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The conservation status and management of mountain hares

(ROAME No. F05AC316)

For further information on this report please contact:

Rob Raynor
Scottish Natural Heritage
Great Glen House
INVERNESS
IV3 8NW
Telephone: 01463-725244
E-mail: robert.raynor@snh.gov.uk

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COMMISSIONED REPORT

Summary

The conservation status and management of mountain hares

Commissioned Report No. 287 (ROAME No.F05AC316)
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Background

Evidence suggests that mountain hare numbers may have declined in recent years; however the extent and nature of this decline is unclear. In some areas hares are an important quarry species, but they are also culled for pest control and increasingly for the control of ticks and louping ill. This study identifies a set of research priorities intended to inform our future sustainable management of the species.

Main recommendations

- Undertake a study to evaluate dung clearance methods as a cost effective and robust methodology to assess mountain hare abundance or density, and evaluate other methods that may be suitable for generating indices of abundance.
- Undertake an analysis of mountain hare licence returns and questionnaire surveys to assess the current hare distribution in Scotland and the level of harvest.
- Use published data on hare density and distribution information gathered during the questionnaire surveys to generate a national estimate of mountain hare abundance.
- Using population assessment techniques, hare distribution maps, and the GIS model, develop a future long-term monitoring programme.

For further information on this project contact:
Rob Raynor, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW
Tel: 01463–725244
For further information on the SNH Research & Technical Support Programme contact:
Policy & Advice Directorate Support, SNH, Great Glen House, Leachkin Road, Inverness, IV3 8NW.
Tel: 01463 725000 or **pads@snh.gov.uk**

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1. Non-technical summary.

Evidence suggests that mountain hare numbers have declined in recent years; however the extent of this decline and whether this represents a long-term decline or is the low phase of a synchronised population cycle is not certain. In some areas mountain hares are an important quarry species, but mountain hares are also culled for pest control and increasingly for the control of ticks and louping ill. Mountain hares are an important prey species for other protected species such as the golden eagle and play a largely unexplored role in the Scottish upland landscape. Against this back drop SNH and Scotland's Moorland Forum have recently expressed concern that there are no reliable estimates of mountain hare abundance. Members of the Scottish Parliament have also raised questions as to the sustainability of mountain hare populations in Scotland in the face of some current management practices.

This project was initiated to make recommendations on; i) assessment of current mountain hare abundance, ii) assessment of the current level of harvest, iii) assessment the conservation status of mountain hares in Scotland, iv) future long-term monitoring programmes for surveillance of mountain hare populations in Scotland, and v) to highlight areas of research necessary to fully assess the impact of harvesting mountain hares on their population and conservation status.

We make a number of recommendations that can be grouped into a structured, progressive programme of work:

1. Assessment of mountain hare abundance is necessary to inform management of mountain hare populations (Section 2) but no simple and widely applicable method has yet been developed. We recommend a 6 month research project to i) evaluate dung clearance methods as a thorough, cost effective and robust methodology to assess mountain hare abundance or density, that will be effective in a wide range of habitats, across a wide range of mountain hare densities and which is scaleable to different sizes of survey areas, and ii) to evaluate a number of cheaper, easily implemented methods that may be suitable for generating indices of abundance.

2. Some of the current concern about the status of mountain hare populations is due to a perceived increase in the level of harvesting, and in particular the use of large-scale culls to control ticks and louping ill. However, very little information is currently available on the level of harvest (Section 4).[1] We recommend i) an analysis of licence returns collected by SNH and the Scottish Government in response to licences granted to under take night shooting and snaring of hares, and ii) to under take a series of questionnaire surveys of land owners, managers, and game keepers to assess the current distribution of mountain hares in Scotland and the level of harvest categorised by reason, method, season and region.

3. In the absence of a sufficiently intensive UK monitoring scheme for mountain hares, with appropriate geographical coverage for this species, existing estimates of national mountain hare abundance are crude, and concerns about recent trends are based on short time-series of simple abundance indices derived from a very small

[1] www.snh.org.uk/pdfs/publications/commissioned_reports/Report%20No278.pdf
See also SNH Commissioned Report No 278 The distribution of Mountain hare (*Lepus timidus*) in Scotland (2006/07) (ROAME No. RO7AC308).

number of sites (48, 1 km^2 blocks) in Scotland. Using both published data on hare density broken down by habitat, underlying geology, and altitude and the data on hare distribution that would be gathered during implementation of the recommendations made in 2 (above) we suggest it is possible to generate a national estimate of mountain hare abundance in Scotland. We recommend that this estimate will be refined over a number of years by a series of local surveys and ground-truthing exercises based on methods developed earlier in this proposal. Finally pulling the population assessment techniques, hare distribution maps, and the GIS model together the project will deliver recommendations on future long-term monitoring programme.

4. We conclude this proposal with a brief description of work needed to fully address the issues of sustainable exploitation of mountain hare populations that would put management of mountain hare populations on a firm scientific basis.

2. Background and rationale.

The management and conservation of mountain hares is of current concern because the conservation aims and responsibilities for the species has been brought into conflict with (a) moorland management for red grouse and (b) the afforestation of upland areas. Recent trends in both land uses have resulted in a demand for increased culling of mountain hares. This has taken place against a background in which mountain hare populations are thought to be declining in Scotland, which holds more than an estimated 99% of the GB population (Battersby 2005; Harris *et al*. 1995; Newson & Noble 2005), and elsewhere in Europe (Thulin 2003).

i) Conservation of mountain hares.

Mountain hare populations are under threat from habitat loss, fragmentation, and local over-exploitation (Harris *et al*. 1995; Macdonald, Mace, & Rushton 1998; Tapper 1999). Mountain hares are most numerous on heather moorland managed for red grouse where predator control and muirburn are thought to benefit hares as well as red grouse (Hewson 1984). The decline in sport shooting and associated loss of heather moorland are likely to have had a negative effect on mountain hare distribution and numbers (Harris *et al*. 1995; Macdonald, Mace, & Rushton 1998; Moorland Working Group 2002; Robertson, Park, & Barton 2001; Tapper 1999). Emerging evidence from Sweden suggests that mountain hares may be threatened with hybridisation with and competition from the brown hare (Thulin 2003; Thulin, Jaarola, & Tegelstrom 1997; Thulin & Tegelstrom 2002; Thulin, Tegelstrom, & Fredga 2003). Furthermore, long-term global climate change is likely to adversely influence the sub-arctic/alpine habitats favoured by mountain hares (Harris *et al.* 1995). Mountain hares are 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'. This means that certain methods of capture are prohibited and may only take place under licence. Member States are therefore required to ensure the conservation status of mountain hares is maintained and that their populations are managed sustainably.

ii) Moorland management.

Mountain hares can play a role in the spread and persistence of ticks and louping-ill which have been implicated in reducing the harvestable surplus of red grouse (Gilbert *et al*. 2001; Laurenson *et al*. 2003). Requests are being made to the Scottish Government for licences for private sporting estates to reduce mountain hare populations to very low densities (< 5 hares km^{-2}) in order to reduce tick borne disease transmission. In other cases, sporting estates want to maintain or develop the harvesting of mountain hares on a sustainable basis.

iii) Woodland management.

Habitat Action Plans, Scottish Rural Development Programme grant schemes require knowledge of the likely impact of mountain hares on woodland re-establishment in order to assess the likely success of the actions. Many areas selected for native woodland establishment are juxtaposed with moorland where mountain hare densities are at their highest. In some cases requests are being made for licences to reduce mountain hare populations to very low densities in order to prevent losses of trees.

SNH and Scotland's Moorland Forum have recently expressed concern that there are no reliable estimates of mountain hare abundance. For SNH, this is a particular problem, because it is required to advise the Scottish Government on licence applications to take mountain hares in the wild. Assessment of hare abundance is necessary to inform management; but no simple and widely applicable method has yet been developed. This document will review existing information and develop a detailed proposal for a longer term project to address issues concerning the conservation status of hares and the sustainability of their management. The key questions identified are:

- What is the conservation status of mountain hares in Scotland?
- What is the current estimated Scottish population of mountain hares?
- Are mountain hare populations managed sustainably?

