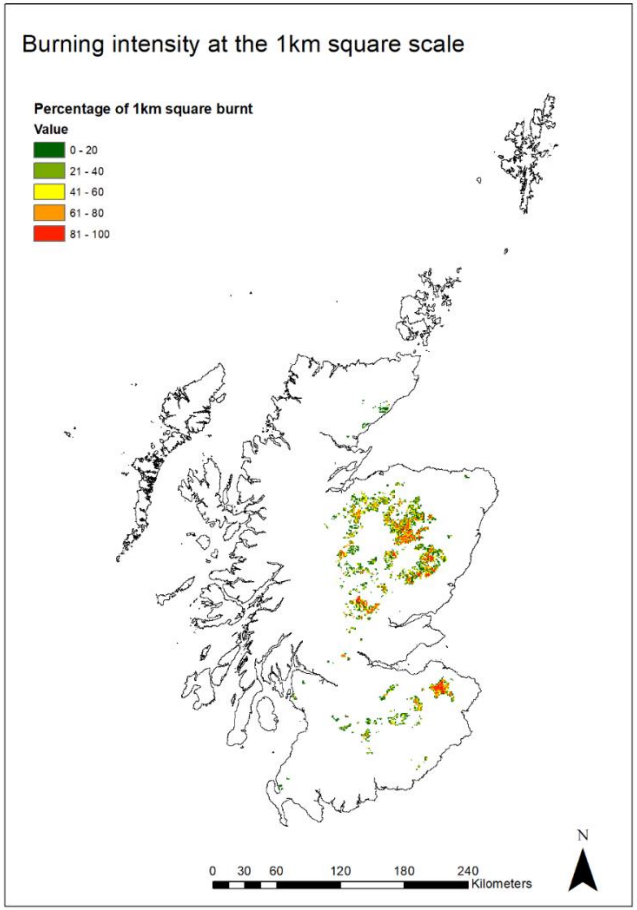
Merlin were recorded as present in 246 hectads across Scotland of which 102 (57%) correspond with squares assessed for muirburn (Table 1). Merlin were present in uplands of the Southern Uplands and Central Uplands, and parts of the North West Highlands (Fig. 8a). Most merlin records are associated with squares with low to moderate (<40%) muirburn, with squares in the 21-40% burn category having the most records (Table 1, Fig. 8b). However, within burn categories the proportion of squares with merlin records increase with greater burning to peak in the 41-60% burn category with a slight decline in the 61-80% burn category and no records in the most burn squares (Table 1, Fig. 8c).

Kestrel are widespread in southern Scotland, the central belt, south and eastern parts of the Central Uplands and eastern parts of the North West Highlands (Fig. 9a). Kestrel were recorded in 399 squares over Scotland and there were records for 116 of 179 (i.e. 64.8%) hectads assessed for muirburn (Table 1). The number of recorded occurrences decline with increasing muirburn, and most records occur below the 41% muirburn category (Table 1, Fig. 9b). However, within burn categories the proportion of squares occupied by kestrel is relatively stable but increases sharply at the highest level of muirburn (Table 1, Fig. 9c). However, the apparently high proportion of highly burnt squares occupied by kestrel is likely influenced by the fact that only one of hectads assessed is categorised as being 81-100% burnt (Table 1).

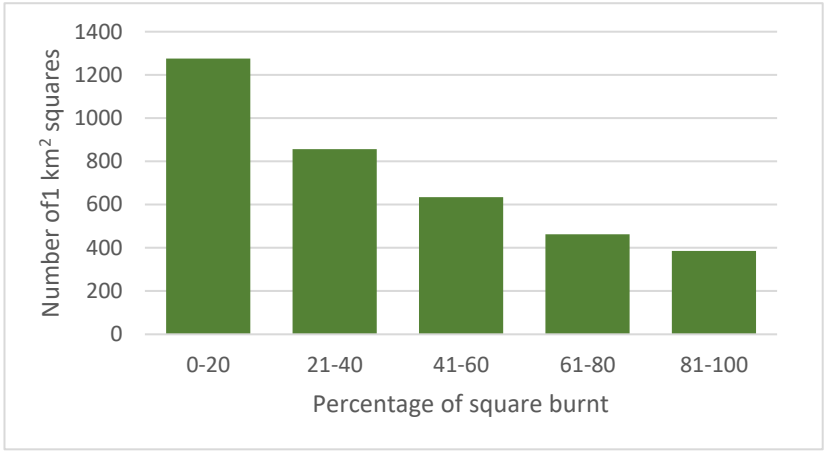
Lesser redpoll show a patchy distribution throughout Scotland with noticeably lower occurrence in the eastern, lowland, extent of the Central Uplands (Fig. 10a). The species had been recorded in a total of 368 hectads and occur in 85 of the 179 hectads assessed for muirburn (47.5%) (Table 1). While most records are from hectads with low to moderate (<41%) burning and few from hectads with higher levels of burning a comparison of the proportion of records within burn categories shows that the proportion of records is reasonably constant at around 0.40 across the 0-20, 21-40, and 41-60 burn categories with a marked peak in the 61-80% burn category – indicating that this species was found in all (n = 8) of the squares with a median burn category of 61-80% (Table 1, Figs. 10b,c).

Whinchat were recorded in 308 hectads across Scotland intersecting with 80 (44.7%) of 179 hectads assessed for muirburn (Table 1). Whinchat was quite widespread throughout the Southern Uplands, southern and western areas of the Central Uplands and North West Highlands, but scarcer in the north east (Fig. 11a). Though most of the species records come from squares with low to moderate (<40%) burning a comparison of the proportion of records within burn categories shows a higher proportion within the 61-80 and 81-100 percent burn categories (Table 1, Figs 11b,c). Though as noted elsewhere this pattern of a high proportion of records within the 81-100% burn category may be influenced by the fact that only one of the hectads falls in this category (Table 1).

a)



b)



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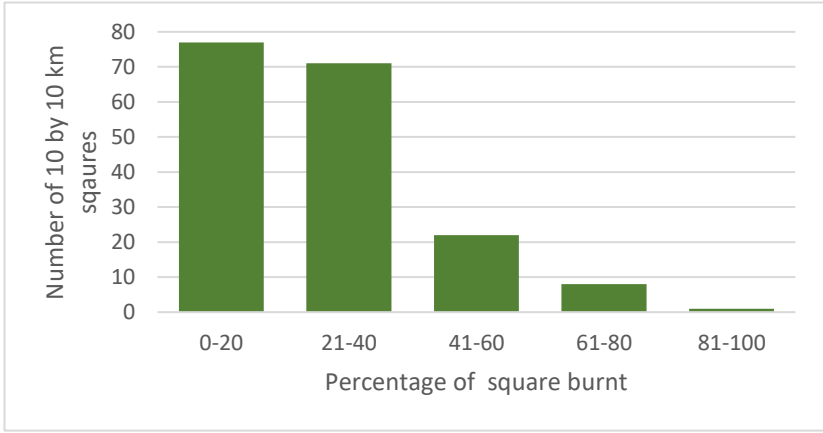
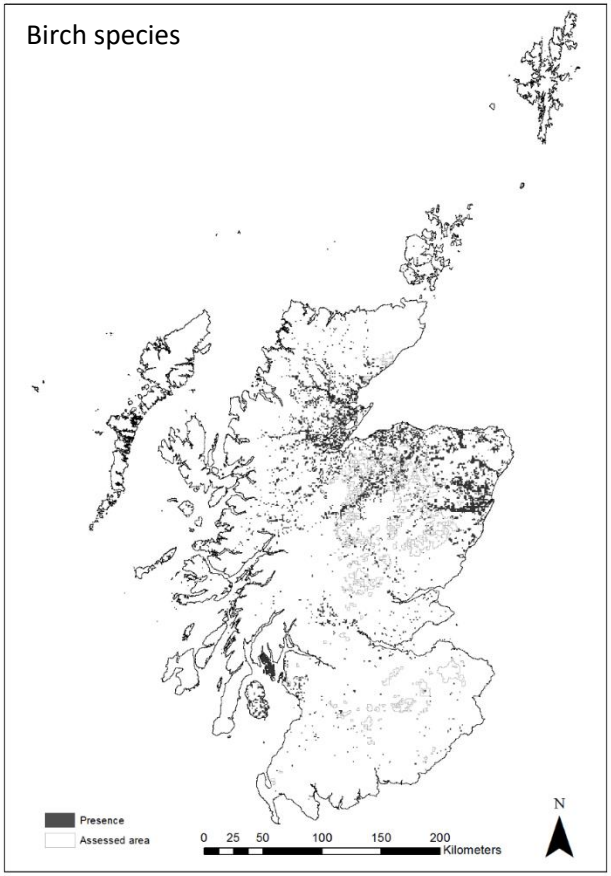


Figure 1. The distribution and number of assessed squares mapped and displayed by percentage burning; a) the distribution of 1 km squares assessed showing the estimated percentage of muirburn within each square (white areas were not assessed), b) the number of 1 km squares within each muirburn category, and c) the number of 10 km by 10 km squares within each muirburn category.

a)



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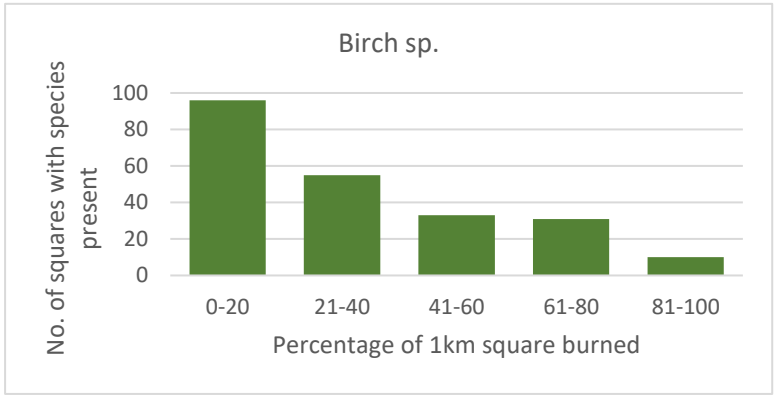


c)

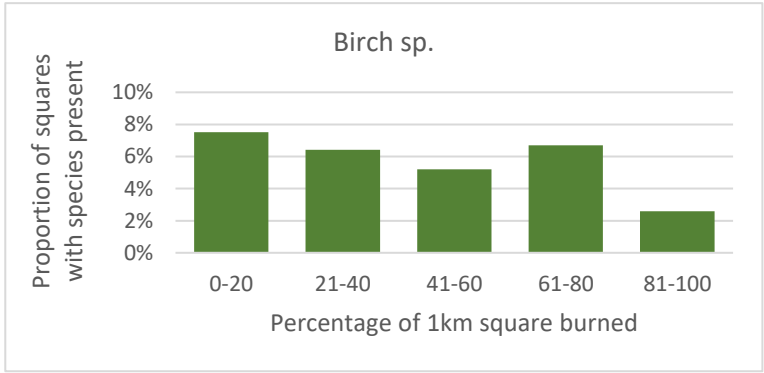


Figure 2. The occurrence (presence only) of birch species records in relation to the intensity of muirburn; a) map showing the occurrence of records for each 1 km square within the area assessed (presence of records only, the absence of records may not reflect absence on the ground), b) the number of 1 km squares where present categorised by the percentage of muirburn recorded for each 1 km square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data courtesy of British and Irish Botanical Society (Prescott et al. 2018) and the National Plant Monitoring Programme (Walker et al. 2015; Prescott et al. 2015; Prescott et al. 2019).

