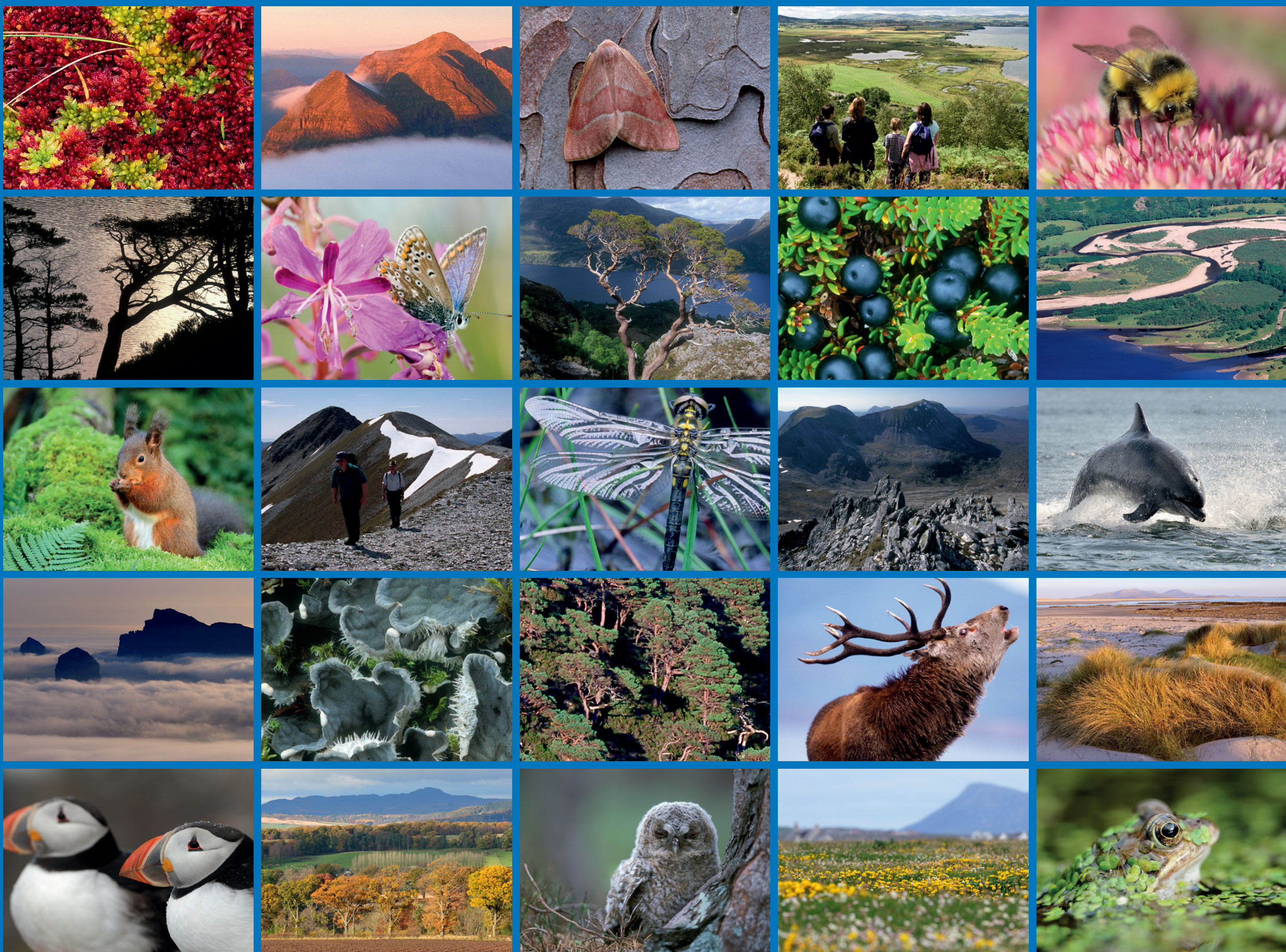
Scottish Natural Heritage
Research Report No. 1076

Designing a monitoring scheme for mountain hare (*Lepus timidus*) in Scotland



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RESEARCH REPORT

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Designing a monitoring scheme for mountain hare (*Lepus timidus*) in Scotland

For further information on this report please contact:

Rob Raynor
Scottish Natural Heritage
Great Glen House
Leachkin Road
INVERNESS
IV3 8NW
Telephone: 01463 725244
E-mail: robert.raynor@nature.scot

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RESEARCH REPORT
Summary

Designing a monitoring scheme for mountain hare (*Lepus timidus*) in Scotland

Research Report No. 1076
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monitoring; surveillance; survey; mountain hare; *Lepus timidus*; citizen science

Background

The mountain hare (*Lepus timidus*) is listed in Annex V of the EC Habitats Directive (1992), as a species 'of community interest whose taking in the wild and exploitation may be subject to management measures'. Member States are therefore required to ensure that the population of mountain hares is maintained in Favourable Conservation Status (FCS) and any management of the species is consistent with this objective.

To inform the local management of mountain hares, and to assess FCS there is a need to establish a national monitoring programme for mountain hares. Here, we have carried out assessment of mountain hare trend from indices of mountain hare abundance in the British Trust for Ornithology's Breeding Bird Survey (BBS), and the Game & Wildlife Conservation Trust's National Gamebag Census (NGC). Using the BBS data we estimate the probable proportion of the national mountain hare population residing in different areas of Scotland. Using the NGC as a basis we carried out a power analysis to help inform the design of a national monitoring programme for mountain hares. Given that mountain hares are widely distributed in Scotland and inhabit a range of habitats we explore the potential of citizen science based surveys using volunteer-led models developed for national monitoring of other taxa.

Main findings

- The NGC data show no significant increase or decrease in the index of the number of mountain hares reportedly killed by estates over the 1996-2016 period, either in the central uplands, Scotland excluding the central uplands, or the whole of Scotland.
- The BBS indices of hare abundance indicate significant declines in the number of hares seen during BBS surveys for both the central uplands and for Scotland excluding the central uplands over the period 1996-2016.
- Estimates of trend from both the NGC and BBS are associated with wide confidence intervals, however a comparison of NGC and BBS trends reveals that there is no significant difference in the estimated trend between the two surveys.
- Estimating trend of mountain hare indices in these data sets is difficult because of the small sample size in any given year, incomplete and short time series, asynchronous population cycles, and large differences in mountain hare density in different areas of their range.

- Using the BBS to estimate the relative abundance of mountain hares in different regions reveals that 48% of the national population occurs within the central uplands, over a third (37%), occur in the Intermediate Uplands & Islands, suggesting that potentially large numbers of mountain hares reside outside of, what is often regarded as, their core range.
- We used mountain hare bag records from the GWCT's NGC to estimate the statistical power associated with a range of sample sizes. However, not all estates contribute data in all years and it is not possible to differentiate between a zero return and missing data. For the whole of Scotland there were a total of 207 contributing estates with an average of 59.4 estates contributing in any one year. For the central uplands there were a total of 125 contributing estates with an average of 40.5 estates reporting in any one year, and for the rest of Scotland (whole of Scotland less the central uplands) there were a total of 82 estates that contributed data with an average of 19 contributing in any one year.
- For the central uplands the power analysis was based on the total number of contributing estates (n = 125) along with random draws of 25, 50, 75 and 100 estates from the total of 125 available. Based on the full data set of 125 contributing estates there is only a 27% probability of detecting a 25% decline over 25 years, and a 76.2% probability of detecting a 50% decline over the 25 years.
- For the rest of Scotland the power analysis was based on the total number of 82 contributing estates and random draws of 25 and 50 estates. Based on an analysis of the full data set of 82 contributing estates there was a 9% probability of detecting a 25% decline over 25 years, and a 15.6% probability of detecting a 50% decline over 25 years.
- Estimates of power should be treated with caution as the calculations are based on small and varying annual sample sizes, it is unknown how many of the missing records are effectively zeros, and annual inter-site variability associated with survey methods is unknown.
- Effective monitoring of mountain hares in Scotland is complicated by high amplitude, asynchronous cyclic population dynamics and geographic differences in density.
- We recommend that data from the planned roll-out of surveys based on direct counts of mountain hares be used to better inform the power and refinement of a national monitoring programme for this species, and that data are continually reviewed to assess scheme efficacy and power to detect the specified trend.
- A review of volunteer-led national monitoring programmes used for birds identified the potential to include data collection of mountain hare sightings with a number of other schemes. These may augment estate-led surveys in areas where estate-led surveys are likely to overlap with bird surveys. Incorporating these may greatly increase the coverage of mountain hare surveys out with grouse moor areas which are unlikely to be covered by estate-led surveys.
- Given the relatively large proportion of mountain hares that appear to occur out with upland areas managed for grouse, we recommend the further development of existing volunteer-based surveys of mountain hares to ensure that coverage extends to these areas.
- A national monitoring programme of mountain hares will draw on a wide range of data sources including environmental-NGOs, private estates, and private individuals. Data governance and management needs to take into account the many different needs of different contributors, and comply with laws relating to the collection and storage of individually identifiable and sensitive data. While ideally we advocate an open data/open access approach, we equally acknowledge the real sensitivities and potential risks associated with sharing data pertaining to wildlife management and the need to ensure anonymity when requested.

For further information on this project contact:
Rob Raynor, Scottish Natural Heritage, Great Glen House, Leachkin Road, Inverness, IV3 8NW.
Tel: 01463 725244 or robert.raynor@nature.scot
For further information on the SNH Research & Technical Support Programme contact:
Research Coordinator, Scottish Natural Heritage, Great Glen House, Leachkin Road, Inverness, IV3 8NW.
Tel: 01463 725000 or research@nature.scot

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1. INTRODUCTION

1.1 Background

The mountain hare (*Lepus timidus*) is listed in Annex V of the EC Habitats Directive (1992), as a species 'of community interest whose taking in the wild and exploitation may be subject to management measures'. Member States are therefore required to ensure that the exploitation of Annex V species 'is compatible with their being maintained at a favourable conservation status'. The Conservation (Natural Habitats, &c.) Regulations 1994[1] (as amended in Scotland[2]) requires the surveillance of species of community interest. The principal objective in managing mountain hare populations in Scotland is to maintain the species in Favourable Conservation Status (FCS) for the purposes of reporting under Article 17 of the Directive. To inform assessment of FCS there is a need to establish a national monitoring programme for mountain hares that is statistically robust and able to identify trends in mountain hare populations at the national, regional and local scale.

There is currently no systematic monitoring of mountain hare numbers in Scotland. The only published information on changes in mountain hare numbers are the Game & Wildlife Conservation Trust's gamebag statistics from the National Game bag Census (NGC) and, from the British Trust for Ornithology's Breeding Bird Survey (BBS) incidental mammal sightings data (Noble *et al.*, 2012; Wright *et al.*, 2014). With assumptions on how bag records (the number of hares reported killed by estates) and hare sightings from daylight surveys relate to actual hare numbers, both of these sources can provide indices of mountain hare abundance at the regional and national scale (Newey *et al.*, 2018). However, caution is needed when interpreting indices of population abundance, as the relationship between the numbers of hares reported killed in the NGC and hares seen during the BBS, and actual number of mountain hares is unknown. In the case of the NGC variation in the number of hares shot may reflect different management objectives and priorities, changes in the sport shooting industry, or hunting legislation. At the same time the BBS is focused on breeding birds and is not designed to collect data on mountain hares, and is based on daylight surveys when hares are known to be less active and visible. However, the NGC and BBS are significantly correlated with each other which does suggest that both schemes do provide indices of actual hare numbers (Noble *et al.*, 2012). The BBS is a randomised systematic survey (Wright *et al.*, 2014), but coverage and sample size for mountain hares in Scotland are relatively limited and largely restricted to the central uplands (mean of 19 1 km^2 squares with positive hare sightings per year, Table 1). The NGC is a voluntary scheme whereby estates submit records of the number of hares killed each year. In Scotland a total of 207 estates have contributed records of mountain hares to the NGC since it was formally established in 1961 however not all estates contribute every year and with on average 59.6 estates contributing in any one year (Table 1). The nature of the NGC makes it impossible to differentiate between a zero record and missing data.

Previous research identified two methods that could be used to produce reliable indices of mountain hare numbers in open heather moorland; direct counts of mountain hares along transects at night using a high powered lamp, and indirect estimates of hare density based on dung accumulation over winter (Newey *et al.* 2018). However, the methods assessed and developed by Newey *et al.* (2018) are not applicable to areas of non-moorland, and arguably non-managed moorland. This is because the methods were primarily developed for use on heather moorland, have only been tested on heather moorland, and direct count methods (lamping/thermal imaging) are unlikely to be effective where visibility is obstructed by tall shrubs, trees, or terrain, and where population density is low (Newey *et al.*, 2018, section 5.2).

[1] The Conservation (Natural Habitats, &c.) Regulations 1994 – www.legislation.gov.uk/uksi/1994/2716/contents/made

[2] Wildlife and Natural Environment (Scotland) Act 2011 – www.legislation.gov.uk/asp/2011/6/contents

While in principle dung accumulation might be suited to non-moorland habitats where visibility is restricted, the method has not been assessed in these environments and the relationship between dung accumulation and hare density has not been evaluated outwith managed heather moorland.

1.2 Mountain hares

Mountain hares are widespread in Scotland, but are strongly associated with upland areas, and particularly with areas of heather moorland managed for red grouse shooting where they appear to benefit from predator control and habitat management carried out for the benefit of red grouse (Hewson, 1984; Patton *et al.*, 2010; Watson *et al.*, 1973). Mountain hares on grouse shooting moors have been relatively well-studied compared to populations of this species in other areas of Scotland, and there are some data on how mountain hare populations vary in abundance or density over time and between areas (Aebischer *et al.*, 2011; Hewson, 1984; Newey *et al.*, 2007b; Tapper, 1992; Watson *et al.*, 1973). Mountain hare density can also vary enormously over small, within estate and between neighbouring estates, spatial scales (Knipe *et al.*, 2013; Newey *et al.*, 2018, 2011, 2003). Mountain hares can reach very high densities of 100 – 150 or more individuals per kilometre square, but occur at much lower densities; typically one to four hares per square kilometre in other habitats and areas within their Scottish distribution (Newey *et al.*, 2007a; Watson *et al.*, 1973; Watson & Hewson, 1973).

Analysis of the National Gamebag Census (NGC) shows that, like mountain hare populations throughout their global distribution, mountain hares in Scotland show high-amplitude population cycles with a mean periodicity of around 9.5 years and can exhibit significant population density changes regularly over time (Newey *et al.,* 2007b; Tapper, 1992). Analyses of gamebag records and counts of hares also reveal distinct geographic differences in amplitude and periodicity of population fluctuations suggesting that populations fluctuate asynchronously (Hewson, 1984; Newey *et al.*, 2007b; Watson *et al.*, 1973). While mountain hares in Scotland are largely concentrated in upland areas managed for driven grouse shooting they also occur throughout large areas of the Scottish lowlands, as well as on islands and in upland woodland, forestry and agricultural habitats. However, little is known about the population ecology and densities of mountain hares in these areas. Mountain hare densities in non-moorland habitats are generally lower than on managed grouse moors, but the extent of these habitats mean they can, potentially, support large numbers of hares. However, existing information on mountain hare population dynamics and ecology in Scotland derives almost exclusively from the Scottish uplands and, more specifically, the areas managed for driven grouse shooting.

Interest in and concern about the contemporary management of mountain hares on driven grouse moors has prompted an evaluation of survey methods that could be used to assess hare density on heather moorland (Newey *et al.,* 2008). This has greatly improved our understanding of how different survey methods perform in this habitat and for population densities typical of upland moorland managed for red grouse shooting (Newey *et al.,* 2018). However, there is no comparable information available on suitability or performance of survey methods for non-moorland habitats (Newey *et al.*, 2018).

1.3 Monitoring programme requirements and study aims

Scottish Natural Heritage (SNH) requires a statistically robust monitoring programme to monitor and assess the conservation status of mountain hares in Scotland. The underlying objectives for the scheme are to:

i) enable a more accurate population estimate to be generated, and

ii) determine with a high degree of confidence whether the mountain hare population is stable, increasing or declining at a range of geographic scales.

The design of the monitoring programme needs to accommodate the cyclic nature, geographic and small scale variability of mountain hare populations across Scotland, should ideally be applicable at a range of spatial scales from the estate level (2 – 10 km^2), regional, and national scales, and ideally accommodate geographic and habitat-specific differences in population density. To inform the design of a monitoring programme that is statistically defensible, further information on sample size, distribution and frequency of sampling and associated statistical power to detect a specified level of decline is needed. Ideally the monitoring programme should be able to detect a 25% change in population over a 25-year time period with 95% confidence with a power of 80% (*i.e.* alpha = 0.05, beta = 0.20). If this is not feasible then assessing the power to detect a 50% decline may be the only practical option.

Non-moorland hare populations and those out with grouse moor areas are likely to face different pressures from those in the central uplands and grouse moor areas and, critically, cannot be effectively monitored by the methods outlined by Newey *et al.* (2018). One or more alternative approaches will be required to monitor them effectively hence we explore the potential for alternative approaches. These may be similar to the citizen science approach used in some bird surveys (*e.g.* BBS), to augment and supplement lamping surveys that may not be practicable in some woodland or agricultural landscapes, and in the remote and extensive areas such as the north-west of Scotland where mountain hares occur at very low densities. The potential and realised benefits of including BBS style citizen science elements, include the involvement and engagement of members of the public and a wider stakeholder pool involved in collecting data, are widely recognised (Battersby & Greenwood, 2004; Bonney *et al.,* 2009; Harris & Yalden, 2004). Such approaches are employed in other UK species monitoring programmes (*e.g.* Brereton *et al.*, 2017; Harris *et al.*, 2018; Newson *et al.*, 2017a, 2015; Wright *et al.*, 2014).

2. METHODS

2.1 Selection of survey regions

For analyses and reporting we adopt the Countryside Survey Environmental Zones (Carey *et al.*, 2008). In Scotland there are three Environmental Zones which correspond to areas of broadly distinct biogeographic characteristics; Lowlands, Intermediate Uplands & Islands, and True Uplands. We further subdivide the True Uplands zone into three subzones; the southern uplands (uplands known as the Southern Uplands lying north of the English border and south of the central belt), the central uplands (uplands lying north and west of the Highland Boundary Fault, and south and east of the Great Glen), and the north west uplands (the uplands widely known as the North West Highlands lying north of the Great Glen) (Fig. 1). These zones and subzones of the True Uplands are intended to group mountain hare populations that occur at similar densities (Watson & Hewson, 1973) and are likely to exhibit similar population dynamics, cyclic periodicity and amplitude (Newey *et al.,* 2007b*)* whilst maximising the number of sites contributing time-series.

We have little information on the population ecology and dynamics of mountain hares in the Scottish lowlands, islands, upland woodland, forestry and agricultural habitats. As a consequence we have little knowledge regarding spatial and temporal variability in these areas which, combined with our poor understanding of the performance, precision and repeatability of survey methods out with heather moorland, greatly limits the potential for power analysis of surveys in these habitats and areas.

We assess whether the trend in the NGC in Scotland away from the central uplands is similar to that in the central uplands by comparing NGC gamebag records from the two areas. We also compare the trend in NGC records for the central uplands with the one from BTO hare counts in the same area. This provides an indication of the degree of synchrony between different areas and consistency between different survey methods.