3. Legal obligations.

In their review of the national and international treaties to which the UK is a signatory Macdonald *et al*. (1998) concluded that the UK government and statutory agencies have a legal obligation to both monitor UK mammal populations and implement sustainable management of selected species of conservation concern. The amendments to the Conservation (Natural Habitats &c.) Regulations 1994 introduced in 2007 include a new regulation requiring Scottish Ministers to make arrangements for the surveillance of Annex V species to ensure the maintenance of favourable conservation status.

4. Overview of existing mountain hare population information.

In the absence of a national mammal monitoring programme population assessments of mountain hares in Scotland are limited. In their review of UK mammals Harris *et al*. (1995) estimated the UK pre-breeding mountain hare population to be 350,000, with a Scottish population of over 349,000. This estimate was based on mean number of hares per km^2 of suitable upland and forestry habitat multiplied by the area of suitable upland and forestry habitat. This estimate has to be treated with caution, but remains the only national population estimate to date.

Long-term data on trends in mountain hare populations are limited to the National Game Census (administered by Game & Wildlife Conservation Trust) and the Breeding Birds Survey (run by the British Trust for Ornithology). The recently initiated Winter Mammal Monitoring Project, run by The Mammal Society and British Trust for Ornithology has only been running since winter 2001/02 and does not have a long enough time series for any meaningful assessment of trends, and suffer from very poor coverage in Scotland..

The National Game Census

The National Game Bag Census (NGC) was established by the G&WCT in 1961 to provide a central repository of records from shooting estates in England, Wales, Scotland and Northern Ireland. The records comprise information from shooting and game keeping activities on the numbers of each quarry species shot annually ("bag data"). They also include data on the numbers of game birds released each year. Through the inclusion of data from historical game books, records for several species extend back to the early 20th century and for a few game species the early 19th century. Data on predatory species that may be legally controlled have also been collected systematically since 1961.

The G&WCT operates the census via postal questionnaires, mailed to members annually. Each estate contributing data has a unique identifier, based on its region and county within that region, with location recorded in six-digit British National Grid format.

The survey coverage is UK wide. Between 1961 and 2001, the total number of estates contributing data to the NGC was 1,602 for game species and 1,222 for predatory species, with annual averages of 636 and 364, respectively. In comparison with other monitoring schemes, the sample sizes are large for species that are difficult to detect by conventional survey methods. Coverage was highest in Scotland (25% of estates), East Anglia (15%), south-east England (14%) and north-east England (11%); it was lowest in Northern Ireland (1%) and Wales (5%). By area, NGC estates cover 5% of the UK, varying regionally from 15% in eastern Scotland to under 1% in the Midlands and Northern Ireland.

The long runs of well-documented data on many predatory and game species make bag returns an important source of information on the changes in numbers killed and, by inference, on population densities. They also provide a unique historical perspective on changes in shooting itself. Because a substantial proportion of the countryside is managed for shooting, the data potentially reflect trends in national and regional abundance for a wide range of species, many of which are poorly monitored by government schemes.

Examination of game bag records (Tapper 1992) collected since 1900 showed that high numbers of hares were shot around the early 1900's and after WW1. Bag records show a peak in the number of mountain hares shot in the 1930's. Low bag numbers during and immediately following WW2 were followed by an increase during the 1950's. Although the number of animals shot since the 1950's shows large inter-annual variation there is a general decline through the 1960's, 70's and early 80's. The subsequent peak in the number shot in the early 1990's is similar to the bag records of the 1950's. The peak in number of hares shot in the early 1990's was followed by a decline to levels similar to those shot in the 1960's and 80's (G&WCT, unpublished data). Large inter-annual fluctuations in the number of hares shot make assessment of trend difficult, but there appear to have been more hares shot pre-1940 than afterwards ((Tapper 1992); Figure 1).

Tapper (1995) report to the JNCC

A questionnaire survey carried out by G&WCT in 1995 (Tapper 1996) on the distribution and level of exploitation of mountain hares in Scotland received information on 5,785 1 km squares from shooting estates. Approximately 66% of squares were located in upland habitat and mountain hares were found in 69% of those squares and 14% of the remaining lowland squares. Of 107 responses 55 indicated some level of exploitation amounting to a total harvest of 16,341 hares over the year December 1994 – November 1995. Assuming that the survey represented half of the estates that exploit hares Tapper (1996) estimated an annual take of not more than 30,000 animals.

The results showed distinct regional differences in the level of cull; 57% of estates in the Southern uplands, 56% in the central highlands, and 28% in the north-west highlands killed hares. The level of harvest also varied between regions with estates in the central highlands accounting for 89% of the total annual take.

In the central highlands organised commercial shoots accounted for 62% of the harvest whilst culling hares during informal shoots, control, baits, or for dog food accounted for the remainder. Most culling took place in the autumn, winter and spring but hares were shot for sport and management throughout the year. In the north-west and southern highlands more hares were taken for control purposes than for sport and most culling was undertaken over the winter.

Some of the respondents suggested that mountain hare had disappeared from some areas where they had been historically present. On comparing the distribution of hares identified in this survey Tapper (1996) with the only other comprehensive distribution map of Arnold (1993) found that although hares had been lost in some small areas but found no evidence for widespread decline in distribution or numbers (Tapper, 1996).

Breeding Birds Survey - Mammals

Mammal recording was introduced to the Breeding Bird Survey (BBS) in 1995 with a view to help improve our knowledge of the distribution and population trends of some of our commoner mammals. Even though mammal recording has always been a voluntary addition to the scheme, more than 85% of BBS observers now actively record mammal sightings and signs during their bird-count visits.

By recording the number of each mammal species seen during the BBS survey, which consists of a 2 km walked transect, the BBS has the potential to monitor UK mammal populations. From an average of more than 1,700 1km BBS squares surveyed for mammals each year between 1995 and 2002, 47 species of British mammal were recorded, including several rare species. However, the main strength of a survey of this kind is its potential for identifying changes in abundance and distribution of commoner species.

Population trends were calculated only for species recorded on a mean of thirty or more squares each year (red deer, roe deer, fallow deer, Reeve's muntjac, brown hare, mountain/Irish hare, rabbit, grey squirrel and red fox).

The distribution of survey squares in which mountain hares were present (n=48) means that mountain hare populations could only be assessed at the UK level, including the Peak District, Northern Ireland as well as Scotland. Over the period 1995-2002 mountain hares showed a significant decline of 14%. However, large fluctuations in numbers between years, and the relatively small area surveyed in areas of mountain hare range suggest that this may not be an underlying trend (Newson & Noble 2005).

Tracking Mammals Partnership

Launched in 2003 The Tracking Mammals Partnership (TMP) is a collaborative initiative, involving 24 organisations with a variety of interests in UK mammals, which aims to improve the quality, quantity and dissemination of information on the status of mammal species in the UK. Many sections of the mammal community, as well as Government at UK, country, and regional and local levels, require good quality data on the distribution and population trends of all UK mammals to guide conservation and wildlife management policy. Joint working by organisations within the partnership seeks a coordinated approach to standardizing survey design, assessing where information is missing, exchanging data and expertise, sharing best practice, sharing information on new technology and data collected, as well as cooperating to recruit, train and support the networks of volunteers who carry out the surveys.

The TMP collates data from a large number of sources and recently published its first assessment of the species status and population trends for UK mammals (Battersby 2005). The TMP's assessment of mountain hares is based entirely on the NGC and BBS data already discussed above. The TMP conclude that while the best available data suggest that mountain hares are declining; generally since 1940, and more recently since the peak in the mid-1990's that the large inter-annual variation make interpretation of trend very difficult. In conclusion the TMP suggest that both the NGC and the BBS data could be used to assess future trends in mountain hare abundance but emphasises the need for more survey work.