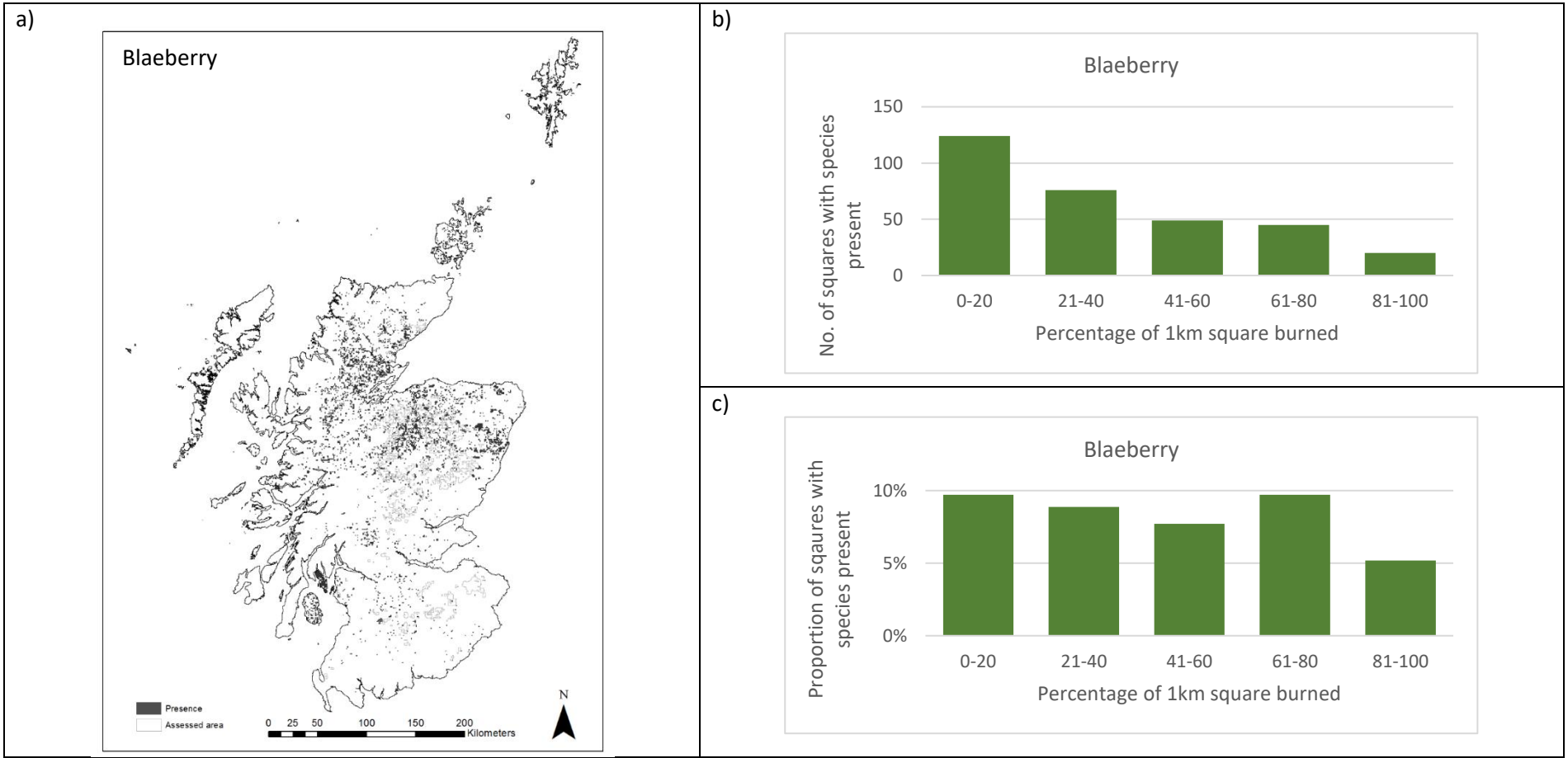
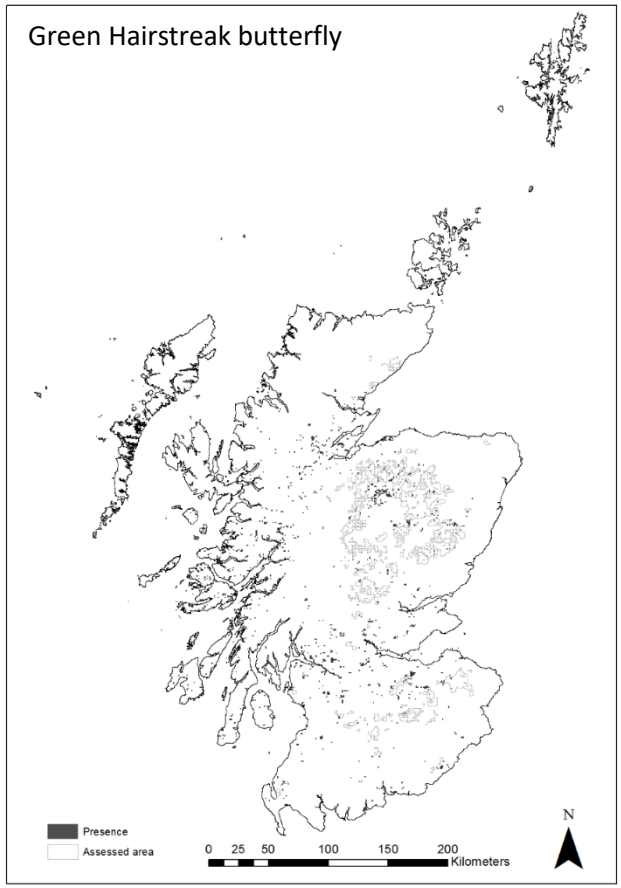
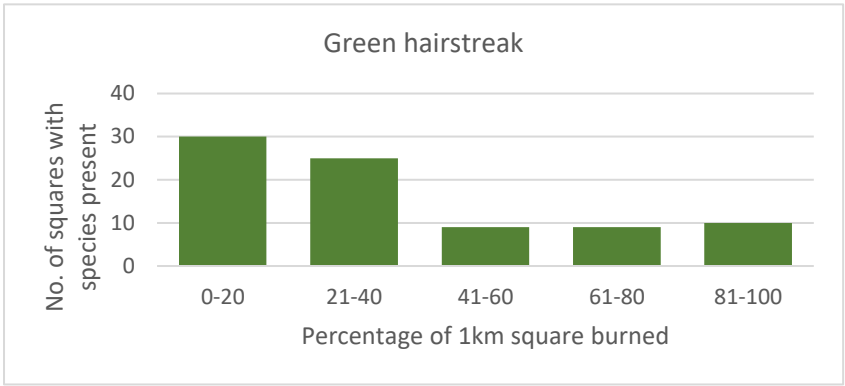


Figure 3. The occurrence (presence only) of blaeberry records in relation to the intensity of muirburn; a) map showing the occurrence of records for each 1 km square within the area assessed (presence of records only, the absence of records may not reflect absence on the ground), b) the number of 1 km squares where present categorised by the percentage of muirburn recorded for each 1 km square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data courtesy of British and Irish Botanical Society (Prescott et al. 2018) and the National Plant Monitoring Programme (Walker et al. 2015; Prescott et al. 2015; Prescott et al. 2019).

a)



b)



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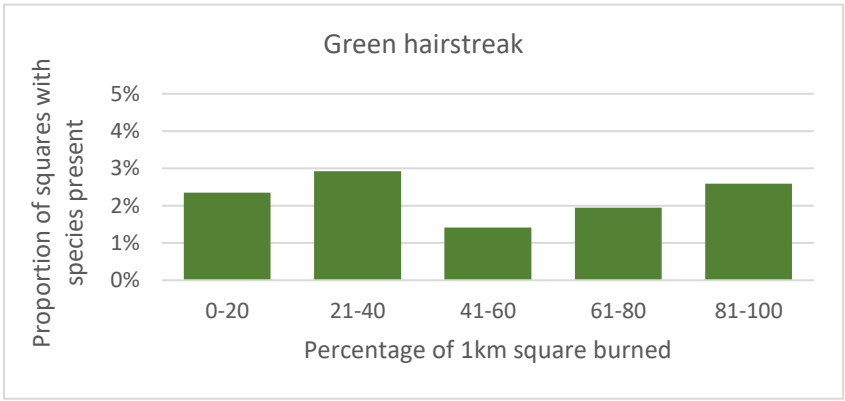
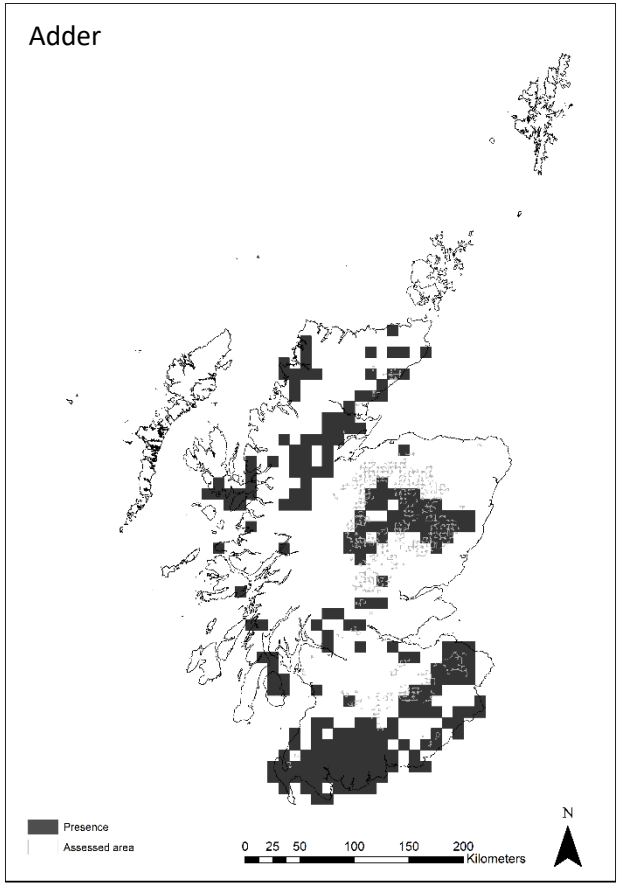


Figure 4. The occurrence (presence only) of green hairstreak butterfly records in relation to the intensity of muirburn; a) map showing the occurrence of records for each 1 km square within the area assessed (presence of records only, the absence of records may not reflect absence on the ground), b) the number of 1 km squares where present categorised by the percentage of muirburn recorded for each 1 km square, and c) the proportion of squares within each category of muirburn with species present. Species occurrence data from NBN (2020) and courtesy of NBN data partners (Appendix 1).