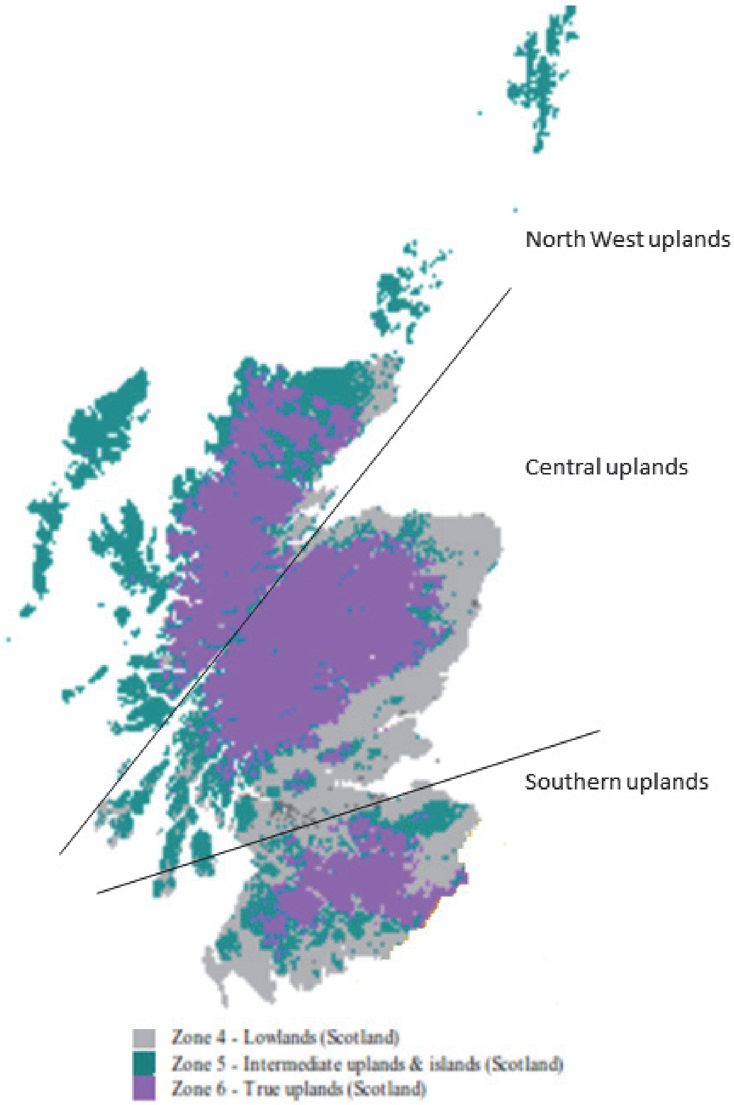

Figure 1. Schematic map of Scotland showing the Country Side Survey Environmental Zones for Scotland and the approximate demarcation of the three subzones of the True Uplands used in this report. After Carey et al. (2008).

2.2 National Gamebag Census

The NGC is a privately funded repository of bag records that records the number of animals killed by estates during sport shooting and predator control, from estates across the UK, managed and maintained by the Game & Wildlife Conservation Trust (Tapper, 1992). It was formally established in 1961, and is a voluntary scheme that currently collects bag statistics from over 650 shooting estates annually in England, Wales, Scotland and Northern Ireland. At the end of the shooting season, each participating estate completes an annual bag survey form detailing the numbers of each species shot or culled, the area (size) of the estate and, in the case of upland estates, the extent of moorland area. When expressed as the numbers of animals shot per unit area, the data provide temporal and regional trends in bags on shooting estates (Aebischer & Baines, 2008; Tapper, 1992). Overall, the NGC collates data on the shooting bags of 57 species, of which 20 species are mammals, including mountain hare.

Hunting statistics (gamebag records) are widely used in wildlife research and management (e.g. Elton & Nicholson, 1942; Krebs *et al.*, 2001). However, gamebag records provide a measure of the number of animals reportedly killed and may be confounded by changes in hunting effort (e.g. Willebrand *et al.*, 2011). Other factors that influence the number of animals killed (e.g. changes to hunting regulations), and the correlation between the number of animals killed and the actual number of animals present are usually unknown. Cattadori *et al.* (2003) have shown that the number of red grouse shot on grouse moors is correlated to the actual number of birds present determined from direct counts of grouse prior to shooting. For mountain hares in Scotland Hewson (1976) found a strong association between mountain hare bag records and the hare density assessed from capture-mark-recapture. A comparison of trends of mountain hare indices from the NGC and BBS (see below) found a strong correlation (Noble *et al.*, 2012). Overall the evidence suggests that while caution is of course needed, the NGC appears to provide a reasonable reflection of mountain hare population changes at the national scale.

To obtain estimates of trend and associated variability for the power analysis (see below) we analysed data from 1961 to 2016, the most recent year for which data are available. The NGC includes data extending back further, but data from 1961 are more complete and consistent. They encompass 57 years of data and on average five mountain hare population cycles, which allows the effect of population cycles on the long-term trend to be smoothed out (the mean periodicity of mountain hare cycle in Scotland is 9.5 years; Newey *et al.* 2007b).

Scottish sites within the NGC (n = 207) that returned bag data on mountain hares were split regionally into those within the central uplands (n = 125) (as described in Section 2.1), and the remaining environmental zones (n = 82) (Table 1). The former was considered to be a relatively homogeneous area within which hare population dynamics and cyclicity are likely to be roughly similar, whereas the remainder was considered to be heterogeneous in terms of trends, and therefore likely to represent a worse-case scenario for the purposes of power analysis (Newey *et al.,* 2007b).

2.3 Breeding Bird Survey

In 1995, the BTO expanded the scope of the national bird-monitoring scheme, the Breeding Bird Survey (BBS), to include the collection of information on UK mammals. BBS participants, who are almost all volunteers, were asked to provide information on any mammals detected or known to be present whilst carrying out bird surveys on randomly allocated 1 km squares or during any other visits to these sites. This was the first volunteer-based, multi-species, annual mammal survey to be carried out in the UK and although the focus was on medium- to large-sized easily identifiable species, which included mountain hare, observers have the opportunity to record any mammal species that they encounter (Harris *et al.*, 2018; Massimino *et al.*, 2018; Wright *et al.*, 2014).

2.4 Trend analysis

We analyse both the NGC and BBS data to assess long-term population trend of these indices. The statistical approaches differ due to the large difference in the length of time the two schemes have been running.

2.4.1 National Gamebag Census

Analysis of mountain hare bags was based on annual shoot returns from 1961 to 2016, for sites contributing two or more years of data. Note that any instances when zero animals were shot on a particular site in a particular year were not included in the shoot returns and therefore had to be treated as missing data. Bag data were analysed using the GenStat statistical computer package (Lawes Agricultural Trust, Rothamsted), following the approach of Aebischer *et al.* (2011). This involves fitting a generalised linear model (McCullagh & Nelder, 1996) with a Poisson error distribution and logarithmic link function, with site and year as factors and the logarithm of site moorland area as an offset variable. The year coefficients were exponentiated to give an index of bag size on the arithmetic scale. All index values were thus relative to the start year, which took a value of 1.

To measure the percentage change in the underlying long-term trend (smoothing out population cycles), a generalized additive model (GAM) with two degrees of freedom (Hastie & Tibshirani, 1990) was fitted to the bag indices, then the percentage change calculated from the GAM fitted values. We specified two degrees of freedom for fitting the GAM as this effectively smooths the time series and removes the effect of population cycles, but retains more flexibility than a straight line. The calculation of confidence intervals around the index values and percentage change was obtained by bootstrapping at the shoot (estate) level: for each of 999 bootstrap runs, sites equal in number to the original sample were selected at random, with replacement, and a new set of indices obtained as described above (Efron & Tibshirani, 1986). For each quantity of interest, the confidence limits were taken as the appropriate lower and upper percentiles of the distribution of all 1,000 values. For comparison with BBS estimates, the time period for calculation of percentage change was set to 1996-2016, 85% confidence intervals were adopted, and the calculations of change repeated for a GAM with degrees of freedom set to be approximately 0.3 times the number of years for comparison with BBS time series. Using 85% confidence intervals, non-overlap between estimates corresponds to a difference that is significant at the 5% level (Payton *et al.*, 2003).

2.4.2 Breeding Bird Survey

Population trends were estimated from BBS data for all Scotland, as well as for the more restricted area of the central uplands, which contains more mountain hare BBS records than any of the other zones. The numbers of records for this species from other True Upland areas, as well as from Intermediate Upland and Lowland zones, were too small to derive separate trends for these areas.

BBS involves two visits to a 1 x 1 km square, during which birds are recorded by sight and sound on two 1 km long transect surveys. Most BBS surveyors (91% in 2017) now count the mammals encountered during these surveys. First visits are carried out between April and mid-May, while second visits are carried out at least four weeks later, between mid-May and the end of June. Volunteers are asked to begin their counts in the early morning, and most squares can be surveyed in around 90 minutes.

For each square, the total number of mountain hares recorded was summed for each visit, and the highest count from the two survey visits taken as the annual measure of relative abundance. When a square had only been surveyed once, the total count from the single visit was used. Population trends were estimated in the statistical analysis package SAS (SAS 1996, SAS Institute, Cary NC) using a log-linear regression model with Poisson error terms. The SAS GENMOD procedure fitted the model using the maximum likelihood method and corrects for over-dispersion using the ‘dscale’ option. In order to account for missing data (arising from many survey squares only having been covered in a subset of years), the identity of the survey square was included as a variable in the model. Squares counted in only one year were excluded from the model. Proportional coverage (the proportion of 1 km squares covered in BBS) varies between regions and over time. The contributions of squares to the trend were therefore weighted by the inverse of the coverage for the squares’ survey region in that year. Finally, smoothed trends were calculated to provide an assessment of long-term change with minimised influence of non-directional inter-annual noise. To reduce the effects of annual population fluctuations the time series were smoothed using a thin-plate smoothing spline with the degrees of freedom set to be approximately 0.3 times the number of years. Eighty-five percent confidence limits were produced using a bootstrapping procedure involving 999 replicates. Population change between 1996 and 2016 with 85% confidence was also estimated from the smoothed trends (*sensu* Payton *et al.*, 2003).

2.5 Relative abundance

The structured and random survey design of the BBS enabled us to assess the relative abundance and overall proportion of mountain hares in each region. Using the last three years (2015 – 2017) of BBS data, relative abundance of mountain hares was estimated for each of the three True Upland zones, as well as for the Intermediate Upland and Lowland zones. Relative abundance was calculated as the average yearly count of mountain hares returned from BBS surveys of 1 x 1 km squares in each of these areas. Squares covered in more than one year contributed the average count of hares recorded over all (up to three) survey years. The proportion of the Scottish mountain hare population within each of these zones was estimated by multiplying the index of relative abundance for each zone by the area of land within it, summing these, and working out the proportional contribution of each zone to the total. Bootstrapping of the data from each zone, with 1,000 replicates, was used to produce 95% confidence intervals around these values.

2.6 Power analysis

The bootstrap samples from the NGC described in section 2.4.1 were used to give an indication of the possible power of different sample sizes to detect a 25% decline over 25 years, and a 50% decline over 25 years. Unfortunately, it was not possible to regard the variation in one of these series as representing plausible variation in mountain hare populations for a 4 km^2 survey area square. The critical factor in determining the required sample size is the variation in year effects between 4 km^2 squares. However, the NGC data do not allow us to separate this from the measurement error arising from using the density of animals shot as a proxy for hare population density. Although the data of Newey *et al.* (2018) provide estimates of measurement error associated with the proposed methods of lamping and dung counting, they provide no information about how year effects differ between sites as opposed to how mean density varies between sites.

The power of the NGC data to detect a 25% or 50% decline over 25 years was estimated for the full NGC data set (1961-2016; n = 125 for the Central Uplands and n = 82 for the rest of Scotland) and for bootstrap samples comprising smaller numbers of estates (25, 50, 75, and 100 estates for the Central Uplands, and 25 and 50 estates for the rest of Scotland). For each series I_t a corresponding series A_t with a 25% reduction at a constant rate in the long-term trend over 25 years was created by calculating $A_t = I_t$ *for* t = 1961 … 1990, $A_t = \exp[(t-1991)/25*\ln(0.75) + \ln(I_t)]$ for t=1991 … 2016. Note that this corresponds to a reduction of just over 1% each year, rather than to a step change. This was repeated for a 50% decline. This does not include any adjustment for the trend present in the original series, so may not actually represent a 25% or 50% decline, but does represent a 25 or 50% change. However, there is too much uncertainty around the trend in the original data to allow an adjustment to be made reliably.

In each case a trend was estimated based on the difference in the fitted values from a GAM with eight degrees of freedom for 2016 and 1991 divided by the fitted value for 1991. Here we fitted a GAM with eight degrees of freedom to better capture the annual variation in mountain hare numbers, and this is the value used in the trend analyses. However, if a series which is shorter than 25 years is to be analysed then it may be appropriate to use a smaller number of degrees of freedom; thus BBS uses approximately 0.3 times the number of years following the recommendation of Fewster *et al.* (2000). Confidence intervals for the trend in the original data were estimated based on the percentiles of the declines and a critical value was found based on the 95% percentile. The percentage of estimated trends for the modified data series exceeding this critical value was used as an estimate of power to detect a 25% decline. When applied to real data the method of determining whether there has been a significant decline would be to use bootstrapping to provide a confidence interval for the trend and to regard the trend as significant if the confidence interval does not contain zero. However, as this would provide a single estimate of the confidence interval based on the 1,000 bootstrapped series A_t it is not possible to use this as a means of estimating power.

2.7 Alternative survey approaches

The available evidence suggests that mountain hares in Scotland are largely concentrated in upland areas managed for driven grouse shooting (Patton *et al.*, 2010; Watson & Hewson, 1973). Mountain hares in these areas could be effectively surveyed by the game management community and other stakeholders using the methodologies recommended by Newey *et al.* (2018) and set out in the preceding sections. However, mountain hares also occur throughout large areas of the Scottish intermediate uplands, lowlands, the north-west uplands, as well as on islands, and in upland woodland, forestry and agricultural habitats (Patton *et al.*, 2010; Watson & Hewson, 1973). Mountain hare populations in these areas cannot be effectively monitored by lamping surveys because the applicability of these methods in these areas may be limited by factors associated with habitat and landscape, availability of surveyors, or mountain hare density (Newey *et al.*, 2018). We consider the potential for alternative survey approaches to augment and supplement surveys carried out by the game management community or other stakeholder groups applying lamping surveys through one or more types of survey methodology that are better suited to engaging a wide volunteer community. In particular, we consider four types of survey, all of which are currently used to principally survey bird species; i) Traditional BBS (Breeding Birds Survey), ii) BBS Upland Rovers, iii) mountain transects, and iv) unstructured recording (*e.g.* BirdTrack). However, we do not rule out the use of *lamping* surveys by non-estate staff.

We assess the potential of these schemes to contribute to a national mountain hare monitoring programme. We discuss the quality and representativeness of the data these methods would generate; interpretation of these data to make conclusions about mountain hare populations; comparability of findings with those generated through other methods; the size and nature of the potential survey community; and other factors likely to influence survey coverage. Taking these factors into consideration, we suggest how volunteer surveys by members of the public could be developed to maximise their contribution to our understanding of mountain hare populations in Scotland. The data do not allow any assessment of required sample size.

3. RESULTS

3.1 Distribution and sample size

From 1961 to 2016 an annual mean of 59.4 NGC sites contributed mountain hare bag records, with two-thirds of records coming from the central upland zone (Table 1). Mountain hares were recorded from a mean of 19 1 km BBS squares surveyed in two or more years in Scotland between 1995 and 2017, with most squares being located in the central upland zone (Table 1).

Table 1. Sample size of 1 km squares recording mountain hare (total squares surveyed) for the whole of Scotland, and regions stratified according to environmental zone for both the NGC and BBS. NGC - Annual mean; for the NGC refers to the average number of estates that contributed gamebag records in any one year, for the BBS this refers to the number of contributing survey squares in any one year. For the BBS this table (and subsequent analyses) exclude data from 2001, during which few squares were surveyed due to Foot and Mouth disease access restrictions.

Year	Whole of Scotland	Intermediate Uplands and Islands	Lowlands	North West Uplands	Central Uplands	Southern Uplands
NGC						
Total	207	31	23	9	125	19
Annual mean	59.4	7.9	5.1	1.0	40.5	4.9
BBS						
1995	19 (283)	2	0	4	13	0
1996	25 (308)	6	0	4	14	1
1997	27 (313)	6	0	3	18	0
1998	19 (309)	2	0	1	16	0
1999	27 (275)	5	0	1	20	1
2000	17 (246)	1	0	1	15	0
2002	23 (231)	3	1	1	16	2
2003	24 (274)	4	2	1	15	2
2004	15 (305)	4	0	1	10	0
2005	11 (305)	1	0	3	6	1
2006	17 (336)	2	2	1	11	1
2007	19 (517)	6	0	2	8	3
2008	15 (436)	5	0	1	7	2
2009	16 (431)	7	0	0	7	2
2010	13 (331)	2	0	0	9	2
2011	15 (359)	2	0	0	10	3
2012	13 (383)	6	0	1	4	2
2013	14 (473)	3	0	0	10	1
2014	25 (482)	4	0	1	17	3
2015	19 (476)	7	0	1	10	1
2016	19 (490)	9	0	0	9	1
2017	23 (519)	8	0	2	13	0
Mean	19	4	0	1	12	1

3.2 Population trends

3.2.1 National Gamebag Census

Annual estimates of the number of mountain hares reported in the NGC are characterised by wide confidence intervals, and show a pattern of semi-regular multi-annual fluctuations consistent with “cyclic\quasi-cyclic” (q.v. Newey *et al*., 2007b) population dynamics (Fig. 2). None of the 1996-2016 trends differed significantly from zero (Table 2). The overlap in 85% confidence intervals between the trend for central uplands and that for the rest of Scotland indicated that the trends for the two zones did not differ significantly.

Table 2. Percentage change, with 85% confidence intervals, in mountain hare bag indices from GWCT’s NGC for the period 1996 to 2016. GAM(2df) shows the results when the time series are smoothed using a GAM with 2 degrees of freedom to remove the influence of population cycles on the long-term trend, GAM(BBS) shows the results from an analysis that is comparable to the approach used in the analysis of the BBS data using degrees of freedom approximately 0.3 times the number of years.

Method	Central Uplands	Rest of Scotland	Scotland overall
$GAM_{(2df)}$	-15.3 (-39.4 – 15.0)	19.9 (-50.8 – 84.5)	-9.6 (-33.9 – 20.5)
$GAM_{(BBS)}$	-9.3 (-43.7 – 43.6)	57.1 (-69.4 – 199.1)	0.9 (-35.0 – 58.5)

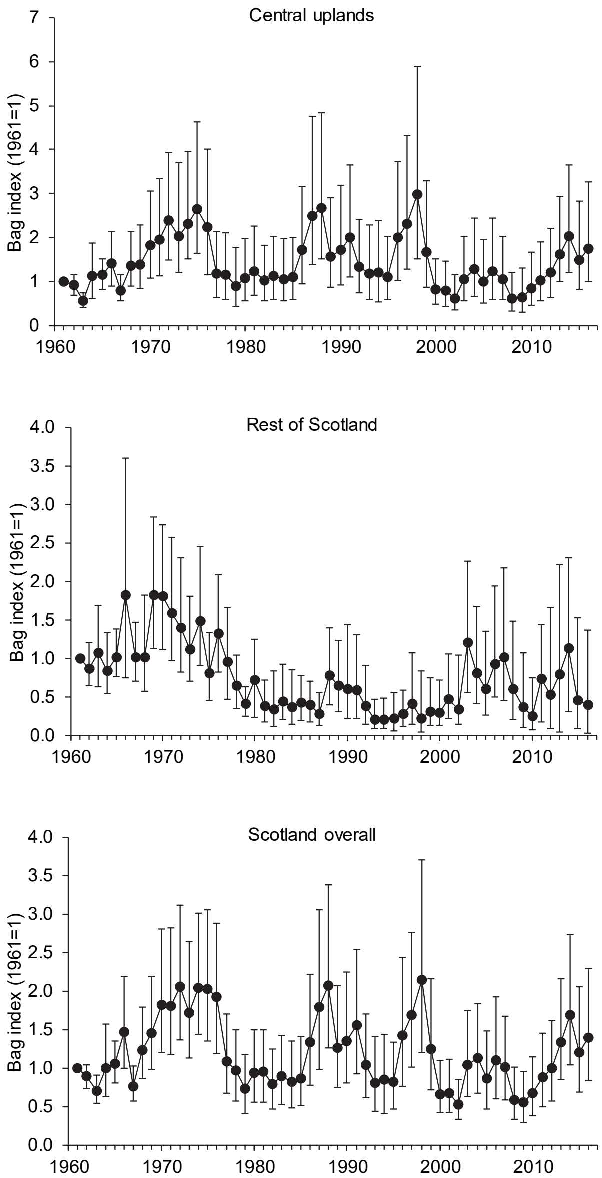

Figure 2. Mountain hare annual bag indices and 85% confidence intervals from 1961 to 2016, for the central uplands, the rest of Scotland, and Scotland overall. Error bars show the 85% confidence intervals.