5. The issues concerning the assessment of conservation status, sustainability of current management practices and the limitations to progress

Assessment of mountain hare abundance is necessary to inform management of mountain hare populations (Section 2) but no simple and widely applicable method has yet been developed (Section 6). The Tracking Mammals Partnership and previous scoping studies have all highlighted the enthusiasm and need for better monitoring of British mammals (Macdonald, Mace & Rushton 1998; Macdonald & Tattersall 2003; Macdonald & Tattersall 2004; Toms, Siriwardena, & Greenwood 1999). In particular the first report of the Tracking Mammals Partnership emphasises the paucity of data on mountain hare populations in Scotland (Battersby 2005). Some of a wide range of possible methods are discussed below (Section 6). Indirect methods based on dung counts offer a number of advantages over direct counts of animals themselves. It is recognised, however, that direct methods of counting hares are likely to be favoured over indirect methods by estate managers and their staff. We therefore recommend that a suite of methods are evaluated (Section 7). However, in this section we first review some of the pertinent issues of surveying mountain hares in Scotland, and make recommendations for obtaining a national population assessment.

Issues concerning conservation and population assessment

Mountain hare populations in many areas of Scotland exhibit large multi-annual fluctuations in abundance (Flux 1970). Two time-series studies based on game bag records gathered as part of the NGC show that approximately half of the time-series examined showed cyclic or weakly cyclic dynamics with a mean periodicity of around 9 years (range 7-12) (Newey 2005; Tapper 1987; Tapper 1992). The apparent occurrence of regular fluctuations in bag data pooled across large areas has been interpreted to imply large scale synchronous dynamics (Tapper 1987) although this has never been formally explored and other, limited, data suggest asynchronous dynamics (Watson *et al*. 1973).

Direct counts of mountain hares at sites across Scotland show that density can range from 0 to 300 hares km^{-2} (Watson *et al*. 1973). Mean mountain hare density varied between regions, altitude, and underlying geology (Watson & Hewson 1973); with generally fewer hares at lower altitude and over acidic rock. Hares were most abundant in the central and eastern highlands, with fewer hares in west and south Scotland. Any proposed survey methodology must be flexible enough to accommodate this extreme range in density.

Although mountain hares can be seen during the day, and may be diurnal at certain times of year they are largely crepuscular or nocturnal. Total counts during day light hours are therefore not an option. Thus, any surveillance of mountain hares during day light hours must accommodate this behaviour and uncertain detection. Mountain hares in Scotland generally moult, with an associated colour change twice a year; white to brown in spring, and brown to white in autumn. Moult is thought to be controlled by a combination of hours of day light and air temperature (Hewson 1958; Watson 1963). Thus the rate and stage of moult vary with latitude, altitude, and weather and in some instances colour change may be incomplete (Hewson 1958; Hulbert *et al*. 2004; Watson 1963). The likely detection of hares will change with stage of moult, weather and snow-

lie, again; any survey method that relies on direct counts of individuals must be robust to changes in detection probability. While standardising surveys will help increase accuracy and precision regional (*e.g.* latitude), local (*e.g.* altitude), and yearly (*e.g.* weather) differences will make this difficult.

Population and conservation assessment of mountain hares must be take into account the characteristics of this species, its distribution and population dynamics. The current debate surrounding the mountain/Irish hare in Ireland exemplifies the problems of failing to accommodate species biology in to management plans and conservation assessment (Dingerkus & Montgomery 2002; Environment and Heritage Service 2000; Tosh *et al*. 2004; Reynolds *et al*., In prep.).

National population assessment of mountain hare in Scotland

A national assessment of mountain hare distribution and abundance is an essential prerequisite to the assessment of mountain hare status and the development of sustainable management plans. The regional variation, range and local variation in density, unstable dynamics with possibly asynchronous dynamics, and mountain hare ecology, make population assessment, trend analysis and national estimates of hare abundance problematic. We therefore recommend a two stage process where initial coarse estimates based on mean habitat specific densities stratified by region, geology, altitude and habitat and national estimates of habitat area are increasingly refined over a number of years by a series of local surveys and ground truthing exercises. We further suggest that this element of the proposal is combined with the exercise to make recommendations for a long term monitoring programme (Section 8).

Methods

We recommend a desk-based study to review literature and available data on regional and habitat specific hare densities. Mean mountain hare densities, stratified by region, habitat/vegetation, and altitude could then be incorporated into a GIS containing national habitat/vegetation, and a digital elevation model. Regional mountain hare densities should be estimated by multiplying habitat and altitude specific densities by the area of each habitat type in each region. This methodology would represent a refined version of that used for the Harris *et al*. (1995) estimate of GB mountain hare abundance (see Section 4). The initial estimate will be very crude. We recommend that this initial estimate is refined, probably over a number of years, by a series of fully costed ground truthing and local surveys.

Outputs

The GIS analysis would provide regional and a national estimate of mountain hare abundance. These estimates could be based on historic data and so in the first instance, until sufficient, current regional and habitat specific data are available, these estimates will not relate to the current population status. Furthermore, it is important to highlight that due to the reasons discussed above, along with limitations (scale and age) of national vegetation maps, and the paucity of data on regional and habitat specific mountain hare densities that initial estimates would be very crude. We suggest that this work is combined with the work to draw up recommendations for a long-term monitoring programme .

6.Evaluation of different counting methodologies and recommended approaches to monitoring mountain hares.

-See Macdonald *et al.* 1998, Toms *et al.* 1999 and Battersby 2005.

Direct Methods

Direct methods count the hares individually. All direct count methods rely on being able to detect or capture individuals of the species of interest and make a number of assumptions about heterogeneity in detection or capture probabilities. Estimates derived from direct methods are limited to the time period over which the survey was under taken and are thus prone to bias or error associated with short-term movements and local, short term conditions (Jachmann 1991).

Distance sampling and Capture-Mark-Recapture

With good survey design distance sampling and capture-recapture methods are robust to individual, seasonal, and yearly differences in detection or capture probability (Borchers, Buckland, & Zucchini 2002; Buckland *et al*. 2001; Buckland *et al*. 2004; Kendall & Pollock 1992; Pollock 1982; Pollock *et al*. 1990; White *et al*. 1982). Previous work has shown that distance sampling can give reasonable estimates of mountain hare density in heather moorland (Newey *et al*. 2003; Shewry, Buckland, & Shaw 2002) although hare behaviour and extremes of density present methodological problems. While estimates based on distance sampling are robust to seasonal and habitat differences in detection probability and flushing behaviour Newey *et al*. (2003) identified problems associated with obtaining sufficient encounters at low hare density to generate a reliable detection function. Conversely at high hare density it became difficult to accurately determine and count each hare, and there was “chain reaction” where one flushing hare would flush many others causing problems in accurately recording distances and numbers. In woodland, direct counts of mountain hares are unlikely to be of any use because of the difficulty of seeing them.Furthermore, sample size is problematic due to low densities. Given sufficient resources and man-power capture-recapture methods can be very effective but are intrusive and stressful to the animals, labour intensive, require expertise to analyse data, and are thus expensive. Both of these methods may be applied to scientific studies but are analytically complex, expensive and are therefore not suitable for more widespread surveys.