a)



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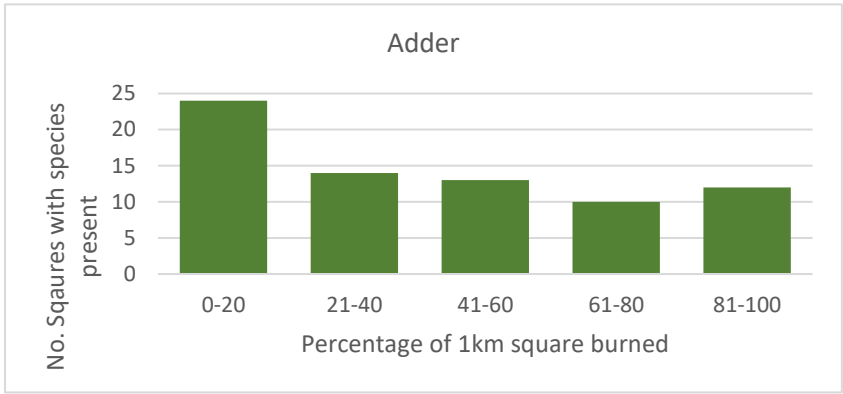


c)

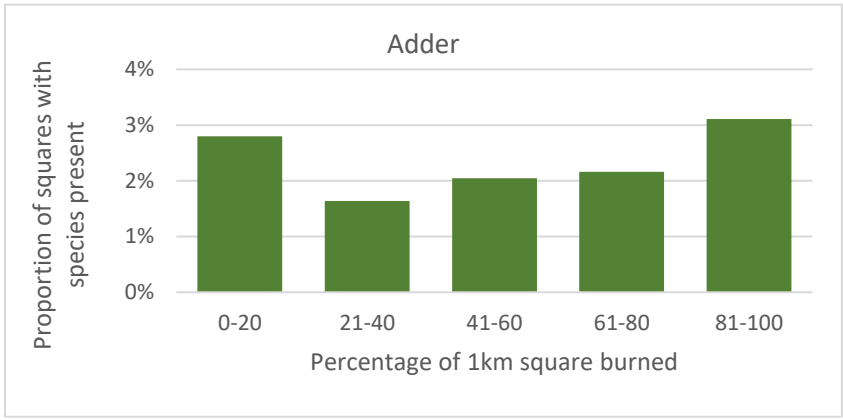
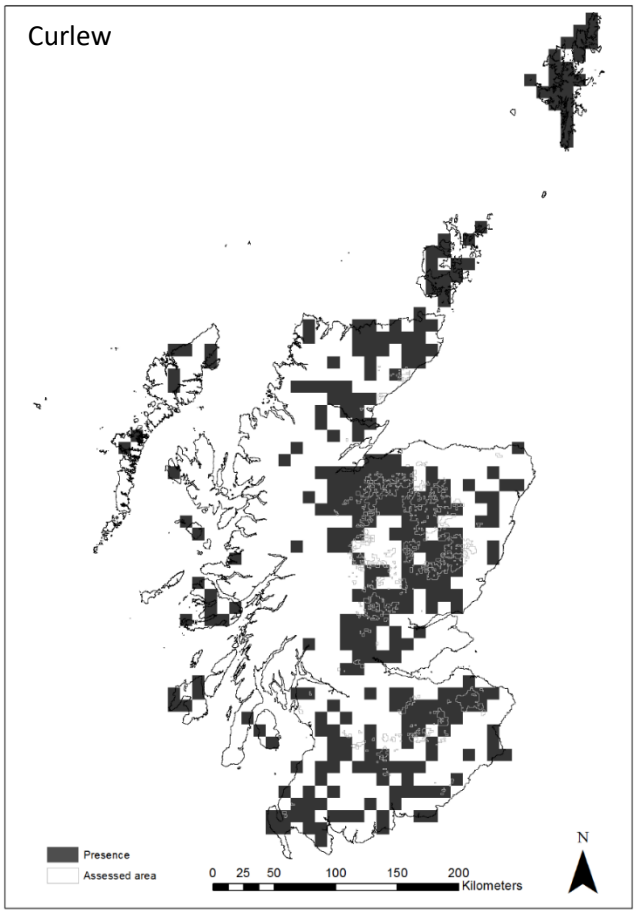


Figure 5. The occurrence (presence only) of adder records in relation to the intensity of muirburn; a) map showing the occurrence of records for each 10 by 10 km square* within the area assessed (presence of records only, the absence of records may not reflect absence on the ground), b) the number of 1 km squares where present categorised by the percentage of muirburn recorded for each 1 km square, and c) the proportion of squares within each category of muirburn with species present. Species occurrence data from NBN (2020) and courtesy of NBN data partners (Appendix 1). * Data were analysed at the 1 km scale but, are mapped at the 10 by 10 km square scale at the request of the data holders.

a)



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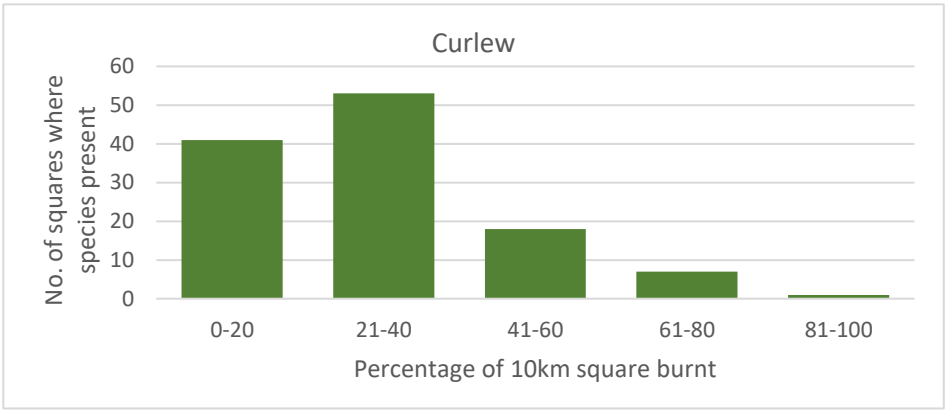

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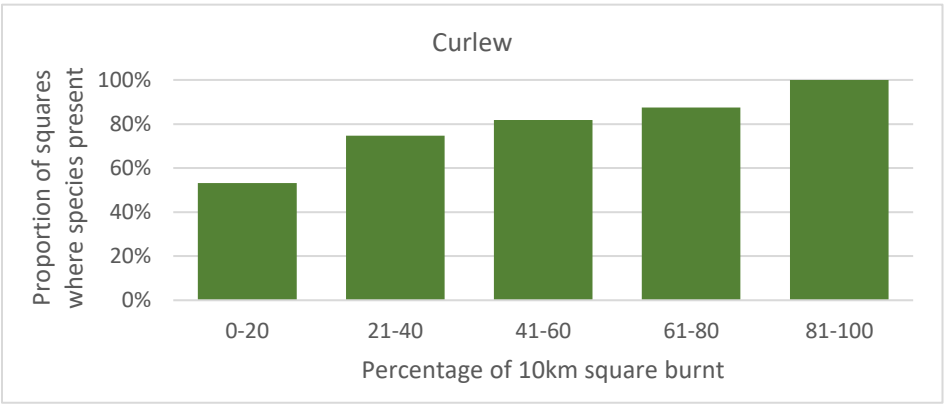

Figure 6. The distribution of curlew in relation to the intensity of muirburn; a) map showing occurrence at the 10 by 10 km square scale within the assessed area, b) the number of 100 km^2 squares where present categorised by the percentage of muirburn recorded for each 100 km^2 square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data from BTO BBA (Gillings et al. 2019).

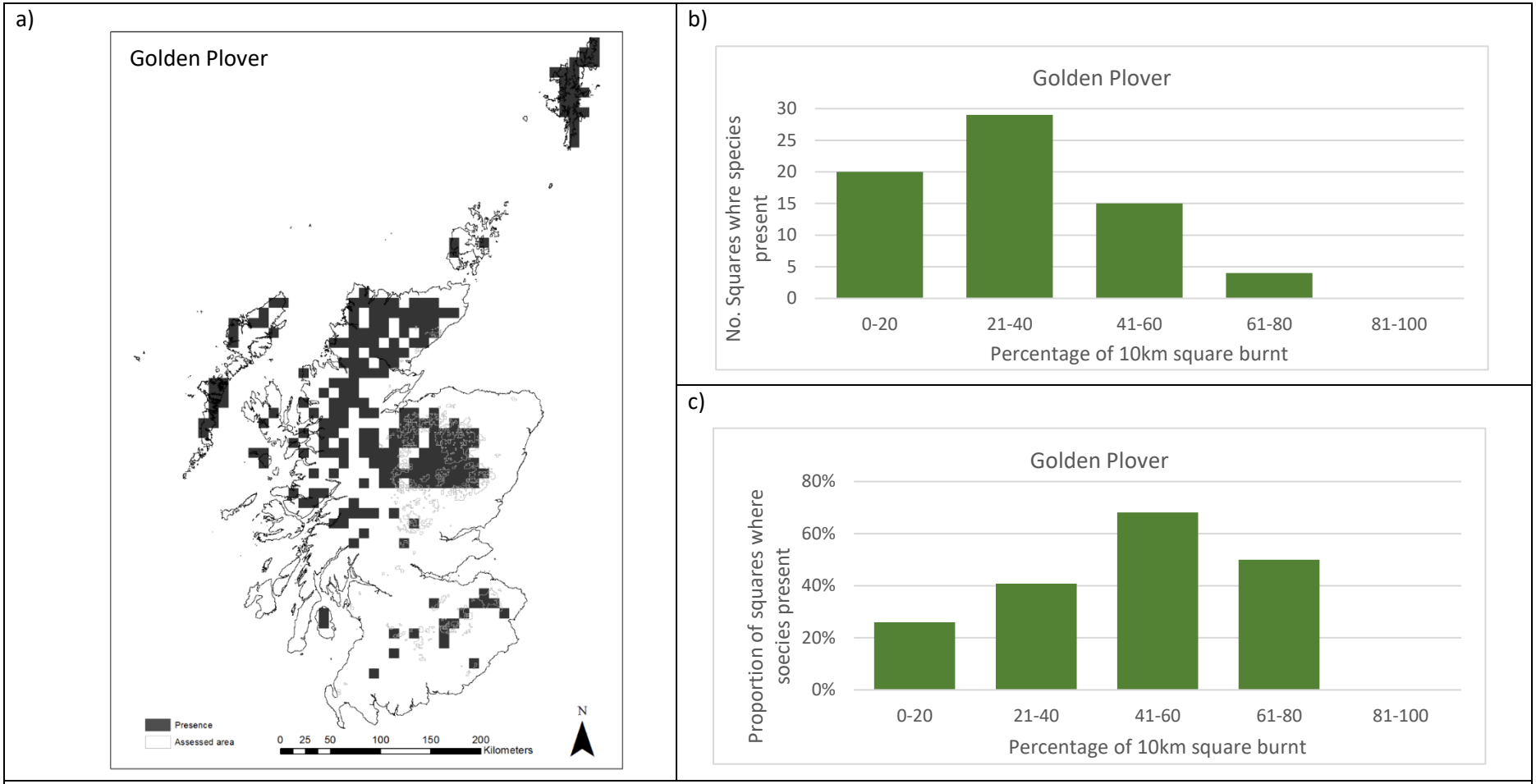

Figure 7. The distribution of golden plover in relation to the intensity of muirburn; a) map showing occurrence at the 10 by 10 km square scale within the assessed area, b) the number of 100 km^2 squares where present categorised by the percentage of muirburn recorded for each 100 km^2 square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data from BTO BBA (Gillings et al. 2019).