3.2.2 Breeding Birds Survey

Population change and trends from the BBS data can only be reported for the whole of Scotland and for the central upland zone, with the caveat that the sample size for both areas falls below the threshold minimum of 30 squares (Table 1) that are usually considered necessary for robust analysis and so should be treated with caution (Fig. 3). For the whole of Scotland, the population change of mountain hares based on the smoothed trend between 1996 and 2016 represented a significant decline of -58% (-81% to -16%). The population change of mountain hares for central uplands alone was also -58% (-81 to -16%). In both cases the 85% confidence intervals overlapped with those from the corresponding NGC trends, thus the trends from the two surveys did not differ significantly (see section 2.4.1).

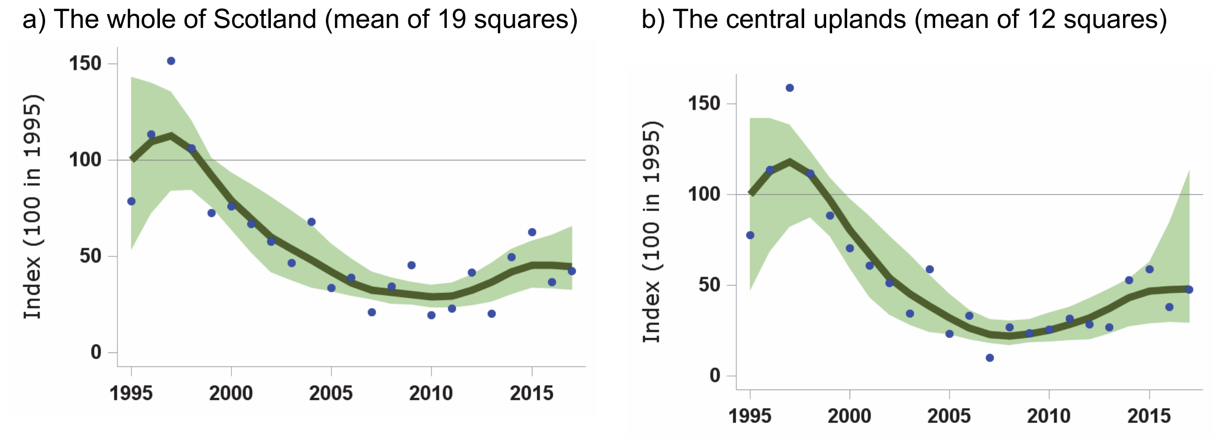

Figure 3. Population trends for mountain hare for 1995-2017 for a) the whole of Scotland, and b) the central upland zone. Green line shows smoothed trend, shaded band shows 85% confidence intervals.

3.3 Relative abundance

In Table 3 we present an estimate of relative abundance, based on the average count of mountain hares in the three true upland zones and for the intermediate upland and lowland zone in Scotland. This is based on a small sample size of BBS squares recording mountain hare and so is a crude estimate, but suggests that the central upland zone supports about 48% (31-67% - 95% confidence intervals) of the Scottish mountain hare population. The Intermediate Upland zone supports around 37% (23-56%), the north-west uplands 15% (0-33% - 95% confidence intervals), and the southern uplands less than 1% (0-2% - 95% confidence intervals).

Table 3. Relative abundance of mountain hare within the three True Upland zones, and for the Intermediate Upland and Lowland zone.

Environmental Zone	Area (km^2)	2015	2016	2017	Mean	Proportion of mountain hare population (95% CI)
Intermediate Uplands & Islands	29,796	0.45	0.32	0.22	0.33	36.6% (22.8 – 55.8%)
Lowlands	23,084	0.00	0.00	0.00	0.00	0%
North West Uplands	11,052	0.39	0.00	0.73	0.37	15.2% (0.0 – 33.1%)
Central Uplands	15,787	0.72	0.65	1.05	0.81	47.6% (31.0 – 66.6%)
Southern Uplands	5,195	0.05	0.04	0.00	0.03	0.6% (0.0 – 1.8%)

3.4 Power analysis

The results of the power calculations show that with a sample size of 125 survey areas in the central uplands the estimated power to detect a 25% decline over 25 years is 27.4%, and 76.2% to detect a 50% decline (Table 4). For the rest of Scotland, a sample size of 82 survey areas gives an estimated power of 8.8% to detect a 25% decline and 15.8% for a 50% decline. However, it should be noted that in any given year the NGC contains positive shoot returns from far fewer than 125 sites in the central uplands and 82 in the rest of Scotland (Table 1).

As the NGC does not distinguish between null and zero values, it is not known to what extent these missing data are truly missing and to what extent they are zero values. On average there are around 40 sites per year contributing positive counts in the central uplands and around 19 in the rest of Scotland. This means that the results shown here are conservative and we would expect that power would be higher than indicated in Table 4 for a scheme in which survey data were available for every contributing site in every year. A power of 27% to detect a 25% decline in the Central Uplands is therefore likely to be achievable with somewhere between a lower limit of 40 and an upper limit of 125 sites providing data every year. It is possible that if we had complete data for all 125 sites then the power might be closer to 50% than 27%. These power calculations are therefore very approximate and for this reason we do not think it is appropriate to extrapolate beyond the total number of estates contributing time series within each zone. Our analysis was based on estates because these were the units that were available in the NGC, but we think it is reasonable to assume that if survey areas are 4 km^2 (*i.e.* tetrads, q.v. Newey *et al.*, 2018) then a similar number might be needed, with the possibility that each estate may host more than one survey area.

Table 4 Confidence intervals for trend in the NGC data over the period 1991-2016 and power to detect a 25% or 50% decline in this trend for different numbers of estates within the central uplands and the rest of Scotland. Number of estates refers to the number of estates that contributed data to the NGC over the 1961-2015 period. (n = estimated number of contributing estates).

Zone	Number of contributing estates	95% confidence interval for trend (n)	Power to detect 25% decline	Power to detect 50% decline
Central Uplands	125	-40.1 - 88.5 (40.5)	27.4%	76.2%
	100	-41.4 - 100.4 (32.4)	23.5%	69.7%
	75	-51.5 - 120.6 (24.3)	18.0%	54.5%
	50	-58.3 -172.4 (16.2)	15.2%	42.2%
	25	-77.5 - 396.4 (8.1)	10.8%	24.1%
Rest of Scotland	82	-83.6 - 290.9 (18.9)	8.8%	15.8%
	50	-88.6 - 361.2 (11.8)	9.0%	14.9%
	25	-92.3 - 442.8 (6.2)	7.7%	12.5%

It is also not known how variation in the shoot data per estate compares with variation in the lamping and dung count data per 4 km^2. However, the results would suggest that well in excess of 125 squares would be needed to be able to detect a 25% decline over 25 years in the central uplands region with 80% probability, though there appears to be reasonable power to detect a 50% decline over the same time period. This approach is unlikely to be feasible in the rest of Scotland.

3.5 Alternative approaches

The similarity between the trends derived from BBS data and those derived from NGC data corroborate previous comparisons (Noble *et al.*, 2012). The records comprising both sets of data derive principally from a relatively small portion of the mountain hare's Scottish range, in the eastern part of the central uplands (Table 1). This area is more accessible than many other upland areas, being close to areas of moderate human population density in the agricultural lowlands of the north-east, and so has relatively good BBS coverage (Figs. A1.1-A1.3). Moreover, because this area holds higher densities of mountain hare than other parts of Scotland, the proportion of BBS surveys during which mountain hares are detected is relatively high. Mountain hare habitat in this area is dominated by managed moorland, so the higher hare densities combine with a greater potential for gamebag returns to yield more NGC data from this area than from others. The similarity in trends from the NGC and BBS is reassuring, as it increases our confidence in the suitability for both datasets to potentially derive trends in mountain hare populations.

The spatial overlap between these datasets means that current BBS coverage (Figs. A.1.1-A1.2) adds limited data from parts of the mountain hare's distribution where moorland-based survey techniques are not currently operating or may be established in future. Figures A.1.1 and A1.2 illustrate the problem of uneven coverage in remote areas, for example in 2018 only around 40% of available BBS squares were surveyed (Fig. A1.1). So, although volunteer-based schemes such as BBS have the potential to generate good data on mountain hares, enhanced survey coverage will be needed in areas away from the central upland zone for these to make a significant contribution to what can be gained from a monitoring scheme based on the methods of Newey *et al.* (2018).

An obvious and promising possibility is for the contribution made by BBS itself to be enhanced through the new Upland Rover scheme, which started in 2017 (Figs. A1.1, A1.2). The traditional model of BBS, where volunteers take on particular squares and commit to carrying out two visits each year in these squares, has proven difficult to promote in upland areas, where many of the randomly selected survey squares are remote and difficult to access, and the number of potential volunteers is low. The newly developed Upland Rovers initiative encourages potential volunteers to make one-off visits to uncovered upland BBS squares. This has the dual effect of increasing the pool of potential participants to people that don't live in an area but are willing to make a one-off visit to survey one or more squares there, and increasing the likelihood that locals will volunteer (due to a decrease in the time commitment). Just a year since its inception, almost 100 upland squares have a survey visit pledged, with around 85% of squares receiving one survey visit and around 50% being surveyed twice (Fig. A1.3). Uptake and number of completed visits is highest where survey squares are closer to large urban areas, for example; around the central belt, Stirling and Inverness, with squares in more remote areas more likely not to be surveyed or to only receive one visit (Figs. A1.2, A1.3). However, Upland Rovers recognises the benefit of fewer site visits compared to no data at all. If the Upland Rover approach to BBS is encouraged to develop further, it has the potential to add hundreds more surveys squares each year to the BBS dataset.

Disadvantages of this new model of BBS are related to consistency and thoroughness of coverage. Some squares covered through Upland Rovers may only receive one visit in a year, or be surveyed by different people between, or even within, years. The extent to which these disadvantages are realised, and their consequences for the data collected, are currently under investigation and will be monitored carefully over the coming years. However, early indications are promising (Massimino & Gillings, 2017), and it is likely that information from Upland Rovers surveys will add to our understanding of population change in upland species.

Over the 24 year period 1994-2017 (excluding 2001) the number of Scottish BBS squares surveyed in one year ranged from 231 – 517 (Table 1, Harris *et al.*, 2018). Over the same period mountain hares have been reported in between 11 and 27 BBS squares (3.5 – 10% of squares) in any given year, and in 2017 of the 519 BBS squares surveyed mountain hares were reported from only 23 (4.4%) of them. Therefore, only a small proportion of BBS squares would be likely to hold mountain hares, and therefore contribute a positive record. In standard BBS analyses, the threshold sample size below which data are deemed too sparse to reliably detect population trends has been taken to be an average of 40 squares with positive records per year, for UK trends. This threshold has been reduced to an average of 30 squares per year for countries and regions, and ongoing work suggests that, for populations inhabiting relatively homogenous areas and landscapes, for which there is little spatial variation in population trend, it might be possible to reduce this threshold to 20 squares, or even fewer (BTO, unpublished data). This is borne out by the observation that the trends presented in this report which are based on fewer than 20 positive records per year, give estimated trends that are consistent with previous comparisons and with analyses of NGC trends presented here. We are therefore optimistic that upland BBS coverage can contribute to our understanding of mountain hare trends, particularly the case for the central upland zone, where a quarter of all BBS surveys to date have reported mountain hare.

To increase the average annual sample size, *i.e.* the number of squares reporting hares, to 20 for the central uplands would require the number surveyed each year to be increased by an estimated 39 extra squares. In contrast, to achieve a similar sample size in the north-west uplands, southern uplands and intermediate zones would require annual increases in the numbers of squares surveyed to be increased by between 200 and 400 squares in each zone. The larger sample is necessary due to a combination of low population density and greater spatial variability, and that as far as the BBS is concerned it is the average number of squares from which a species is recorded that contributes to the analysis of trend. At very low densities of mountain hares, the number of squares needed to be surveyed before hares are recorded in an average of 30 squares per year is likely to be very large. The potential for BBS alone to yield robust trends for these zones, in which coverage by stakeholders willing to undertake *lamping* or dung surveys is also likely to be poor, is limited.

Another type of volunteer survey that could generate records for upland mountain hares is semi-structured mountain transect survey (Calladine & Wernham, 2009; Darvill *et al.*, 2016). The location of such transects can be determined randomly, if these transects are to be carried out by paid workers, but otherwise are likely to be non-random volunteer-led. This can make the data generated by such surveys less representative of the wider regions or zones from which they are drawn than data from systematic surveys like BBS. However, with careful stratification, this kind of survey can yield high quality data, and has the potential to take advantage of contributions from a much wider range of stakeholders and upland users than more rigorous survey designs such as BBS and Upland Rovers. Previous projects that have trialled this approach have reported problems in getting volunteers to reliably report 'zero' data (*i.e.* findings from surveys where target species were not found), potentially leading to over-estimates of site occupancy or abundance measures (Calladine & Wernham, 2009), and in involving people that lacked experience (or confidence) in bird surveying and identification (Darvill *et al.*, 2016).

A volunteer survey that is even less structured, such as BirdTrack, could also contribute to Scotland-wide understanding of mountain hares, particularly of their distribution. The relatively casual nature of BirdTrack recording makes it attractive to participants with limited skills or experience ('entry-level' surveyors), and also makes it feasible to combine recording with the professional and recreational activities of a wide suite of stakeholders and upland users. The *What's Up* project found that it was easier to engage new volunteers in this kind of recording than to involve them in more structured surveys such as BBS or Mountain Transects (Darvill *et al.,* 2016). However, issues of under-recording of zero data and lack of information about survey effort also apply to casual records in BirdTrack. Capture of survey effort in BirdTrack is possible, particularly through compilation of complete lists, where all species encountered are recorded. The number and diversity of species can then be taken as a proxy of survey effort, and used to adjust numbers recorded to account for what has been missed (Newson *et al.*, 2016), though care is needed in interpreting this type of survey in heterogeneous habitats such as the highlands. However, in its current form the BirdTrack system cannot easily be used to generate complete lists in upland environments, particularly by inexperienced recorders. This is due to the current lack of several factors, including a 'pinpointing' facility to identify the location of birds recorded in complete lists; customisability of complete species lists (restricting them to species of interest or according to an observer's abilities); and lack of suitable background maps for upland areas. In theory, however, temporal trends in abundance for mountain hares could be produced from a system like BirdTrack if these (and, potentially, other mammals) were included among the species recorded during complete list surveys.

Data generated by the methods described above will vary in terms of how counts or other abundance measures relate to one another and to real densities of mountain hares. However, while it may not be possible to make useful comparisons between estimates derived from different methods, it should still be possible to combine these data to produce composite trends by firstly standardising them (*e.g.* setting abundance estimates from all datasets in the first year to 1), and then weighting the contribution of each dataset according to the proportion of the population it was thought to represent.

Whatever method or combination of alternative approaches is used to generate annual information on mountain hare populations, it may be possible to supplement these with periodic surveys. These could either aim to increase volunteer coverage of annual survey types, or else could involve directing volunteer effort towards a separate survey method (such as the transect surveys that Bird Atlas 2007-2011 was based on). Another possibility is that such periodic coverage could be boosted through the involvement of professional surveyors, the use of which can make it much easier to target available survey effort towards remote areas where data are known to be particularly lacking (*e.g.* Southern Scotland bat report, Newson *et al.*, 2017b).

4. DISCUSSION AND RECOMMENDATIONS

Management of wildlife populations relies on accurate data on distribution and abundance, and knowledge of how these change over time and why, for instance in response to land-use change, climate change or management. Monitoring, the regular collection of data on species distribution and abundance, is necessary for effective management, but is also one of the most difficult aspects of wildlife management (Elphick, 2008; Newey *et al.*, 2010). Monitoring wildlife populations is a legal requirement for a number of species. Under the EU Habitats Directive the UK is required to monitor and report on the status of listed species, which includes mountain hare. Mammals are an important element of the UK biodiversity but are arguably one of the least effectively monitored components of UK wildlife (Battersby & Greenwood, 2004; Harris *et al.,* 1995; Macdonald *et al.,* 1998; Macdonald & Tattersall, 2003; Wright *et al.,* 2014).

4.1 Trends in mountain hare populations

Analyses of the NGC suggest a non-significant decline in the number of mountain hares reported killed in the central uplands, and no significant increase or decrease in the rest of Scotland, or Scotland as a whole over the period 1996-2016. Analyses of the BBS reveal a significant decline in the number of mountain hares seen in the central uplands and the whole of Scotland over the same period. The results of both the NGC and BBS are characterised by wide confidence intervals associated with large variability of the underlying indices, and are likely exacerbated by asynchronous cyclic periodicity of local mountain hare populations, incomplete time-series, and that the 1996-2016 time period used in the trend analysis is short relative to the mean cyclic periodicity found in mountain hares in Scotland. The BBS is also based on a relatively small sample size. Although the two surveys appear to indicate some differences, the direction of the trends is the same, and their 85% confidence intervals overlap, indicating no statistical ($p < 0.05$) difference between the trends derived from NGC and BBS data. The wide confidence intervals associated with the NGC represent large differences between estates in the number of mountain hares killed each year as a result of other factors. These include different and changing management objectives, the effect of weather on number of shoot days, and the fact that while the BBS represents an index of the number of mountain hares seen in the smaller pre-breeding or breeding population, the NGC provides an index of the number of mountain hares killed in the post-breeding population that is, itself, highly variable. Daylight counts of mountain hares along transects carried out in autumn tend to detect a variable and only a very small proportion of the number of hares counted along the same transect at night, which may also contribute to the low variance estimate. In addition the BBS makes use of repeat visits to the same survey squares year-on-year which may result in greater precision.

Analysis of time series from cyclic populations and identifying trend in cyclic time series is notoriously difficult (Haydon *et al.*, 2002; Kerlin *et al.*, 2007; Royama, 1992; Turchin, 2003). Identifying trend from pooled time series of indices of mountain hare numbers is further complicated by differences in the amplitude, periodicity, and asynchronous cycles found in mountain hare populations from different localities (Hewson, 1985; Newey *et al.*, 2007b). Both the NGC and BBS are indices of mountain hare abundance, in the case of the NGC of the number of mountain hares reported killed by estates, or for the BBS, seen during early morning daylight counts in spring and summer. However, it is unknown how these indices relate to the actual number of mountain hares present in the area indexed or how this relationship is influenced by local site characteristics, weather, or density of hares (Cattadori *et al.*, 2003; Newey *et al.*, 2007b; Tapper, 1992). The challenges of unambiguously identifying long-term trends from these indices underpin the need for a rigorous national monitoring programme for the species.

4.2 Relative abundance

The randomised nature of the BBS allows us, for the first time, to provide an estimate of proportion of the Scottish national mountain hare population found in the different Environmental Zones, and subzones used in this study. The small sample size of data available means that care is needed when interpreting these results. However, the results show that although 65% of the Scottish population is likely to be found in the True Uplands, with approximately 48% being found in central uplands, around a third of the national population is found in the Intermediate Uplands and Islands. This demonstrates the potential importance of hare populations outside of what is often considered their preferred habitat and core range, and highlights the need for a monitoring programme that includes these hill edge and island habitats.