Transect Counts

Direct counts of the number of animals seen along a walked or driven transect is probably the simplest method available. If all animals within a known distance of the transect line are detected it is possible to estimate absolute density. However, as it is seldom possible to assume that all animals are seen with certainty, transect counts can usually only provide an index of relative abundance. The usefulness of simple counts of mountain hares seen along a transect line remains to be tested, but at best will be limited to open habitats. Furthermore, along with the formal distance sampling methods tested by Newey *et al*. (2003) direct counts of hares along transects are likely to be of limited use at very low density (< 20 hares km^{-2}) and very high density (> 120 hares km^{-2}) because of problems of obtaining sufficient encounters at low density and of counting animals at high density. The flushing behaviour of mountain hares is known to vary with

season and daily temperature (Flux, 1970), and the detection of hares is likely to be affected by the stage of moult and snow-lie. Simple counts of the number of animals seen or encounter rates are not robust to seasonal or habitat differences in detection or flushing behaviour. Simple counts of the number of animals seen might be improved upon by grouping sightings into broad distance categories and then undertaking a simple distance sampling analysis. While this later method forms the basis of both the BBS (Mammals) and Winter Mammal Monitoring programmes the method has never been validated. Furthermore, the aims of both the BBS (Mammals) and WMM programmes are to monitor trends and not to estimate absolute abundance, and all analysis is undertaken by the BTO.

Counts using dogs

A variation on simple transect counts is to use dogs to increase the likelihood of flushing animals. Dog counts have been used to estimate hare abundance (Gilbert *et al*. 2001; Laurenson *et al*. 2003; Watson *et al*. 1973; Watson & Hewson 1973). However, although Watson *&* Hewson*.* (1973) and Watson *et al*. (1973) found that dog counts were useful at high densities the coefficients of variation at medium and low densities suggest that dog counts are of dubious use (Watson *et al*. 1973) as critically the coefficients of variation change strongly with density. Furthermore, comparisons of hare density estimates derived from distance sampling and dog counts suggests that dog counts underestimate hare density by 2 – 10 fold (Fig 2a; Newey & Smith, unpublished).

Night counts

Another variation on simple transect counts is to use a spotlight (either visible or infra-red) or thermal imaging equipment to identify target species. Spotlight counts may be useful in some circumstances and have been suggested as monitoring tool for mountain hares (Macdonald, Mace, & Rushton 1998), but like any direct method the use of spotlight counts is likely to be limited by weather, and the method is prone to errors due to short-term changes in local abundance. Night counts with the aid of a spotlight have been used successfully for assessing brown hare abundance and vehicle based spotlight counts are used in Northern Ireland to count mountain/Irish hares (Dingerkus & Montgomery 2002; Preston *et al*. 2003; Tosh *et al*. 2004), but again these were carried out in low lying, open agricultural areas. The use of spotlights for counting mountain hares in the Scottish highlands remains to be thoroughly tested, but preliminary studies suggest that spotlight counts might be useful in generating indices of relative abundance at least (Fig. 2b; Newey, unpublished data).

The use of night counts using thermal imaging equipment are likely to be limited due to weather and cost and although the method has not been thoroughly evaluated limited trials suggest that the method is not suitable for use along walked transects (Newey, unpublished data).

Vantage point counts

Mountain hares are crepuscular and thus while vantage point counts might offer an intuitive and simple method of estimating relative abundance, they are likely to be of little use of vantage points to assess absolute abundance are likely to be of little use (Fig. 2c; Newey, unpublished data).

Clearance/Drive counts

Total censuses using clearance, or drive counts, where all the animals present are driven from a large area by a group of people and are counted have been used to assess brown hare populations in arable areas of the continent. Drive counts are also used to assess deer abundance in small areas of woodland and red grouse on open moorland. Such techniques demand significant labour to successfully clear an area, count the animals that are flushed, and make the assumption that all animals are flushed from the area and accurately counted. The use of clearance methods in brown hare studies is limited to the wide, open arable habitats or as a method against which to calibrate or compare other less labour intensive methods.

The use of clearance methods for mountain hares is likely to be very limited due labour and logistical constraint, but may have a place in local, small scale assessments, particularly when used in association with other management activities that involve driving or beating particular areas. They may be applied to specific scientific studies and used to help calibrate other methods, but like direct counting methods, are unlikely to be suitable for more widespread national or large scale surveys.

Game bag data

Game bag data, or hunting statistics, have been used to assess long-term national or regional trends in animal numbers but without first establishing the relationship between number of animals shot and the number of animals on the ground game bags are of little use in assessing absolute abundance. Furthermore, shooting records for mountain hares are not as thoroughly maintained as for economically important game species (Macdonald, Mace, & Rushton 1998). Game bag records are known to exaggerate high and low densities which is especially problematic as it is at high and low densities that management is likely to be most needed (Finerty 1980; Royama 1992).

It is important to realise that bag data depend on effort as well as on abundance, so the interpretation of trends is not necessarily straightforward. Bag data are potentially as much a reflection of shooting or trapping effort as of species abundance and the lack of information about the effort involved has been put forward as a major limitation of game bag data (Macdonald, Mace, & Rushton 1998). Gamekeeper density is one measure of effort that is available in the NGC. Although gamekeeper density was strongly related to bag size for all species, the estimates of percentage change obtained with and without adjusting for gamekeeper density were similar across regions and across species (Whitlock, Aebischer, & Reynolds 2003). Furthermore, when comparing population changes in game bag data compared to BBS data Whitlock *et al*. (2003) found that there was generally a good agreement between NGC and BBS estimates of population change, although of the species compared (red fox, grey squirrel and rabbit) the strongest agreement was found in the conspicuous grey squirrel. Cattadori *et al*. (2003) found that bag records of red grouse were strongly correlated with population changes assessed by direct counts of red grouse using dogs. The validity of bag records for mountain hares has not been formally investigated. However, Hewson (1976) however does report a significant correlation between the numbers of hares shot and live trapped for one study site in eastern Scotland.

In 2003, the JNCC entered into a partnership with G&WCT to develop the surveillance potential of the NGC, which was recognised as having some valuable data, particularly for mustelids (*e.g.* stoat and weasel). Based on analyses of bag data of red fox, rabbit,

brown rat, grey squirrel, stoat and weasel, Whitlock *et al*. (2003) assessed the coverage, error rates and usefulness of the NGC to monitor species abundance.

The statistical power of the NGC to detect temporal change was estimated for notional declines over 25 years of 10%, 25% and 50% in weasel bags from southeast England. The power to detect a 50% decline was over 98% from sample sizes of 40 estates or more. For a 25% decline, power exceeded 80% for sample sizes greater than 130. There was no power to detect a decline of 10% within the range of sample sizes considered (1–133). This compares favourably with the power of other mammal monitoring schemes.

Indirect Methods

Indirect methods, such as dung plots, give an assessment of the population over a period of time prior to the survey and therefore offer the significant advantage of being less prone to sampling error than are direct counts (Jachmann 1991). Indirect methods are also less intrusive, impose minimal stress to the animals and are generally cheaper.

Estimates of dung density can be used as a relative index of abundance or to estimate abundance. While indices of relative abundance are suitable for many purposes setting harvest and cull levels and monitoring long-term status demands absolute abundance estimates. Abundance estimates based on dung density can be classified into three categories; faecal standing crop, faecal accumulation rate (Campbell, Swanson, & Sales 2004; Marques *et al*. 2001; Mayle 1996; Putman 1984) and faecal correlation methods based on a previously established correlation of dung density or accumulation with an independent estimate of animal abundance derived from other methods (Angerbjorn 1983; Krebs *et al*. 1987; Krebs *et al.* 2001; Murray *et al*. 2002).

Standing crop methods are widely used in large herbivore research and require estimates of defecation (appearance) and decay (disappearance) rates of dung along with an estimate of dung density. Both defecation and decay rates have been demonstrated to be highly variable and may depend on substrate, weather, aspect, sex, age and diet (Barnes 2001; Mitchell *et al*. 1985; Nchanji & Plumptre 2001) and are thus prone to bias. The heterogeneity of decay rates has frequently been compounded by the conventional method of estimating decay rates that have relied on prospective rates of mean time to disappearance (decay) based on monitoring dung until it has disappeared (Laing *et al*. 2003). This problem is often further aggravated by the use of a common “rule of thumb” estimate. Reliable estimation of animal abundance needs a site and time specific retrospective estimate derived over the time period leading up to the dung survey (Buckland *et al*. 2001; Laing *et al*. 2003). Estimating such retrospective decay rates involves a minimum of two visits.

