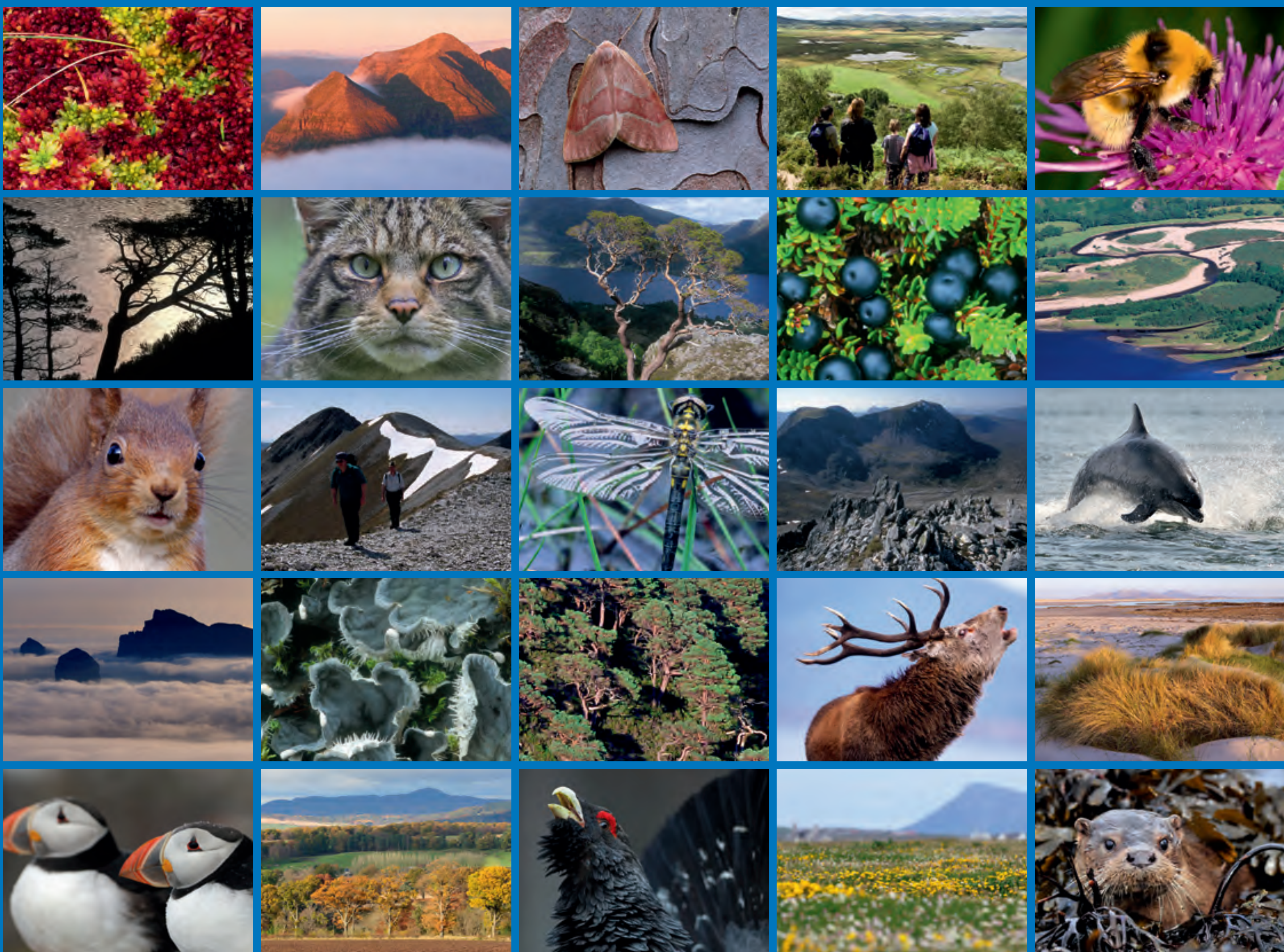
Scottish Natural Heritage
Commissioned Report No. 741

Black grouse conservation in southern Scotland



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Black grouse conservation in southern Scotland

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COMMISSIONED REPORT

Summary

Black grouse conservation in southern Scotland

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Keywords

Black grouse; southern Scotland; heather moorland; lek range.

Background

Black grouse in southern Scotland have declined in both numbers and range, with the Scottish Black Grouse Biodiversity Action Plan Steering Group identifying this area as a priority area for conservation action. Recent studies from north Perthshire have identified the importance of retaining heather moorland habitats within a forest-moorland landscape mosaic. The remaining moorland habitats in southern Scotland may be at risk from increased afforestation driven by government policy to expand woodland cover, changes in farming practice, wind farm developments and reductions in grouse moor management. To effectively conserve black grouse in southern Scotland, information on how the scale and quality of moorland habitats influences black grouse numbers and distribution are required. In this report we explored long term trends in black grouse numbers from shooting bag records. We assessed habitat composition within lek ranges of occupied leks and assessed the effect of habitat variables and moorland management on lek size. Similarly, we explored temporal changes from a sample of sites surveyed between 1989-99 and again 2006-12. We also considered how scale and management of moorland habitat patches influence occupancy.

Main findings

- Black grouse are in long term decline in the region. Shooting bag records illustrate that the numbers of birds shot per km^2 peaked in 1910 and then declined. By the 1980s they were infrequently harvested. Recent lek surveys showed a 64% decline between 1989-99 and 2006-12.
- Heather moorland was present within all occupied lek ranges. Leks were a median 110m from heather moorland, with the majority situated on acid grassland habitats.
- Twice as many males attended leks in areas where gamekeepers were employed and driven red grouse shooting was practised.
- Moorland patches occupied by black grouse were 25 times larger than unoccupied patches. We found 90% of males to be associated with six moorland patches, with the Moorfoot Hills and Tweedsmuir Hills patches supporting 62% of males. Only one large moorland patch larger than 100km^2, the Lammermuirs Hills, was unoccupied.
- To effectively conserve black grouse in southern Scotland a landscape-scale strategic approach is required. The fundamental objectives of this will be to secure and protect core populations associated with the larger moorland patches, prior to instigating

measures to increase population size and the connectivity with other patches in the landscape.

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1. INTRODUCTION

1.1 Background

Black grouse (*Tetrao tetrix*) were once widespread in Britain but have declined in both numbers and range over the past 100 years (Sharrock, 1976; Hancock *et al*., 1999). In recent decades the decline has accelerated, falling from an estimated 25,000 lekking males in the early 1990s (Baines & Hudson, 1995) to 5,100 males in 2005 (Sim *et al*., 2008). Two thirds of the remaining birds are now found in Scotland, with approximately 1,000 males in northern England and 200 in Wales (Sim *et al*., 2008). In England and Wales, numbers have stabilised following the instigation of conservation measures, but range has continued to contract, especially in Wales (Lindley *et al*., 2003; Warren *et al*., 2011). In contrast, in Scotland, numbers declined by 29% between 1995/6 and 2005. Trends varied between region with stability in the Scottish Highlands, but 49% and 69% declines in south-west and south-east Scotland which reduced numbers to an estimated 807 (516-1176 95% CI) and 257 (45-577 95% CI) males respectively (Sim *et al*., 2008). Due to their threatened conservation status, black grouse have been red-listed as a species of high conversation concern (Eaton *et al*., 2009) and are a 'Priority Species' of the UK Biodiversity Action Plan (Anonymous, 1995) with its own Species Action Plan to restore both numbers and range. The Scottish Black Grouse Biodiversity Action Plan Steering Group has identified southern Scotland as a high priority for conservation action.

In Britain, black grouse are associated with a variety of moorland and forest fringe ecotones (Baines, 1996a; Baines *et al*., 2007). To satisfy their seasonal dietary requirements birds utilise a range of differing habitats throughout the year (De Francheschi *et al.,* 1997; Borchtchevski, 2000; Starling-Westerberg, 2001; Beeston *et al*., 2005). Females use diverse moorland habitats which provide protein rich food sources prior to breeding, nesting cover and insect-rich areas in which to raise their chicks (Baines, 1990). In the winter, trees such as downy birch (*Betula pubescens*), alder (*Alnus cinerea*) and hawthorn (*Crataegus monogyna*) provide important feeding resources and cover (Baines, 1994). Regional variations in habitat utilisation occur, with birds in northern England frequenting open, virtually treeless landscapes (Baines, 1994; Warren *et al*., 2013) where they are found associated with the fringes of heather (*Calluna vulgaris*) moorland managed primarily for red grouse (*Lagopus lagopus scoticus*) shooting (Hudson & Newborn, 1995). This contrasts with the Scottish Highlands, where birds are associated with moorland and forest fringes and utilise a range of tree species including downy birch, larch (*Larix spp.*) and alder throughout the winter months (Parr & Watson, 1988; Baines, 1990; White *et al*. 2013a). The widespread declines observed throughout their UK range have been associated with the direct loss, degradation and fragmentation of moorland fringe habitat mosaics due to agricultural intensification and overgrazing by sheep (*Ovis aries*) *(*Starling-Westerberg, 2001*)*, commercial afforestation (Pearce-Higgins *et al*., 2007; White *et al*., 2013b) and overgrazing by red deer (*Cervus elaphus*) (Baines *et al*., 1994). Other contributing factors include increasing numbers of generalist predators (Tapper, 1992) and fatal collisions with deer fences (Baines & Andrew, 2003).

Black grouse were once a common and widely distributed bird in southern Scotland (Chapman, 1889; Scott, 1937) but recent surveys show a significant decline in numbers (Sim *et al*. 2008). Following a major period of commercial afforestation between the 1950s and the 1980s (Mason, 2007) southern Scotland has seen a large increase in conifer cover, with almost all the planting occurring on heather moorland, rough grassland and blanket mire (Mackey *et al*., 1998). It is widely accepted that black grouse initially respond favourably to the establishment of commercial conifer plantations planted on heather moorland, but resultant canopy closure and the shading out of favoured ground vegetation, has led to subsequent declines (Cayford, 1993; Pearce-Higgins *et al*., 2007; White *et al*., 2013b). New government policy aims to increase forest cover again in Scotland, from 18% to 25% by

2050, split 3:2 as ‘productive’ forest and ‘non-productive’ forest (Forestry Commission Scotland, 2006). The first phase proposes 1,000km^2 of new forest (1.3% of the land area in Scotland) by 2022 (Woodland Expansion Advisory Group, 2012). Recent research from north Perthshire has identified the importance of retaining heather moorland habitats available to black grouse within a forest-moorland landscape mosaic (White *et al*., 2013b). Black grouse leks associated with moorland remained stable, whilst leks associated with production-based forestry declined. Given the planned woodland expansion, the remaining moorland habitats may be under increasing risk of afforestation which may impact upon black grouse numbers, particularly in southern Scotland where declines have been greatest and population fragmentation is most evident.