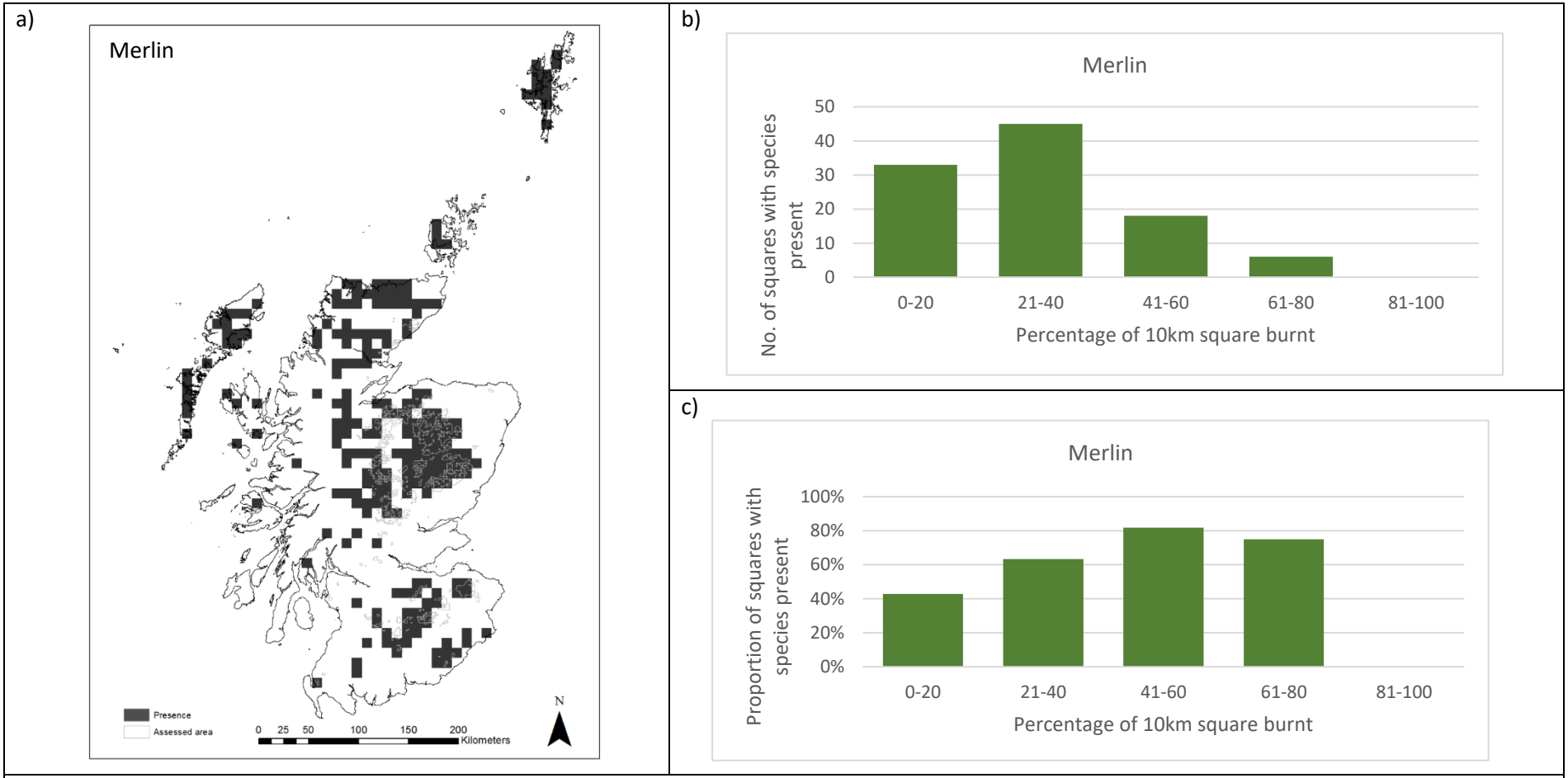

Figure 8. The distribution of merlin relation to the intensity of muirburn; a) map showing occurrence at the 10 by 10 km square scale within the assessed area, b) the number of 100 km^2 squares where present categorised by the percentage of muirburn recorded for each 100 km^2 square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data from BTO BBA (Gillings et al. 2019).

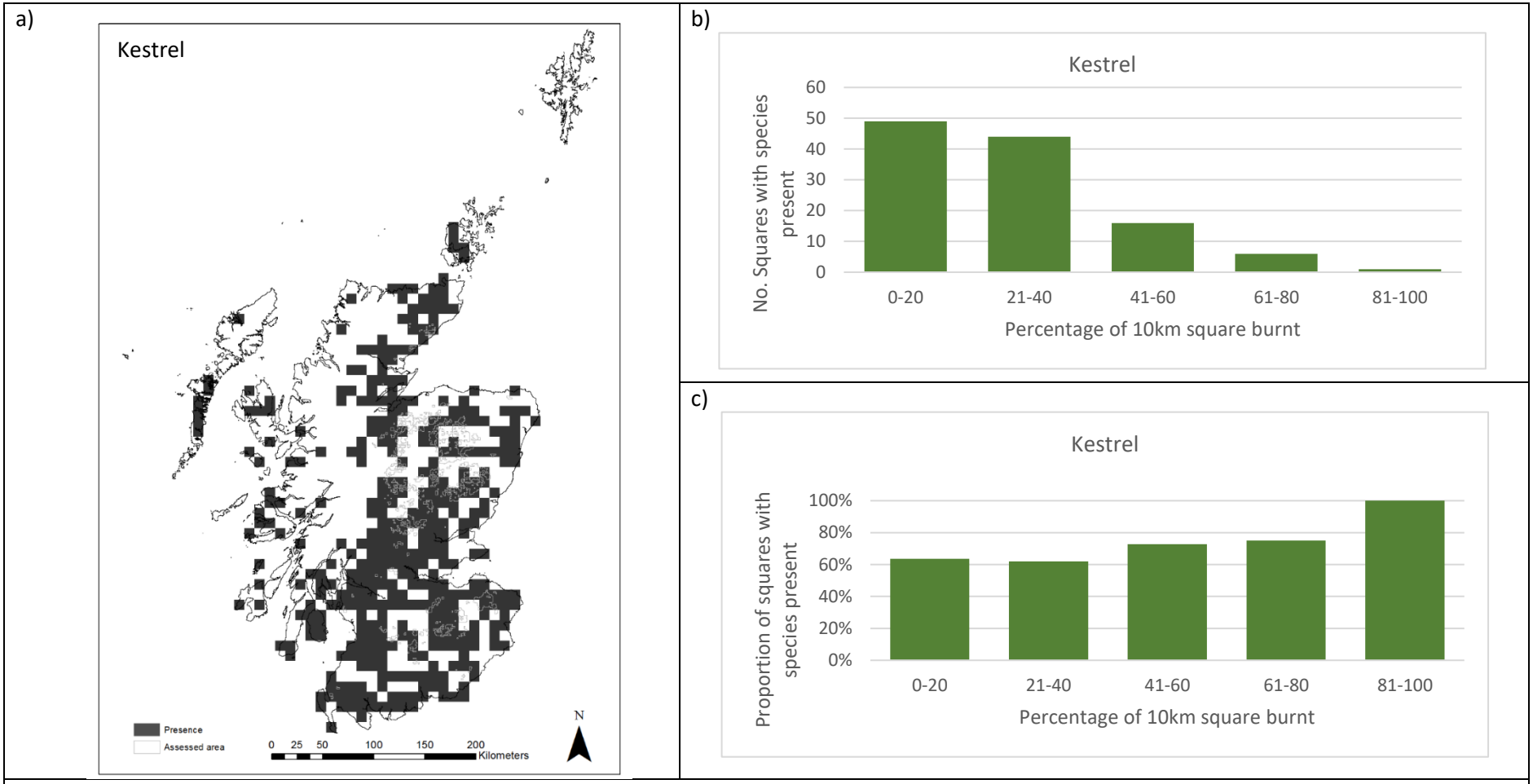

Figure 9. The distribution of merlin relation to the intensity of muirburn; a) map showing occurrence at the 10 by 10 km square scale within the assessed area, b) the number of 100 km^2 squares where present categorised by the percentage of muirburn recorded for each 100 km^2 square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data from BTO BBA (Gillings et al. 2019).

