Changes in the abundance of some ground-nesting birds on moorland in South West Scotland

Research Report to Scottish Land & Estates and Scottish Gamekeepers Association

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Executive summary

When bird surveys conducted in the 1980s were repeated across 13 upland regions of the UK some 20 years later, they showed some clear declines in several species of ground-nesting birds. A combination of factors appears responsible for these declines, including loss and fragmentation of heather moorland through afforestation, and intensified farming and associated increases in numbers of some generalist predators. Management of moors for red grouse *Lagopus lagopus scotica* can help retain heather moorland. Accordingly, grouse moors may form relatively stable habitats, where traditional rotational burning and sympathetic grazing, together with control of predators, can help conserve numbers of some upland birds.

Such changes in moorland birds are likely to have occurred in South West Scotland, and are considered here. National and regional bird datasets have been compiled from a range of sources, which this study reviews. We consider national (Scotland) bird trends and compare them with those in South West Scotland, (defined as Ayrshire, Dumfriesshire, Kirkcudbrightshire, Lanarkshire, Renfrewshire, Wigtownshire), and also with trends from two more intensively researched case studies in the region.

Analysis of annual red grouse National Gamebag Census records showed that the biggest changes in bag densities in South West Scotland occurred post-1950. Although by the end of the last century this region retained marginally higher densities of red grouse shot than North West and North East Scotland, the number of participating moors was much lower. Analysis of NGC bag data for black grouse *Lyrurus tetrix* from 1890 to 1990 showed that South West Scotland had steeper declines in numbers shot than other Scottish regions. More recently, data for 1980 and 2016 showed a 100% decline from 28 birds shot down to zero by 2012, which probably reflects a voluntary moratorium on shooting as well as a population decline. Mean numbers of displaying or lekking male black grouse were consistently lower in the West of Scotland than in other regions of Scotland during the period 1989-1993. Subsequent national surveys found a 29% decline in the Scottish population between 1995-96 and 2005, with the more recent survey estimating that 24% of the Scottish population remained in South West Scotland. At two study areas within the South West region, numbers of birds attending leks declined by 80% during an approximate 15-year period from the early 1990s onwards, while a wider study across southern Scotland found two-fold more lekking males where gamekeepers were employed to provide driven grouse shooting.

Repeated national surveys of breeding hen harriers *Circus cyaneus* between 1988 and 2016 have seen fluctuating population estimates, but declines in Scotland as a whole of 20% and 9% reported from the two most recent surveys in 2004-10 and 2010-16. Similarly, Scottish Raptor Monitoring Scheme data for 2003 to 2015 has seen a decline in the number of known occupied territories across Scotland. Within South West Scotland there has been no such trend, but here increases in the Langholm - Newcastleton Hills SPA contrasted with a collective decline at the Glen App - Galloway Moors and Muirkirk & North Lowther Uplands SPAs. This pattern is also reflected in breeding success, with Langholm supporting levels of breeding success more than twice as high as those at either Muirkirk or Glen App. Trends in merlin *Falco columbarius* are less apparent, partly due to smaller sample sizes in some years and regions. Although national surveys suggest an overall stable population, SRMS data from 2003 – 2015 indicate a Scotland-wide decline in known occupied territories, but no detectable trends in breeding success.

In the first case study area of Muirkirk & North Lowther Uplands SPA, repeat surveys of both red and black grouse between 1992 and 2017 showed significant declines in abundance and

breeding success, which were associated with declines in levels of moorland keepering. For breeding waders, Breeding Bird Survey data showed significant Scottish declines for oystercatcher *Haemotopus ostralegus*, golden plover *Pluvialis apricaria*, lapwing *Vanellus vanellus* and curlew *Numenius arquata* between 1995-2015. Upland bird surveys from the early 1980s onwards in the area of the now SPA have consistently reported significant declines in breeding waders, whether those nesting on moorland or on adjacent farmland, with the most recent survey in 2015 citing declines of 84%, 88% and 61% for golden plover, lapwing and curlew respectively and an apparent disappearance of redshank from one farmland study area. Thus waders and harriers declined in parallel with those of red grouse once levels of moorland management by gamekeepers had been reduced.