This desk-based study uses lek data collected in southern Scotland to consider how scale, habitat composition and management of moorland habitats influences black grouse numbers and distribution both temporally and spatially. The results will contribute to the evidence base for recommendations of where creation of favoured types of new woodland may be advantageous to black grouse, where establishment of production-based forests may cause minimal negative impacts, and whether current moorland management can be improved to increase carrying capacity for black grouse or to help mitigate against any losses of moorland to forecasted forest development. This is a stand-alone project but could, subject to its results, funding and engagement with other partners, form the foundation (phase 1) of a wider partnership project (phase 2) that informs relevant forest design plans and develops a strategic conservation plan for black grouse in southern Scotland delivered through targeted advice and agri-environment schemes.

1.2 Objectives

The objectives of this research were to:

1. Quantify how local black grouse population size is determined by the size and quality of moorland habitat patch size;

2. Establish whether moorland carrying capacity is related to on-going management practices and their intensity.

To achieve these objectives we:

(a) Explored the historic abundance of black grouse on moors in southern Scotland from shooting bag records and put this in context with changes in red grouse numbers as an index of change in grouse moor management over the same period.
(b) Assessed recent changes in numbers of black grouse males at leks by comparing data collected at sample sites between 1989 and 1999 with those collected between 2006 and 2012.
(c) Related any changes in (b) to habitat variables and indices of moorland management.
(d) Quantified habitat composition around occupied leks and assessed whether the number of males at a lek were associated with habitat composition and indices of moorland management.
(e) Assessed how heather moorland patch size determines the presence of a black grouse lek and the density of males.

2. METHODS

The study was undertaken in southern Scotland, the northern boundary of which was defined as the Glasgow/Edinburgh central belt (Figure 1), and the southern boundary defined as the English border. The analysis was dependent on the availability of and access to black grouse lek data, shooting bag data, habitat data and moorland management information for southern Scotland. Therefore the initial phase of the project involved the collection of these data, error checking and entry into a Geographic Information System ArcMap v.10.1 (ESRI, 2012).

2.1 Long term and more recent trends in black grouse and red grouse

Black grouse are often associated with the fringes of the heather moorland managed primarily for red grouse shooting (Warren & Baines, 2004), where gamekeepers are employed to control generalist predators and to undertake rotational heather burning to produce harvestable surpluses for 'driven' shooting (Hudson & Newborn, 1995; Sotherton *et al.*, 2009). Here red grouse are the main quarry species, with black grouse historically a secondary quarry species shot on driven red grouse shooting days (Baines & Hudson, 1995) or on walked up days on the moor fringe (Tapper, 1992). We therefore also considered changes in numbers of red grouse shot over the same timeframe to assess changes in grouse moor management (Robertson *et al.,* 2001). To assess the long term trends of black grouse and red grouse we used data collected by the Game & Wildlife Conservation Trust's (GWCT) National Gamebag Census (NGC) which collects annual shooting bag (number of birds shot per annum) returns from over 600 estates in the UK (Aebischer & Baines, 2008; Tapper, 1992). This dataset includes returns from upland estates (from herein 'moors') where black grouse and red grouse are the quarry species, and returns from lowland estates where the primary quarry species are pheasants (*Phasianus colchicus*), grey partridges (*Perdix perdix)* and red-legged partridges (*Alectoris rufa*). The NGC dataset included the numbers of birds harvested per annum and the area of heather moorland managed. We used data from 31 moors which had long term bag records collected during the period 1900-2012. Due to incomplete data series, and therefore the number of sample moors varying between years, we expressed annual bags as the mean numbers of birds shot per km^2 of heather moorland.

Following the severe declines of black grouse, estates refrained from shooting them from the 1960s, and by the 1990s few birds were shot, thus estimating their abundance from bag records became meaningless (Baines & Hudson, 1995). Subsequently, males have been routinely surveyed at display sites known as 'leks'. Counting black grouse males attending leks in spring is now the usual way of determining abundance and monitoring any changes in either numbers or distribution (Gregory *et al.*, 2002).

2.2 Recent trends, habitat composition and moorland management within occupied lek ranges

Leks form the focal points for black grouse with males often attending leks throughout the year (Baines, 1996b) and juvenile males tending to recruit into the local lek (Warren & Baines, 2002). Similarly, females nest on average 600m (range 129-2464m) from the local lek (Warren *et al.*, 2012). Thus, numbers of displaying males at leks are likely to have been driven by past productivity and survival, with habitat composition within the vicinity of leks likely to be an important driver influencing the number of attending males (Hjeljord & Fry, 1995; Pearce-Higgins *et al.,* 2007). In this study, we defined leks as those occupied by two or more males combined with those occupied only by solitary males. In robust populations, leks occupied only by solitary males are likely to be young inexperienced males without an established lek (Höglund & Stöhr, 1996), but in declining populations solitary males may remain at historic sites. To assess recent changes in abundance, we compared lek data collected at sites surveyed between 1989 and 1999 which were resurveyed between 2006 and 2012 and related changes in numbers to habitat composition and moorland management data collected in the 2006–12 period. We used lek data collected between 2006 and 2012 to quantify habitat composition around occupied leks and to assess whether the number of males attending leks is affected by habitat composition and indices of moorland management.

2.2.1 Black grouse lek data

Lek data were sourced from the GWCT from sample sites in the Southern Uplands (*n*=76 lek site records), Lammermuir Hills (*n*=10), Galloway (*n*=5) and east Ayrshire (*n*=13) which were surveyed during the 1989-99 period (Table 1, Figure 1). These sites were all re-surveyed as part of more extensive lek surveys commissioned over the 2006-12 period by a range of partners. The Southern Uplands Partnership (SUP) completed lek surveys in the Southern Uplands in 2006 and 2007 (Table 1), with a dedicated project officer initially surveying sites in the Yarrow and Ettrick Valleys. Surveys were expanded during the second phase of the project between 2010 and 2012 to establish numbers and range of black grouse throughout the Southern Uplands (Figure 1). The Lammermuir black grouse group surveyed all suitable habitats in the Lammermuir Hills between 2009 and 2012. Forestry Commission Scotland and RSPB surveyed across the FCS estate, which included their largest holding, the Galloway Forest Park which supports core black grouse populations in Dumfries and Galloway, and smaller forests in the Southern Uplands from 2007 onwards. To assess black grouse distribution in east Ayrshire adjoining the Galloway Forest Park, a one-off survey was commissioned by SNH in 2007 (Zisman *et al.,* 2009). Lek data were also sourced from the Langholm Moor demonstration Project surveyed annually between 2008 and 2012 and from the GWCT which surveyed five 10km grid squares in the Cheviot Hills (NT60, NT70, NT71, NT81 & NT82) in 2011.

Table 1. Years in which black grouse lek surveys were undertaken in the two survey periods 1989-99 and 2006-12 in southern Scotland by partner organisations

	Years lek data collected in the survey periods	
Survey areas (contributing partners)	**1989 – 1999**	**2006 – 2012**
Southern Uplands (GWCT, RSPB, SNH & SUP)	1989 – 1999	2006 - 2007, 2010 - 2012
Lammermuir Hills (GWCT)	1992 – 1998	2009 – 2012
East Ayrshire (GWCT & SNH)	1992 – 1997	2007
Cheviot Hills (GWCT & SNH)		2011
Galloway Forest Park (FCS & RSPB) and all FCS forests in southern Scotland	1992-1993	2007 – 2012
Langholm Moor		2008 – 2012

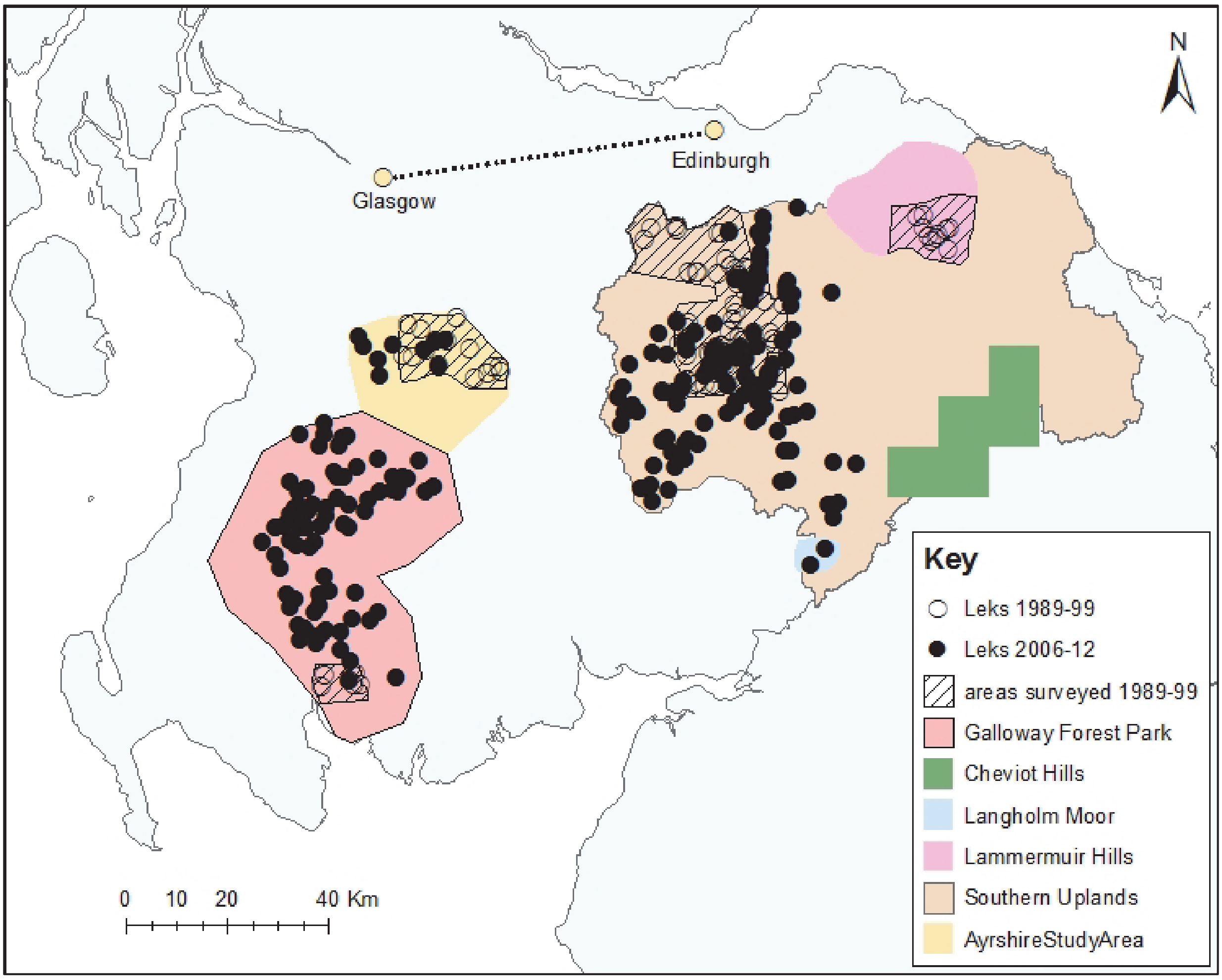

Figure 1. Black grouse leks surveyed between 1989 and 1999 in southern Scotland and the leks and areas surveyed by partner organisations between 2006 and 2012

Count methodology was similar across areas, being undertaken in accordance with the standardised methodology for lek counting (Baines, 1996b; Hancock *et al.,* 1999; Sim *et al.,* 2008). Two visits were made to most potential lekking habitats (moorland, farmland and forest clearings), one in the second half of April and one in the first half of May and observers listened for display calls and visually scanned habitat with binoculars/telescopes. Counts took place between dawn and 07.00 hours and were conducted only in suitable weather conditions. All displaying males were recorded and the count for a site was taken as the maximum number of males observed over the two visits.