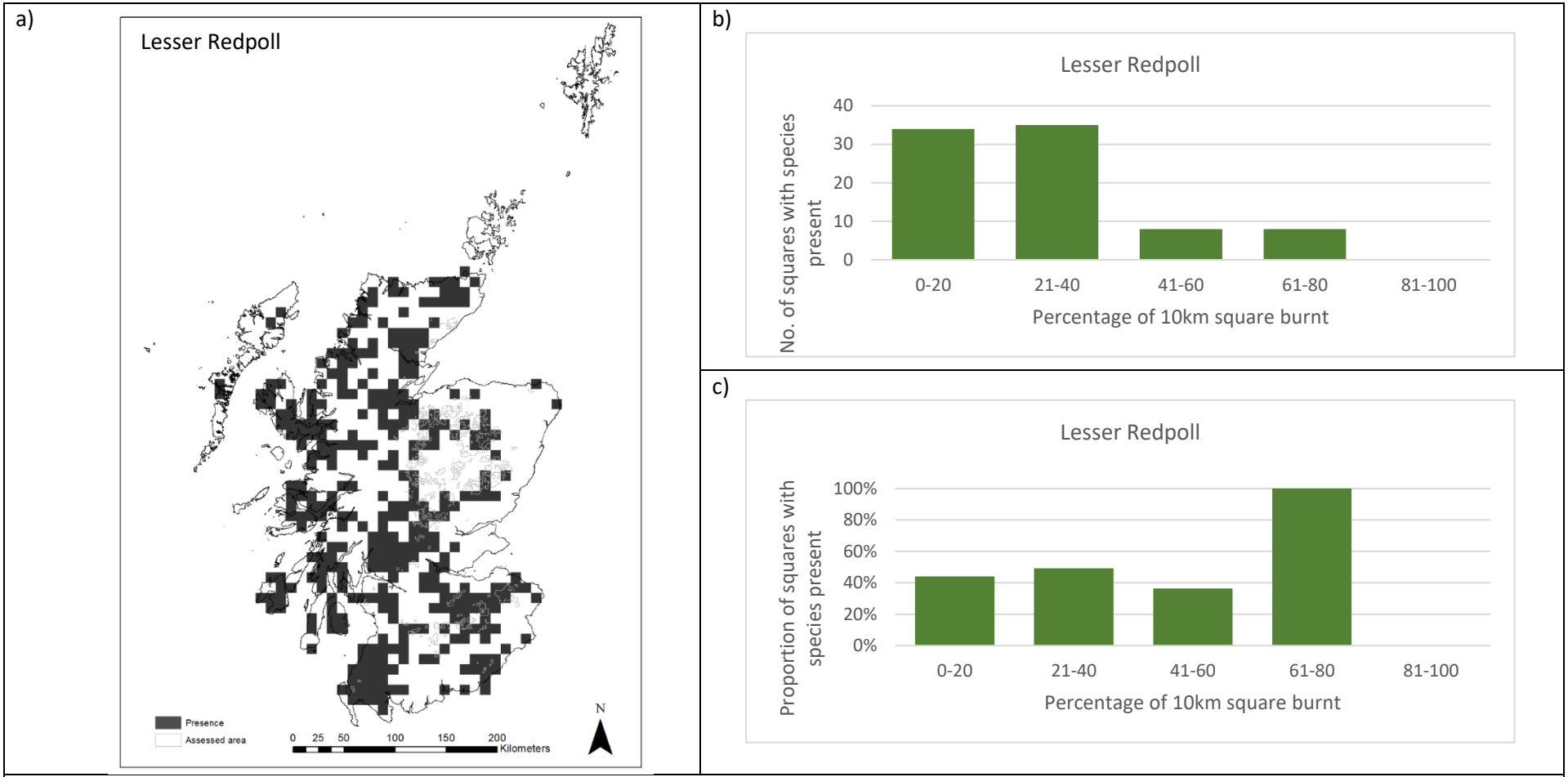

Figure 10. The distribution of lesser redpoll relation to the intensity of muirburn; a) map showing occurrence at the 10 by 10 km square scale within the assessed area, b) the number of 100 km^2 squares where present categorised by the percentage of muirburn recorded for each 100 km^2 square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data from BTO BBA (Gillings et al. 2019).

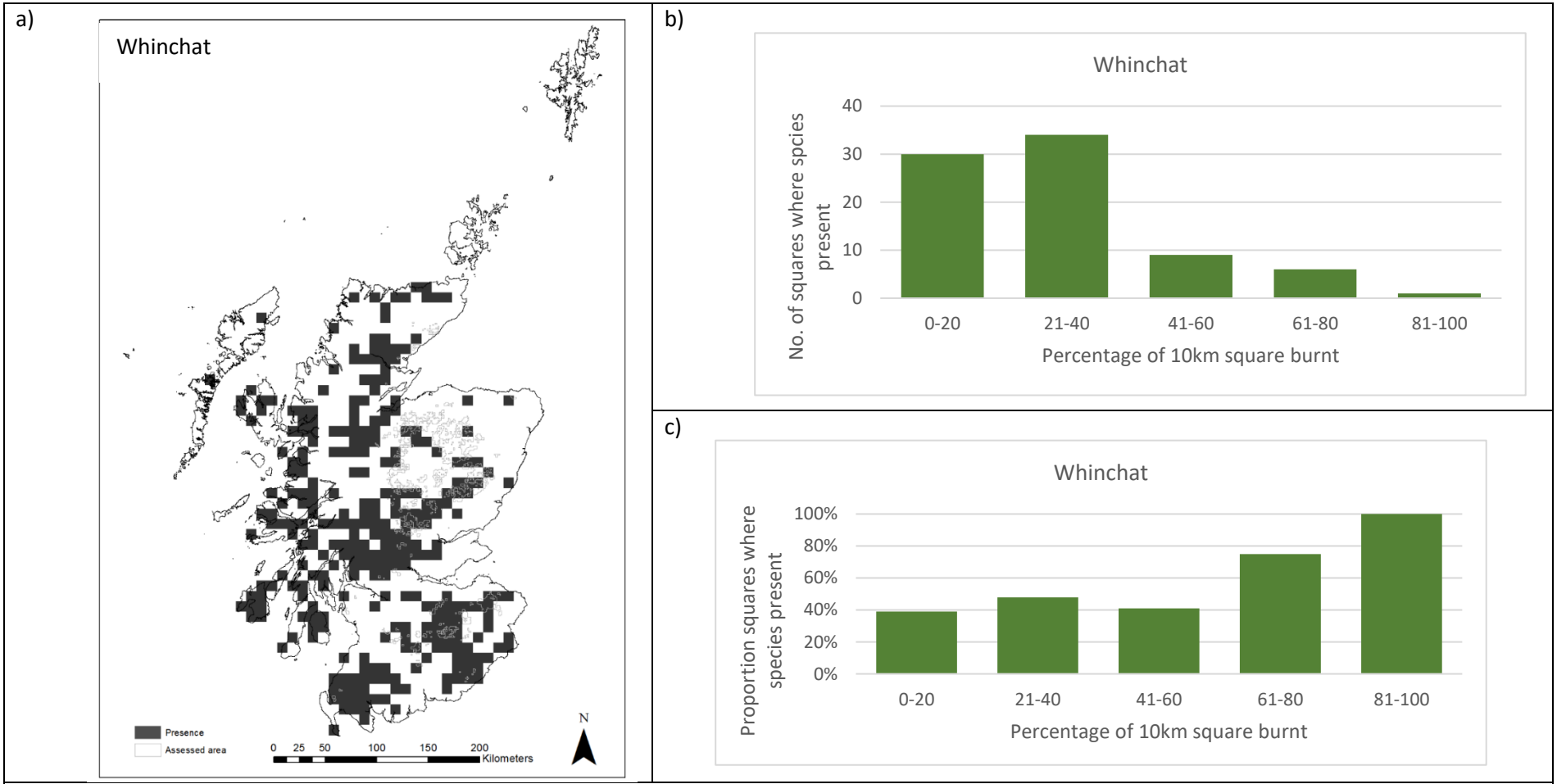

Figure 11. **The distribution of whinchat in relation to the intensity of muirburn;** a) map showing occurrence at the 10 by 10 km square scale within the assessed area, b) the number of 100 km^2 squares where present categorised by the percentage of muirburn recorded for each 100 km^2 square, and c) the proportion of squares within each category of muirburn with species present. Species distribution data from BTO BBA (Gillings et al. 2019).

5 Discussion

Birch sp. are regarded as pioneer species associated with primary succession of open ground and dwarf shrub communities to shrub and woodland habitats. Birch tends to favour well drained and acidic soils, though downy birch *B. pubescens* tolerates poorer drainage and grows in wetter heavier soils than silver birch *B. pendula*. Rotational muirburn is likely to kill emerging tree saplings and suppress succession and establishment of birch species. While the pattern of occurrence of birch in relation to percentage muirburn is not entirely clear the proportional occurrence shows an overall decline with increasing burning which suggests that muirburn supresses the colonisation and establishment of birch woodland. The negative impact of muirburn on a tree species is not surprising given that one of the reasons for muirburn is to suppress succession and to maintain an open dwarf-shrub habitat. Though burning is likely to be the main driver limiting woodland succession on suitable areas of moorland other factors such grazing and wild herbivore management, altitude and exposure may also be important factors in some areas. Birches form open canopy woodlands which allows a variety of mosses, grasses, and flowering plants to grow beneath, and directly and indirectly supports a range of other vertebrate and invertebrate species (e.g. Kennedy & Southwood 1984; Brandle & Brandl 2001).

Blaeberry is a common dwarf shrub that only comprises a small percentage of the vegetation cover on heather moorland, yet it often dominates field-layer vegetation in boreal and temperate conifer forests on acidic soils (Welch et al. 1994; Lohmus & Remm 2017). In moorland and woodland habitats blaeberry may be an important seasonal food source for wildlife. In terms of biodiversity blaeberry directly and indirectly supports several vertebrate and invertebrate herbivores, frugivores and insectivores (Welch et al. 1994; Wegge and Kastdalen, 2008). Fire removes the aerial shoots but if the rhizomes are not destroyed plants can rapidly recolonise through vegetative growth, though there is some evidence that blaeberry may decline under regular burning (Welch et al. 1994; Glaves et al. 2013). Blaeberry therefore appears tolerant to moderate to high levels of muirburn but may be suppressed at the highest (>81%) levels of muirburn. Blaeberry tends to favour drier soils and therefore may also benefit from moorland drainage if and where this practice is carried out. The eastern and north-eastern distribution of this species may also therefore be influenced by the fact that the north-east of Scotland tends to be drier than the west.

The green hairstreak butterfly is widespread throughout Britain and occurs in a wide range of habitats from chalk and rough grassland, bogs and moorlands but tends to be associated with shrub habitats. Though the species is recorded as feeding on a range of food plants (e.g. bird's-foot trefoil *Lotus corniculatus*, gorse *Ulex europaeus*, and broom *Cytisus scoparius*) on heather moorland blaeberry is used almost exclusively (Butterfly Conservation, 2020). The species was most commonly recorded on moorland with low to moderate (<40%) muirburn but, the pattern in the proportion of sightings is less clear and interpretation is difficult due to the small number (n = 83) of records that intersect with the area surveyed. In addition, as the species is “semi-cryptic” detection may be influenced by habitat with the species potentially being more visible in recently or extensively burnt habitat areas.

The adder is distributed, albeit patchily, throughout mainland Scotland, though more common in the lowlands it is also found up to 600 m and occasionally higher (Mcinerny & Minting 2018; Reading et al. 1994). On the mainland the distribution is patchy, with concentrations in parts of Caithness and Sutherland, Wester and Easter Ross, Aberdeenshire, Angus, Perth and Kinross; and further to the south in Argyll and Bute, Stirlingshire, Strathclyde, Ayrshire, Scottish Borders, East Lothian and Dumfries and Galloway (Mcinerny & Minting 2018; Reading et al. 1994). Adders are present in a range of habitats including coastal habitats, cliffs, screes and boulder fields, woodland clearings and golf courses, though most are found on upland moors and lowland mosses and flows (Mcinerny & Minting 2018; Reading et al. 1994). The effects of muirburn and wider grouse moor management on adders and other herptiles is not well understood (Glaves et al. 2005, 2013). Most reptiles require open, sunny

areas and natural succession on unmanaged sites can reduce habitat suitability for reptiles, hence land management, including burning, can have an important role to play in halting succession and maintaining suitable conditions. However, fire can also kill animals (either when active or while hibernating - adders hibernate from around September to March) (Baker et al. 2004; Glaves et al. 2005). In their review of the effects of muirburn on herptiles in England Glaves et al. (2005) found few pertinent studies and those that were reviewed reported both positive and negative effects. Mcinerny & Minting (2018) also note that muirburn may have a negative impact on adder populations in Scotland. The results presented here suggest that adders occur, at low levels, consistently across the intensity range of muirburn indicating that they are tolerant of a range of muirburn and/or benefit from other aspects of grouse moor management. The results presented here do not take into account "detectability" and it could be that adders are more visible on heather moorland with a high percentage of burning. Adders also likely prefer dry open moorland found in the east of Scotland where a large proportion of grouse moors are found, though the concentration of adder records from Dumfries and Galloway is not necessarily consistent with that.