4.3 Power analysis

Using the NGC to derive estimates of site and year variability to parametrise the power analysis proved to be very challenging because of the species population ecology and the limited data on which to base power calculations. The most extensive data that are available are based on bag records that by their nature are incomplete and difficult to interpret due to ambiguity in the meaning of zero or missing data and a lack of understanding of the relationship between the index value and the actual number of animals present. While the bootstrap realisations provided a measure of site variability, site effects were effectively averaged out by a variable and unknown number of estates contributing data to any given year. In addition, year effects on the index of mountain hares shot may have been influenced in unknown ways due to individual estate management priorities and for example, weather that may influence the number of mountain hares killed in any one year. It also proved difficult to split apart the variation in estimated year effects into the component due solely to year and that due to measurement error, so we were not able to substitute the lamping or dung survey measurement errors for the NGC measurement error (noting that the variation in estimated year effects influences power). While the advantages, disadvantages and inherent risks of analysing this type of data are well known and were understood (and discussed, along with alternative approaches, with SNH) at the outset, the full extent of these issues only became apparent during the analysis (as this type of analysis of the NGC data had not been attempted in this way before). This approach was adopted because, although Newey *et al.* (2018) provide estimates of sampling error, there is no information on between year differences (each study site in that study was only used once to maintain independence between sample points), so the NGC was used with the intention of obtaining information on annual variability in hare populations, and both time and resources prohibited alternative approaches.

The subsampling approach adopted does not allow us to extrapolate beyond the total number of estates that contributed records over the entire time period. Also without a better understanding of how mountain hare density differs across different management areas of an estate it is also unclear how additional 4 km^2 survey areas within estates will influence power.

Limitations aside, and while estimated power needs to be treated with caution, the low power is not surprising and is likely to reflect the challenges posed by the species' population ecology. As we have already noted mountain hare populations on areas of heather moorland managed for grouse shooting show high amplitude cyclic dynamics (Hewson, 1985; Newey *et al.*, 2007b; Tapper, 1992). Though synchrony has not been formally assessed there is evidence that these cycles are asynchronous (Hewson, 1985; Newey *et al.*, 2007b). The lower power for the rest of Scotland compared to the central uplands reflects geographic differences in mountain hare density (Watson & Hewson, 1973) and cyclic dynamics (Hewson, 1985; Newey *et al.,* 2007b) and greater variability in mountain hare bag records outside of the central uplands.

The results of power analysis do not allow us to make firm recommendations on required sample size. Based on these findings the development of recommendations for a national monitoring programme for mountain hares is difficult. However, we recommend that the results from the phased rollout of a national mountain hare monitoring programme are used to refine survey design and estimates of required sample size. This approach has the distinct and real advantage of using data collected by scheme participants from a wide geographic area.

4.4 Alternative approaches

Volunteer recruitment and retention can be difficult, and ensuring sufficient survey effort and coverage can be challenging for volunteer based citizen science surveys. Clearly, the surveys of mountain hares based on BBS and BBS type approaches will benefit from the BTO's established network of co-ordinators and volunteers, and especially from ongoing efforts, primarily through Upland Rovers, to increase BBS coverage in upland areas. Because Upland Rovers was launched halfway through the BBS season in 2017, preliminary findings derive mostly from late surveys. Mountain hares moult from white winter pelage to brown summer pelage in April-May making them less detectable during late visits than at the start of the BBS season (Hewson, 1958; Hulbert *et al.*, 2008). However, timing and rate of moult vary with altitude, latitude, and annually with weather (Hewson, 1958; Hulbert *et al.*, 2008; Zimova *et al.*, 2018). If detection is heavily influenced by stage of moult and snow lie there is a risk of geographic and annual bias in the number of hares seen (Newey *et al.*, 2008). Therefore, it is not yet possible to gauge how effectively this species will be recorded by Upland Rovers surveys. However, assuming detection is comparable to that in traditional BBS surveys, and given the initial uptake (of just over 100 squares, with around 85% surveyed at least once) in 2018, the number of additional records generated could rapidly improve our understanding of population change in Scotland, particularly in the central upland zone, where one in four BBS surveys have encountered mountain hares. Participation in Upland Rovers should, as far as possible, be promoted and facilitated, while keeping track of the contribution this makes to mountain hare records in Scotland, as well as in each of the zones or regions for which estimates are desired.

Implicit in the concept of monitoring is the regular and ongoing effort to collect data allowing population changes to be studied over time. However, it is likely to be difficult to ensure sufficient survey effort of all areas on an annual basis. It will therefore likely be necessary to consider less frequent surveys. This might be achieved by undertaking annual surveys of a rotating subset of a much larger sample; the idea of Sampling with Partial Replacement, though any subsampling or rotation of sites needs to be implemented to avoid introducing any bias (Macdonald *et al.*, 1998; Skalski, 1990). Another option might be periodic concerted survey effort targeted at mountain hares, and possibly other upland bird and mammal species. It might also be necessary to consider combining largely volunteer-led surveys with surveys by contract surveyors to ensure sufficient coverage and robustly representative samples from areas that are remote (or prone to patchy or sparse coverage for any other reason).

While the BBS can certainly augment and extend hare monitoring the capacity of the BBS itself to contribute further mountain hare data is likely to be limited largely because the focus of the BBS is to survey breeding birds and tends to attract bird enthusiasts. Other less formal and more flexible 'BBS type' (*e.g.* Upland Rovers) surveys have potential to contribute mountain hare data and particularly to extend survey coverage into non-moorland areas that are unlikely to be suitable for night time lamping surveys due to locality, availability of surveyors, and terrain. However, due to the less focused nature of these more flexible survey types, data quality may be lower than that gathered during BBS surveys because the principle aim of participants undertaking them is usually completing an outdoor activity rather than counting mountain hares. However, two factors might help to compensate for this. Firstly, the length of 'transect' and the number of surveys per year that could be carried out by hillwalkers and other upland users could equate to annual surveys of tens or hundreds of kilometres by individual surveyors, which is much more than most participants in BBS can carry out each year. Secondly, the size of the potential survey audience is very large. In 2017, the number of upland walking trips made by people living in Scotland was estimated at 9.8 million[3]. To put this into context, the total number of 2017 BBS visits in Scotland (including those to lowland squares) was just over 500 (equating to about 1,000 km of transects).

In developing the Upland Rovers initiative, the aim has been to improve rates of BBS uptake among volunteers in upland areas, where BBS coverage by volunteers has historically been low. Reasons for this low coverage include remoteness from centres of human population, ruggedness, and lack of roads. The two main changes to volunteer recruitment introduced by Upland Rovers are; i) lack of requirement to 'commit' to coverage of a BBS square for an indefinite period in the future, and ii) the ability to view and choose between the available squares when thinking about whether to participate. Participants taking on standard BBS squares cannot view the available squares in their area and must express their interest in participating to a regional survey organiser, who then suggests one or more squares for them to cover. The reasoning behind this is to try to minimise the influence of volunteer choice on survey uptake - recognising that if volunteers are given a full set of available squares to choose from, they may gravitate consistently towards certain types of squares (and away from others). However, in areas with very small numbers of potential participants, it was decided that being able to see the available upland squares before choosing them could make the prospect of participating seem more appealing.

The existing sign-up system for Upland Rovers is rudimentary but potential volunteers can view available squares on an online sign-up map[4]. This map only shows squares for which one or more survey visits have still to be covered. Volunteers can click on any of these squares, which will take them to a simple sign up form that allows them to express an interest in covering any available visits for the square, and allows them to view a detailed OS map of the square in question. This information is sent to survey organisers, who then liaise with the volunteer to arrange their further participation in the survey.

The Southern Scotland Bat Survey also engaged volunteers via a sign-up map, which was based on one that had been used for several years in the similarly structured Norfolk Bat Survey. However, this differed in a number of details. Firstly, although this was a three-night survey, all nights were typically done in a single survey block. This meant that no distinction needed to be made between squares where one or two visits were available. Instead, squares were colour coded based on their 'priority', and whether they were already 'taken'. Priority squares were randomly selected from those squares where human population density was lower than a threshold level, on the basis that uptake of squares with lots of people living in them was expected to be relatively high. Volunteers were encouraged to take on priority squares wherever possible but allowed to sign up for any square in the region (provided another participant had not already selected it). As well as dealing with square assignment, the online system enabled participants to book out bat surveying equipment from one of 12 centres around the region, allocating the equipment to them for a period of four days. The system dealt automatically with the whole enrolment process, requiring minimal interaction with survey organisers to sign volunteers up and send them the instructions they needed to participate.

4.5 Survey design and roll out of a national programme

The low power to detect the desired level of population change probably reflects the true difficulties of monitoring mountain hares in Scotland. There is, however, a desire to implement

[3]https://www.nature.scot/sites/default/files/2018-04/Upland%20Path%20user%20survey%20report.pdf
[4]https://app.bto.org/bbs/public/upland-rovers.jsp NB This is from the 2018 survey programme and is no longer maintained [Last accessed: 21/09/2018].

national monitoring of this species. While previous work has identified methods that can be used to provide reliable indices of hare density on heather moorland, how these can contribute to a national monitoring programme remains to be considered. Here we provide some details on the three elements that will be required to effectively monitor mountain hare populations throughout their distribution in Scotland; i) a pilot phase, ii) predominantly tetrad lamping based surveys of mountain hares in the central uplands where the major land use is grouse moor, and iii) the development of alternative, BBS type, approaches that will be required to effectively survey mountain hares out with managed heather moorland. Each of these complimentary elements is discussed below. We assume that the survey will be administered by SNH, or appointed representatives/contractors who will oversee the scheme, provide coordinates of survey areas, maps, data recording sheets, and agree any fine scale changes needed, and who will ultimately collect, manage and analyse data, and disseminate findings.

4.5.1 Pilot phase

A pilot, or test, phase is essential. It has been agreed that, initially, it is prudent to limit the number of participants to a small "test group" to allow the scheme administrator to develop and refine outreach and training material, field protocols, and data management processes with a small group before engaging with a wider community. This should involve four Moorland Groups, representing around 30-40 estates, from different areas of Scotland to join the scheme (as discussed and agreed at a meeting between GWCT, SNH and JHI on the 29/05/2018). Feedback from this test group should also be sought to further refine processes and expectations. Recruiting participants should be led by SNH and, or partner organisations as appropriate.

To minimise survey bias, survey tetrads should ideally be randomly allocated over the upland area of each moorland group. To ensure a good sample size we suggest one tetrad per beat (management unit of an estate). Ideally, tetrads should be separated by at least 2 km and there should be scope to move tetrads by up to 1 km to avoid, or minimise, overlap with large water bodies, built up (housing or industrial) areas, and other infrastructure. However, for the pilot phase tetrad placement is not critical and we note that flexibility for tetrad placement will be required during the pilot phase because, for example; moorland beats may be too small to accommodate a tetrad while maintaining a 2 km spacing between tetrads. Where random placement is not suitable a systematic layout may be preferable and easier to implement at the moorland group scale. The critical issue from a sampling point of view is that tetrads placement is random relative to the distribution and abundance of mountain hares. Examples of how survey tetrads might be laid out are shown in Annex 2**.** More detailed discussion of tetrad placement can be found below (Section 4.5.2). It is not anticipated that all the tetrads used in the pilot phase will be monitored long-term, but a subset of tetrads should ideally be retained and contribute to a national scheme. A national monitoring programme for mountain hares will be a long-term project over the duration of which habitat and land use will change (for example; current forest plantation will be felled) and it is important that the survey design can detect changes in mountain hare numbers associated with land use change. It is therefore necessary that tetrads include suboptimal mountain hare habitat, for example plantation.

Tetrads should be surveyed as described by Newey *et al.* (2018 - Annex 3), and a key element of the first year will be to develop guidance and training to participating estates. Scottish Natural Heritage or a partner organisation will initially train two representatives from each of the participating moorland groups. These individuals will then become trainers and train their colleagues, who in turn can train others, thus cascading the knowledge and skills to a wide community. It will be important throughout the roll out of the scheme, but particularly in the first years, to monitor how effective this cascade training is.

Detailed guidance and training in carrying out surveys is being developed and undertaken in another project and will not be covered here, but in summary; survey participants should initially be provided with the coordinates of their allocated tetrad along with a map of the area. Any fine-scale changes needed to the tetrad location should be agreed prior to undertaking the survey. Once the location is finalised the transect lines need to be mapped. Lamping surveys should be undertaken during October-November before there is substantial snow fall and snow lie. Each tetrad nominally comprises four parallel transect lines, where each transect is 2 km long. Transects should be orientated to run up-down the prevailing slope. The transect lines are 500 m apart and start 250 m in from the edge of the tetrad. One replicate survey of the four transect lines should be carried out over two to four nights; either surveying one transect each night, or if preferred and practical two transects can be surveyed each night in which case non-adjacent transects should be surveyed (*i.e.* two adjacent transects should not be surveyed in the same night. Surveys can be carried out on consecutive nights, or over the course of a week. Precision is increased if each transect is surveyed twice, in which case the second survey should be carried out about a week after the first survey. Lamping surveys should start one to two hours after sunset when hares are most active. It takes around 90 minutes to complete one 2 km transect (plus time to travel to and from the survey area). Surveys should only be undertaken in suitable weather with good visibility and no or only light wind, and avoid fog, rain/snow, and strong winds.

Reliable and consistent data recording is a key element of a monitoring scheme. Ideally, participants should be provided with a standardised recording form, or at least a crib sheet of minimum required information. The data recorded should include data, name of surveyor, location (which should include a reference number or grid reference), broad habitat type, and for each transect; start and end times, notes on weather and changes in weather - including approximate wind speed and direction, cloud cover, precipitation, visibility, and an indication of percentage of snow cover, and the number of mountain hares seen during the course of each transect. Survey data needs to be collected and collated by the scheme administrator. Copies of paper-based records could be submitted to the scheme organiser, or – as we recommend below – via a web-based tool to ensure consistent data format, basic error checking, and to allow easy collation and extraction of data for mapping and analysis. Further discussion of data management and analysis are given below (section 4.6).

After the first season of surveys the scheme organisers and project partners should undertake a thorough debrief and appraisal and of all aspects of the survey design to identify areas for improvement for roll out of a national scheme the following year. We envisage that the estates involved in the pilot phase will continue to contribute to the national programme, but that not all survey tetrads will continue to be surveyed beyond the pilot phase.

4.5.2 Rollout and development of lamping tetrad-based surveys in the central uplands

The central uplands cover around 15,787 km^2, or about 19% of the land area of Scotland, and includes many of the greater Scottish mountain ranges. Management of large areas of land in Speyside, Donside, Deeside, and the Angus Glens is for grouse shooting. The area also contains an estimated 48% of the Scottish mountain hare population. The central and eastern parts of the central uplands; the Monadhliath Mountains, Drumochter Hills, Cromdale Hills, Ladder Hills, the eastern Grampian Mountains, and Angus Glens might be considered the core range of mountain hares in Scotland. While the area supports some of the highest densities of mountain hares recorded in Scotland, areas to the west have very low densities, and there is evidence of localised declines in some areas (Hulbert *et al.*, 2008; Patton *et al.*, 2010; Watson & Hewson, 1973; Watson & Wilson, 2018). In this section we build on the pilot phase to discuss the design and implementation of mountain hare surveys in the central uplands. Given the dominance of grouse moor management and open hill habitat in this region we focus on night-time lamping surveys and engagement with estate staff, however, lamping surveys could equally well be carried out by other stakeholders, *e.g.* reserve staff or members of local mammal groups. The central uplands area also includes large areas of steep mountainous terrain (*e.g.* Glencoe) where night-time tetrad-based surveys will not be practical, and where alternative approaches will be needed (section 4.5.3).

Beyond the pilot phase the rate of roll-out will be very much dependent on the level of interest and uptake, and on the resources committed to administering the scheme, and capacity to, for example; allocate tetrads, provide maps, training provision (including risk assessment), data management, and feedback to participants. As a guide we suggest aiming to double the number of participants from a range of land users and stakeholders per year for years two and three is an ambitious, but reasonable target. While the results of the power analysis were not clear cut, and we recommend an 'adaptive sampling' design, as a guide we suggest that a national scheme should aim to consistently and annually monitor between 200-400 tetrads in central uplands by year five and beyond (alternative survey approaches will be in addition to this). Critically however, we recommend that the results from the test group should be evaluated to assess precision of estimated trend and to fine tune the required sample size. Further, we strongly recommend that the survey design should include an element of 'adaptive sampling' based on periodic appraisal of survey results and estimated trend, and these used to continually refine the survey design and adjust sample size to achieve the desired level of statistical power.

To minimise survey bias tetrads should, like BBS squares, be randomly allocated over the upland area of the central uplands. Because the survey is targeted at mountain hares, unsuitable habitat such as urban, suburban, and marine or permanent water bodies should be excluded from consideration. Random placement should be constrained to ensure that tetrads are at least 2 km apart. For practical purposes there should be enough leeway to allow surveyors to shift tetrads by half a tetrad width (*i.e.* 1 km) to avoid, or minimise, overlap with private property/houses, large roads, or land which is impractical or unsafe to survey. In some cases, it may be necessary to completely relocate a tetrad that, for example, includes a village or other large commercial and industrial facilities, transport infrastructure, or steep cliffs or other terrain that unsafe or impractical to survey. It is however important that as far as is practical and safe, tetrad placement is random. It is inevitable that in some cases a tetrad will include, or entirely comprise of, suboptimal habitat (*e.g.* forestry plantation, or fenced woodland regeneration scheme). It is important that these areas are included. Mountain hare population trends will be assessed over decadal, a minimum of 25 year, time scales. Over this time land use may change substantially; plantations will be felled, and woodlands will be planted, mature and fences removed, and it is important that the potential influences of these changes on hare populations are captured. Tetrad placement is not stratified by land holding (in contrast to the pilot phase), meaning that tetrads may cross land ownership boundaries. While this may pose some added complications it is important that tetrads are allowed to straddle ownership boundaries as like habitat and land use these will change over time, and selective placement will introduce bias. Analysis can then be stratified by region, habitat, and other factors as appropriate and sample size allows.

The design outlined here includes a total of 400 randomly placed tetrads; 200 primary which should be allocated first, and an additional 200 tetrads that can be allocated if there is sufficient uptake and resources (Annex 3). Tetrads should be considered permanent, and because this scheme is focused on monitoring trend (as opposed to estimating population size) we suggest that effort should be focused on annually monitoring at least the primary 200 tetrads. The example survey tetrads shown and listed in Annex 3 are randomly selected and so likely to be representative of the range of variation in habitat, elevation, land management and other factors likely to influence mountain hare distribution and abundance. However, a random survey design cannot and does not guarantee representative uptake of selected tetrads for survey, especially where surveys are carried out largely or exclusively by volunteers, especially in an area such as upland Scotland, where many of the selected squares are likely to be difficult for potential surveyors to get to. In addition, access to and suitability of tetrads for survey, due to terrain, safety or land ownership, cannot be guaranteed. Ensuring that this survey design translates into a representative sample, which can be used to generate robust estimates of population change, will require active management of surveyors and, or additional fieldwork by contract surveyors who can be directed to areas with low coverage by estate staff and other stakeholders. Should survey coverage still be uneven, post-hoc stratification based on one or more variables (*e.g.* slope characteristics, or distance from the nearest road) that explain variation in coverage may help to counter any influence of such a skew on survey interpretation.