2.2.2 Data processing

All lek data were collated in an excel spreadsheet, with each individual lek record entered into a row, described by a six figure Ordnance Survey (OS) grid reference and the maximum count of males observed in each survey year (1989 to 2012) entered in separate columns. Data were checked for duplicates. All lek data were plotted onto a 1:50,000 OS map in the GIS package ArcMap v10.1 (ESRI, 2012). The locations of all grid references were checked to ensure that they had been correctly recorded and entered (i.e. errors in the grid reference which were clearly outside the area it was collected).

2.2.3 Habitat composition around leks and proximity to heather moorland

To describe habitat composition around leks, all lek locations were mapped and a circle of 1km radius drawn around each lek. A 1km radius was selected as within continuous suitable habitat, leks tend to be spaced at 2km intervals. A 1km radius also minimised overlap, with all overlapping circles between neighbouring leks split equally. This encompasses female breeding habitats, with females nesting on average 600m from the local lek (Warren *et al.*, 2012). A comparison of habitat composition within a 1km radius compared to a 1.5km radius in north Perthshire showed no significant difference in habitat composition (White *et al.*, 2013a).

Habitat data for southern Scotland were sourced from the Land Cover Map 2007 (LCM2007) obtained under licence (#60634) from the Centre for Ecology and Hydrology (Morton *et al.,* 2011). This dataset included 23 separate land cover classes, based on the UK's terrestrial Broad Habitats (Jackson, 2000) mapped to a minimum mappable area of 0.5ha. We extracted all habitat classes from within a 1km radius of all leks, with 14, LCM2007 land cover classes present within lek ranges (Table 2). We combined these into eight broad habitat types (Jackson, 2000); (1) Heather moorland, (2) Acid grassland, (3) Farmland, (4) Broad-leaved woodland, (5) Conifer woodland, (6) New woodlands, (7) Felled woodlands, and (8) Other. The 'Other' category included habitats deemed as unsuitable to black grouse, such as freshwater, urban and montane habitats. The broad-leaved and conifer woodland categories of the LCM2007 dataset included sub-categories of 'New woodlands' (less than 10 years old) and 'Felled woodlands'. We extracted these habitats, as new woodlands are attractive to breeding black grouse (Cayford, 1993; Pearce-Higgins *et al*., 2007; White *et al*., 2013b) and felled areas may create suitable open habitats to attract breeding females (Haysom, 2001) and created 'New woodland' and 'Felled woodland' categories.

To assess the distance of leks from heather moorland, we measured the straight-line distance from each lek to the nearest 'heather moorland'.

Table 2. Description of the broad habitat types used in the study and the Land Cover Map 2007 (Morton et al., 2011) habitat classes which they are comprised

Broad habitat type	Land Cover Map 2007 Habitat classes and description of habitat
Heather moorland	(a) **Heather**, vegetation that has >25% heath. Generally occurs on well drained, nutrient poor, acid soils. (b) **Heather grassland**, Vegetation that has >25% heath but spectral differences allow separate classification from Heather sub classes, (c) **Bog**, Vegetation dominated by cotton grass (*Eriophorum* spp.) which occurs on deep peat.
Acid grassland	(a) **Acid grassland,** vegetation dominated by grasses and herbs on a range of lime-deficient soils. (b) **Rough grassland,** Mix of areas of managed, low productivity grassland, plus some areas of semi-natural grassland, which could not be assigned confidently to Neutral, Calcareous or Acid Grassland.
Farmland	(a) **Improved grassland**, Characterised by fast growing grasses, such as *Lolium* spp. and white clover (*Trifolium repens*) on fertile neutral soils. Typically managed or mown regularly for silage. (b) **Arable and horticulture**, Broad habitat includes annual and perennial crops, orchards, horticultural land, leys and fallow.
Broad-leaved woodland	(a) **Broad-leaved woodland**, Characterised by vegetation dominated by trees >5m high when mature, with tree cover >20%. Scrub (<5m) requires cover >30 % for inclusion. It includes stands of both native and non-native broad-leaved trees and yew.
Conifer woodland	(a) **Coniferous woodland**, Characterised by trees >5m high when mature, forming a canopy >20%. Includes semi-natural stands and plantations.
Felled woodlands	Newly felled areas recolonized by rough grass heath or scrub.
New woodlands	The <10 years old new woodlands sub class was extracted from the Broad-leaved and the Coniferous woodland habitat classes
Other	(a) **Freshwater**, Includes standing open water such as lakes, meres and pools and man-made waters such as canals, ponds and reservoirs. Also includes rivers and streams from bank top to bank top or to the extent of the mean annual flood. (b) **Inland rock**, Includes both natural and artificial exposed rock surfaces such as inland cliffs, caves, screes and limestone pavements and quarries (c) **Urban**, Includes built up areas including residential, commercial and industrial. Also domestic gardens and allotments. (d) **Suburban**, Suburban and rural developments including rural settlements, farm buildings and caravan parks. (e) **Montane habitats,** range of vegetation types in the montane zone characterised by prostrate dwarf shrub heath, sedge, rush and moss heaths

2.2.4 Moorland management

Estates employ gamekeepers to provide harvestable surpluses of game birds for shooting (Tapper, 1992). On moorland managed for red grouse shooting, gamekeepers are employed to control generalist predators throughout the year and undertake rotational heather burning to produce harvestable surpluses of red grouse for driven shooting (Hudson & Newborn, 1995). This management contrasts with other moorland estates where gamekeepers are employed to rear and release pheasants on the edges of moorland and the low ground, providing them with supplementary food and protection from generalist predators (Tapper, 1999). It also contrasts with other moorland landholdings where there is no shooting interest and thus no gamekeepers employed. Indices of moorland management were derived from the GWCT's National Gamebag Census, contributed annually up until 2012, and a GWCT Gamekeeper Survey. The latter was originally undertaken in 2000 and updated, for this study area only, to 2012 through discussions with the SUP Black Grouse

Project Officer and the GWCT's South of Scotland Advisor to confirm and update numbers of gamekeepers employed and the estate boundaries. Data were available from 51 sporting estates contributing to the NGC in southern Scotland, 31 of which had contributed long term data (1900-2012). The other 20 were newer contributors, providing data since the 1960s. This dataset included annual gamebird harvest records, whether driven red grouse shooting was practised, numbers of gamekeepers employed and the boundary of the landownership. Similar data, but without bag records, were available for a further 24 estates from the GWCT survey originally undertaken in 2000 which we updated. These datasets were combined to create a moorland management data layer in ArcMap v10.1 (ESRI, 2012). Any gaps in coverage of grouse moor management were checked by adding the FCS landholding boundaries, and using Google Maps to identify any moorland areas where rotational strip burning of heather (an indicator of grouse moor management) was being undertaken outside of existing known estate boundaries. No further estates were identified.

To investigate effects of moorland management at each lek, we used NGC records and the GWCT gamekeeper survey for the 2006 to 2012 period, to create estate specific indices of moorland management which were placed into three moorland management categories; (1) No predator control; (2) Intermediate - gamekeepers employed, but primarily for low ground shooting of released game; and (3) High - gamekeepers employed to produce red grouse for driven shooting for the period 2006-12. Of the 75 estates, 19 employed gamekeepers to produce red grouse for driven shooting. A further 41 estates employed gamekeepers, but primarily for low ground shooting of released game.

2.3 Occupancy of moorland patches

Recent studies in Scotland (White *et al*., 2013a) and northern England (Warren *et al*., 2011) found black grouse leks to be closely associated with both heather moorland and acid grassland habitats. To assess which factors influence whether a lek is found within a moorland patch, we first defined moorland patches as contiguous areas of heather moorland and acid grassland (Table 2). We created a moorland patch layer in ArcMap v10.1 (ESRI, 2012) using the 'Aggregate polygons' function and we combined all heather moorland and acid grassland patches that were next to each other and set a minimum area of 40ha as smaller than this is insufficient to support black grouse lekking groups.

To assess which factors were associated with the occupancy of moorland patches by black grouse, we used area-based surveys, where all areas of suitable habitat as well as known lek sites were surveyed (Sim *et al*., 2008). We restricted these analyses to areas where intensive area-based surveys had been undertaken and we were confident that all areas of suitable habitats had been surveyed. This resulted in two regions being identified, (1) the Southern Uplands area (4,324km^2) (Figure 2), surveyed by the SUP, with additional data from the Langholm Moor Demonstration Project, GWCT and the Lammermuirs Black Grouse Group; and (2) the Galloway study area (2,752km^2), comprising the Galloway Forest Park surveyed by FCS and RSPB, and east Ayrshire surveyed by SNH. This resulted in two leks being excluded from the patch size analysis as these were associated with isolated FCS properties and not considered part of a complete area-based survey. Patches that intersected the border with England were excluded as habitat data from the Land Cover Map 2007 were available only for Scotland.

We recorded the size of each patch and its degree of 'isolation', defined by its linear straight-line distance to the nearest other moorland patch. To define the occupancy of moorland patches, we overlaid the lek distribution map and attributed all leks to the nearest moorland patch. The gamekeeper data were collected at the level of the moor and as some moorland patches were overlaid by multiple moors and forests, some which employed gamekeepers and some which did not, the gamekeeper index used at the level of the lek was not applicable. Therefore for each moorland patch we calculated a weighted average gamekeeper density (mean for the period 2006-12) by first measuring the area covered by individual moors and extracting the overall gamekeeper density (gamekeepers/km^2) for the moor in ArcMap v10.1. We then calculated a weighted average gamekeeper density for each moorland patch using the equation ((A1 x B1) + (A2 x B2)) / (B1 + B2) where A = gamekeeper density on an individual moor, and B = the area of the moor within the moorland patch.