Methods based on faecal accumulation rates on the other hand involve revisiting plots that have previously been cleared of dung and thus involve two site visits. Given the defecation rate and assuming no intermediate decay of pellets, animal density can be estimated from the density of accumulated dung. The faecal accumulation method therefore avoids the error associated with estimated decay rates.

Using both simulated and field data of woodland deer two recent studies suggest that standing crop methods are more precise than clearance methods for any given density of deer and level of survey effort (Campbell, Swanson, & Sales 2004; Smart, Ward, & White 2004). Other authors however have found that clearance methods are superior to

standing crop methods especially at high deer density and certainly common sense would suggest that removing the error associated with estimates of decay rates should improve the performance of clearance methods (Buckland 1992; Mayle, Peace, & Gill 1999). The apparently poor performance of clearance methods over standing crop methods can be attributed to at least two possible factors; i) the short time between clearing plots and estimating accumulation means that many sampling plots contained no dung thus inflating variance leaving more time between visits or using larger plots are likely to improve the performance of clearance methods, ii) the estimate of mean time to decay is usually, and certainly in the Smart, Ward & White (2004) study, based on a small sample size of dung groups that fail to give a good estimate of the true variance in decay rates for different habitat types. Also the prospective rates used in most studies may not be representative of the time period covered by the survey and are likely to be less representative than the retrospective approach advocated by Laing *et al*. (2003).

Faecal correlation methods are the simplest methods and rely on the correlation between dung density, either standing crop or clearance methods (the latter is less prone to error), and animal density calculated from an independent and usually direct method *e.g.* capture-recapture or distance sampling. This method has been developed and used in a number of snowshoe hare studies (Krebs *et al.* 1987; Krebs *et al*. 2001; Murray *et al*. 2002) and mountain hare (Angerbjorn 1983) studies. Minimising the error in estimated dung density and the sampling and model error in the original estimates are critical.

All of the methods rely on estimating dung density based on counting dung in sampling plots. The shape of the plot and the survey design all influence the estimate of dung density and thus the level of precision and accuracy of the final population estimate (Doney 1998; Krebs *et al*. 1987; Krebs *et al*. 2001; McKelvey *et al*. 2002; Murray *et al*. 2002; Newey *et al*. 2003; Staines & Ratcliffe 1987). Counting dung in plots also assumes that all dung is detected with certainty. Partly due to the problems associated with counting dung in plots Marques & Buckland (2003) advocate the use of line transects and distance sampling to obtain estimates of dung density which alleviates the necessity for 100% detection. However, any estimate of dung density based on transects does not lend itself to dung clearance methods.

7. Recommendations for developing a cost-effective, simple and practical method to assess mountain hare populations.

Rational

There is a need for a method to provide robust, precise and accurate estimates of mountain hare density, that is applicable in a variety of habitats and will provide reliable estimates at a wide range of hare densities. There is also a need for a method that will provide rough estimates of hare abundance that can be rapidly deployed with minimal cost and that could be undertaken by volunteers or estate workers.

We believe that dung-plot clearance methodologies are the most effective and easily developed means for establishing mountain hare density that will be effective in a wide range of habitats and mountain hare densities. However, we note that there are concerns over time, skill and cost implications of dung-clearance methods for widespread and general use. We therefore also propose the evaluation of the usefulness of other less accurate but simpler and cheaper methods that could be used by relatively unskilled workers, and could be more widely used during the course of routine estate management.

We propose dung clearance methods that maximise the advantages of clearance methods and overcome the problems of having to estimate defecation rates. Using intensive sampling, relatively large sampling plots, and a 4-6 week sampling interval, we aim to minimise the problems of inflated variance often associated with clearance methods. Repeating the dung surveys before and after a known number of hares have been removed would, for the first time in any lagomorph study, enable us to calibrate the method. Once calibrated, practitioners will only have to undertake two site visits; the first to mark out and clear plots, and the second to count the fresh dung, in order to estimate hare abundance.

While we believe that this method has the potential to realise accurate, precise and cost effective estimates of abundance and could be used in a wide range of habitats, and will be effective at a wide range of densities, we recognise that clearing and revisiting dung plots may not always be practical. We therefore propose the evaluation of simple transect counts of the number of hares seen. Simple counts of the number of hares seen along a walked transect offer an intuitive, simple and potentially cheap method of assessing hare abundance in open habitats. The numbers of hares seen and encounter rates would be generated during distance sampling surveys and the use of simple counts and encounter rates will be investigated as a possible method of assessing relative indices of abundance. The use of categorising sightings into broad distance categories should be investigated as a possible method of assessing absolute abundance.

Spotlight counts of hares at night have been suggested as a possible method of estimating hare abundance (Macdonald, Mace, & Rushton 1998) and are seen as a method that could potentially be incorporated into routine estate activities. Thus we propose to evaluate and test the use of spot light counts as a method of deriving relative and absolute abundance estimates. While it is not possible to evaluate all of the other potential methods here, any proposed project should include a review of other possible methodologies (*e.g.* dog counts and clearance counts) using existing data sets and other

opportunistic data.

Methods

- We propose that dung-plot based techniques should be tested a) against transect counts based on distance-sampling and b) by quantifying the change in accumulation rates after a known number of hares have been removed from the study populations. The method proposed is widely used for research and monitoring purposes of snowshoe hares throughout North America covering a wide range of habitat types and hare density (Krebs *et al*. 1987; Krebs *et al*. 2001; Murray *et al*. 2002).

- At the first visit the plots should be marked, and all the dung in the plots and a margin around the plots, counted and removed.

- Hare density should be estimated using distance sampling techniques (Newey *et al*. 2003; Shewry, Buckland, & Shaw 2002). Encounter rates and strip estimates should also be derived from night time lamp counts. Four-six weeks after marking and clearing the dung plots a known (but not pre-determined) number of hares should be culled (in the course of routine estate management and commercial shoots). Immediately before or after hares are culled the dung plots should be revisited, and the accumulated dung counted and removed. Finally approximately 4-6 weeks after hares have been killed the dung plots would be revisited and the accumulated dung counted.

- The distance estimates of hare abundance, encounter rate, and lamp count indices will be correlated against i) estimated hare abundance based on the faecal accumulation method, and ii) mean dung accumulation rate. By incorporating the number of hares removed from the population, and the proportional change in observed mean dung accumulation rate before and after the cull, it will be possible to derive an estimate of absolute population abundance and, critically, to calibrate the relationship between hare numbers and mean dung accumulation rate.

Outputs

- Once calibrated and validated, mean dung accumulation rates have the potential to provide an inexpensive, simple and effective method for estimating hare abundance. The proposed methods will give researchers, land managers and statutory organisations an inexpensive, simple and effective method of estimating mountain hare abundance by simply clearing and revisiting marked dung plots over a 4-6 week period. The method will not require any sophisticated field equipment, analysis or prior knowledge. The method to be developed is not dependent on weather unlike the methods of counting hares directly. As dung methods give an estimate of hare numbers over the time scale between initial clearance and subsequent revisit the method is robust to short-term changes in hare residency due to weather or disturbance. Additionally, because the method will rely solely on mean accumulation rate there is no need for estimates of defecation or decay rates.

- The utility of transect counts; i) number of hares seen, ii) encounter rate, and iii) grouping of sightings into broad distance categories will be investigated by comparison with the validated estimates from the dung clearance studies.

- The precision, accuracy and utility of night-time lamp counts will also be evaluated by comparison with estimates of abundance from dung clearance method.

Time Scale

This fieldwork would need to begin in February and run until mid-April. Funding would need to be in place in at least September of the preceding year.