Here we have focused on the central uplands but note that night-time lamping surveys will be perfectly applicable to managed moorland and, potentially other open habitats, in the southern uplands too. However, due to known differences in population dynamics and population densities care will be needed in merging survey data from the central and southern uplands. While much of the central uplands may be effectively surveyed by estate and reserve staff, and other stakeholders prepared to carryout night-time lamping surveys, other areas, particularly areas in the central Cairngorm massif and mountainous areas to the west, will not be suitable for lamping surveys and alternative approaches will be required (see below). Mountain hares are potentially impacted upon by a range of land use and land management practices, and engagement with a wide range of different land users and uses will be required to build trust in the scheme and results.

Night-time lamping surveys as described by Newey *et al.* (2018) do not generate absolute abundance or density estimates, only indices of population density. Night-time lamping combined with the survey design outlined here are intended to provide indices of mountain hare density that can be used to assess long-term trends in mountain hare numbers. By combining night-time lamping surveys with Distance sampling (Buckland *et al.*, 2004) it should be possible to obtain population density estimates for a subsample of sites, that might then be used to better calibrate indices of the number of hares seen with an absolute density estimate (though the surveys used to generate indices should be different to those used to generate density estimates) (Newey *et al.*, 2018). Undertaking Distance sampling surveys and analysing the data is not simple and is unlikely to be carried out by estate staff or other volunteers and will need specialist input. We also note that while Distance sampling has been used for mountain hare surveys and population assessment, species ecology, behaviour, habitat and terrain all pose a number of problems for the collection and analysis of data suitable for estimating hare abundance (Newey *et al.*, 2018, 2008, 2003; Shewry *et al.*, 2002).

4.5.3 Alternative approaches

The lamping and dung plots methods evaluated and recommended by Newey *et al.* (2018) are only applicable to heather moorland and potentially, though they have not been evaluated out with heather moorland, other open habitats. It is therefore not possible to develop a national monitoring programme for mountain hare using only these methods. In addition it is unclear what the level of uptake of night-time lamping surveys is likely to be outside of the game management community (and maybe nature reserves or other areas, where for example local mammal groups might undertake lamping surveys) and in any event is likely to be limited due to the demands of under taking night time wildlife surveys in the Scottish mountains in autumn and early winter. Therefore, while it is envisaged that lamping surveys, undertaken by a range of stakeholders, would be applicable throughout large areas of the uplands, particularly the southern and central uplands, to ensure national coverage and inclusion of non-moorland habitats it will be essential to foster and develop alternative, BBS and BBS-type approaches. Incorporating alternative approaches will also have the benefit of engaging a wide and diverse range of stakeholders that will be essential to build support and trust in the scheme and results.

In addition, there is no reason why areas that are effectively covered by night-time lamping surveys cannot also be surveyed using alternative approaches by the same or different stakeholder groups. Where alternative approaches and lamping surveys overlap there is an opportunity to compare the data from the different methods and use these to potentially calibrate the methods to allow easy comparisons. Outside of areas where lamping and dung plot surveys are appropriate or where uptake is low, alternative methods should be seen as the primary source of data on mountain hare trends.

There are a number of alternative approaches that we have discussed so far; BBS, BBS style Upland Rovers, Bird Tracks and Mountain Transects. The overall survey design for the alternative approaches remains to be determined and will be very much driven by availability of participants willing to carry out these surveys. Initially, at least, we strongly suggest collaboration with the BTO to encourage mammal recording within the BBS and BBS-type surveys. This would have the distinct advantage of making use of the BTO's extensive network of surveyors and survey infrastructure, as well as an established route to recruiting new participants. The BBS itself is not going to provide the necessary geographic coverage needed, it will therefore be necessary to promote and, or develop less formal survey models such as the Upland Rovers, and Bird Track. These will need to be promoted to as wide a group of potential participants as possible, including mammal and natural history groups, hill walkers, and other outdoor users. A national mountain hare monitoring scheme should seek to collaborate with other organisations and stakeholder groups undertaking wildlife surveys for other species, and even habitats, to build partnerships and synergies between surveys. In addition to developing and encouraging uptake of quantitative mountain hare surveys, we suggest it would be worthwhile to promote the wider reporting of wildlife sighting records (*e.g.* North East Scotland Biodiversity Recording Centre).

Key to engaging with, recruiting and retaining "citizen science" surveyors is to make the enrolment, data recording, and data entry as straightforward and undaunting as possible, and to provide participants with valuable feedback. Here we suggest that any national monitoring scheme draw on the experience and lessons learnt from the BTO's Upland Rovers and Bat Survey initiatives and provide internet pages and interactive map-based enrolment that provides detailed information on potential survey areas and enables participants a large degree of control to choose a convenient survey area and requires only a relatively light commitment compared to, say, the BBS itself.

Successfully involving hill walkers and other outdoor users in hare surveys requires the design and methodology of the surveys to interfere as little as possible with the main activities of participants (Maffey *et al.*, 2016; Wood *et al.*, 2011). Further, it should be straightforward and convenient to record the necessary information, and to submit this information to the organisers (Joppa, 2015; Maffey *et al.*, 2016; Wood *et al.*, 2011). Recent experience has demonstrated that the use of mobile digital technology to facilitate and enable the collection of wildlife and monitoring data has huge potential (Joppa, 2015; Maffey *et al.*, 2016; Wal & Arts, 2015; Wood *et al.*, 2011), and one of the best ways of achieving these aims is likely to be through the development and use of a mobile device app with the following features:

- **Suitable background maps**: a selection of background maps to allow users to orient themselves in relation to the surrounding landscape (and any hares they can see in it). These should include at least one aerial photography layer, and a map (such as the OS Explorer 1:25,000 series) depicting useful elements such as terrain features, woodland cover and contour lines.
- **User preferences**: allowing users to select the species they consider themselves capable of surveying during a typical walk, and applying these settings by default (with option to over-ride in instances where one or more species wasn't covered effectively), would help to ensure the capture of vital 'zero' data is achieved reliably and in a way that minimises inconvenience to the user.
- **Defining transects**: transect location and timings should be defined according to GPS tracks, with start and end defined by the user (by a single click of a button in the field).

In cases where users forget to click 'stop' at the end of survey, rules can be applied (e.g. identifying movement consistent with motorised vehicles, or where user movements becomes short and non-linear for an extended period, indicating camping) to automatically identify an endpoint.

- **Defining animals**: observation position and timing should default to the live time and position of the observer, but with the ability to specify (pinpoint) different location and time of animals where appropriate. Animal identity should be chosen from a drop-down type menu, with bespoke boxes to capture further details like number, behaviour, age and sex.
- **Clear and comprehensive guidance**: the app should be as intuitive to use as possible, but particularly for functions requiring users to change default settings, instructions should be as easy to find and to follow as possible.

Several apps (*e.g.* eBird[5], BirdTrack[6], and MammalTracker[7], MammalMapper[8] but also other mountain user GPS apps such as AlpineQuest[9]) meet some of these criteria, but no app that we are aware of fulfils all of them. The evaluation and testing of mobile applications was beyond the scope of this report, but we note that MammalMapper is aimed at recording British mammals, allows users to filter the species to be recorded, and automatically records route (thereby recording geographic coverage, and survey effort, and thereby also records zero data). Developing and optimising such an app would require considerable investment, but the benefits of delivering all of the above features would include enhanced user appeal (such an app could actually be a useful tool to hillwalkers by providing good maps, easy route capture, and statistics of interest to walkers). It would also enable more robust capture of zero data (by recording zeros for all routes walked by users capable of recording a species, and with app active, where the species isn't recorded), and (if 'pinpointing' facility used) more detail on record location than is provided by many other types of surveys. Once developed, such an app would be useful not only for surveying mountain hares, but also a wide range of other taxa (including upland birds) that are of conservation interest in Scotland.

It is unlikely that uptake of BBS and similar surveys by stakeholder groups and volunteers will be sufficient to obtain and maintain sufficiently regular and optimal geographic coverage. It is therefore likely that annual surveys by volunteers will need to be supplemented by use of contract surveyors to fill in gaps in geographic coverage.

4.6 Data management

To inform management, policy and statutory reporting, survey data need to be collected, collated and stored in an accessible form that can bring multiple and different data sources, and associated metadata, together for processing. The data then need to be analysed and the results disseminated. Some of the challenges and opportunities of data management and governance are discussed by Macdonald *et al.* (1998). Data management and governance are complex topics, with some areas covered by law. Here, we can only provide some general thoughts and recommendations.

Any national monitoring programme for mountain hares is going to have to draw upon multiple sources of data from contributing organisations (*e.g.* ENGOs), national data archives (*e.g.* NBN Gateway), and private landowners and individuals. Doing this successfully will require multiple user agreements, and flexible processes and systems not only capable of handling

[5] https://ebird.org/home (Wood *et al.*, 2011)
[6] https://www.bto.org/volunteer-surveys/birdtrack/about/introducing-birdtrack-home
[7] http://www.brc.ac.uk/mammal_tracker/
[8] http://www.mammal.org.uk/volunteering/mammal-mapper/
[9] http://www.alpinequest.net/

multiple data streams, but also meet the data processing requirements stipulated by contributors and legal frameworks.

Survey data collected by BTO, and other NGOs, will benefit from the host organisations' infrastructure and processes. However, information collected by private landowners, individuals or interest groups will need to be collected and entered into a suitable database by one or more organisations. For analysis, data will ultimately need to be collated and analysed at a designated organisation or institute with the necessary resources and expertise. A critical question therefore becomes who will be responsible for collating and analysing data, and disseminating results.

To facilitate collection of data from individuals and estates we recommend data are entered by these individuals into a web based form. This has the advantages of ensuring data and associated meta-data are entered and held in a consistent format, and allows data to be easily extracted for analysis. A web-based data entry form is unlikely to be suitable for collecting data from organisations or other users submitting large amounts of data, and it will be necessary to develop standardised formats and processes to transfer and allow data to be imported into a central database with no or minimal reformatting.

Other organisations have already developed web-based systems to record different types of wildlife survey data. For example; Scottish Wildcats[10], Scottish Squirrels[11], and North East Scotland Biological Records Centre[12] all provide online forms where users (often members of the public) can submit wildlife sightings. These online systems offer simple webpages, often with both drop-down menus and freeform data entry options, and interactive maps to allow users to provide sighting and location data. However, for more systematic, transect based, surveys these are likely to be unsuitable and we suggest that a national hare monitoring scheme look to, for example, the online data entry systems and supporting infrastructure developed by BTO for data input and management from their BBS, and BBS-type, transect based surveys[13], and the systems developed for the Southern Scotland Bat Survey (Newson *et al.*, 2017a, 2017b), and the British Bat Survey[14]. These are more complex than the simple web pages offered by for example Scottish Wildcats, and are capable of capturing systematic survey data. The greater complexity however makes these systems more difficult to use for surveyors wanting to enter data.

For more informal surveys, *e.g.* BirdTrack, a system that can capture more *ad hoc* 'transects' and survey routes, from for example a day's hill walking, will be needed that can capture the spatial detail of, for example, a day's walk along with spatially and temporally referenced sighting data. For these informal surveys mobile apps offer many advantages, including automated route mapping and georeferencing sighting data, but a manual web-based interface will likely still be needed. We recommend that SNH look at for example the recently launched MammalMapper[15] project, and associated app – which offers automated route mapping, simple sighting entry with automatic geo-referencing, run by the Mammal Society[16] to see what has worked and whether the app could be used as is for mountain hare surveys or adapted. We also note that SNH has developed a site condition monitoring app (SWIFT[17]) for mobile devices and should look to see what software and technical solutions are used with this system.

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[10] http://www.scottishwildcataction.org/how-you-can-help/#report
[11] https://scottishsquirrels.org.uk/squirrel-sightings/
[12] http://www.nesbrec.org.uk/recording-services/online-form/
[13] https://www.bto.org/volunteer-surveys/bbs/taking-part/bbs-online
[14] https://app.bto.org/bat-vis/NorfolkBatSurvey/
[15] http://www.mammal.org.uk/volunteering/mammal-mapper/
[16] http://www.mammal.org.uk/
[17] https://www.eurosite.org/wp-content/uploads/1.2-The-SWIFT-app-Zoe-Russell.pdf

There are now a number of biodiversity recording apps for a range of species or groups, for example; the popular citizen science iRecord[18], and wider family of apps, developed by the Centre for Ecology and Hydrology[19]. We recommend that SNH look at existing mobile applications and back end infrastructure to assess whether any of these would be suitable or could be adapted for mountain hare surveys, and to learn from the experience of others. In addition to biodiversity focused apps, more generic mobile data collection platforms (*e.g.* EpiCollect/EpiCollect+[20], developed by Imperial College) may also be suitable, particularly for more systematic surveys.

A key aspect influencing the success or otherwise of "citizen science" based projects appears to be the provision of timely feedback and results. Though this is not itself a data collection and management issue it is something that should, and needs to be, considered at the data management design stage. Related issues are to what extent data analysis is automated, and whether the system offers users results or analytical tools. A good example here is the British Bat Survey and associated web pages[21] that offer users a range of analyses and results that participants can access and explore.

Clearly both data privacy and maintaining the anonymity of the data source and provenance need to be considered. For analysis georeferenced data at the tetrad scale should be used. However, for reporting purposes data from private landowners may need to be geographically aggregated at a spatial scale that ensures data cannot be assigned to a specific land holding. There will inevitably be trade-offs between maintaining spatial resolution for analyses and maintaining anonymity. Collation and use of data also need to consider the privacy of data providers and the obligation of publicly funded bodies or those undertaking publicly funded research to meet open data legislation. These are all important issues that need to be resolved as early as possible in the design and implementation of a national monitoring programme. We suggest that it would be worthwhile looking at the monitoring systems and programmes other countries have in place for surveillance of what are regarded as small game species, for example Norway, Sweden, Finland, Germany and France which have strong wildlife management and hunting traditions (see *e.g.*; Newey *et al.*, 2010).

Where compatible with other interests and noting the issues raised by Pearce-Higgins *et al.* (2018), we strongly advocate an open data approach consistent with the global and national movement towards open data, open science and open government (European Commission, 2016; Pearce-Higgins *et al.*, 2018; Scottish Government, 2016). We encourage all those organisations and individuals involved in mountain hare surveys to contribute data to those national monitoring programmes that are committed to placing data in national data repositories such as the National Biodiversity Network (NBN) Atlas[22], and to make all such data available in the public domain and free to use (in the sense of open access, and not for profit). We acknowledge the genuine concern and sensitivities over data ownership and privacy, but note that open data is becoming the norm and that researchers are increasingly expected to make all data available in the public domain. We are however also aware that wildlife management and sport shooting are emotive and controversial subjects (Leader-Williams, 2009; Oldfield *et al.*, 2003), and that data management and sharing must protect the confidentiality of contributors from the genuine risk of threat to property and safety.

[18] https://www.ceh.ac.uk/citizen-science-apps
[19] https://www.ceh.ac.uk/
[20] https://five.epicollect.net/
[21] https://app.bto.org/bat-vis/NorfolkBatSurvey/
[22] https://nbn.org.uk/

4.7 Recommendations

We recommend:

- The establishment of a national mountain hare monitoring programme initially focusing on sporting estates in the (true) uplands zones of Scotland, starting with a test group as soon as is practical. Initially sample size and coverage are likely to be limited by uptake, but should aim to include sites in southern, central and north-west upland areas, with more sites in the central uplands.
- The roll out of a national monitoring scheme should engage with ENGOs (*e.g.* BTO) and other interest groups (*e.g.* local mammal groups) as soon as possible to promote the uptake of alternative BBS and BBS-type volunteer-led surveys for mountain hares. These will be essential to augment lamping surveys and serve as the main source of hare data in areas where lamping is inappropriate or uptake is low.
- The most relevant existing Scottish-wide citizen science scheme for mountain hare monitoring is the BBS. Coverage of BBS in upland areas, particularly through the Upland Rovers initiative, should be encouraged. In the short to medium term, the most promising means of increasing information on mountain hares outside of the central and southern uplands is through alternative types of volunteer survey that are flexible enough in their design to allow volunteers to select their own survey routes and make use of 'platforms of opportunity' that can capture information on survey effort effectively. To facilitate the development of these types of survey, a mobile device app should be developed to ensure consistency in reporting and maximise ease of use, value of data, and appeal to volunteers.
- Sample size should be determined by analysis of data collected by the test group. In the longer term, monitoring efficacy and power should be continually assessed to allow ongoing refinement of a national monitoring programme for this species.
- Annual evaluations of sample sizes available to produce trends for areas or strata of interest should inform the overall monitoring strategy. In particular, efforts to increase mountain hare records should focus on particular areas or particular types of survey to most effectively deliver the sample sizes necessary to inform assessment of trends.
- The roll out a national monitoring scheme to estates and wider stakeholder community will require outreach, training and support. We note that this is being developed elsewhere.
- A national monitoring programme should try to take advantage of efforts to collect mountain hare data, particularly where these involve new or modified elements of surveying, to improve monitoring of other taxa where feasible. Our understanding of data deficient species and those of conservation concern could be enhanced particularly wherever such synergies can be found.
- Assessing trend in mountain hare populations in Scotland will require decades of monitoring. Any national programme should continue to make full use of existing schemes, namely the NGC and BBS as these represent long-term and growing data sets. Corroboration or divergence of trends from these very different schemes can be used as evidence in assessing trends from these and other schemes. However, as shown here both the BBS and NGC are largely monitoring the same areas so care is needed in drawing conclusions.
- As a priority it is necessary to consider data management and governance, and how data will be analysed and used to inform management, policy and reporting.
- That every effort should be made to learn from schemes in other countries where "small game" are routinely monitored.

5. REFERENCES

Aebischer, N.J. & Baines, D. 2008. Monitoring gamebird abundance and productivity in the UK: The GWCT long-term datasets. *Revista Catalana d'Ornitologia*, 24, 30–43.

Aebischer, N.J., Davey, P.D. & Kingdon, N.G., 2011. National Gamebag Census: Mammal Trends to 2009. Game & Wildlife Conservation Trust, Fordingbridge http://www.gwct.org.uk/ngcmammals.

Battersby, J.E., & Greenwood, J.J.D. 2004. Monitoring terrestrial mammals in the UK: past, present and future, using lessons from the bird world. *Mammal Review*, 34, 3–29.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V. & Shirk, J. 2009. Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, 59, 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Brereton, T.M., Botham, M.S., Middlebrook, I., Randle, Z., Noble, D.G. & Roy, D.B. 2017. United Kingdom Butterfly Monitoring Scheme report for 2016. Centre for Ecology & Hydrology & Butterfly Conservation.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., & Thomas, L. 2004. Introduction to Distance Sampling: Estimating abundance of biological populations. Oxford University Press, Oxford.

Calladine, J. & Wernham, C. 2009. Extensive monitoring of rock ptarmigan *Lagopus mutus* in Scotland: a pilot to test the efficacy of using volunteer surveyors for monitoring arctic-alpine birds. *Avocetta*, 33, 217–224.

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B. *et al*. 2008. Countryside survey: UK results from 2007. Centre for Ecology & Hydrology.

Cattadori, I.M., Haydon, D.T., Thirgood, S.J. & Hudson, P.J. 2003. Are indirect measures of abundance a useful index of population density? The case of red grouse harvesting. *Oikos*, 100, 439–446. https://doi.org/10.1034/j.1600-0706.2003.12072.x

Darvill, B., Oldershaw, L.E. & Wernham, C. V. 2016. "What"s Up?' - monitoring change in Scotland's upland birds: final report. BTO Research Report No. 686.

Efron, B. & Tibshirani, R.J. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science*, 1, 54–77.

Elphick, C.S. 2008. How you count counts: the importance of methods research in applied ecology. *Journal of Applied Ecology*, 45, 1313–1320. https://doi.org/10.1111/j.1365-2664.2008.01545.x

Elton, C. & Nicholson, M. 1942. The Ten-Year Cycle in Numbers of the Lynx in Canada. *Journal of Animal Ecology*, 11, 215–244.