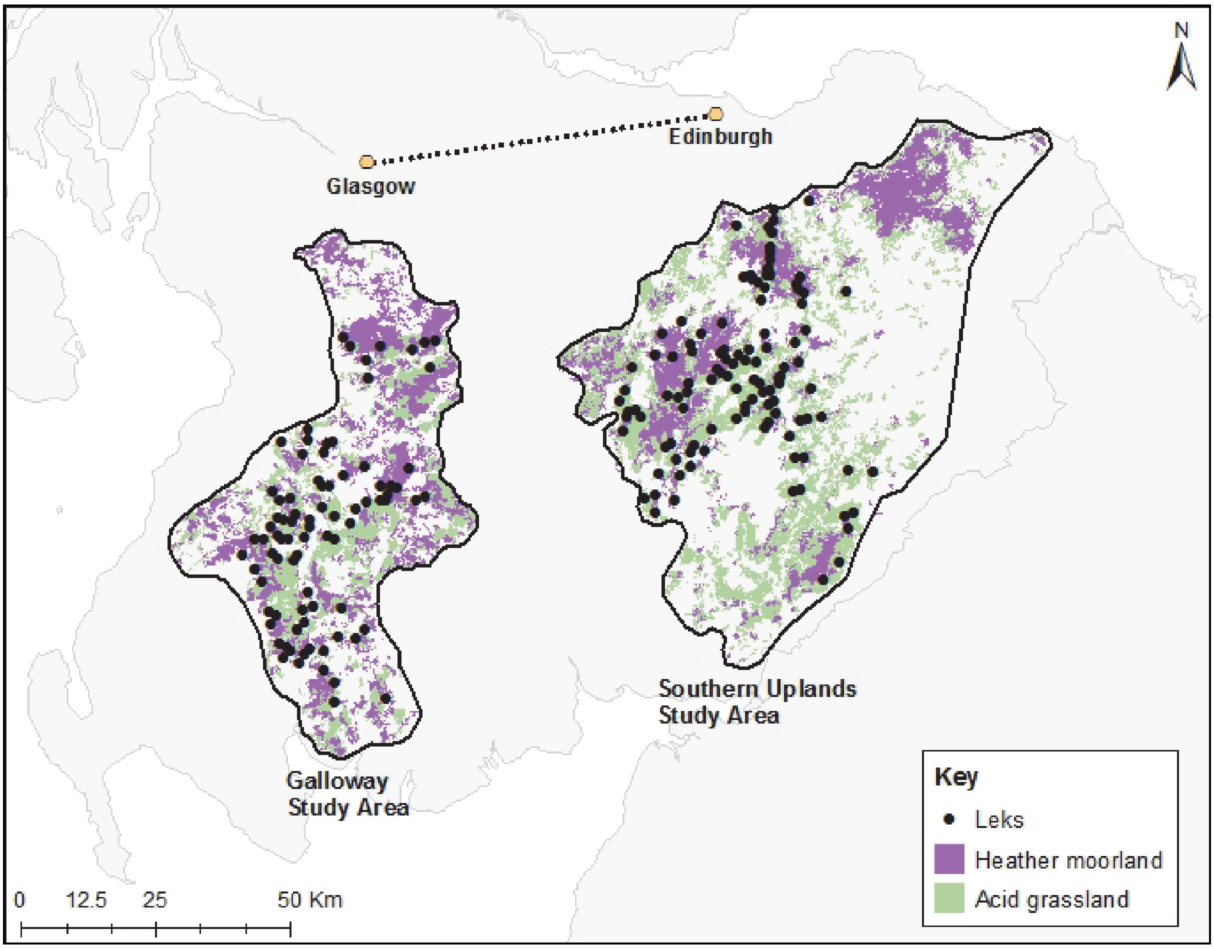

Figure 2. The distribution of leks in the two study areas in southern Scotland in relation to the distribution of heather moorland and acid grassland patches. Habitat data sourced from Land Cover Map 2007 (Licence #60634)

2.4 Statistical analyses

2.4.1 Recent trends

We assessed changes in the numbers of males attending leks in survey areas that were surveyed in both the 1989-99 and 2006-12 periods (Figure 1). Due to variation in the number of years a particular lek was counted we used, as our unit of analysis, the mean count across years for the periods 1989-99, and 2006-12. We calculated the log ratio of change in mean numbers of males at each individual lek between the two periods (y = ln (mean lek size (2006-12) / (mean lek size (1989-99)). We investigated whether the between survey period change was related to region, the proportion of acid grassland, conifer woodland and heather moorland (all arcsin transformed) within lek ranges, and the index of moorland management at the lek (for the 2006-12 period) and all two way interactions (the region*moorland management interaction was not included as no full time gamekeepers employed for red grouse shooting were present at the sample leks in Galloway). We tested using a Generalised Linear Model (GLM) with a normal distribution and an identity link function in Genstat 16 (Payne *et al*., 2009) and used a backwards stepwise procedure. To check that the assumed model was a valid model, we assessed the distribution of the residuals and checked for overdispersion. Inter-correlations occurred between the predictor variables acid grassland, heather moorland and conifer woodland, with negative correlations between acid grassland and conifer woodland (R=-0.66), heather moorland and conifer woodland (R=-0.31), and acid grassland and heather moorland (R=-0.28).

2.4.2 Habitat composition and moorland management within occupied lek ranges

To examine habitat composition within lek ranges (2006–12 period) we used compositional analyses (Aebischer *et al.*, 1993) for the eight habitats described in section 2.2.3. As the proportions when summed equal one, and therefore cannot be considered independent of each other, data were transformed to log-ratios using 'other' as the denominator. We used multivariate analysis of variance (MANOVA) and the Wilk's Lambda statistic to assess differences between habitat components within lek ranges occupied by solitary males and leks, and between the two regions Galloway and the Southern Uplands (categorical variables).

To explore differences in the habitat types in which leks were situated, we used χ^2 contingency tables to assess differences between solitary displaying males and leks, and between regions. To explore the proximity of leks to heather moorland, we tested using a GLM with a poisson error distribution and a log link function. Distance from lek to heather moorland was entered as the dependent variable, with solitary males or leks, and region as the categorical variables and the two-way interaction.

We used a GLM with a poisson error distribution and the log link function and used a backward stepwise procedure to consider whether the mean numbers of males at individual leks were related to region, the proportion of acid grassland, heather moorland and conifer woodland (all arcsin transformed), distance to heather moorland, and the index of moorland management. All two way interactions were included. Inter-correlations occurred between the predictor variables, heather moorland area and distance to moorland (R=-0.65), acid grassland and conifer woodland (R=-0.61), and acid grassland and heather moorland (R=-0.60).

2.4.3 Occupancy of moorland patches

To assess whether heather moorland patch size, the connectivity with other patches and gamekeeper density were related to occupancy by black grouse, we modelled the presence or absence of black grouse associated with patches using logistic regression, with region as a categorical explanatory variable, size of patch (log transformed), distance to neighbouring patch (log transformed) and gamekeeper density as continuous explanatory variables. Size of patch was negatively correlated with distance to neighbouring patch (R=-0.58).

We used a GLM with a poisson error distribution and the log link function to assess whether the density of males within the occupied moorland patches was influenced by patch size (log transformed), distance to neighbouring patch (log transformed) and gamekeeper density.

3. RESULTS

3.1 Long term trends

Within the period 1900-2012, black grouse were shot on all 31 moors providing data. The numbers shot peaked in 1910 with an average 2.2 birds shot per km^2 of moorland. They subsequently declined and from 1980 to 2002 only an average 0.01 birds per km^2 were shot, with only one bird reported shot since 2002 (Figure 3).

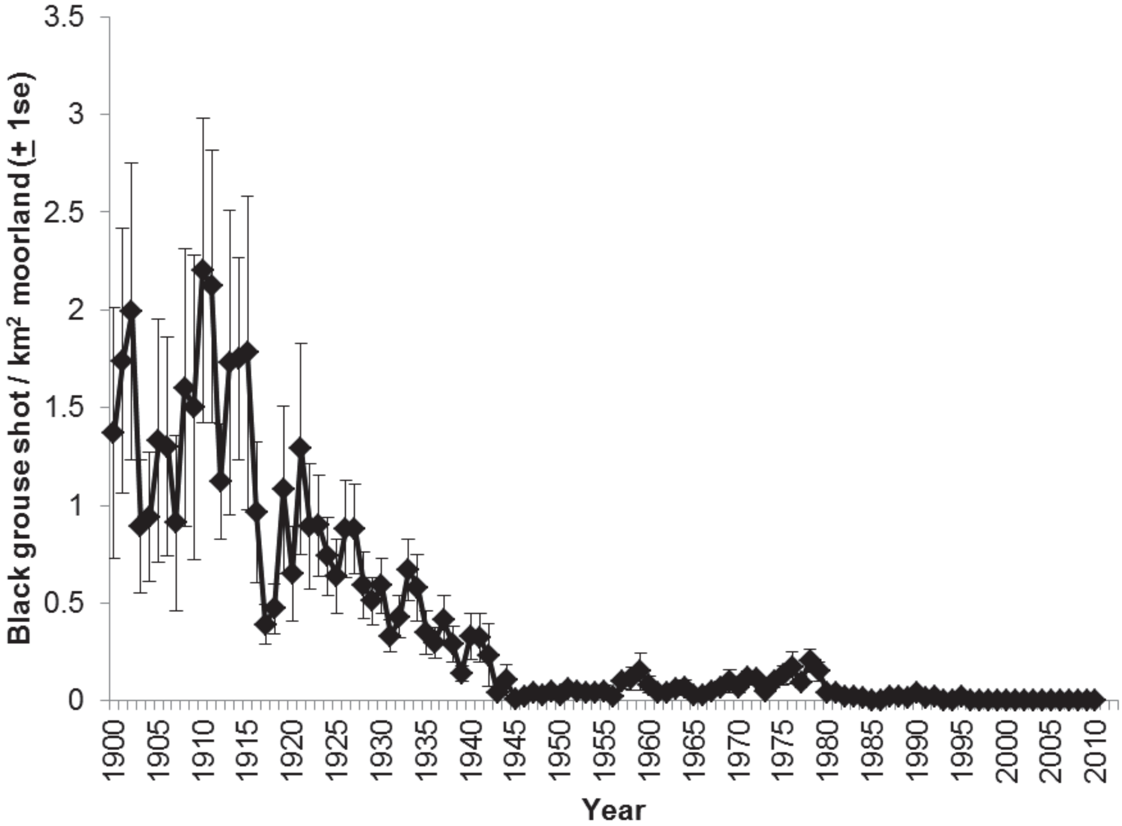

Figure 3. Long-term trend in the density of black grouse shot on 31 moors in southern Scotland between 1900 and 2012

The density of red grouse shot peaked in 1912, with 41 grouse shot per km^2 of moorland (Figure 4). Limited shooting occurred during the First and Second World Wars. Following the Second World War, the density of birds shot increased to 13 shot per km^2 in 1953 and then stabilised between the 1960s and 1990s before declining. By 2012, red grouse were no longer shot on 42% of the 31 moors.