Curlew and golden plover are ground nesting waders that are known to benefit from grouse moor management practices including muirburn and predator control (Fletcher et al. 2010; Newey et al. 2016; Douglas et al. 2017; Mustin et al. 2018; Littlewood et al. 2019). The results here show that the proportion of hectads with curlew increase with increasing percentage burn, which contrasts with golden plover which show a strong response to low and particularly intermediate levels of burning and occur in a very small proportion of squares with higher levels of burning. Disentangling the effects of muirburn per se from other grouse moor management practices, wider landscape effects, and even the effects of geography and geology, is not possible within this study. Curlew have been shown to be most abundant where vegetation structure is relatively heterogeneous, and golden plover to be positively associated with short vegetation, particularly dwarf shrub cover (Pearce-Higgins & Grant 2006). In their study of avian diversity among upland estates with differing management objectives and practices, Newey et al. (2016) show that curlew and golden plover are strongly influenced by percentage burning, longitude and within estate habitat diversity but, that land management objectives per se had a less strong effect. Littlewood et al. (2019) from an analysis of avian data from 18 grouse moors from northern England and Scotland show that predator control has a strong positive effect on golden plover and curlew but, that muirburn has only a weak positive effect on numbers of these two species. Overall the results presented here and evidence from the wider literature strongly suggest that curlew and golden plover benefit from low to moderate muirburn and associated grouse moor management, though golden plover appear to benefit more from less intense burning as heather cover may be reduced, while curlew may benefit from the heterogenous mosaic of vegetation.

The merlin is widespread throughout Scotland (Rebecca & Bainbridge 1998; Ewing et al. 2011). As an upland species in the breeding season merlin are, in Scotland, largely ground nesting and nest in banks of older tall and thick heather. The species prefers open habitats such as moorland and scrubland where in the breeding season it hunts and primarily feeds on small birds particularly meadow pipits, but its diet also includes skylark and wheatear and occasionally insects which they take on the wing. As a ground nesting bird that prefers open habitats with good numbers of small passerines, merlin benefit from moorland management, but too high a frequency of burning may be detrimental due to loss of nesting habitat and a more homogeneous habitat (Ewing et al. 2011; Heavisides et al. 2017). The fact that merlin benefit from some level of intermediate burning is supported by the data here which show that merlin were most frequently recorded in areas with low to moderate levels of muirburn, and within muirburn classes the proportion of hectads with records increased up to 41-60% burning before declining rapidly with greater burning.

Kestrels are widespread throughout much of Scotland. Field voles (short-tailed field vole, *Microtus agrestis*) are by far the kestrels preferred food but, they will readily take other small mammals such as wood mice and shrews, insects and earthworms. Though in urban areas where small mammals are

absent or less available, kestrels will take small birds. Kestrel numbers are positively related to vole numbers and show higher survival and breeding success when voles, which themselves show regular and marked 3-5 -year fluctuations (Lambin 2008), occur in high numbers. Field voles are an important prey item for a number of upland predators (Redpath et al. 1995, 2002a,b). Field voles are ubiquitous and locally numerous in the UK, though absent from some islands. They inhabit rough, often damp, ungrazed grassland, including forest plantations where there is still grass cover, but are sparse in marginal habitats such as hedgerows, woodlands, bogs, and moorland wherever grass is available (Lambin 2008; Redpath et al. 2002a,b). As grass cover tends to decline with muirburn, along with the abundance of other grass favouring species such meadow pipit, field vole numbers and hence their predators, in this case kestrel, may also be expected to decline with increasing muirburn (Smith et al. 2001; Redpath et al. 2002a,b; Pearce-Higgins & Grant 2006). However, while the pattern in kestrel occurrences suggests that kestrel is favoured by light to moderate levels of burning, the pattern in proportion of occurrence across burn categories is relatively consistent suggesting that kestrel is indifferent to the level of muirburn. This pattern may be an artefact of the small number of squares and/or the small number of kestrel records for squares with high levels of burning. Kestrel may also respond to other aspects of grouse moor management not measured here.

Lesser redpoll is a widespread breeding species in Scotland, though largely absent from the NE and the larger upland massifs of the Cairngorms and western mountains. Lesser redpoll feed on the seeds of birch, aspen, willow, spruces and pines, though insects may be important during the breeding season. As a tree nesting species, lesser redpoll is often common in birch and alder woodland and are likely to favour areas with little or no burning. Certainly, most records are from hectads where there is little or moderate burning and a similar pattern is found in the proportion of hectads with records which, on the whole, suggests that this species favours areas with little to intermediate burning. The very high (100%) proportion of hectads with records in the 61-80% burn category may, as with some other species, be a result of small sample sizes in one or both of the number of squares in that burn category or the small number of records in that category. As the distribution of lesser redpoll is likely to be driven by the distribution of its preferred woodland/scrub habitat other aspects of grouse moor management that impact on tree establishment and growth, such as domestic and wild herbivore management, are also likely to affect lesser redpoll too.

Whinchats are a UK breeding migrant and were once widespread throughout the lowlands of the UK but, are now largely confined to upland and marginal upland areas where extensive semi-natural habitats including grassland, moorland, bracken, scrub and scattered trees support breeding populations (Calladine & Bray 2012; Border et al. 2016). Whinchats are largely insectivorous, hunting insects from a perch, but also eat seeds, and prefer open grassy country with scattered shrubs to provide song perches and vantage points for foraging. Breeding territories on moorland are associated with dense vegetation particularly bracken and a mix of fine grasses and dwarf shrubs, and also with wet flushes, though whinchat seem to avoid short graminoids (Pearce-Higgins & Grant 2006). Previous studies have shown that whinchat are less abundant on grouse moors than other moors, though the reasons for this dissociation are not entirely clear. It is likely that muirburn removes favoured dense vegetation and perches (Tharme et al. 2001; Newey et al. 2016). However, the results here do not show a clear pattern. While the majority of records are for hectads with little to moderate burning the pattern in the proportion of hectads with different levels of burning suggests that the proportion of hectads with whinchat records increases with greater burning. However, this may again be due to small sample sizes associated with the number of records and squares with a high percentage of burning.

Occurrence data for adder, green hairstreak butterfly and the BSBI data for birch and blaeberry are opportunistic sightings or data from unstructured surveys. These data only show where a species, or signs of that species, have been seen and recorded. Without statistical modelling it is not possible to infer anything about absence from these data, or where a species might reasonably be expected to occur given its environment and habitat requirements. While the NMPS data are from a structured

survey and the records from each plot are likely to represent an accurate species list for each plot, so that it is possible to infer absence of a species from any given plot, it is not possible without modelling to extrapolate beyond the sampling plots. The BBA on the other hand is a large-scale systematic survey that covers the whole of the UK and the presence or absence of a species within each hectad is likely to be a good indication of the presence or absence of that species, though absences should be considered pseudo-absences because it is not possible to imply with absolute confidence that the absence of a record represents absence of a species.

Relying on sighting data of species has the advantage of simplicity and transparency, but also confounds factors such as survey effort, expertise in species identification, and detectability. Records are often concentrated around urban areas, and often represent popular and/or easily identified species. Combined, these factors result in limited sample size and geographic coverage. One solution to this problem would be to use species distribution modelling that combines species occurrence records, habitat and environmental data to model, or 'predict', where the species would be likely to occur throughout the area of interest. This approach greatly increases the effective geographic coverage allowing assessment beyond the areas where physical records exist. Allowing for the issues of sighting data, the current assessment is somewhat limited by the small number of spatially unique occurrences that intersect with the area assessed for muirburn.

The estimate of muirburn per kilometre square used here is based on an assessment of 25 cells, within each 1 km^2, i.e. a grid 5 by 5 cells where each cell measured 200 m by 200 m, so each cell represents 4% of the area of each square. A cell was classed as burnt if more than 50% of the cell showed evidence of burning. Therefore, estimates of percentage burn may, depending on the area within each cell burnt, represent over- or under- estimates of the actual ground burnt. For example, a square where every cell showed at least 51% burning would have been classed as 100% burnt when the actual area burnt would have been between 51% - if every cell were just over 50% burnt, and 100% - if every cell was completely burnt. On the other hand 1 km square where every cell was less than 51% burnt would be classified as 0% burnt even though up to 50% of the square could in reality be burnt. Further, a 1 km square classed as 4% burnt, that is there was one cell classed as (>50%) burnt, could be between 2 – 4% burnt.

The estimated percentage muirburn at the hectad scale may be influenced by the distribution of 1 km squares assessed, because in some cases not all 100 1 km squares within a hectad were assessed. This means that if only a small number of squares had been assessed the median, used as the estimated percentage burn for hectads, may be unduly influenced by extreme values. It is notable that relatively few hectads had more than 61% median burn values and this is likely due the fact that areas of intense muirburn are quite small and isolated. Assessment of the distribution of muirburn and the effects of muirburn would be greatly improved by increasing the area assessed. This would give greater geographic coverage, intersect with more species occurrence data, and include a greater diversity of muirburn intensity.

Interpretation of aerial imagery is not straightforward and identification of muirburn which, depending on time since burnt can vary enormously in presentation and characteristics, can be difficult, though previous studies have successfully used this approach (Yallop et al. 2006; Douglas et al. 2015; Newey et al, 2016). All image interpretation work was carried out by one interpreter (DF) with extensive expertise and experience of upland vegetation and management research. Any bias will at least be consistent across the whole data set, any errors in classifying cells as burnt (>50% burn) or unburnt (<50%) will, assuming errors are random, cancel out.

Here we have assessed the occurrence of ten species in relation to intensity of muirburn in areas of Scotland where grouse moor management is an important land use. Overall, it proved challenging to identify clear patterns in the occurrence of these species relative to intensity of muirburn; birch is the only species assessed here where prevalence appeared to decline with increasing intensity of muirburn, though blaeberry also showed evidence of lower prevalence at the highest category of

muirburn. Green hairstreak butterfly, adder, and kestrel showed fairly consistent occurrence across the range of muirburn measured. Whereas golden plover and merlin occurrence peaked at intermediate levels of muirburn. Curlew, whinchat and lesser redpoll appeared to increase in prevalence with increasing percentage of ground classed as burnt. However, for all species care is needed in interpreting the relationship between species occurrence and the high levels of muirburn as the sample size of both the number of assessed squares within each burn category, and the number of species records are low for these high intensity burn categories.

6 References

Amphibian and Reptile Groups of the UK (2019). Record Pool. Occurrence dataset https://doi.org/10.15468/zen1gd accessed via GBIF.org on 2019-11-14.

Biological Records Centre (2017). Reptiles and Amphibians Dataset. Occurrence dataset https://doi.org/10.15468/1lhrhx accessed via GBIF.org on 2019-11-15.