European Commission, 2016. EU Open Innovation, Open Science, Open to the World, European Commission. https://doi.org/10.2777/061652

Fewster, R.M., Buckland, S.T., Siriwardena, G.M., Baillie, S.R. & Wilson, J.D. 2000. Analysis of population trends for farmland birds using generalized additive models. *Ecology*, 81, 1970-1984.

Harris, S., Morris, P.A., Wray, S. & Yalden, D.W. 1995. A Review of British Mammals : Population Estimates and Conservation Status of British Mammals other than Cetaceans. JNCC, Peterborough.

Harris, S. & Yalden, D.W. 2004. An integrated monitoring programme for terrestrial mammals in Britain. *Mammal Review*, 34, 157–167.

Harris, S.J., Massimino, D., Gillings, S., Eaton, M.A., Noble, D.G., Balmer, D.E., Pearce-Higgins, J.W. & Woodcock, P. 2018. The Breeding Bird Survey 2017. The British Trust for Ornithology, Norfolk.

Hastie, T.J. & Tibshirani, R.J. 1990. Generalized Additive Models. Chapman & Hall, London.

Haydon, D.T., Shaw, D.J., Cattadori, I.M., Hudson, P.J. & Thirgood, S.J. 2002. Analysing noisy time-series: describing regional variation in the cyclic dynamics of red grouse. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 269, 1609–1617.

Hewson, R. 1985. Long-Term Fluctuations in Populations of Mountain Hares (*Lepus timidus*). *Journal of Zoology*, 206, 269–273.

Hewson, R. 1984. Mountain hare, *Lepus timidus*, bags and moor management. *Journal of Zoology*, 204, 563–565.

Hewson, R. 1976. A Population Study of Mountain Hares (*Lepus timidus*) in North-East Scotland from 1956-1969. *Journal of Animal Ecology*, 45, 395-395.

Hewson, R. 1958. Moults and winter whitening in the mountain hare (*Lepus timidus scoticus*) Hilzheimer. *Proceedings Zoological Society of London*, 131, 99–108.

Hulbert, I.A.R., Iason, G.R., Hewson, R. & Dingerkus, S.K. 2008. Mountain Hare/Irish Hare *Lepus timidus*. In: Harris, S. ed. The New Handbook of British Mammals. Blackwell Scientific Publication, Oxford.

Joppa, L.N. 2015. Technology for nature conservation: An industry perspective. *Ambio*, 44, 522–526. https://doi.org/10.1007/s13280-015-0702-4

Kerlin, D.H., Haydon, D.T., Miller, D., Aebischer, N.J., Smith, A.A. & Thirgood, S.J. 2007. Spatial synchrony in red grouse population dynamics. *Oikos*, 116, 2007–2016.

Knipe, A., Fowler, P., Ramsay, S., Haydon, D.T., McNeilly, A.S., Thirgood, S. & Newey, S. 2013. The effects of population density on the breeding performance of mountain hare *Lepus timidus*. *Wildlife Biology*, 19, 473–482. https://doi.org/10.2981/12-109

Krebs, C.J., Boonstra, R., Boutin, S. & Sinclair, A.R.E. 2001. What Drives the 10-year Cycle of Snowshoe Hares? *Bioscience*, 51, 25–35.

Leader-Williams, N. 2009. Conservation and Hunting: Friends or Foxes? In: Dickson, B., Hutton, J. & Adams, W.M. Recreational Hunting, Conservation and Rural Livelihoods. Wiley-Blackwell, pp. 7–24. https://doi.org/10.1002/9781444303179.ch1

Macdonald, D.W., Mace, G.M. & Rushton, S.J. 1998. Proposals for future monitoring of British mammals. DETR/JNCC, UK.

Macdonald, D.W. & Tattersall, F.H. 2003. The State of Britain's Mammals 2003. People's Trust for Endangered Species/Mammals Trust UK, UK.

Maffey, G., Irvine, R.J., Reed, M. & van der Wal, R. 2016. Can digital reinvention of ecological monitoring remove barriers to its adoption by practitioners? A case study of deer management in Scotland. *Journal of Environmental Management*, 184, 186-195. https://doi.org/10.1016/j.jenvman.2016.09.074

Massimino, D. & Gillings, S. 2017. Breeding Bird Survey visit timing and trends. Draft Project Report. BTO, Norfolk, UK.

Massimino, D., Harris, S.J. & Gillings, S. 2018. Evaluating spatiotemporal trends in terrestrial mammal abundance using data collected during bird surveys. *Biological Conservation*, 226, 153–167. https://doi.org/https://doi.org/10.1016/j.biocon.2018.07.026

McCullagh, P. & Nelder, J.A. 1996. Generalized Linear Models, 3rd ed. Chapman & Hall, London.

Newey, S., Bell, M., Enthoven, S. & Thirgood, S.J. 2003. Can distance sampling and dung plots be used to assess the density of mountain hares *Lepus timidus*? *Wildlife Biology*, 9, 185–192.

Newey, S., Dahl, F. & Kurki, S. 2010. Game monitoring systems supporting the development of sustainable hunting tourism in Northern Europe: A review of current practises, Ruralia Institute Reports. University of Helsinki, Finland.

Newey, S., Dahl, F., Willebrand, T. & Thirgood, S. 2007a. Unstable dynamics and population limitation in mountain hares. *Biological Reviews*, 82, 527–549. https://doi.org/10.1111/j.1469-185X.2007.00022.x

Newey, S., Fletcher, K., Potts, J. & Iason, G. 2018. Developing a counting methodology for mountain hares (*Lepus timidus*) in Scotland. Scottish Natural Heritage Research Report No. 1022.

Newey, S., Iason, G. & Raynor, R. 2008. The conservation status and management of mountain hares. Scottish Natural Heritage Commissioned Report No. 287.

Newey, S., Potts, J., Baines, D., Castiillo, U., Duncan, M., Harrison, A., Ramsay, S., Thirgood, S.J. & Iason, G. 2011. Development of a reliable method for estimating mountain hare numbers. Scottish Natural Heritage Commissioned report No. 444.

Newey, S., Willebrand, T., Haydon, D.T., Dahl, F., Aebischer, N.J., Smith, A.A. & Thirgood, S.J. 2007b. Do mountain hare populations cycle? *Oikos*, 116, 1547–1557. https://doi.org/10.1111/j.2007.0030-1299.15868.x

Newson, S.E., Evans, H.E., Gillings, S., Jarrett, D., Raynor, R. & Wilson, M.W. 2017a. Large-scale citizen science improves assessment of risk posed by wind farms to bats in southern Scotland. *Biological Conservation*, 215, 61–71. https://doi.org/10.1016/j.biocon.2017.09.004

Newson, S.E., Evans, H.E., Gillings, S., Jarrett, D. & Wilson, M.W. 2017b. A survey of high risk bat species across southern Scotland. Scottish Natural Heritage Commissioned Report No. 1008.

Newson, S.E., Evans, H.E. & Gillings, S. 2015. A novel citizen science approach for large-scale standardised monitoring of bat activity and distribution, evaluated in eastern England. *Biological Conservation*, 191, 38–49. https://doi.org/10.1016/j.biocon.2015.06.009

Newson, S.E., Moran, N.J., Musgrove, A.J., Pearce-Higgins, J.W., Gillings, S., Atkinson, P.W., Miller, R., Grantham, M.J. & Baillie, S.R. 2016. Long-term changes in the migration phenology of UK breeding birds detected by large-scale citizen science recording schemes. *Ibis*, 158, 481–495. https://doi.org/10.1111/ibi.12367

Noble, D.G., Aebischer, N.J., Newson, S.E., Ewald, J.A. & Dadam, D. 2012. A comparison of trends and geographical variation in mammal abundance in the Breeding Bird Survey and the National Gamebag Census. JNCC, Peterborough.

Oldfield, T.E.E., Smith, R.J., Harrop, S.R. & Leader-Williams, N. 2003. Field sports and conservation in the United Kingdom. *Nature*, 423, 531–533. https://doi.org/10.1038/nature01678

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, 313–326. https://doi.org/10.1111/j.1365-2907.2010.00162.x

Payton, M.E., Greenstone, M.H. & Schenker, N. 2003. Overlapping confidence intervals or standard error intervals: What do they mean in terms of statistical significance? *Journal of Insect Science*, 3, 34.

Pearce-Higgins, J.W., Baillie, S.R., Boughey, K., Bourn, N.A.D., Foppen, R.P.B., Gillings, S., Gregory, R.D., Hunt, T., Jiguet, F., Lehikoinen, A., Musgrove, A.J., Robinson, R.A., Roy, D.B., Siriwardena, G.M., Walker, K.J. & Wilson, J.D. 2018. Overcoming the challenges of public data archiving for citizen science biodiversity recording and monitoring schemes. *Journal of Applied Ecology*, 55, 2544-2551. https://doi.org/10.1111/1365-2664.13180

Royama, T. 1992. Analytical population Dynamics. Chapman & Hall, London.

Scottish Government. 2016. Open Government Partnership Scottish National Action Plan 2016-2017. Scottish Government, Edinburgh. https://www.gov.scot/Resource/0051/00511323.pdf

Skalski, J.R. 1990. A design for long-term status and trends monitoring. *Journal of Environmental Management*, 30, 139–144. https://doi.org/https://doi.org/10.1016/0301-4797(90)90011-K

Shewry, M.C., Buckland, S.T. & Shaw, P. 2002. Distance sampling and its application to monitoring selected species, RSM Report. Scottish Natural Heritage, Battleby.

Tapper, S.C. 1992. Game Heritage: An ecological review from shooting and game keeping records. The Game Conservancy Limited, Fordingbridge, UK.

Turchin, P. 2003. Complex Population Dynamics: A Theoretical/Empirical Synthesis, Monographs in Population Biology. Princeton University Press.

Wal, R. van der & Arts, K. 2015. Digital conservation: An introduction. *Ambio*, 44, 517–521. https://doi.org/10.1007/s13280-015-0701-5

Watson, A. & Hewson, R. 1973. Population densities of mountain hares (*Lepus timidus*) on western Scottish and Irish moors and Scottish hills. *Journal of Zoology*, 170, 151–159.

Watson, A., Hewson, R., Jenkins, D. & Parr, R. 1973. Population densities of mountain hares compared with red grouse on Scottish moors. *Oikos*, 24, 225–230.

Watson, A. & Wilson, J.D., 2018. Seven decades of mountain hare counts show severe declines where high-yield recreational game bird hunting is practised. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13235

Wood, C., Sullivan, B., Iliff, M., Fink, D. & Kelling, S. 2011. eBird: Engaging Birders in Science and Conservation. *PLOS Biology*, 9, 1–5. https://doi.org/10.1371/journal.pbio.1001220

Willebrand, T., Hornell-Willebrand, M. & Asmyhr, L., 2011. Willow grouse bag size is more sensitive to variation in hunter effort than to variation in willow grouse density. *Oikos*, 120, 1667–1673.

Wright, L.J., Newson, S.E. & Noble, D.G. 2014. The value of a random sampling design for annual monitoring of national populations of larger British terrestrial mammals. European *Journal of Wildlife Research*, 60, 213–221. https://doi.org/10.1007/s10344-013-0768-x

Zimova, M., Hackländer, K., Good, J.M., Melo-Ferreira, J., Alves, P.C. & Mills, L.S. 2018. Function and underlying mechanisms of seasonal colour moulting in mammals and birds: what keeps them changing in a warming world? *Biological Reviews*, 93, 478–1498. https://doi.org/10.1111/brv.12405

ANNEX 1. MAPS OF BBS AND UPLAND ROVER COVERAGE AND UPTAKE

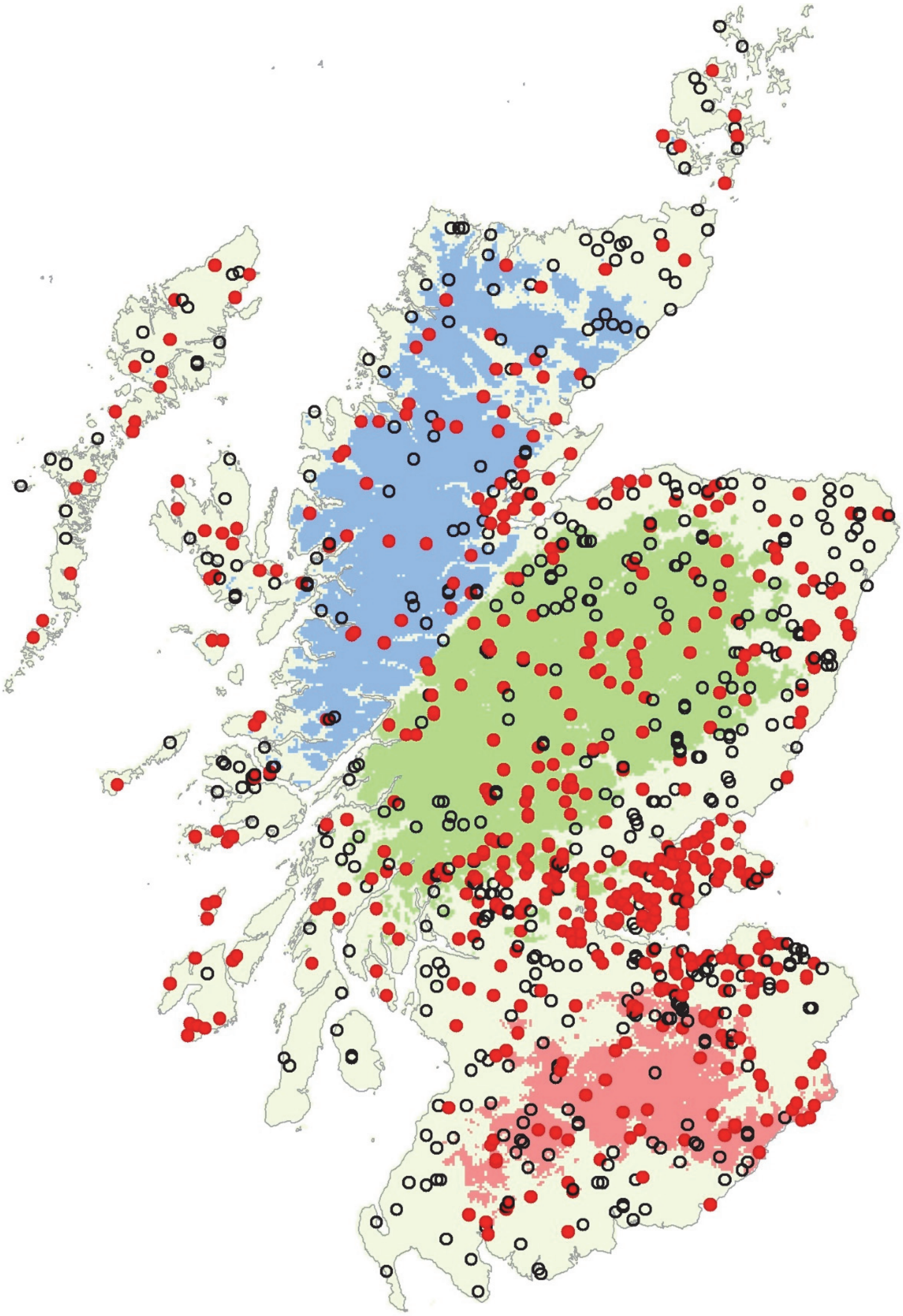

Figure A1.1. Map showing the distribution and uptake (surveys completed) for BBS surveys in 2018 showing all BBS squares for which data were received in 2018 - shaded red, all other BBS squares. Back ground shading shows the extent of the True Uplands.

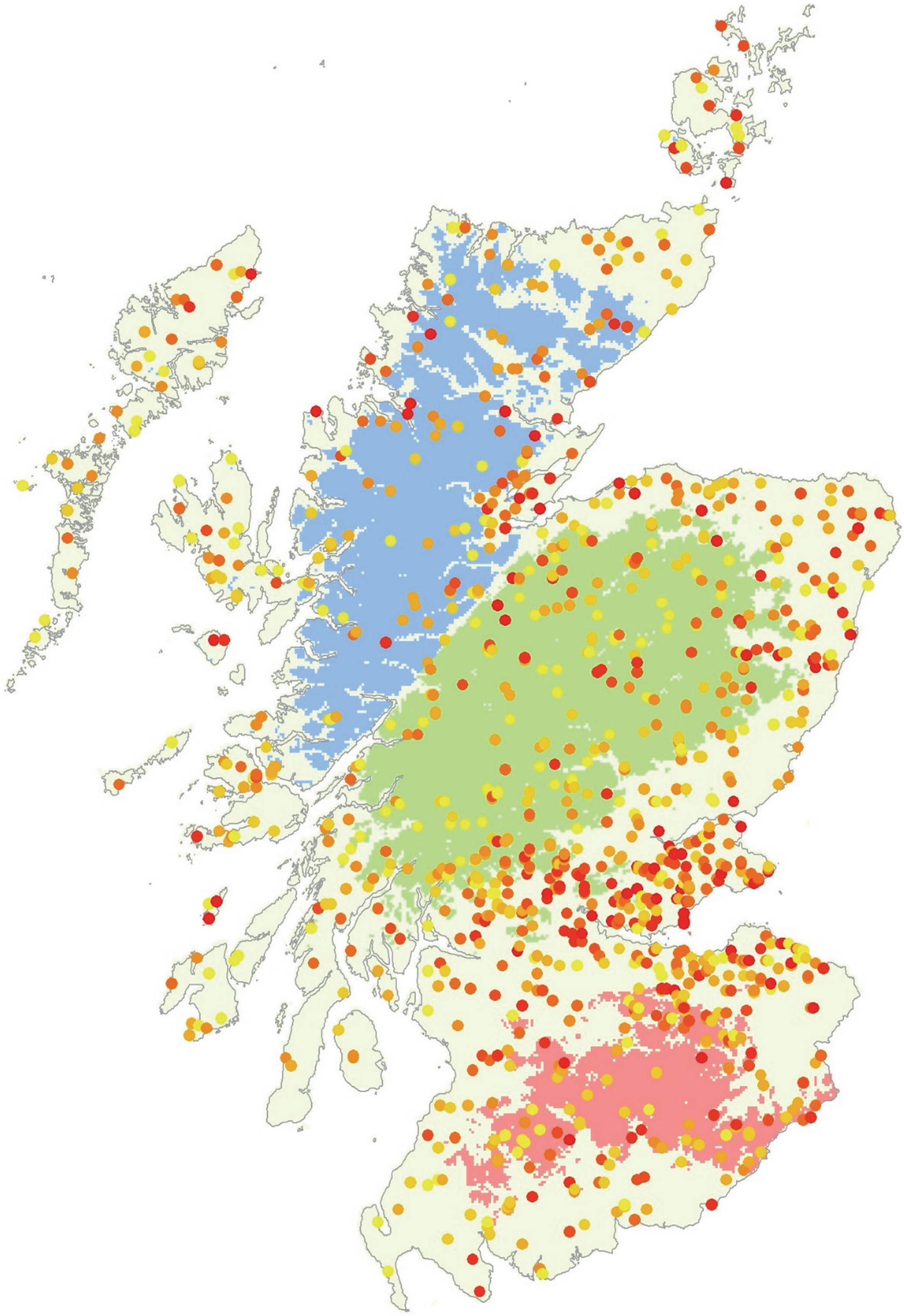

Figure A1.2. Maps showing the distribution and percentage coverage of BBS squares between 1994 and 2018 indicating the percentage (yellow – low, red – high) of possible years (n= 25 years) in which each square has had a BBS survey carried out. Back ground shading shows the extent of the True Uplands.