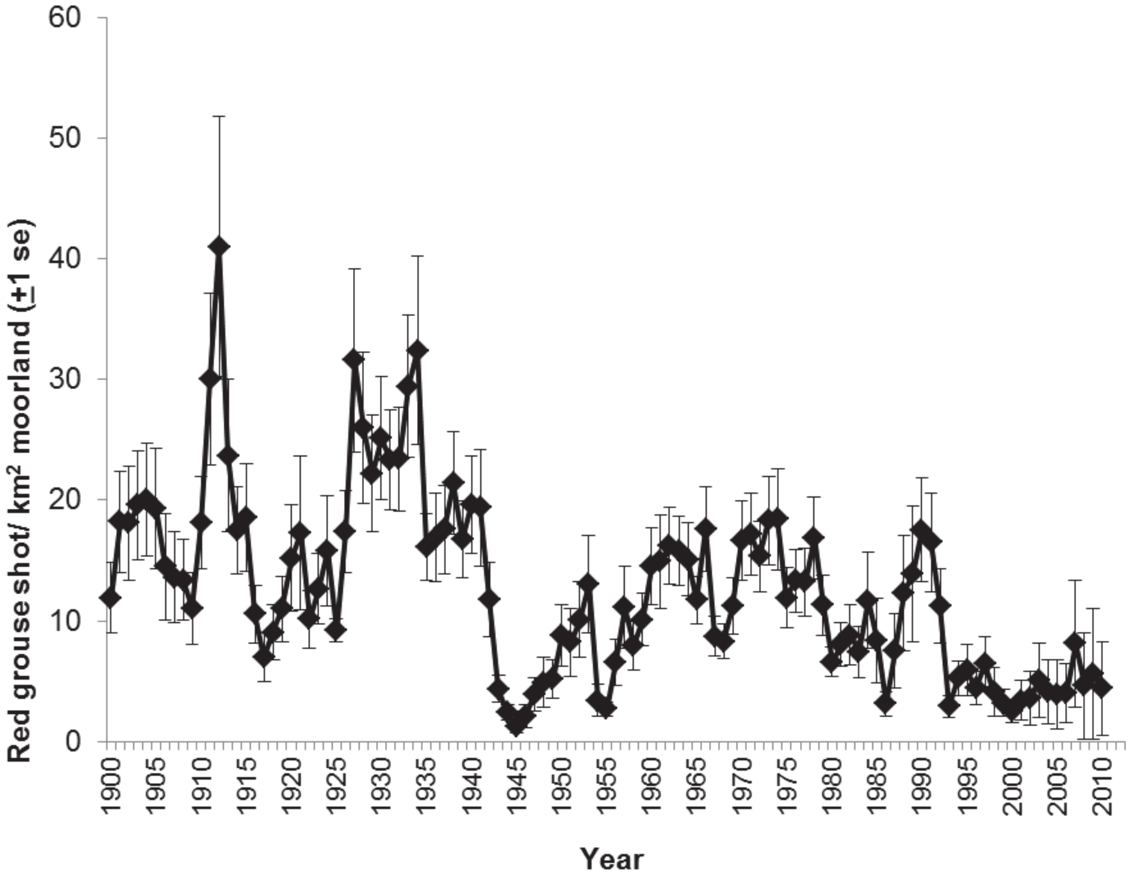

Figure 4. Long-term trend in the density of red grouse shot on 31 moors in southern Scotland between 1900 and 2012

3.2 Recent trends

The number of males attending leks in the study areas surveyed in both the 1989-99 and 2006-12 periods declined by 64% from 410 to 147 males (Table 3). No males were recorded during the repeat surveys in the Lammermuir Hills. The index of population change at leks between the two periods was positively associated with the proportion of acid grassland ($F_{1,120}$=38.95, p<0.001, slope=0.03$\pm$0.02se) (Table 4, Figure 5).

Table 3. Total numbers of males attending leks at survey sites in 1989–1999 compared with 2006–2012

	Total number of males at leks (number of leks)			
Area	**1989–99**		**2006–12**	
Lammermuir Hills	42	(10)	0	(0)
Southern Uplands	298	(76)	133	(41)
East Ayrshire	53	(13)	12	(4)
Galloway	17	(5)	2	(1)
Total	**410**	**(104)**	**147**	**(46)**

Table 4. Results from the GLM using a backward stepwise procedure testing for the effects of region, proportion of acid grassland, heather moorland and conifer woodland and moorland management on changes in numbers of males at leks between the 1989-99 and 2006-12 survey periods

(a) All terms	df	*F*-ratio	*p*
Region	1	1.70	0.196
Conifer woodland	1	0.30	0.586
Heather moorland	1	1.50	0.223
Acid grassland	1	7.53	0.007
Moorland management	2	0.76	0.471
Region*Heather moorland	1	3.58	0.061
Region*Acid grassland	1	1.40	0.239
Region*Conifer woodland	1	0.16	0.692
Moorland management*Heather moorland	2	0.17	0.845
Moorland management*Acid grassland	2	1.22	0.299
Moorland management*Conifer woodland	2	0.64	0.531
Error	106		
(b) Final model			
Acid grassland	1	38.95	<0.001
Error	120		

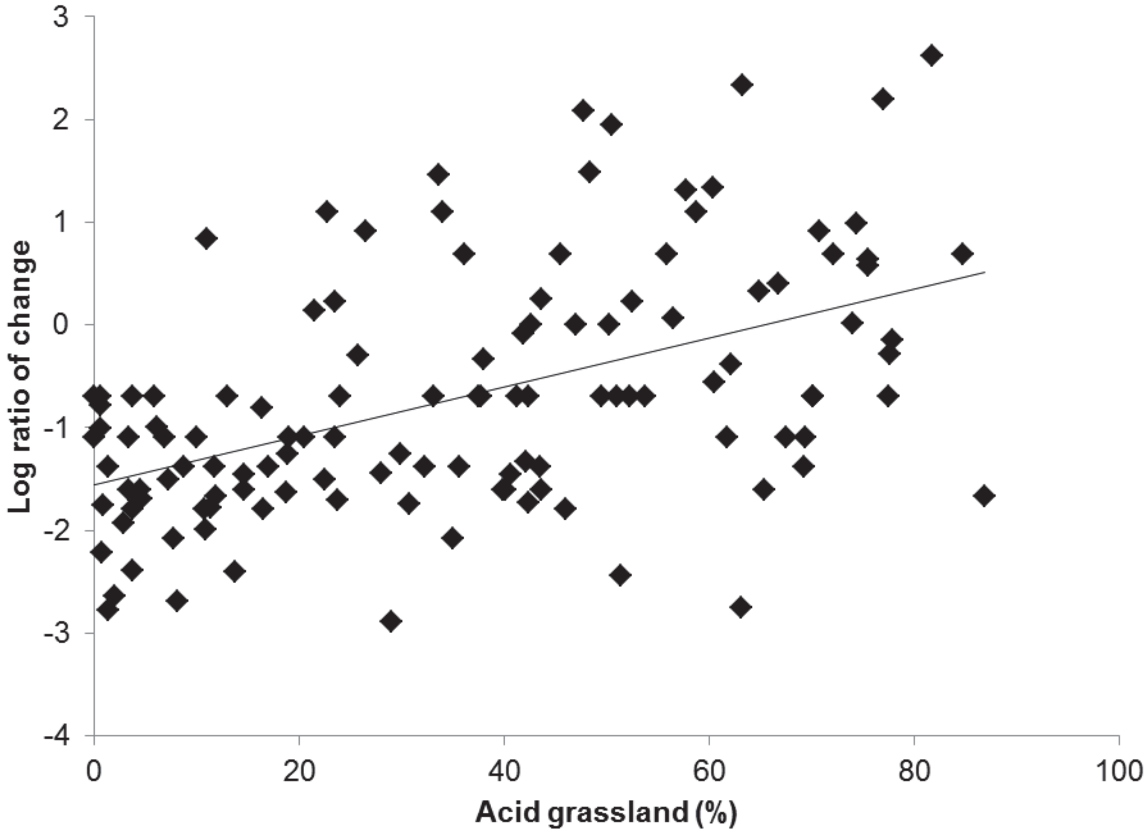

Figure 5. The log ratio of change in the numbers of males at leks between 1989–99 and 2006–12 in relation to percentage of acid grassland within lek ranges

3.3 Habitat composition within lek ranges

Black grouse lek data were available from 197 lek locations from the 2006-12 period in the two regions (Galloway and the Southern Uplands) of which 67 were solitary displaying males and 130 occupied by two or more males. There was no evidence that habitat composition around leks was different between sites occupied by solitary males or those by two or more males (Wilk's $Lambda_{8,188}$=0.97, p=0.74), thus we combined. Habitat composition differed between region (Wilk's $Lambda_{8,188}$=0.23, p<0.001). Lek ranges in the Southern Uplands were dominated by acid grassland which comprised 55% of all habitats, but only 29% in Galloway (Table 5), and was present within all and 99% of lek ranges respectively (Table 6). There was no evidence that the proportion of heather moorland within lek ranges was different between regions and was present within all lek ranges. Farmland was four-fold more prevalent within lek ranges in the Southern Uplands (8%, compared with 2% in Galloway). In contrast, lek ranges in Galloway were more afforested, with three-fold more woodland cover (32%, compared with 12% in the Southern Uplands). The type of woodland cover differed between region, with conifer over four-fold more prevalent in Galloway (27%, compared with 6% in the Southern Uplands), and present in 92% of all lek ranges. In contrast, the Southern Uplands had three-fold more broad-leaved woodland cover (3%, compared with 1% in Galloway). No recently planted woodlands were located within lek ranges in Galloway in comparison with the Southern Uplands, where they were present within 77% of lek ranges, although on average, this habitat accounted for less than 3% of the total lek range.