Border, J. A., Henderson, I. G., Redhead, J. W., & Hartley, I. R. (2016). Habitat selection by breeding Whinchats Saxicola rubetra at territory and landscape scales. Ibis, 159(1), 139–151. https://doi.org/10.1111/ibi.12433

Brändle, M., & Brandl, R. (2001). Species richness of insects and mites on trees: Expanding Southwood. Journal of Animal Ecology, 70(3), 491–502. https://doi.org/10.1046/j.1365-2656.2001.00506.x

Brooker, R. W., Hester, A. J., Newey, S., & Pakeman, R. J. (2018). Socio-economic and biodiversity impacts of driven grouse moors in Scotland: Part 2 Biodiversity impacts of driven grouse moors in Scotland (p. 49). p. 49. Retrieved from https://sefari.scot/document/socio-economic-and-biodiversity-impacts-of-driven-grouse-moors-in-scotland-part-2

Buglife (2017). Invertebrate records from sites that are mainly across Scotland. Occurrence dataset https://doi.org/10.15468/aaxvmc accessed via GBIF.org on 2019-11-14.

Butterfly Conservation (2018). Butterfly distributions for Scotland from Butterfly Conservation and the Biological Records Centre. Occurrence dataset ALSO "Data were provided from the Butterflies for the New Millennium recording scheme, courtesy of Butterfly Conservation" https://doi.org/10.15468/tqf8z3 accessed via GBIF.org on 2019-11-15.

Caledonian Conservation (2017). Incidental herptile records 2005-16. Occurrence dataset https://doi.org/10.15468/xab51h accessed via GBIF.org on 2019-11-15.

Calladine, J., & Bray, J. (2012). The importance of altitude and aspect for breeding Whinchats *Saxicola rubetra* in the uplands: Limitations of the uplands as a refuge for a declining, formerly widespread species? Bird Study, 59(1), 43–51. https://doi.org/10.1080/00063657.2011.623767

Reading, C. J., Buckland, S. T., McGowan, G. W., Gorzula, S., Jayasinghe, G., Staines, B. W., Ahmadi, S. (1994). Status of the Adder *Vipera berus* in Scotland. Scottish Natural Heritage Research, Survey and Monitoring Report No. 38.

Douglas, D. J. T., Beresford, A., Selvidge, J., Garnett, S., Buchanan, G. M., Gullett, P., & Grant, M. C. (2017). Changes in upland bird abundances show associations with moorland management. Bird Study, 64(2), 242–254. https://doi.org/10.1080/00063657.2017.1317326

Dumfries and Galloway Environmental Resources Centre (2017). Amphibian and reptile data for Dumfries and Galloway. Occurrence dataset https://doi.org/10.15468/016wkv accessed via GBIF.org on 2020-01-13

Ewing, S. R., Rebecca, G. W., Heavisides, A., Court, I. R., Lindley, P., Ruddock, M., … Eaton, M. A. (2011). Breeding status of Merlins *Falco columbarius* in the UK in 2008. Bird Study, 58(4), 379–389. https://doi.org/10.1080/00063657.2011.606497

Fletcher, K., Aebischer, N. J., Baines, D., Foster, R., & Hoodless, A. N. (2010). Changes in breeding success and abundance of ground-nesting moorland birds in relation to the experimental deployment of legal predator control. Journal of Applied Ecology, 47(2), 263–272. https://doi.org/10.1111/j.1365-2664.2010.01793.x

Froglife (2018). Amphibian and reptile records for Great Britain 2016-2017. Occurrence dataset https://doi.org/10.15468/niyja0 accessed via GBIF.org on 2019-11-14.

Glaves, D. J., Haycock, N. E., Costigan, P., Coulson, J. C., Marrs, R. H., Robertson, P. A., & Younger, J. (2005). Defra Review of the Heather and Grass Burning Regulations and Code: Science Panel Assessment of the Effects of Burning on Biodiversity, Soils and Hydrology. Habitat, (June), 119. https://doi.org/10.13140/RG.2.2.34027.75044

Glaves, D. J., Morecroft, M., Fitzgibbon, C., Owen, M., Phillips, S., & Lepitt, P. (2013). Natural England Review of Upland Evidence 2012 - The effects of managed burning on upland peatland biodiversity, carbon and water. Natural England Evidence Review, Number 004. Natural England.

Heavisides, A., Barker, A., & Poxton, I. (2017). Population and breeding biology of Merlins in the Lammermuir Hills. British Birds, 110(December), 138–154. Retrieved from https://britishbirds.co.uk/article/population-breeding-biology-merlins-lammermuir-hills/

Hesford, N., Fletcher, K., Howarth, D., Smith, A. A., Aebischer, N. J., & Baines, D. (2019). Spatial and temporal variation in mountain hare (*Lepus timidus*) abundance in relation to red grouse (Lagopus lagopus scotica) management in Scotland. European Journal of Wildlife Research, 65(3), 33. https://doi.org/10.1007/s10344-019-1273-7

Highland Biological Recording Group (2018a). HBRG Insects Dataset. Occurrence dataset https://doi.org/10.15468/u1p4wc accessed via GBIF.org on 2019-11-15.

Highland Biological Recording Group (2018b). HBRG P.F. Entwistle Insects Dataset. Occurrence dataset https://doi.org/10.15468/fmcwyl accessed via GBIF.org on 2019-11-15.

Highland Biological Recording Group (2018c). HBRG P.F. Entwistle Insects Dataset. Occurrence dataset https://doi.org/10.15468/fmcwyl accessed via GBIF.org on 2019-11-15.

Highland Biological Recording Group (2018d). HBRG Vertebrates (not Badger) Dataset. Occurrence dataset https://doi.org/10.15468/vaassa accessed via GBIF.org on 2019-11-15.

John Muir Trust (2017). Species Records for John Muir Trust Properties Nevis, Sandwood, Quinag and Schiehallion 2010. Occurrence dataset https://doi.org/10.15468/n9dwn0 accessed via GBIF.org on 2019-11-14.

John Muir Trust (2017a). Species Records for John Muir Trust Properties 2007-2009. Occurrence dataset https://doi.org/10.15468/p5lw5z accessed via GBIF.org on 2019-11-14.

John Muir Trust (2017b). Species Records for John Muir Trust Properties 2007-2009. Occurrence dataset https://doi.org/10.15468/p5lw5z accessed via GBIF.org on 2019-11-14.

Kennedy, C. E. J., & Southwood, T. R. E. (1984). The Number of Species of Insects Associated with British Trees: A Re-Analysis. The Journal of Animal Ecology, 53(2), 455. https://doi.org/10.2307/4528

Lambin, X. (2008). Field voles. In S, Harris & D.W.Yalden, eds,. Mammals of the British Isles: Handbook, 4th Edition, pp. 100-1007, The Mammal Society.

Littlewood, N. A., Mason, T. H. E., Hughes, M., Jacques, R., Whittingham, M. J., & Willis, S. G. (2019). The influence of different aspects of grouse moorland management on nontarget bird assemblages. Ecology and Evolution, ece3.5613. https://doi.org/10.1002/ece3.5613

Lõhmus, A., & Remm, L. (2017). Disentangling the effects of seminatural forestry on an ecosystem good: Bilberry (*Vaccinium myrtillus*) in Estonia. Forest Ecology and Management, 404(July), 75–83. https://doi.org/10.1016/j.foreco.2017.08.035

Lorn Natural History Group (2018a). LNHG Biological Records Dataset. Occurrence dataset https://doi.org/10.15468/ejve6c accessed via GBIF.org on 2019-11-15.

Lorn Natural History Group (2018b). LNHG Biological Records Dataset. Occurrence dataset https://doi.org/10.15468/ejve6c accessed via GBIF.org on 2019-11-15.

Matthews, K., Miller, D., Gandossi, G., Fielding, D. & Newey, S. (2020). Mapping the areas of moorland that are actively managed for grouse and the intensity of current management regimes. Part 3 - Research to assess socioeconomic and biodiversity impacts of driven grouse moors and to understand the rights of gamekeepers. Available at: https://sefari.scot/document/part-3-mapping-the-areas-and-management-intensity-of-moorland-actively-managed-for-grouse

Mcinerny, C., & Minting, P. (2016). The Amphibians & Reptiles of Scotland. The Glasgow Natural History Society, Glasgow, Scotland.

Mustin, K., Arroyo, B., Beja, P., Newey, S., Irivine, R. J., Kestler, J., & Redpath, S. M. (2018). Consequences of game bird management for non-game species in Europe. Journal of Applied Ecology, 55(5), 2285–2295. https://doi.org/10.1111/1365-2664.13131

National Trust for Scotland (2018). National Trust for Scotland Species Records. Occurrence dataset https://doi.org/10.15468/a5y1cz accessed via GBIF.org on 2019-11-15.

National Trust for Scotland (2018). National Trust for Scotland Species Records. Occurrence dataset https://doi.org/10.15468/a5y1cz accessed via GBIF.org on 2019-11-15.

Newey, S., Mustin, K., Bryce, R., Fielding, D., Redpath, S., Bunnefeld, N., … Irvine, R. J. (2016). Impact of Management on Avian Communities in the Scottish Highlands. PLOS ONE, 11(5), e0155473. https://doi.org/10.1371/journal.pone.0155473

North East Scotland Biological Records Centre (2017a). NE Scotland butterfly and moth records 1800-2010. Occurrence dataset https://doi.org/10.15468/7nnp7d accessed via GBIF.org on 2019-11-14.

North East Scotland Biological Records Centre (2017b). North East Scotland Amphibians & Reptiles 1850 - 2016. Occurrence dataset https://doi.org/10.15468/ruf7hc accessed via GBIF.org on 2019-11-14.

Patton, V., Ewald, J. A., Smith, A. A., Newey, S., Iason, G. R., Thirgood, S. J., & Raynor, R. (2010). Distribution of mountain hares *Lepus timidus* in Scotland: results from a questionnaire. Mammal Review, 40(4), 313–326. https://doi.org/10.1111/j.1365-2907.2010.00162.x

Pearce-Higgins, J. W., & Grant, M. C. (2006). Relationships between bird abundance and the composition and structure of moorland vegetation. Bird Study, 53, 112–125.

Rebecca, G. W., & Bainbridge, I. P. (1998). The breeding status of the Merlin *Falco columbarius* in Britain in 1993–94. Bird Study, 45(2), 172–187. https://doi.org/10.1080/00063659809461089

Redpath, C. J., Thirgood, S. J., & Redpath, S. M. (1995). Evaluation of methods to estimate field vole *Microtus agrestis* abundance in upland habitats. Journal of Zoology, 237(1), 49–55. https://doi.org/10.1111/j.1469-7998.1995.tb02745.x

Redpath, S M, Amar, A., Madders, M., Leckie, F. M., & Thirgood, S. J. (2002). Hen harrier foraging success in relation to land use in Scotland. Animal Conservation, 5, 113–118.