8. Options for long-term monitoring strategies and recommendations on the most appropriate way forward.

Establishment of a long-term monitoring strategy will require development and implementation of a single or suite of methods that should; a) provide accurate, repeatable estimates of population density, b) be objective enough to be employed by different people, applying it in different places at different times, c) be easy to establish, without requiring special expertise over and above that which can be followed by simple, pre-prepared protocols, d) be efficient as possible in the use of resources, particularly staff time, and e) be flexible enough to yield reliable estimates in a range of habitat types and at different hare densities. Furthermore, to accommodate the large multi-annual fluctuations characteristic of some mountain hare populations surveys should be repeated for a number of consecutive years followed by a number of years without surveys. In this way it should be possible to identify the phase of population growth and identify trend from multi-annual or short-term fluctuations.

Indices of abundance might be appropriate for monitoring population change (Caughley & Sinclair 1994; Wilson *et al*. 1996), although ideally the relationship between the true density and index should be linear and monotonic this relationship is seldom met (Wilson *et al*. 1996). Thus, if an index is used, it should be calibrated against known hare densities so that an estimate of actual numbers is provided.

The ideal method(s) and survey design should be applicable and scaleable to a range of scales from local (2-10 km^2) to regional and national. The chosen method(s) and survey protocol must also be applicable, at these scales, as well as regional and national scales.

Standardisation to a particular time of year to account for variation within years may be appropriate, but due to the reasons discussed above might not resolve all of the problems associated with using methods that are not robust to heterogeneity in detection. However, it will be important to decide whether a pre- or post- breeding estimate is most useful. Surveys undertaken during the breeding season are likely to be of little use as the population will be “open” and changing rapidly. Post-breeding surveys may offer the advantage of providing an estimate of the harvestable population, but because peaks in hare mortality occur post-breeding in late summer/early autumn with a second, pre-breeding peak in late winter. The most stable population is thus most likely to be in late winter/early spring and will represent the breeding population.

Without the benefit of the results of the work proposed in section 7, a definitive strategy for long-term monitoring cannot be recommended. The brief review (above) provides a guide to the range of techniques available to be adapted to a longer-term monitoring

strategy. The errors and problems associated with each are relevant to the effectiveness of each method at meeting the criteria required.

Long-term changes in hare abundance may be due to changes in density occurring within the suitable core area and habitats of the range occupied by the species; these may be influenced by climate or changes in land use and management particularly those affecting habitat quality and suitability. Long-term changes may also be brought about by complete habitat replacement with other less suitable alternatives, such as forest. It is, therefore, recommended that a long-term monitoring strategy should gather data in the central core of distribution of mountain hares in each region, and should also assess their abundance in areas and habitats considered 'marginal' for mountain hares. In this way, any long-term changes in numbers in core areas of favoured habitats will be detected, as will changes in occupancy of both these areas and more marginal areas. Additionally, changes in land use or in practise or intensity of management under the same land-use, perhaps coupled with changes in ecology of the system due to climate change, are all likely to contribute to long-term changes in numbers. Hence the monitoring strategy should incorporate areas occupied by mountain hares and which include these possible changing conditions.

Outputs

At this stage we are unable to offer any firm recommendations. The optimal strategy will undoubtedly combine more than one technique, and will depend heavily on the level of change the monitoring programme should be able to detect, over what time scale, and with what power. Considerably more information is needed on the variation and efficiency associated with different methods, mountain hare distribution and monitoring criteria before possible options can be more fully explored.

We suggest that, after the methodological outputs from Section 7, and distribution data from Section 9 are obtained, then it would be possible to draw up recommendations for a long-term national monitoring programme for mountain hares in Scotland. We suggest that these recommendations draw on the expertise of organisations and agencies that already manage, or are planning, national monitoring programmes. The recommendations would also need input from SNH on the desired criteria of the national monitoring programme, and statistical expertise to assess the level of effort and feasibility of the criteria specified by SNH. The final output would be a report detailing the issues, possible methodologies, and recommendation for implementing a long-term monitoring programme.

To provide a coherent and cost effective solution we recommend that this element of the proposal is combined with the national population assessment exercise (Section 5).

9. Recommendations for undertaking a review of the current level of offtake from hare populations: licence returns, game bag data and other information provided by estates.

Mountain hares are killed for a variety of reasons, including sport/commercial shooting, crop protection, protection of forest regeneration/restoration, and increasingly tick control. Hares may be legally killed by shooting and they may be snared under licence. Although there is a closed season on the sale of carcasses (March-July inclusive) there is no closed hunting season – mountain hares can be killed at any time of year (except on Sunday and Christmas Day in England & Wales). Tapper (1996) demonstrated that there are significant regional and seasonal differences the numbers of hares killed for different reasons (sport or vermin control). This review is now 10 years old and, as acknowledged at the time was incomplete. We recommend a Scotland-wide questionnaire survey of land owners, game keepers, and field sports enthusiasts to assess the current level of harvest and at the same time map the distribution of mountain hares in Scotland.

Night time shooting with the aid of a lamp, and snaring can only be carried out under licence issued by the Scottish Government. These licence applications and licence returns – detailing the number of hares culled are also a potential source of useful data. We recommend an analysis of licence applications, and more importantly, licence returns to assess the reasons and level of licenced culls. However given the current absence of any restrictions on the number of hares that can be legally shot by day, data on licenced cullscan only provide an incomplete picture.

Methods – Questionnaire survey[2]

We propose to mail a machine-readable questionnaire and map showing the estate/property owned and managed or keepered to names and addresses held on three databases by the G&WCT; the National Game Bag Census, Scottish G&WCT members, and Scottish Land Owners. We recommend an approach to the Scottish Gamekeepers Association (SGA) to access their members' database. Although there is some overlap between the databases each has a different geographic and membership coverage.

The questionnaire should ask for details of the number of hares killed broken down by season, reason, and method. Respondents should also be asked to mark on the map provided areas where mountain hares are currently present. Questionnaire responses and map data could then be imported into a GIS for latter analysis.

Methods – Licence returns

Initial enquiries to the Scottish Government and the Scottish Agricultural Science Agency (SASA) suggest that there are probably less than 30 licence returns on file. The data will be summarised by region, purpose and method of culling. Where possible these data should be incorporated into the questionnaire database.

[2] Undertaken in 2007.
See www.snh.org.uk/pdfs/publications/commissioned_reports/Report%20No278.pdf

Outputs

- Maps from questionnaire data would provide a comprehensive description of mountain hare distribution in Scotland. This will not only feed into the national assessment of Scottish hare abundance, but will also provide information on population fragmentation and help guide future survey and monitoring work. For reasons of confidentiality and to comply with data protection regulations of both G&WCT and external (SGA) contact lists these data would only be made available to project partners at a 10 km^2 scale.

- The questionnaire data would provide detailed information on the level, reason, method and timing of harvest of mountain hares. These data would provide valuable information on the level of exploitation and inform the debate on the sustainability of current management of mountain hare populations. For reasons of confidentiality and to comply with data protection regulations of both G&WCT and external (SGA) mailing lists these data would only be made available to project partners at an administrative scale (e.g. Parish, Deer Management Group).

10. Recommendations for a retrospective and calibrated analysis of historic data.

Current evidence suggests that mountain hare numbers have declined, however the extent of this decline and whether this represents part of a long-term decline or cyclic low is not certain (Battersby 2005). Evidence for the observed decline is based on a very short time-series (1995-2002) collected during the BBS (Mammal) survey. It is therefore difficult to identify whether the observed decline in the BBS index of hare abundance since 1997 represents the decline phase of a population cycle or a real overall decline (Battersby 2005).

There have been a significant number of studies that have generated indices of mountain hare abundance, which could be repeated in the same area as originally if sufficiently precise methodological details were available. By re-surveying these historic sites using the original survey method, and calibrating that method against one of the methods developed earlier in this proposal to derive an absolute estimate of abundance, it should be possible to gain an insight in to the long-term trend in hare abundance. The original studies would have had to have been undertaken at a known stage of a population fluctuation, or to have been conducted over a sufficiently long run of years to enable it to be determined. Table 1 lists these studies, the methods they used, and identifies whether sufficient detail is available to repeat the methods both in terms of methodology and geographical location.