Table 5. Habitat composition within a 1km radius of leks in Galloway and the Southern Uplands in Scotland

	Percentage habitat composition within a 1km radius of leks ($\pm$1se)			
	Southern Uplands (112 leks)	**Galloway (85 leks)**	**Regional differences in % cover**	
Habitat			$F_{1,195}$	p
Heather moorland	22.4 $\pm$ 1.9	32.6 $\pm$ 2.5	0.02	0.883
Acid grassland	55.2 $\pm$ 2.1	29.1 $\pm$ 2.6	19.36	<0.001
Farmland	8.1 $\pm$ 1.0	2.1 $\pm$ 0.6	39.42	<0.001
Broad-leaved woodland	3.2 $\pm$ 0.4	0.9 $\pm$ 0.2	18.09	<0.001
Conifer woodland	5.9 $\pm$ 1.0	27.4 $\pm$ 2.5	42.36	<0.001
Felled woodland	0.2 $\pm$ 0.1	3.5 $\pm$ 0.8	11.18	0.001
New woodland	3.0 $\pm$ 0.4	0 $\pm$ 0.0	90.55	<0.001
Other	2.0 $\pm$ 0.6	4.3 $\pm$ 1.0	3.67	0.057

Table 6. Presence (%) of habitat types within a 1km radius of leks in Galloway and the Southern Uplands where habitat composition at leks was assessed

Habitat	**Southern Uplands (112 leks)**	**Galloway (85 leks)**
Heather moorland	100	100
Acid grassland	100	99
Farmland	84	41
Broad-leaved woodland	88	40
Conifer woodland	63	92
Felled woodland	16	56
New woodland	77	0
Other	41	48

The leks themselves were situated in six of the eight habitats. They were not situated in broad-leaved or new woodlands. There was no evidence of differences in dominant habitat type at the lek between solitary males and leks (χ^2_5=4.21, p=0.38) therefore we combined them. The habitat type at leks varied between region (χ^2_5=27.6, p<0.001). In the Southern Uplands, 70% of leks were found on acid grassland compared with 43% in Galloway (Table 7).

Table 7. The percentage of habitat types in which leks are situated in the Southern Uplands and Galloway

Habitat	Percentage of leks in Southern Uplands (112 leks)	Percentage of leks Galloway (85 leks)
Heather moorland	20	39
Acid grassland	70	43
Farmland	6	0
Conifer woodland	2	9
Felled woodland	0	5
Other	2	4

There was no evidence that the distance between leks and heather moorland was different for leks attended by solitary displaying males and those by two or more males (χ^2_1=0.39, p=0.53) or between region (χ^2_1=3.09, p=0.08) and with no region*lek interaction (χ^2_1=1.25, p=0.29). Leks were located a median 110m from heather moorland (Figure 6).

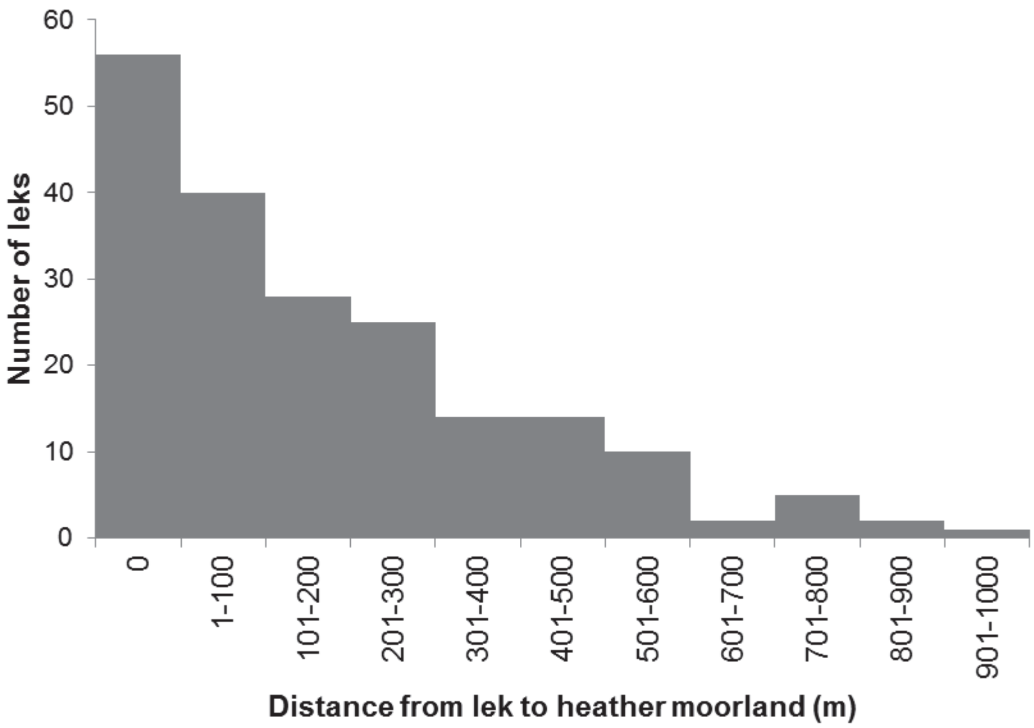

Figure 6. Frequency histogram of distances of leks from heather moorland in southern Scotland (197 leks)

3.4 Number of males at individual leks in relation to habitat composition and moorland management

We estimated the overall population size from the total number of males attending leks averaged over the 2006–12 period as 538 males, 187 in Galloway and 351 in the Southern Uplands. There was no evidence that the numbers of males attending leks was different between regions ($F_{1,192}$=1.15, p=0.28), we thus combined them. The mean lek size was 2.8$\pm$0.2se (range 1–19) (Figure 7). The numbers of males at leks were positively associated with the proportion of heather moorland ($F_{1,191}$=11.21, $p<0.001$), acid grassland ($F_{1,191}$=6.97, p=0.008), the distance to moorland ($F_{1,191}$=10.07, $p=0.002$) and with the index of moorland management ($F_{2,191}$=29.32, p<0.001) (Table 8). Numbers of males at leks were two-fold greater where gamekeepers were employed to provide driven red grouse shooting compared with leks with no predator control or where low ground gamekeepers operated (Figure 8).

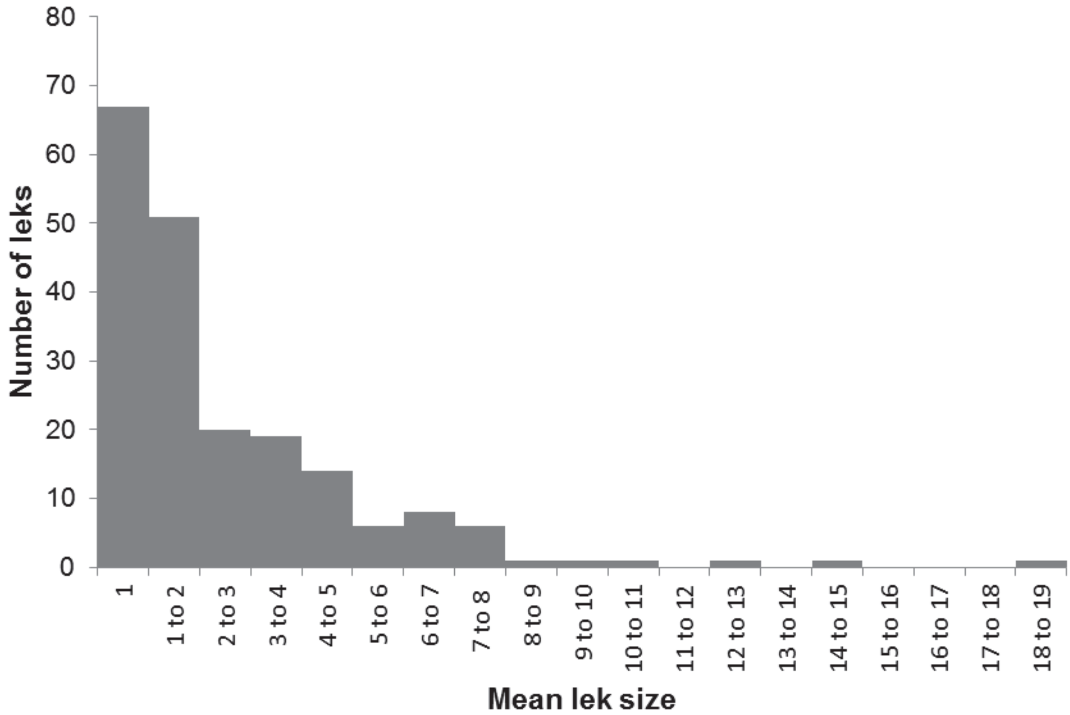

Figure 7. Frequency histogram of mean lek size (197 leks) in southern Scotland (2006-12)

Table 8. Results from the GLM using a backward stepwise procedure testing for the effects of region, proportion of acid grassland, heather moorland, conifer woodland, distance to moorland and moorland management on numbers of males at leks

(a) All terms	df	*F-ratio*	*p*
Region	1	0.10	0.757
Conifer woodland	1	0.26	0.609
Heather moorland	1	6.22	0.013
Acid grassland	1	6.03	0.014
Moorland management	2	24.08	<0.001
Distance to moorland	1	10.12	0.001
Region*Heather moorland	1	3.46	0.063
Region*Acid grassland	1	0.00	0.959
Region*Conifer woodland	1	0.01	0.914
Region*Distance to moorland	1	6.19	0.013
Moorland management*Heather moorland	2	1.12	0.325
Moorland management*Acid grassland	2	2.01	0.135
Moorland management*Conifer woodland	2	0.75	0.473
Moorland management*Distance to moorland	2	0.24	0.787
Error	178		
(b) Final model			
Acid grassland	1	6.97	0.008
Distance to moorland	1	10.07	0.002
Heather moorland	1	11.21	<0.001
Moorland management	2	29.32	<0.001
Error	191		

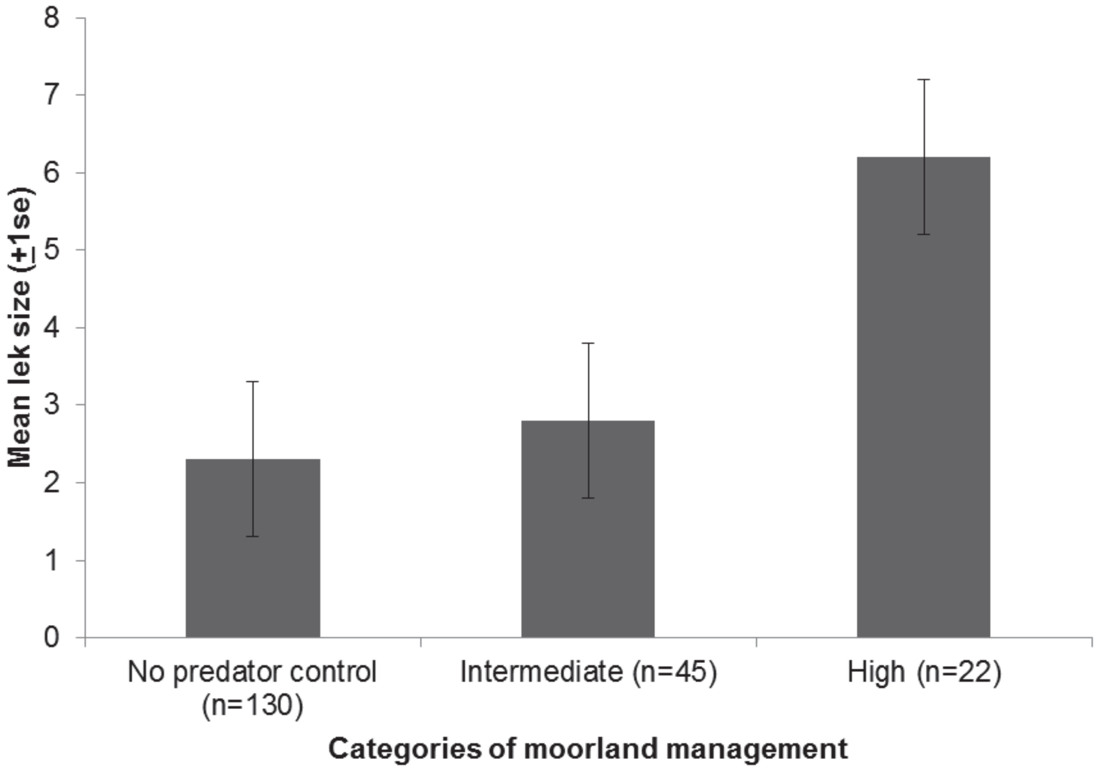

Figure 8. Mean lek sizes in southern Scotland in relation to the moorland management index (n=number of leks)

3.5 Occupancy of moorland patches

We identified 309 moorland patches within the study areas, of which 27 were occupied and 282 were not. We found 83% of leks and 90% of males to be associated with six moorland patches (Table 9 & Figure 9) with 62% of males associated with the Moorfoot Hills and Tweedsmuir moorland patches.