Redpath, Stephen M, Thirgood, S. J., & Clarke, R. (2002). Field Vole *Microtus agrestis* abundance and Hen Harrier *Circus cyaneus* diet and breeding in Scotland. Ibis, 144(1), E33–E38. https://doi.org/10.1046/j.0019-1019.2001.00032.x

Scottish Wildlife Trust (2018). Commissioned surveys and staff surveys and reports for Scottish Wildlife Trust reserves - Verified data. Occurrence dataset https://doi.org/10.15468/a6snhl accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018). Survey and monitoring records for Scottish Wildlife Trust reserves from reserve convenors and Trust volunteers - Verified data. Occurrence dataset https://doi.org/10.15468/yyd4b9 accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018a). Casual records for Scottish Wildlife Trust reserves - Verified data. Occurrence dataset https://doi.org/10.15468/zeay1d accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018b). Commissioned surveys and staff surveys and reports for Scottish Wildlife Trust reserves - Verified data. Occurrence dataset https://doi.org/10.15468/a6snhl accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018c). Survey and monitoring records for Scottish Wildlife Trust reserves from reserve convenors and Trust volunteers - Verified data. Occurrence dataset https://doi.org/10.15468/yyd4b9 accessed via GBIF.org on 2019-11-15.

Smith, A. A., Redpath, S. M., Campbell, S. T., & Thirgood, S. J. (2001). Meadow pipits, red grouse and the habitat characteristics of managed grouse moors. Journal of Applied Ecology, 38(2), 390–400. https://doi.org/10.1046/j.1365-2664.2001.00601.x

Sotherton, N., Baines, D., & Aebischer, N. J. (2017). An alternative view of moorland management for Red Grouse *Lagopus lagopus scotica*. Ibis, 159(3), 693–698. https://doi.org/10.1111/ibi.12489

Tharme, A. P., Green, R. E., Baines, D., Bainbridge, I. P., & O'Brien, M. (2001). The effect of management for red grouse shooting on the population density of breeding birds on heather-dominated moorland. Journal of Applied Ecology, 38(2), 439–457. https://doi.org/10.1046/j.1365-2664.2001.00597.x

The Wildlife Information Centre (2017). City of Edinburgh Natural Heritage Service - Ranger Ad-hoc records and sightings. Occurrence dataset https://doi.org/10.15468/ealk6c accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). Borders Backyard Biodiversity. Occurrence dataset https://doi.org/10.15468/jfymio accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). TWIC Biodiversity Field Trip Data (1995-present). Occurrence dataset https://doi.org/10.15468/ljc0ke accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018a). City of Edinburgh Natural Heritage Service - General Public Records. Occurrence dataset https://doi.org/10.15468/mfkmtz accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018b). City of Edinburgh Natural Heritage Service - Green Hairstreak Survey. Occurrence dataset https://doi.org/10.15468/ajaozn accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018c). TWIC Biodiversity Field Trip Data (1995-present). Occurrence dataset https://doi.org/10.15468/ljc0ke accessed via GBIF.org on 2019-11-15.

Thompson, P. S., Douglas, D. J. T., Hoccom, D. G., Knott, J., Roos, S., & Wilson, J. D. (2016). Environmental impacts of high-output driven shooting of Red Grouse *Lagopus lagopus scotica*. Ibis, 158(2), 446–452. https://doi.org/10.1111/ibi.12356

UK Butterfly Monitoring Scheme (2017). UK Butterfly Monitoring Scheme (UKBMS). Occurrence dataset https://doi.org/10.15468/gmqvmk accessed via GBIF.org on 2019-11-15.

UK Butterfly Monitoring Scheme (2017). Wider Countryside Butterfly Scheme (WCBS). Occurrence dataset https://doi.org/10.15468/jgm7ci accessed via GBIF.org on 2019-11-15.

Wegge, P., & Kastdalen, L. (2008). Habitat and diet of young grouse broods: Resource partitioning between Capercaillie (*Tetrao urogallus*) and Black Grouse (*Tetrao tetrix*) in boreal forests. Journal of Ornithology, 149(2), 237–244. https://doi.org/10.1007/s10336-007-0265-7

Welch, D., Scott, D., Moss, R., & Bayfield, N. G. (1994). Ecology of blaeberry and its management in British moorlands. ITE Publications. Retrieved from http://nora.nerc.ac.uk/id/eprint/7902/1/Ecology_of_Blaeberry.pdf

Werritty, A. (2019). Grouse Moor Management Review Group: Report to the Scottish Government.

Yallop, A. R., Thacker, J. I., Thomas, G., Stephens, M., Clutterbuck, B., Brewer, T., & Sannier, C. A. D. (2006). The extent and intensity of management burning in the English uplands. Journal of Applied Ecology, 43(6), 1138–1148. https://doi.org/10.1111/j.1365-2664.2006.01222.x

Annex 1. NBN Data Sources Used in the Study

Amphibian and Reptile Groups of the UK (2019). Record Pool. Occurrence dataset https://doi.org/10.15468/zen1gd accessed via GBIF.org on 2019-11-14.

Biological Records Centre (2017). Reptiles and Amphibians Dataset. Occurrence dataset https://doi.org/10.15468/1lhrhx accessed via GBIF.org on 2019-11-15.

Buglife (2017). Invertebrate records from sites that are mainly across Scotland. Occurrence dataset https://doi.org/10.15468/aaxvmc accessed via GBIF.org on 2019-11-14.

Butterfly Conservation (2018). Butterfly distributions for Scotland from Butterfly Conservation and the Biological Records Centre. Occurrence dataset ALSO "Data were provided from the Butterflies for the New Millennium recording scheme, courtesy of Butterfly Conservation" https://doi.org/10.15468/tqf8z3 accessed via GBIF.org on 2019-11-15.

Caledonian Conservation (2017). Incidental herptile records 2005-16. Occurrence dataset https://doi.org/10.15468/xab51h accessed via GBIF.org on 2019-11-15.

Dumfries and Galloway Environmental Resources Centre (2017). Amphibian and reptile data for Dumfries and Galloway. Occurrence dataset https://doi.org/10.15468/016wkv accessed via GBIF.org on 2020-01-13

Froglife (2018). Amphibian and reptile records for Great Britain 2016-2017. Occurrence dataset https://doi.org/10.15468/niyja0 accessed via GBIF.org on 2019-11-14.

Highland Biological Recording Group (2018). HBRG Insects Dataset. Occurrence dataset https://doi.org/10.15468/u1p4wc accessed via GBIF.org on 2019-11-15.

Highland Biological Recording Group (2018). HBRG P.F. Entwistle Insects Dataset. Occurrence dataset https://doi.org/10.15468/fmcwyl accessed via GBIF.org on 2019-11-15.

Highland Biological Recording Group (2018). HBRG P.F. Entwistle Insects Dataset. Occurrence dataset https://doi.org/10.15468/fmcwyl accessed via GBIF.org on 2019-11-15.

Highland Biological Recording Group (2018). HBRG Vertebrates (not Badger) Dataset. Occurrence dataset https://doi.org/10.15468/vaassa accessed via GBIF.org on 2019-11-15.

John Muir Trust (2017). Species Records for John Muir Trust Properties 2007-2009. Occurrence dataset https://doi.org/10.15468/p5lw5z accessed via GBIF.org on 2019-11-14.

John Muir Trust (2017). Species Records for John Muir Trust Properties 2007-2009. Occurrence dataset https://doi.org/10.15468/p5lw5z accessed via GBIF.org on 2019-11-14.

John Muir Trust (2017). Species Records for John Muir Trust Properties Nevis, Sandwood, Quinag and Schiehallion 2010. Occurrence dataset https://doi.org/10.15468/n9dwn0 accessed via GBIF.org on 2019-11-14.

John Muir Trust (2017). Species Records for John Muir Trust Properties Nevis, Sandwood, Quinag and Schiehallion 2010. Occurrence dataset https://doi.org/10.15468/n9dwn0 accessed via GBIF.org on 2019-11-14.

Lorn Natural History Group (2018a). LNHG Biological Records Dataset. Occurrence dataset https://doi.org/10.15468/ejve6c accessed via GBIF.org on 2019-11-15.

Lorn Natural History Group (2018b). LNHG Biological Records Dataset. Occurrence dataset https://doi.org/10.15468/ejve6c accessed via GBIF.org on 2019-11-15.

National Trust for Scotland (2018). National Trust for Scotland Species Records. Occurrence dataset https://doi.org/10.15468/a5y1cz accessed via GBIF.org on 2019-11-15.

National Trust for Scotland (2018). National Trust for Scotland Species Records. Occurrence dataset https://doi.org/10.15468/a5y1cz accessed via GBIF.org on 2019-11-15.

North East Scotland Biological Records Centre (2017). NE Scotland butterfly and moth records 1800-2010. Occurrence dataset https://doi.org/10.15468/7nnp7d accessed via GBIF.org on 2019-11-14.

North East Scotland Biological Records Centre (2017). North East Scotland Amphibians & Reptiles 1850 - 2016. Occurrence dataset https://doi.org/10.15468/ruf7hc accessed via GBIF.org on 2019-11-14.

Scottish Wildlife Trust (2018). Casual records for Scottish Wildlife Trust reserves - Verified data. Occurrence dataset https://doi.org/10.15468/zeay1d accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018). Commissioned surveys and staff surveys and reports for Scottish Wildlife Trust reserves - Verified data. Occurrence dataset https://doi.org/10.15468/a6snhl accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018). Commissioned surveys and staff surveys and reports for Scottish Wildlife Trust reserves - Verified data. Occurrence dataset https://doi.org/10.15468/a6snhl accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018). Survey and monitoring records for Scottish Wildlife Trust reserves from reserve convenors and Trust volunteers - Verified data. Occurrence dataset https://doi.org/10.15468/yyd4b9 accessed via GBIF.org on 2019-11-15.

Scottish Wildlife Trust (2018). Survey and monitoring records for Scottish Wildlife Trust reserves from reserve convenors and Trust volunteers - Verified data. Occurrence dataset https://doi.org/10.15468/yyd4b9 accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2017). City of Edinburgh Natural Heritage Service - Ranger Ad-hoc records and sightings. Occurrence dataset https://doi.org/10.15468/ealk6c accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). Borders Backyard Biodiversity. Occurrence dataset https://doi.org/10.15468/jfymio accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). City of Edinburgh Natural Heritage Service - General Public Records. Occurrence dataset https://doi.org/10.15468/mfkmtz accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). City of Edinburgh Natural Heritage Service - Green Hairstreak Survey. Occurrence dataset https://doi.org/10.15468/ajaozn accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). TWIC Biodiversity Field Trip Data (1995-present). Occurrence dataset https://doi.org/10.15468/ljc0ke accessed via GBIF.org on 2019-11-15.

The Wildlife Information Centre (2018). TWIC Biodiversity Field Trip Data (1995-present). Occurrence dataset https://doi.org/10.15468/ljc0ke accessed via GBIF.org on 2019-11-15.

UK Butterfly Monitoring Scheme (2017). UK Butterfly Monitoring Scheme (UKBMS). Occurrence dataset https://doi.org/10.15468/gmqvmk accessed via GBIF.org on 2019-11-15.

UK Butterfly Monitoring Scheme (2017). Wider Countryside Butterfly Scheme (WCBS). Occurrence dataset https://doi.org/10.15468/jgm7ci accessed via GBIF.org on 2019-11-15.