It is evident from Table 1 that there are very few studies for which sufficient methodological information exits to allow a re-survey, for many of the studies there is no information on the stage of population growth, or the studies were too short for this to be determined. Furthermore, many of the historic counts are based on dog or vantage point counts which are thought to poorly index true density. Hewson (1976) represents the only published long-term population study of mountain hares and includes sufficient data on methodology, location and population dynamics to allow a resurvey using vantage point counts and possibly capture-recapture. The 9 year time-series for three study sites in the Cairngorms presented by Watson & Hewson (1973) could potentially be re-

surveyed using dog counts if the count areas could be relocated with sufficient accuracy. Additionally it would be possible to re-survey sites on Orkney and Shetland that Hewson (1988, 1995) surveyed using vantage point counts, although there are insufficient data to identify the stage of population growth. However, vantage point count and dog counts are thought to be of little use in obtaining absolute estimates of abundance or density (Section 6), although it would be possible to obtain indices of abundance. Given the small number of potential sites, and the limitations of vantage point counts and dog counts we do not recommend pursuing a retrospective surveys of these historic study areas.

Of the 12 sites surveyed using distance sampling techniques by Newey *et al*. (2003, Newey unpublished data) only 3 sites were surveyed in two consecutive years in 2000 and 2001. The remaining sites were only surveyed once in 2002. These sites could easily be re-surveyed, although there are no data on the stage of population growth. The exact location of the 8 sites surveyed by Rao *et al*. (2003) using dung plots is currently unknown, but this information is thought to be available in which case these sites could easily be re-surveyed, but again there is no information on the stage of population growth. Similarly the site in Glenbuchat should also be suitable for re-surveying. However, all of these surveys are recent, since 1989, and is questionable whether re-surveying these sites would contribute to our understanding of what is happening to mountain hare populations. Therefore we do not recommend resurveying these sites.

11. Recommendations for a study of the impact of offtake on hare populations.

There is surprisingly little known about the factors that limit or regulate mountain hare populations (Newey 2005). Similarly there are little data on how mountain hare demography; birth, death, immigration and emigration rates change with density (Newey 2005). To address some of these shortcomings pertinent to the current discussion we recommend a series of large scale, replicated population reduction experiments to investigate how birth, death, immigration and emigration rates change in relation to level of harvest.

There is also a paucity of data on how tick abundance changes in response to a reduction of mountain hare density in the presence of other competent hosts. Thus, these experiments should also investigate whether reducing mountain hare density in the presence of deer has an effect on tick abundance. Developing detailed and costed proposals is beyond the scope of this proposal. Work packages to investigate the effects of harvesting mountain hares on their population dynamics, other upland herbivores and predators, and habitat are being pursued in the Macaulay Institute under the direction of the Scottish Government's 2005-2009 science strategy.

12. Prioritisation of the key elements of the proposed programme of work.

In order of priority:

1. Develop and validate survey methodology. Much of the future work needed on mountain hare ecology and conservation status is dependant on reliable and cost effective methods of population assessment. We urge that this work package be undertaken as soon as is practicable. The proposed methodology relies on taking advantage of the relatively stable population size that occurs at the end of the winter and before the breeding season, and will be calibrated against the harvest of hares that occurs during commercial hare shooting which generally takes place during February-April. If this work is to be undertaken in a particular year, the funding would need to be place in place by September of the previous year.

2. Much of the current concern surrounding mountain hares stems from the apparent increase in the level of harvest, in particular blanket culls in response to rising tick burdens and Louping Ill incidence. To inform the discussion on hare management we suggest that an assessment of the level of harvest should also be a priority. To take advantage of exiting mailing schedules this work would be scheduled to start in spring of the year for which it is proposed. The design and production of machine readable questionnaires and preparation of databases means that funding for this work package should be in place by end of the previous year.

3. A national estimate of hare abundance and recommendations for a long-term monitoring programme first demand that we that we have a suite of reliable and validated survey methods in place, along with a better understanding of mountain hare distribution. Initial survey and monitoring efforts may also be prioritised by a better understanding of the patterns of harvesting being undertaken. We recommend that initial efforts to derive a national estimate of abundance and recommendations on a long-term monitoring programme are combined into one work package. As this work needs to be informed by outputs from 1 and 2 above we recommend that this work be undertaken subsequent to those two components.

4. Studies to investigate the effects of exploitation on hare population dynamics are much needed but are beyond the remit of the current proposal. Survey methods are first needed; information on distribution, fragmentation, abundance, and the occurrence and level of harvest are also needed to design suitable experiments.

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Figure 1.

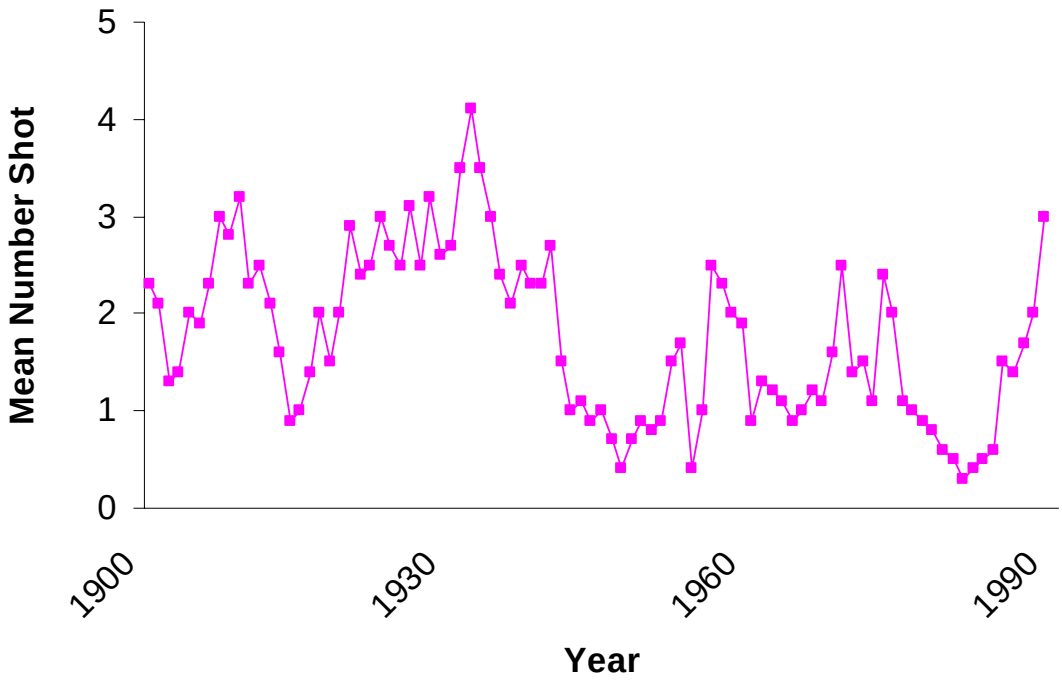

Figure 1. Mean number of hares shot per km² on 44 moors in Scotland (after Tapper, 1992).

Figure 2.

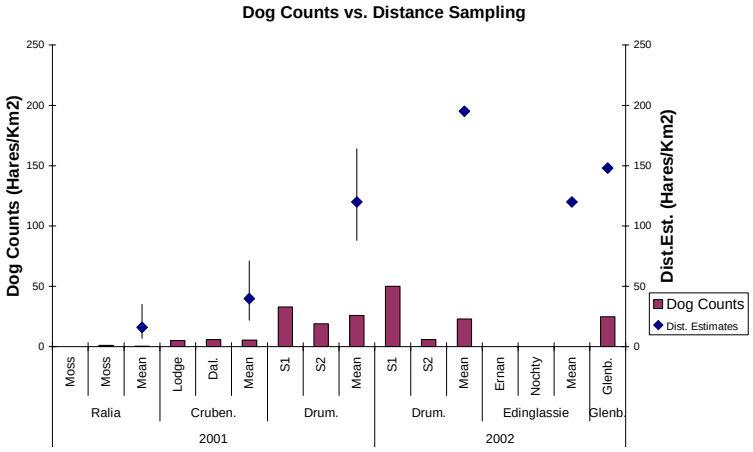

Figure 2a. Comparison of density estimates from dog counts and distance sampling.