Table 9. The six key moorland patches identified in southern Scotland, the area of patches and the associated numbers of males and leks

	Area (km^2)	**Total males**	**Density of males ($males/km^2$)**	**Total leks**	**Density of leks ($leks/km^2$)**
Tweedsmuir Hills	1042	224	0.21	81	0.08
Moorfoot Hills	189	112	0.59	23	0.12
Galloway West	189	57	0.30	23	0.12
Galloway North	72	35	0.49	13	0.18
East Ayrshire	186	28	0.15	9	0.05
Galloway East	385	25	0.06	14	0.04

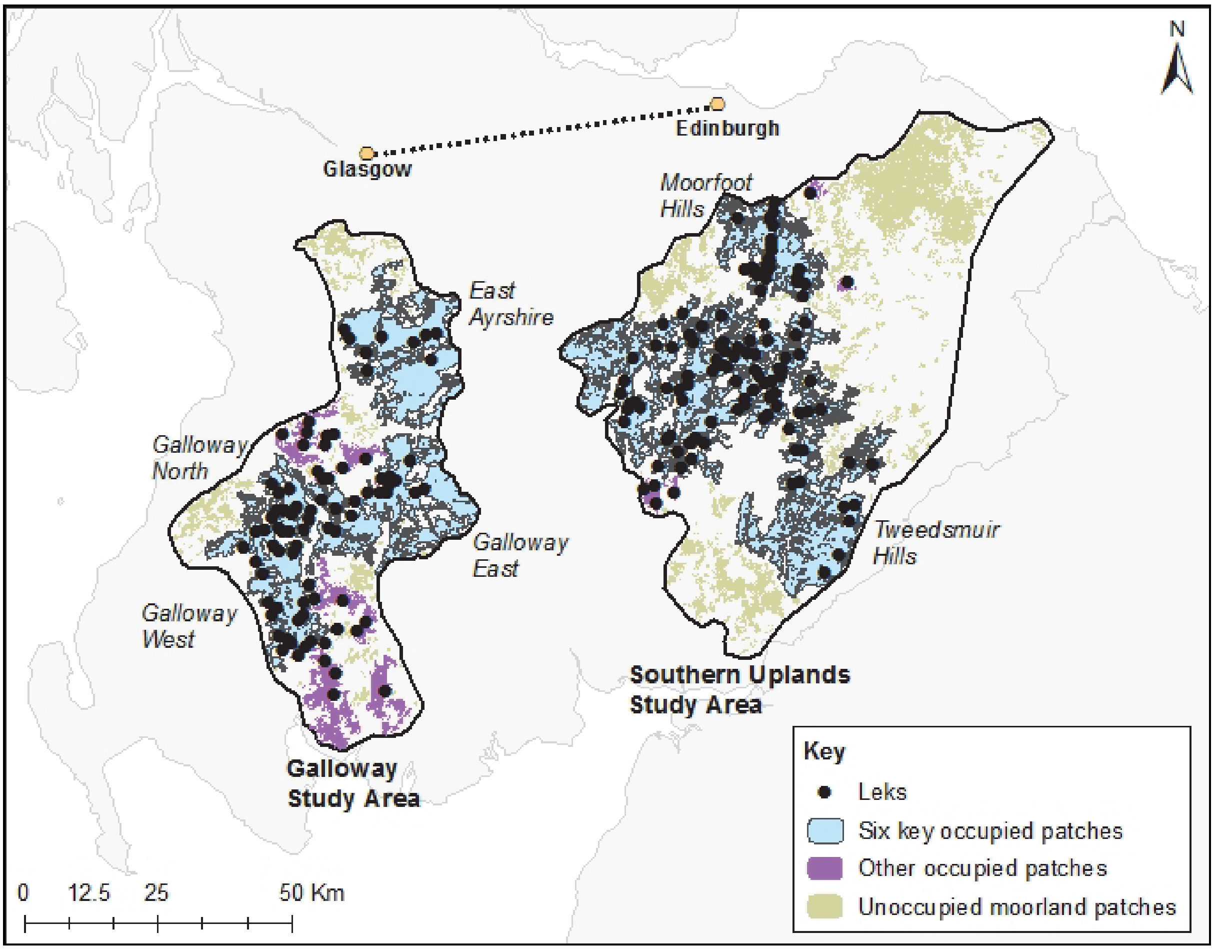

Figure 9. The distribution of moorland patches occupied by black grouse in southern Scotland

The occupation of moorland patches was affected by patch size (χ^2_1=51.44, *p*<0.001) and distance to nearest patch (χ^2_1=15.04, *p*<0.001), but not gamekeeper density (χ^2_1=0.05, *p*=0.83). The mean of the occupied moorland patches was 86.8km^2 (range 0.5-1041.7km^2) and were 25 times larger than the unoccupied moorland patches (Table 10). Overall, 70% of moorland patches larger than 50km^2 were occupied, in contrast to only 5% of patches less than 10km^2 (Figure 10). Only one large moorland patch larger than 100km^2 was unoccupied (the Lammermuir Hills).

Table 10. The occupancy of moorland patches in the study area in relation to patch size, distance to nearest patch and gamekeeper density

	Patch occupancy	
	Present (27 patches) Mean ± 1se	**Absent (282 patches)**
Patch size (km^2)	86.8 ± 40.5	3.4 ± 1.2
Distance to nearest patch (m)	91 ± 22	254 ± 19
Gamekeeper density (gamekeepers/ km^2)	0.007 ± 0.003	0.004 ± 0.002

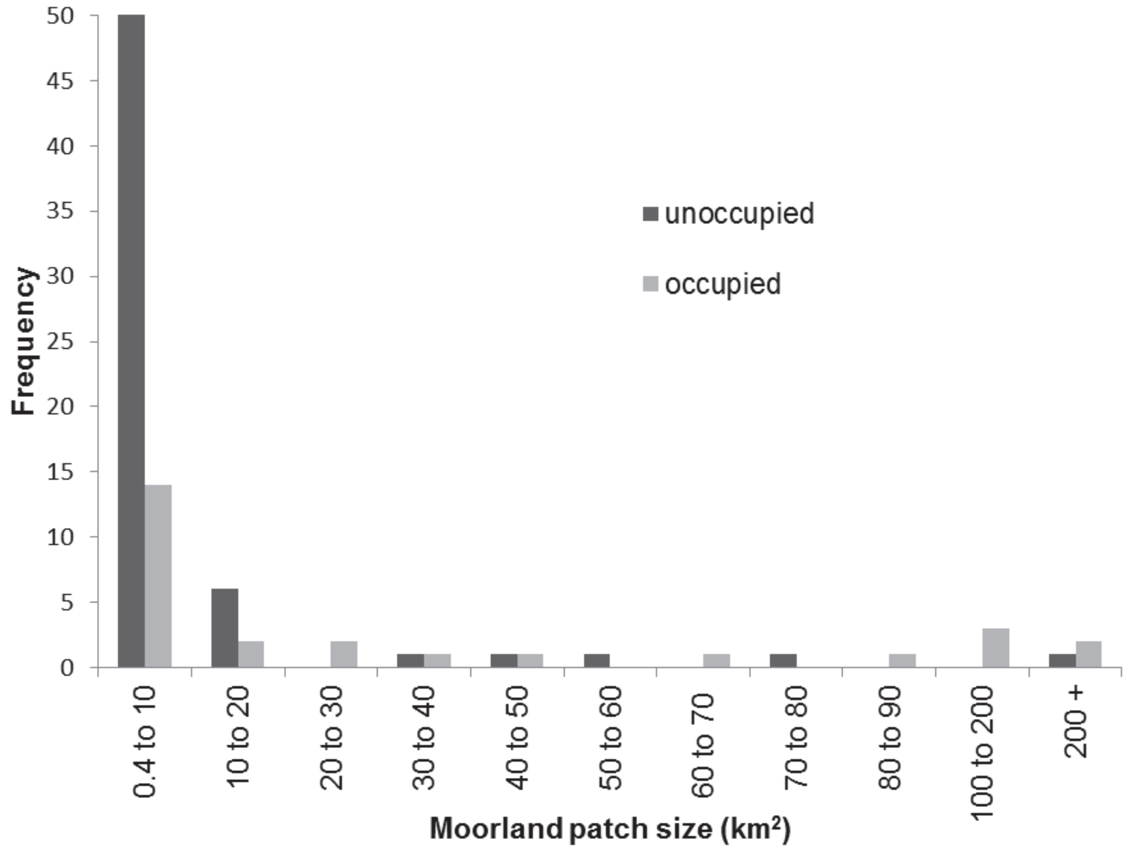

Figure 10. Frequency histogram of occupied (27) and unoccupied (282) moorland patches in southern Scotland (note: 271 unoccupied patches were in the 0.4-10km^2 category).

The densities of black grouse associated with a moorland patch were negatively associated with patch size ($F_{1,23}$=13.67, *p=0.001*, slope=-0.31$\pm$0.08se) (Figure 11), but not with gamekeeper density ($F_{1,23}$=1.91, *p*=0.18) nor distance to nearest moorland ($F_{1,23}$=0.65, *p*=0.44).