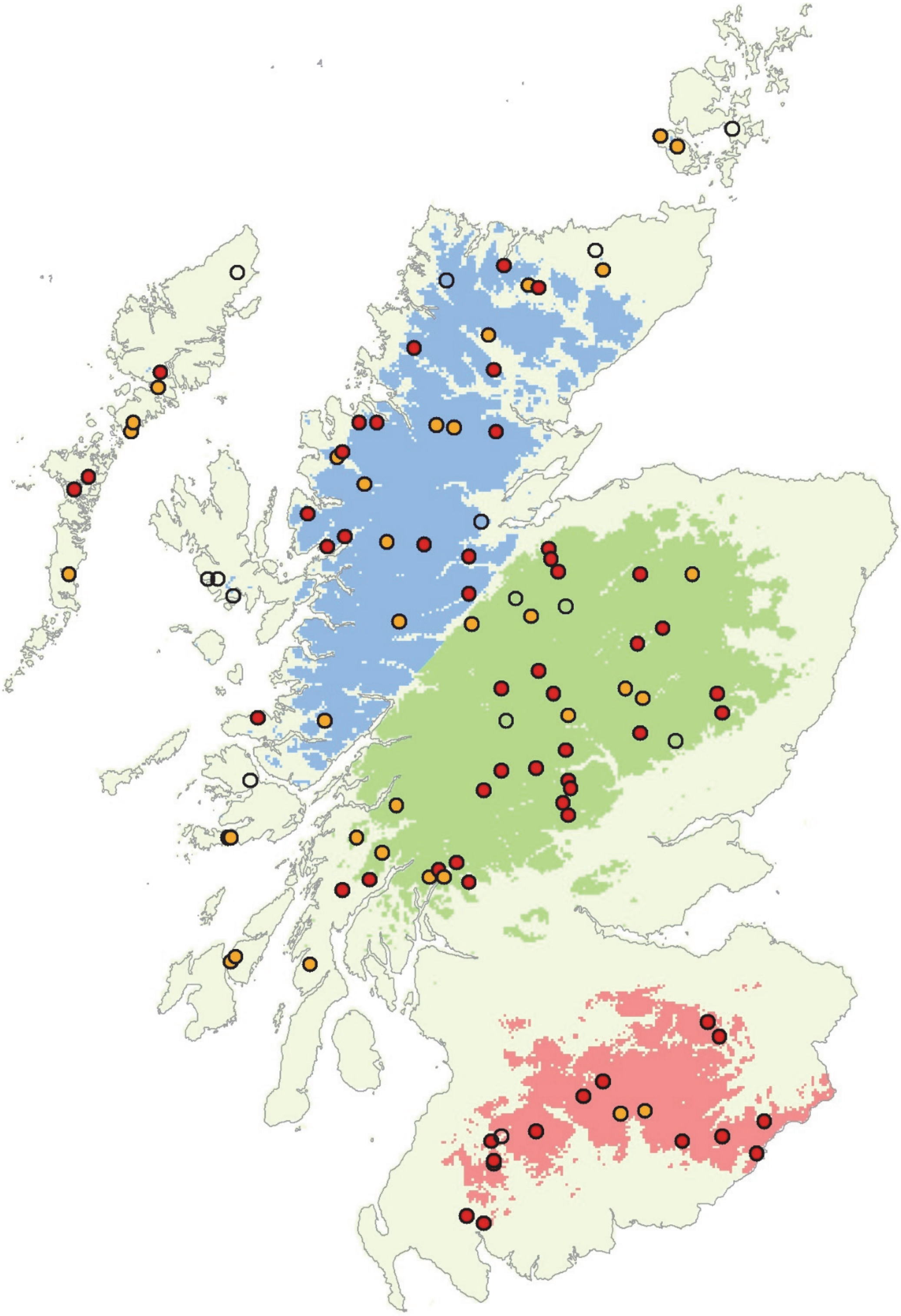

Figure A1.3. Maps showing the distribution of coverage of Upland Rover BBS squares in 2018. It also provides a minimum estimate of data returned from Upland Rover squares in 2018, with colour indicating number of visits; red = two survey visits covered, orange = one survey visit covered, hollow = no data returned at time of reporting. Back ground shading shows the extent of the True Uplands.

ANNEX 2: PILOT SCHEME TETRAD LAYOUT

For the pilot study we suggest one of two approaches depending on the size of total area and participating estates. Ideally tetrads should be placement randomly across the upland areas of each of the estates within each Moorland Group at a density of one tetrad per beat (or management unit). However, in some circumstances such as if the moorland management area is relatively small, for example as in the Lammermuir Hills, a systematic layout may be more appropriate. In the examples below, we show how random and systematic layouts might be achieved considering the recommendations in section 4.5.1 that tetrads should be 2 km apart, and that there is scope to move tetrads by up to 1 km from their initial location. However, we recognise that in the pilot phase it might not be possible to accommodate one tetrad per beat due to size and spacing considerations.

A2.1 Random layout

Figure A2 (A2.1 and A2.2) shows the initial and final layout of tetrads for a hypothetical Moorland Group consisting of three estates (A, B, and C), where each estates comprises 2 or 3 beats; A1, A2, B1, B2, C1, C2, D1, D2, and D3 giving nine land parcels and nine potential tetrads. One tetrad is randomly placed within each land parcel (Fig. A2.1). The initial placement is clearly not compliant with the spacing criteria, and one tetrad in area B1 includes a large area of water. We therefore suggest that tetrads can be moved or removed to ensure compliance, working through each land parcel clockwise from top-right;
A1 – is OK,
A2 – is too close to A1, and cannot be moved and remains within the designated area and so is removed,
B1 – the tetrad includes a large area of water and so is moved (less than 1 km) north until it is clear of the water,
B2 – the tetrad is OK,
C1 – the tetrad includes a large area of forestry plantation, while this is not ideal habitat for mountain hares this area needs to be included as it will be clear felled within the next 25 years and may become suitable for mountain hares.
C2 – it is not possible to place a tetrad in this area while keeping 2 km from any other tetrad so it is removed,
D1 – placement is OK,
D2 – placement is OK,
D3 – it is not possible to place a tetrad in this area while keeping 2 km from any other tetrad so it is removed,
The final layout of tetrads is shown in Figure A2.2.

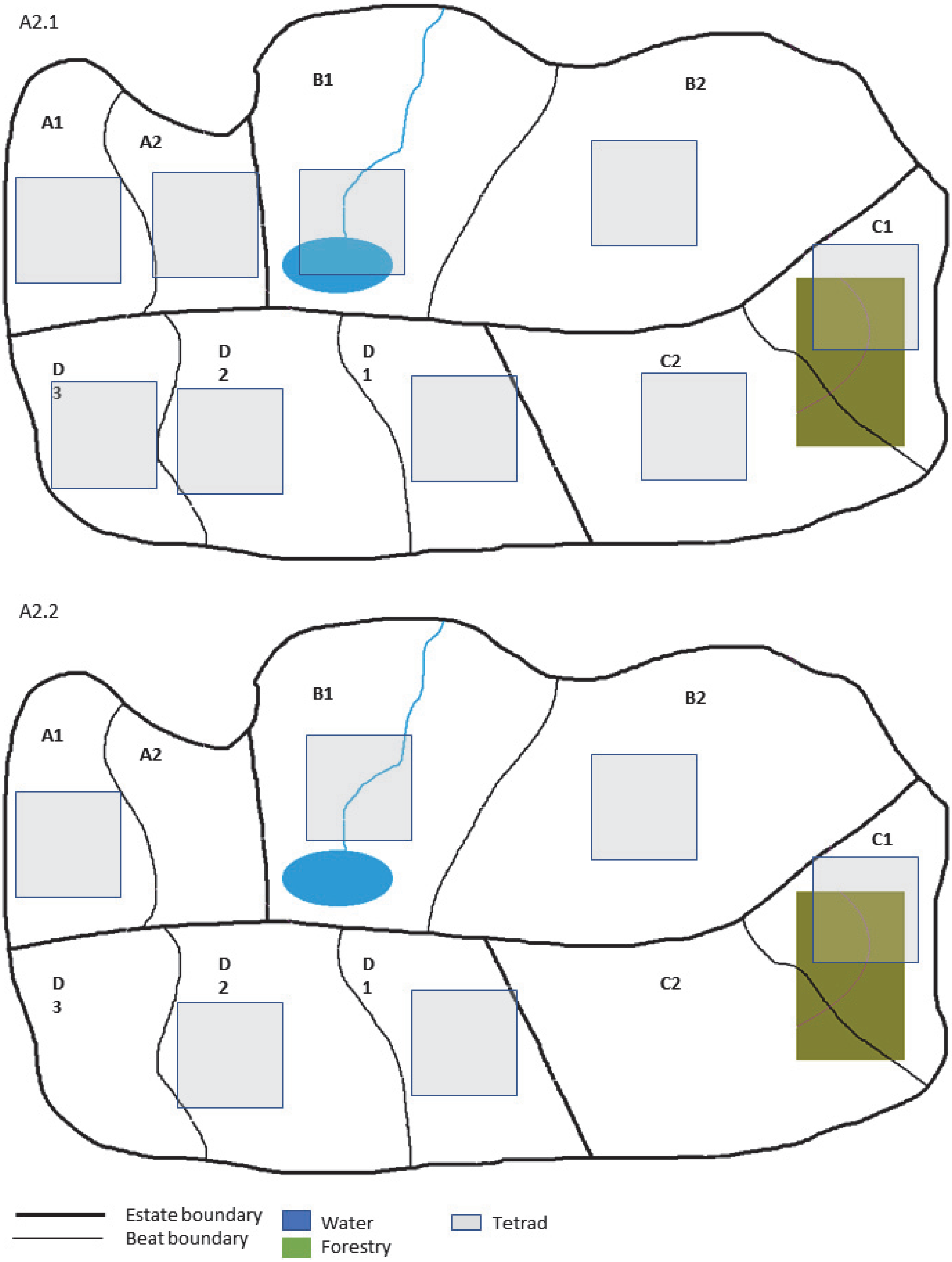

Figure A2. Schematic showing; A2.1 the initial and A2.2 final layout of tetrads for a hypothetical Moorland Group consisting of three estates (A, B, and C), where each estate comprises 2 or 3 beats; A1, A2, B1, B2, C1, C2, D1, D2, and D3 giving nine land parcels and nine potential tetrads.

A2.2 Systematic layout

Using the Lammermuir Hills as an example Figures A2.3 and A2.4 show two options for the systematic layout of tetrads. Estate and beat/management area boundaries are unknown, and the total extent of area covered by both options is deliberately greater than the presumed extent of participating estates and the preferred habitat of mountain hares. For example tetrads in the NW of both the scenarios shown below fall in urban areas and should be excluded from consideration as real survey tetrads.

Figure A2.3 shows a chequer board pattern of tetrads. This option provides a lot of potential survey tetrads, and it is not intended that all would be surveyed. The actual tetrads to be surveyed could, for example, be; i) chosen randomly, ii) chosen in discussion with the estates and other stakeholders, or iii) a combination of these that first eliminates unsuitable/impractical tetrads to generate a candidate list, with the final selection based on a random sample. The chequerboard approach, initially at least, ignores the recommendation of maintaining 2 km separation between tetrads which may be justified in the context of a pilot phase to ensure adequate sample size within a small area.

Figure A2.4 shows a "sparse" chequerboard based on a 2 x 2 km grid where only tetrads in alternate columns and rows represent potential survey areas. This layout ensures 2 km separation between tetrads and allows some room to move tetrads (< 1 km) to avoid, for example, reservoirs. At the same time the spare chequerboard provides fewer potential tetrads, though still more than there are likely to be resources available. Where there are too many potential tetrads these can be reduced by randomly selecting and, or negotiating a subset of tetrads that will be surveyed.

Both the chequerboard and sparse chequerboard have advantages and disadvantages. We suggest that the sparse chequerboard represents a reasonable compromise in identifying potential tetrads while maintaining a 2 km separation and allows room to move tetrads to avoid major obstructions to surveys. Whichever placement scheme is used the key consideration from a sampling perspective is that the tetrads that are surveyed are randomly placed relative to the distribution and abundance of mountain hares.

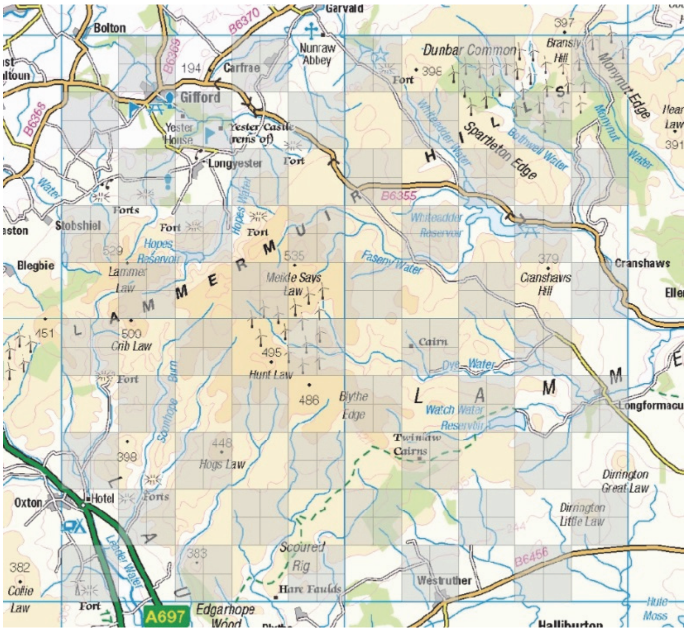

Figure A2.3. Shows a chequerboard layout of potential survey tetrads. Tetrads that are dominated by or include unsuitable areas, for example those in the NW which mostly include urban areas can be excluded, as can those tetrads that overlie roads and large water bodies. However, in this design there is no scope to move tetrads. Coordinates of tetrad centroids are provided in Table A2.1

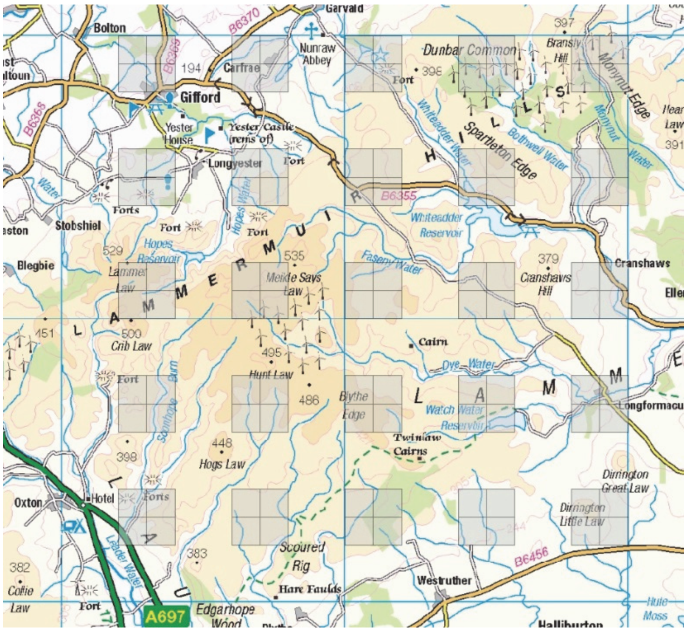

Figure A2.4. Shows a sparse chequerboard layout of potential survey tetrads. Tetrads in the NW that fall over urban areas can be excluded from consideration. Tetrads in the SE which fall on lowland could also be excluded if mountain hares are not thought to occur in these areas. Tetrads in the NE of the area that fall across could be moved up to 1 km to avoid the road. The tetrad in the NE that includes the reservoir should be moved, by up to 1 km, to avoid or minimise, overlap with the reservoir. Coordinates of tetrad centroids are provided in Table A2.2.

Table A2.1. Coordinates of tetrad centroids for chequerboard layout of penitential tetrads for the Lammermuirs pilot area.

Tetrad Code	OS Grid Square	Tetrad Centroid			
		OS Easting	OS Northing	Easting	Northing
NT5369	NT	53	69	353000	669000
NT5769	NT	57	69	357000	669000
NT6169	NT	61	69	361000	669000
NT6569	NT	65	69	365000	669000
NT6969	NT	69	69	369000	669000
NT5167	NT	51	67	351000	667000
NT5567	NT	55	67	355000	667000
NT5967	NT	59	67	359000	667000
NT6367	NT	63	67	363000	667000
NT6767	NT	67	67	367000	667000
NT5365	NT	53	65	353000	665000
NT5765	NT	57	65	357000	665000
NT6165	NT	61	65	361000	665000
NT6565	NT	65	65	365000	665000
NT6965	NT	69	65	369000	665000
NT5163	NT	51	63	351000	663000
NT5563	NT	55	63	355000	663000
NT5963	NT	59	63	359000	663000
NT6363	NT	63	63	363000	663000
NT6763	NT	67	63	367000	663000
NT5361	NT	53	61	353000	661000
NT5761	NT	57	61	357000	661000
NT6161	NT	61	61	361000	661000
NT6561	NT	65	61	365000	661000
NT6961	NT	69	61	369000	661000
NT5159	NT	51	59	351000	659000
NT5559	NT	55	59	355000	659000
NT5959	NT	59	59	359000	659000
NT6359	NT	63	59	363000	659000
NT6759	NT	67	59	367000	659000
NT5357	NT	53	57	353000	657000
NT5757	NT	57	57	357000	657000
NT6157	NT	61	57	361000	657000
NT6557	NT	65	57	365000	657000
NT6957	NT	69	57	369000	657000
NT5155	NT	51	55	351000	655000
NT5555	NT	55	55	355000	655000
NT5955	NT	59	55	359000	655000
NT6355	NT	63	55	363000	655000
NT6755	NT	67	55	367000	655000
NT5353	NT	53	53	353000	653000
NT5753	NT	57	53	357000	653000
NT6153	NT	61	53	361000	653000
NT6553	NT	65	53	365000	653000
NT6953	NT	69	53	369000	653000
NT5151	NT	51	51	351000	651000
NT5551	NT	55	51	355000	651000
NT5951	NT	59	51	359000	651000
NT6351	NT	63	51	363000	651000
NT6751	NT	67	51	367000	651000

Table A2.2. Coordinates of tetrad centroids for sparse chequerboard layout of penitential tetrads for the Lammermuirs pilot area.