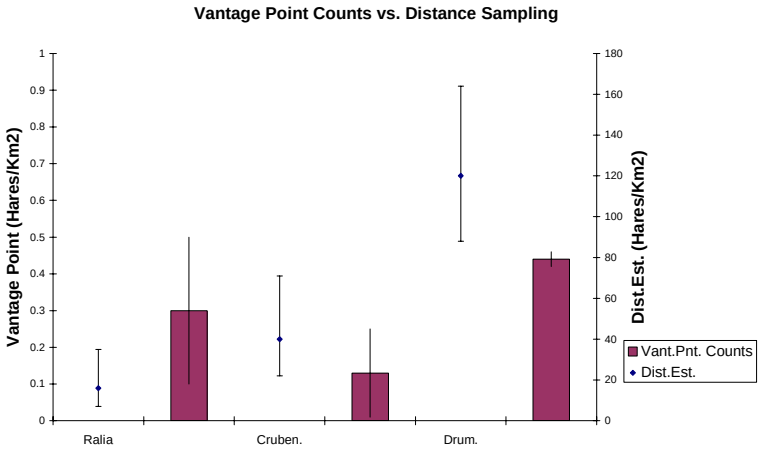

Figure 2b. Comparison of density estimates from vantage point counts and distance sampling estimates.

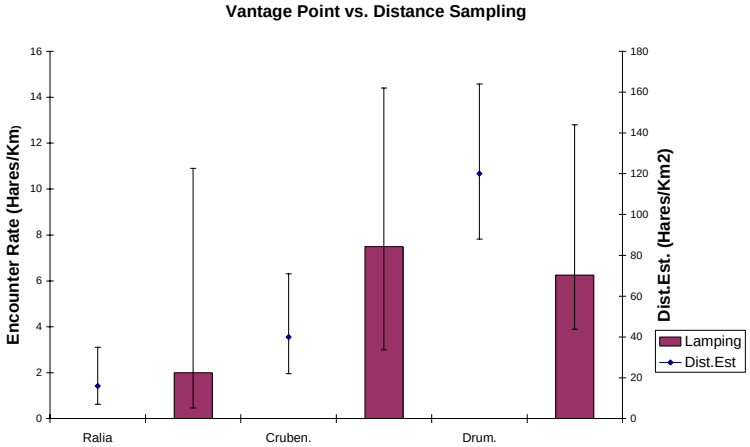

Figure 2c. Comparison of encounter rate indices from lamping and distance sampling density estimate.

Table 1.

Study	Approx location	Method used	Habitat type(s)	Years of study	Popn. stage known	Methods repeatable Technique/Location	Suitable for duplicate study?
Watson *et al.* (1973)[2]	Central Highlands	Dog count – no. seen	Grouse moors	5 (1957-1961) 10 (1962-1971)	No ?	Yes/Yes- possibly for some sites at least	No
Watson & Hewson (1973)[3]	41 sites - West Scotland	Dog count – no. seen	Low moors and arctic alpine	1	No	Yes/No	No
Watson & Hewson (1973)[3]	31 sites - East Scotland	Dog count – no. seen	Low moors and arctic alpine	1	No	Yes/No	No
Watson & Hewson (1973)[3]	3 sites – Central Highlands	Dog count – no. seen	Low moors and arctic alpine	9 (1964-1972)	Yes	Yes/No	Possibly, if sites could be relocated. Question use of dog counts.
Hewson (1988)[4]	Shetland	Vantage point counts	Blanket peat	2 (1984-1986)	No	Yes/Yes	Yes, but question use of vantage point counts.
Hewson (1995)[5]	Orkney (Hoy)	Vantage point counts	Arctic alpine	1 (1984)	No	Yes/Yes	Yes, but question use of vantage point counts.
Hewson (1976)[6]	Deeside - Corndavon	Mean dung accumulation	Heather moor	2 (1971-1973)	No	Yes/No	No
Hewson (1989)[7]	Strathdon	Mean dung accumulation	Heather/Grouse moor	1 (1984-1985)	No	Yes/No	No
Hewson (1976)[8]	Strathdon – Jocks Hill	Vantage points, snaring and trapping	Moorland/Arctic alpine.	14 (1956-1969)	Yes	Yes/Yes – vantage points.	Yes, but question use of vantage point counts.
Newey *et al.* (2003)[9]	4 sites - Strathspey	Distance	Grouse moors	2 (2000 & 2001)	No	Yes/Yes	Yes
Hulbert *et al.* (1996)[10]	Glenbuchat	Dung accumulation,	Upland pasture, young forest,	2 (1989-1991)	No	Yes/Yes	Yes

		trapping index??	and open moorland				
Rao *et al.* (2003)[11]	8 sites - N & NE Scotland	Dung accumulation	Moorland, conifer and birch plantation	3 (1998-2000)	No	Yes/Yes	Yes
Newey (unpublished)	9 sites - Central Highlands	Distance	Grouse moors	1 (2002)	No	Yes/Yes	Yes
G&WCT (unpublished)	30 sites - Central Highlands	Dog count-rank index	Grouse moors	15 (1985-2000)	No[1]	No/Yes	No
G&WCT (unpublished)	30 sites - Central Highlands	Dog count – no. seen	Grouse moors	4 (since 2001)	No[1]	Yes/Yes	Yes, but question use of dog counts.

Table 1. Summary of known studies that include estimates or indices of mountain hare abundance or density, along with information on where the study was carried out, when and for how long, in addition the table shows whether the published study includes sufficient methodological detail to repeat the survey.

1. Stage of population growth might be identified from this time-series. **2.** Watson, A., Hewson, R., Jenkins, D., & Parr, R. (1973) Population densities of mountain hares compared with red grouse on Scottish moors. *Oikos* 24**,** pp. 225-230. **3.** Watson, A. & Hewson, R. (1973) Population densities of mountain hares (*Lepus timidus*) on western Scottish and Irish moors and Scottish hills. *Journal of Zoology, London* 170**,** pp. 159. **4.** Hewson, R. (1988) Spacing and Habitat Preference of Mountain Hares in Shetland. *Journal of Applied Ecology* 25, pp. 397-407. **5.** Hewson, R. (1995) Mountain Hares *Lepus timidus* on Hoy, Orkney, and Their Habitat. *Journal of Zoology, London* 236**,** pp. 331-337. **6.** Hewson, R. (1976b) Grazing by mountain hares *Lepus timidus*, Red deer *Cervus elaphus*, and Red grouse *Lagopus scoticus* on heather moorland in north-east Scotland. *Journal of Applied Ecology* 13**,** pp. 657-666. **7.** Hewson, R. (1989) Grazing Preferences of Mountain Hares on Heather Moorland and Hill Pastures. *Journal of Applied Ecology* 26**,** pp. 1-11. **8.** Hewson, R. (1976a) A population study of mountain hares (*Lepus timidus*) in north-east Scotland from 1956-1969. *Journal of Applied Ecology* 45**,** pp. 395-414. **9.** 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**,** pp. 185-19. **10.** Hulbert, I.A.R., Iason, G. R., & Racey, P. A. (1996) Habitat utilisation in a stratified upland landscape by two lagomorphs with different feeding strategies. *Journal of Applied Ecology* 33, pp. 315-324. **11.** Rao, S.J., Iason, G. R., Hulbert, I. A. R., Daniels, M. J., & Racey, P. A. (2003) Tree browsing by mountain hares (*Lepus timidus*) in young Scots pine (*Pinus sylvestris*) and birch (*Betula pendula*) woodland. *Forest Ecology and Management* 176, pp. 459-471.