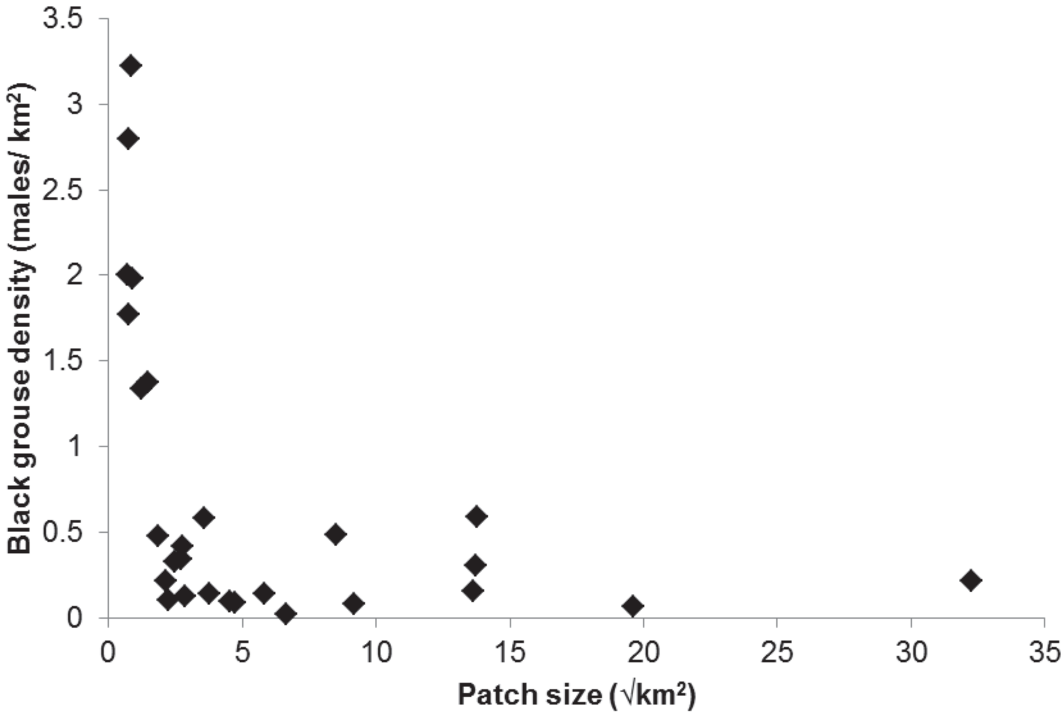

Figure 11. Density of males associated with occupied moorland patches in southern Scotland

4. DISCUSSION

It is evident from shooting bags, national lek-based surveys (Sim *et al.,* 2008) and the lek data collected in the 1989-99 and 2006-12 periods that black grouse in southern Scotland are in long term decline. Further reductions in numbers and range contraction are also likely. Recent more extensive lek survey effort in the 2006 to 2012 period have covered all areas of suitable habitats illustrating that no subtle changes in distribution have occurred. In light of the declines observed in southern Scotland, an additional conservation concern is the recent severe decline observed in the neighbouring north-west Northumberland upland area in northern England. This can be considered part of the same 'southern Scotland' meta-population and black grouse there have collapsed from 100 males in 2002 to zero in spring 2013. Habitats are similar (Warren *et al.,* 2011), with the predator management infrastructure similarly fragmented by other land uses such as commercial forestry and military training. This decline is in contrast to the larger, North Pennines and Yorkshire Dales meta-population in northern England where the majority (95%) of remaining birds are associated with grouse moors (Warren & Baines, 2004) which form a continuous moorland patch and predator management umbrella. Here, numbers are stable with evidence of range expansion on the southern fringe of their range (Warren & Baines 2008, Warren *et al*., 2011). In southern Scotland, shooting bag records illustrate that red grouse bags have also declined, with 42% of 31 moors now no longer shooting red grouse. In the past 100 years there have been significant land use changes in southern Scotland with heather moorland lost and fragmented due to a combination of factors which include overgrazing by sheep, increases in commercial afforestation (Mason, 2007) and declines in grouse moor management.

Heather moorland was a component of all lek ranges in this study, corresponding to similar findings from the north Perthshire, Argyll and Inverness regions of Scotland (White *et al.,* 2013b) and from northern England (Warren *et al.,* 2011). Similarly, acid grassland was found at 99% of all leks comprising 55% of habitats within lek ranges in the Southern Uplands and 29% in Galloway. Changes in numbers of males at leks between 1989-99 and 2006-12 illustrated a positive association with acid grassland cover. The proportion of acid grassland cover was negatively correlated with conifer woodland cover and weakly correlated with heather moorland cover. Thus, observed declines may be attributed to the loss of suitable acid grassland habitats through either conversion to conifer forestry and its subsequent maturation (Pearce-Higgins *et al*., 2007) or through agricultural improvements such as increased sheep grazing or restoration to heather moorland (Calladine *et al*., 2002).

Through combining heather moorland and acid grassland habitats to create moorland patches we found that occupied moorland patches were 25 times larger than the un-occupied patches, with 90% of black grouse associated with six moorland patches greater than 72km^2. Two patches, the Moorfoot Hills and the Tweedsmuir Hills, supported 62% of all males. Only 5% of moorland patches less than 10km^2 were occupied, in direct contrast to patches larger than 50km^2 where 70% were occupied. Only one large heather moorland patch greater than 100km^2 in the study was unoccupied and this was the 322km^2, the Lammermuir Hills. The density of black grouse males in occupied patches was negatively associated with patch size, which is unsurprising as the larger moorland patches are predominantly areas of heather dominated moorland on the higher ground surrounded by acid grassland habitats. Black grouse require some heather moorland, but they favour the transitional zone between moorland and acid grassland which are located around the fringe.

The Lammermuir Hills have only recently lost black grouse in the past 10 years, with sporadic records of females still reported. This is despite the area having high gamekeeper densities and a programme of moorland fringe habitat improvements undertaken. The connectivity with the neighbouring Moorfoot Hills moorland patch has become fragmented, with the maximum distance now 7km to the nearest lek, which is within the dispersal range of female black grouse (mean 9.3km) (Warren & Baines, 2002). Recent surveys have seen local population recovery in the Moorfoot Hills, and therefore natural re-colonisation may occur. Any future conservation programme needs to consider the feasibility of re-colonising the Lammermuir Hills, through restoring acid and rough grasslands on the fringes of grouse moors in the Lammermuirs and the intervening corridor, instigating habitat improvements, and through the consideration of a male translocation project if females are being regularly seen (McEwen *et al.,* 2009).

We found that the number of males attending leks doubled where gamekeepers were employed and driven red grouse shooting practised on the heather moorland. Similarly, in northern England, some 95% of remaining black grouse were associated with grouse moor management (Warren *et al*., 2011). Combined with growing evidence that populations of ground nesting birds, including black grouse, are more likely to be limited by predation than other groups (Gibbons *et al*., 2007; Fletcher *et al*., 2010) this means that any future conservation programme in southern Scotland needs to incorporate the existing predator control infrastructure and secure resources for additional predator control, as any habitat improvements may have more ‘net’ conservation gain in areas where gamekeepers are already employed in relation to areas where there are none operating. Predator management in isolation may not prevent further declines without the provision and maintenance of suitable habitats (Baines, 1996c).

The second phase of this project will be to develop a landscape-scale conservation plan for southern Scotland. A black grouse conservation programme in this area needs to initially target the remaining large, heather moorland habitat patches that retain leks and their adjacent acid grassland dominated habitats to ensure that they are adequately protected from any future significant changes in land use. Many of the larger heather moorland patches, such as the Tweedsmuir Hills, Moorfoot Hills, Muirkirk Uplands, Merrick Fells and Langholm and Newcastleton Hills are already designated by statutory designations such as Sites of Special Scientific Interest (SSSIs) and therefore attract subsidies to maintain and improve habitats. In contrast, the surrounding habitats, typified by acid grassland and marginal hill farming utilised by black grouse, are not designated due to their considered ‘low’ environmental value. Similarly, due to their relatively low economic value as low grade agricultural land these habitats are more likely to be subject to change of use to commercial forestry, and/or the intensification of agriculture often driven by European agricultural policy. The economic value of heather moorland for red grouse shooting (Sotherton *et al*., 2009) means that the larger moorland areas where driven grouse shooting is practicable have considerable economic value and therefore have additional protection from other competing land uses such as forestry and farming. Smaller heather moorland patches, which are not large enough to produce driven grouse and are not protected by statutory designations, may be more likely to be subject to future land use change.

Future Scottish forest policy intends to increase woodland cover from 18% to 25% by 2050 (Woodland Expansion Advisory Group, 2012). The Galloway study area already has 30% conifer forest cover and the Southern Uplands 18% cover, both of which are higher than the area of heather moorland cover in either study area, at 27% and 17% respectively. It is unlikely that intensive farmland and high altitude areas are to be afforested in the future with marginal, middle altitude upland areas, such as acid grassland and small remnant areas of heather moorland more likely to be disproportionately affected by the implementation of this afforestation policy. It is therefore likely that increasing forest cover will further encroach onto black grouse habitats in southern Scotland. With the average black grouse population in this study estimated at only 538 males, it is important that a strategic plan to conserve black grouse in southern Scotland is developed and implemented immediately.

A landscape-scale black grouse conservation plan is required for southern Scotland to ensure that the needs of black grouse are considered in future forest design plans, other development pressures such as wind farms and the targeting of future agri-environment schemes. Currently, black grouse needs appear to be only considered at the site scale, with little consideration for landscape-scale conservation which is critical to retain connected black grouse populations through dispersal between groups (Caizergues & Ellison, 2002; Warren & Baines, 2002) and to facilitate genetic exchange (Höglund *et al*., 2011). A conservation plan would identify core areas and dispersal corridors, which would enable future new woodlands, agri-environment schemes and wind farm developments to be evaluated accordingly. It is clear that black grouse require open heather moorland areas, but there is significant scope to create both beneficial woodlands to provide winter food for black grouse (Warren *et al*., 2013) and establish new sympathetically designed commercial woodlands as long as appropriately targeted in relation to occupied areas and habitat corridors. Forest design plans and new wind farm developments potentially offer opportunities to extend occupied moorland patches and to create open moorland links with other moorland patches.

5. CONCLUSION

Black grouse in southern Scotland are in long term decline and further reductions in numbers and range contraction are predicted. To effectively conserve black grouse in this region, a landscape-scale approach is required. In the short term, resources need to be targeted at the large moorland patches that support birds with conservation measures initially instigated to stem further decline. Once the decline has been stemmed, then effort can be instigated to increase range.

The proposed second phase of this project is to develop a framework to effectively target applied black grouse conservation measures throughout southern Scotland. This project would identify core populations for management based on moorland patch size and predator management and would create a strategic plan to be agreed and adopted by all stakeholders.

The second phase of the project would:

(a) Define core management areas to protect remaining populations
(b) Identify key moorland fringe areas to target agri-environment scheme resources
(c) Identify key habitat corridors and potential stepping stones to provide dispersal routes to neighbouring populations

Sufficient data exist on the extent and connectivity of black grouse populations in southern Scotland, and resources should be targeted to create a strategic plan that outlines key conservation objectives. This would provide an important conservation blueprint to protect key areas for black grouse, particularly as the pressure increases from other land uses on moorland habitats, such as for forestry, agriculture and wind farm developments.

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