Tetrad Code	OS Grid Square	Tetrad Centroid			
		OS Easting	OS Northing	Easting	Northing
NT5369	NT	53	69	353000	669000
NT5769	NT	57	69	357000	669000
NT6169	NT	61	69	361000	669000
NT6569	NT	65	69	365000	669000
NT6969	NT	69	69	369000	669000
NT5365	NT	53	65	353000	665000
NT5765	NT	57	65	357000	665000
NT6165	NT	61	65	361000	665000
NT6565	NT	65	65	365000	665000
NT6965	NT	69	65	369000	665000
NT5361	NT	53	61	353000	661000
NT5761	NT	57	61	357000	661000
NT6161	NT	61	61	361000	661000
NT6561	NT	65	61	365000	661000
NT6961	NT	69	61	369000	661000
NT5357	NT	53	57	353000	657000
NT5757	NT	57	57	357000	657000
NT6157	NT	61	57	361000	657000
NT6557	NT	65	57	365000	657000
NT6957	NT	69	57	369000	657000
NT5353	NT	53	53	353000	653000
NT5753	NT	57	53	357000	653000
NT6153	NT	61	53	361000	653000
NT6553	NT	65	53	365000	653000
NT6953	NT	69	53	369000	653000

ANNEX 3. INDICATIVE DISTRIBUTION OF POTENTIAL SURVEY TETRADS

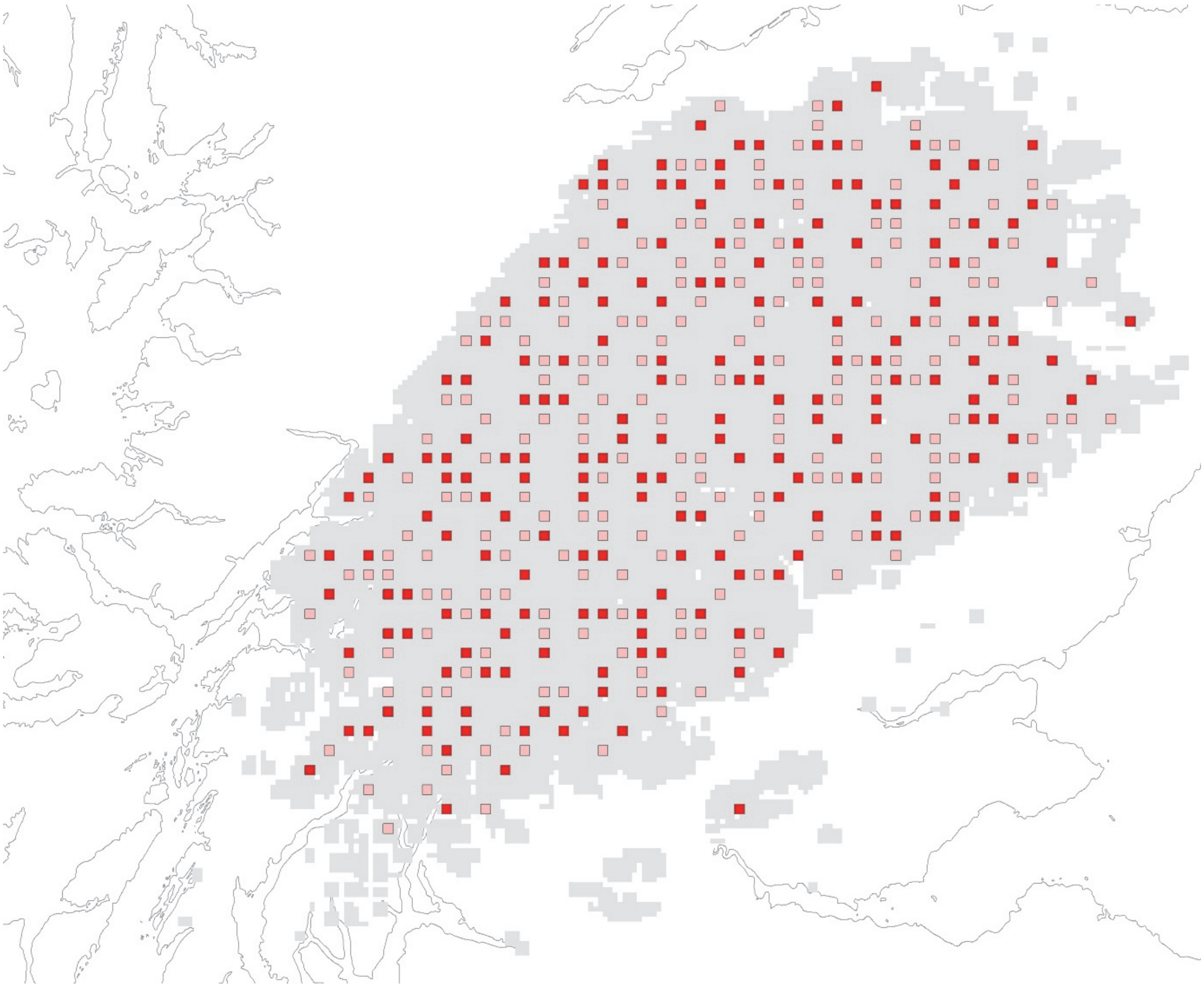

Figure A3.1. An example survey design showing 400 randomly selected survey tetrads in the central uplands region. These are classified into two groups - a high priority group (red) and a low priority group (pink). Selection was made from a subset of tetrads, defined by a sparse grid including only alternate rows and columns. This ensured that each survey tetrad was a minimum of 2 km away from any other. In addition, selection was restricted to tetrads with their centroid located on land, and with a minimum of 75% overlap with the True Uplands region. An even distribution of tetrads across the region was ensured by stratifying tetrad placement by hectad (10 km x 10 km square), so that the number of survey tetrads in each hectad is approximately proportional to the area of its overlap with the True Uplands region. The identities of these tetrads are given in Table A3.1 Pale grey shading shows the extent of True Uplands in the central uplands area.

Table A3.1 Identity and location of 200 priority and 200 secondary survey tetrads randomly located throughout the True Upland region of the central uplands.

Tetrad	Hectad	Easting	Northing		Tetrad	Hectad	Easting	Northing
Priority								
NJ10H	NJ10	313000	805000		NH93I	NH93	293000	837000
NJ30Q	NJ30	337000	801000		NJ00M	NJ00	305000	805000
NJ41D	NJ41	341000	817000		NJ00V	NJ00	309000	801000
NN23D	NN23	221000	737000		NJ01D	NJ01	301000	817000
NN42E	NN42	241000	729000		NJ02K	NJ02	305000	821000
NN42V	NN42	249000	721000		NJ02Z	NJ02	309000	829000
NN54Q	NN54	257000	741000		NJ03N	NJ03	305000	837000
NN68K	NN68	265000	781000		NJ03Y	NJ03	309000	837000
NN88K	NN88	285000	781000		NJ04X	NJ04	309000	845000
NN88Z	NN88	289000	789000		NJ11I	NJ11	313000	817000
NN89L	NN89	285000	793000		NJ12J	NJ12	313000	829000
NO05B	NO05	301000	753000		NJ12S	NJ12	317000	825000
NO07Y	NO07	309000	777000		NJ14U	NJ14	317000	849000
NH40C	NH40	241000	805000		NJ20X	NJ20	329000	805000
NH40X	NH40	249000	805000		NJ20K	NJ20	325000	801000
NH41W	NH41	249000	813000		NJ21Y	NJ21	329000	817000
NH50U	NH50	257000	809000		NJ22C	NJ22	321000	825000
NH51G	NH51	253000	813000		NJ22X	NJ22	329000	825000
NH52U	NH52	257000	829000		NJ23N	NJ23	325000	837000
NH60Z	NH60	269000	809000		NJ23W	NJ23	329000	833000
NH60C	NH60	261000	805000		NJ31G	NJ31	333000	813000
NH61B	NH61	261000	813000		NJ32Q	NJ32	337000	821000
NH62E	NH62	261000	829000		NJ32J	NJ32	333000	829000
NH62K	NH62	265000	821000		NJ33R	NJ33	337000	833000
NH63B	NH63	261000	833000		NJ40A	NJ40	341000	801000
NH70H	NH70	273000	805000		NJ42X	NJ42	349000	825000
NH71I	NH71	273000	817000		NJ42K	NJ42	345000	821000
NH72J	NH72	273000	829000		NJ43Y	NJ43	349000	837000
NH72U	NH72	277000	829000		NJ51G	NJ51	352833	813167
NH73G	NH73	273000	833000		NJ60V	NJ60	369167	801167
NH80E	NH80	281000	809000		NN00E	NN00	201000	709000
NH80P	NH80	285000	809000		NN01Y	NN01	209000	717000
NH81N	NH81	285000	817000		NN03W	NN03	209000	733000
NH82C	NH82	281000	825000		NN04M	NN04	205000	745000
NH82P	NH82	285000	829000		NN05L	NN05	205000	753000
NH83Y	NH83	289000	837000		NN06X	NN06	209000	765000
NH83L	NH83	285000	833000		NN11I	NN11	213000	717000
NH84A	NH84	281000	841000		NN12Q	NN12	217000	721000
NH90H	NH90	293000	805000		NN13T	NN13	217000	737000
NH91G	NH91	293000	813000		NN14S	NN14	217000	745000
NH92U	NH92	297000	829000		NN15G	NN15	213000	753000
NH92F	NH92	293000	821000		NN16J	NN16	213000	769000
NN21N	NN21	225000	717000		NN59G	NN59	253000	793000
NN21W	NN21	229000	713000		NN61N	NN61	265000	717000
NN22K	NN22	225000	721000		NN62C	NN62	261000	725000
NN22Z	NN22	229000	729000		NN62E	NN62	261000	729000
NN24V	NN24	229000	741000		NN63W	NN63	269000	733000
NN24C	NN24	221000	745000		NN63Y	NN63	269000	737000
NN25Y	NN25	229000	757000		NN64V	NN64	269000	741000
NN26K	NN26	225000	761000		NN64A	NN64	261000	741000
NN26Z	NN26	229000	769000		NN65B	NN65	261000	753000
NN27W	NN27	229000	773000		NN66Z	NN66	269000	769000
NN27L	NN27	225000	773000		NN66X	NN66	269000	765000

NN28Z	NN28	229000	789000		NN67N	NN67	265000	777000
NN31I	NN31	233000	717000		NN67B	NN67	261000	773000
NN32F	NN32	233000	721000		NN69D	NN69	261000	797000
NN32U	NN32	237000	729000		NN72H	NN72	273000	725000
NN33G	NN33	233000	733000		NN73G	NN73	273000	733000
NN34Q	NN34	237000	741000		NN74H	NN74	273000	745000
NN35R	NN35	237000	753000		NN75R	NN75	277000	753000
NN36J	NN36	233000	769000		NN76Q	NN76	277000	761000
NN36S	NN36	237000	765000		NN76J	NN76	273000	769000
NN37I	NN37	233000	777000		NN77I	NN77	273000	777000
NN38J	NN38	233000	789000		NN78J	NN78	273000	789000
NN39T	NN39	237000	797000		NN79G	NN79	273000	793000
NN40E	NN40	241000	709000		NN80V	NN80	289000	701000
NN41N	NN41	245000	717000		NN82Z	NN82	289000	729000
NN43D	NN43	241000	737000		NN83Y	NN83	289000	737000
NN43W	NN43	249000	733000		NN84A	NN84	281000	741000
NN44K	NN44	245000	741000		NN84Z	NN84	289000	749000
NN44P	NN44	245000	749000		NN85L	NN85	285000	753000
NN45Y	NN45	249000	757000		NN86A	NN86	281000	761000
NN46P	NN46	245000	769000		NN87W	NN87	289000	773000
NN46A	NN46	241000	761000		NN87N	NN87	285000	777000
NN47B	NN47	241000	773000		NN93R	NN93	297000	733000
NN47L	NN47	245000	773000		NN94U	NN94	297000	749000
NN48X	NN48	249000	785000		NN96S	NN96	297000	765000
NN48M	NN48	245000	785000		NN97R	NN97	297000	773000
NN49L	NN49	245000	793000		NN98S	NN98	297000	785000
NN51I	NN51	253000	717000		NN98J	NN98	293000	789000
NN52Q	NN52	257000	721000		NN99G	NN99	293000	793000
NN55R	NN55	257000	753000		NO06E	NO06	301000	769000
NN56S	NN56	257000	765000		NO06K	NO06	305000	761000
NN56U	NN56	257000	769000		NO08K	NO08	305000	781000
NN57R	NN57	257000	773000		NO08M	NO08	305000	785000
NN58H	NN58	253000	785000		NO09W	NO09	309000	793000
NO15T	NO15	317000	757000		NO37R	NO37	337000	773000
NO16J	NO16	313000	769000		NO38Q	NO38	337000	781000
NO16Q	NO16	317000	761000		NO38S	NO38	337000	785000
NO18S	NO18	317000	785000		NO39R	NO39	337000	793000
NO18Q	NO18	317000	781000		NO46P	NO46	345000	769000
NO19R	NO19	317000	793000		NO47N	NO47	345000	777000
NO25D	NO25	321000	757000		NO48A	NO48	341000	781000
NO26X	NO26	329000	765000		NO48E	NO48	341000	789000
NO26V	NO26	329000	761000		NO49N	NO49	345000	797000
NO27N	NO27	325000	777000		NO58S	NO58	357000	785000
NO28E	NO28	321000	789000		NO59G	NO59	353000	793000
NO28Z	NO28	329000	789000		NO68E	NO68	361000	789000
NO29D	NO29	321000	797000		NO36F	NO36	333000	761000
Secondary								
NJ10Q	NJ10	317000	801000		NH80Z	NH80	289000	809000
NJ30U	NJ30	337000	809000		NH81Y	NH81	289000	817000
NJ41N	NJ41	345000	817000		NH81L	NH81	285000	813000
NN23N	NN23	225000	737000		NH82V	NH82	289000	821000
NN42X	NN42	249000	725000		NH82A	NH82	281000	821000
NN54U	NN54	257000	749000		NH83B	NH83	281000	833000
NN68X	NN68	269000	785000		NH84M	NH84	285000	845000
NN68C	NN68	261000	785000		NH90F	NH90	293000	801000
NN88P	NN88	285000	789000		NH90S	NH90	297000	805000
NN89Y	NN89	289000	797000		NH91T	NH91	297000	817000

NO05N	NO05	305000	757000		NH92J	NH92	293000	829000
NO07L	NO07	305000	773000		NH93G	NH93	293000	833000
NH30Q	NH30	237000	801000		NJ00P	NJ00	305000	809000
NH40A	NH40	241000	801000		NJ00E	NJ00	301000	809000
NH40Z	NH40	249000	809000		NJ01L	NJ01	305000	813000
NH50H	NH50	253000	805000		NJ01B	NJ01	301000	813000
NH50F	NH50	253000	801000		NJ02E	NJ02	301000	829000
NH51T	NH51	257000	817000		NJ02C	NJ02	301000	825000
NH60K	NH60	265000	801000		NJ03D	NJ03	301000	837000
NH60V	NH60	269000	801000		NJ04K	NJ04	305000	841000
NH61L	NH61	265000	813000		NJ04M	NJ04	305000	845000
NH61Y	NH61	269000	817000		NJ11R	NJ11	317000	813000
NH62P	NH62	265000	829000		NJ12Q	NJ12	317000	821000
NH62C	NH62	261000	825000		NJ13I	NJ13	313000	837000
NH70Q	NH70	277000	801000		NJ20V	NJ20	329000	801000
NH70U	NH70	277000	809000		NJ20P	NJ20	325000	809000
NH71R	NH71	277000	813000		NJ21W	NJ21	329000	813000
NH72Q	NH72	277000	821000		NJ21D	NJ21	321000	817000
NH73R	NH73	277000	833000		NJ22A	NJ22	321000	821000
NH80C	NH80	281000	805000		NJ22E	NJ22	321000	829000
NJ23Y	NJ23	329000	837000		NN33R	NN33	237000	733000
NJ24K	NJ24	325000	841000		NN34F	NN34	233000	741000
NJ31R	NJ31	337000	813000		NN34S	NN34	237000	745000
NJ32F	NJ32	333000	821000		NN35T	NN35	237000	757000
NJ33I	NJ33	333000	837000		NN36H	NN36	233000	765000
NJ40E	NJ40	341000	809000		NN37R	NN37	237000	773000
NJ42Z	NJ42	349000	829000		NN38H	NN38	233000	785000
NJ42C	NJ42	341000	825000		NN38Q	NN38	237000	781000
NJ43B	NJ43	341000	833000		NN39I	NN39	233000	797000
NJ50H	NJ50	353000	805000		NN41D	NN41	241000	717000
NJ52H	NJ52	353000	825000		NN41L	NN41	245000	713000
NJ60E	NJ60	361000	809000		NN43Y	NN43	249000	737000
NN01L	NN01	205000	713000		NN44V	NN44	249000	741000
NN02Z	NN02	209000	729000		NN44C	NN44	241000	745000
NN04Z	NN04	209000	749000		NN45N	NN45	245000	757000
NN04A	NN04	201000	741000		NN45B	NN45	241000	753000
NN05B	NN05	201000	753000		NN46V	NN46	249000	761000
NN10H	NN10	213000	705000		NN46M	NN46	245000	765000
NN12S	NN12	217167	724833		NN47N	NN47	245000	777000
NN13R	NN13	217000	733000		NN48V	NN48	249000	781000
NN14J	NN14	213000	749000		NN48Z	NN48	249000	789000
NN14U	NN14	217000	749000		NN49N	NN49	245000	797000
NN15R	NN15	217000	753000		NN49W	NN49	249000	793000
NN16H	NN16	213000	765000		NN52H	NN52	253000	725000
NN20M	NN20	225000	705000		NN53T	NN53	257000	737000
NN20Z	NN20	229000	709000		NN55G	NN55	253000	753000
NN21L	NN21	225000	713000		NN56Q	NN56	257000	761000
NN22X	NN22	229000	725000		NN57T	NN57	257000	777000
NN22M	NN22	225000	725000		NN58U	NN58	257000	789000
NN24X	NN24	229000	745000		NN58Q	NN58	257000	781000
NN24M	NN24	225000	745000		NN59R	NN59	257000	793000
NN25L	NN25	225000	753000		NN61B	NN61	261000	713000
NN25D	NN25	221000	757000		NN62X	NN62	269000	725000
NN26E	NN26	221000	769000		NN62Z	NN62	269000	729000
NN26X	NN26	229000	765000		NN63L	NN63	265000	733000
NN27N	NN27	225000	777000		NN64K	NN64	265000	741000
NN28X	NN28	229000	785000		NN64P	NN64	265000	749000
NN30Q	NN30	237000	701000		NN65D	NN65	261000	757000

NN31R	NN31	237000	713000		NN65Y	NN65	269000	757000
NN32J	NN32	233000	729000		NN66A	NN66	261000	761000
NJ23Y	NJ23	329000	837000		NN33R	NN33	237000	733000
NJ24K	NJ24	325000	841000		NN34F	NN34	233000	741000
NJ31R	NJ31	337000	813000		NN34S	NN34	237000	745000
NJ32F	NJ32	333000	821000		NN35T	NN35	237000	757000
NJ33I	NJ33	333000	837000		NN36H	NN36	233000	765000
NN66E	NN66	261000	769000		NO16U	NO16	317000	769000
NN67L	NN67	265000	773000		NO17R	NO17	317000	773000
NN69B	NN69	261000	793000		NO18U	NO18	317000	789000
NN69W	NN69	269000	793000		NO19G	NO19	313000	793000
NN72F	NN72	273000	721000		NO25B	NO25	321000	753000
NN73T	NN73	277000	737000		NN66E	NN66	261000	769000
NN74Q	NN74	277000	741000		NN67L	NN67	265000	773000
NN75G	NN75	273000	753000		NN69B	NN69	261000	793000
NN76S	NN76	277000	765000		NN69W	NN69	269000	793000
NN77R	NN77	277000	773000		NN72F	NN72	273000	721000
NN78U	NN78	277000	789000		NO26K	NO26	325000	761000
NN78F	NN78	273000	781000		NO26Z	NO26	329000	769000
NN79I	NN79	273000	797000		NO27W	NO27	329000	773000
NN82C	NN82	281000	725000		NO27Y	NO27	329000	777000
NN83W	NN83	289000	733000		NO28P	NO28	325000	789000
NN83D	NN83	281000	737000		NO29W	NO29	329000	793000
NN84M	NN84	285000	745000		NO29B	NO29	321000	793000
NN85Y	NN85	289000	757000		NO36H	NO36	333000	765000
NN86M	NN86	285167	764833		NO37G	NO37	333000	773000
NN86E	NN86	281000	769000		NO38F	NO38	333000	781000
NN87B	NN87	281000	773000		NO39I	NO39	333000	797000
NN93I	NN93	293000	737000		NO46Z	NO46	349000	769000
NN94J	NN94	293000	749000		NO47Y	NO47	349000	777000
NN96F	NN96	293000	761000		NO48P	NO48	345000	789000
NN96H	NN96	293000	765000		NO48M	NO48	345000	785000
NN97T	NN97	297000	777000		NO49D	NO49	341000	797000
NN98Q	NN98	297000	781000		NO58F	NO58	352833	781167
NN99R	NN99	297000	793000		NO58Q	NO58	357000	781000
NO04Z	NO04	309000	749000		NO68K	NO68	365000	781000
NO06Z	NO06	309000	769000		NS19T	NS19	217000	697000
NO06P	NO06	305000	769000		NO26K	NO26	325000	761000
NO08X	NO08	309000	785000		NO09Y	NO09	309000	797000
NO08Z	NO08	309000	789000		NO15I	NO15	313000	757000

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