The second case study focused on Langholm Moor within the Langholm - Newcastleton Hills SPA. This site has, since 1992, hosted two major studies aimed to help resolve raptor-grouse conflicts. During two periods when the moor was managed by gamekeepers for red grouse, and generalist predators were routinely controlled, red grouse and harrier breeding success was two-three-fold higher than during the intervening period when the moor was not managed and generalist predator (foxes and carrion crows) indices of abundance were higher. Whilst numbers of curlew, golden plover and lapwing all showed significant declines when generalist predators were not managed, the resumption of predator control by gamekeepers during the Langholm Moor Demonstration Project in 2008 did not halt this trend. This was unexpected and may highlight the importance of the scale at which management is implemented, reflecting the fact that Langholm is now an isolated moor, with no full-time grouse keepers on any of the surrounding estates.

The declines in moorland birds in South West Scotland reported in this study closely mirror those seen elsewhere in the UK. These declines may be attributed to changes in land-use, including afforestation and agricultural intensification or abandonment, as well as a decline in the extent of grouse moor management. The impact of the latter is clearly illustrated in both case studies, in which significant declines in the suite of ground-nesting moorland birds happened in tandem with evident declines in levels of keepering, which at Langholm for waders was not halted by the restoration of predator control and heather habitat management.

The findings in this report demonstrate that existing funding schemes for managing moorland birds at an appropriate scale are clearly not working. Urgent implementation of measures, which include both habitat management and predator control at an appropriate scale and intensity are needed to prevent further declines, and possible local or regional extinctions, of ground-nesting moorland bird species.

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1. Introduction

Some 20 years on from bird surveys originally conducted in the 1980s, repeated surveys on the same sites across 13 upland regions of the UK have shown some clear declines in several ground-nesting species (Sim *et al.* 2005), mirroring the more precipitous declines already described for the lowlands (Smith 1983, Wilson *et al.* 2005).

Several factors appear responsible for these declines including loss and fragmentation of heather moorland through afforestation, and intensified farming and associated increases in numbers of generalist predators (Douglas *et al.* 2013). Management of moors for red grouse *Lagopus lagopus scotica* can help retain heather moorland (Robertson *et al.* 2001). Accordingly, grouse moors may form relatively stable habitats where traditional rotational burning and sympathetic grazing, together with control of predators, have been practised for more than a century (Robertson *et al.* 2017). These traditional managements can help conserve numbers of some upland birds. Tharme *et al.* (2001) found densities of breeding golden plover *Pluvialis apricaria* and lapwing *Vanellus vanellus* were five times higher and those of red grouse and curlew *Numenius arquata* twice as high on grouse moors as on other moors. Similarly, Fletcher *et al.* (2010) found densities of curlew, golden plover and lapwing three to five times higher on grouse moors than on equivalent moors not managed for grouse. Fletcher et al. (2010) also experimentally demonstrated better breeding success amongst waders, at levels consistent with stable or expanding populations, when predators were routinely controlled by gamekeepers; and poor levels of breeding success associated with declining populations when predators on the same sites were not controlled.

An analysis of upland bird data for parts of the Berwyn Special Protection Area (SPA) in North Wales showed a local extinction of lapwing, 90% loss of golden plover and a 79% reduction in curlew between 1983-5 and 2002 (Warren & Baines 2014). Such declines were associated with a cessation in driven red grouse shooting, which in turn was linked with increases in carrion crow *Corvus corone* and ravens *Corvus corax*, whilst some raptors including buzzards *Buteo buteo* also increased. Quantifying and then highlighting these precipitous declines of key species on such internationally important sites for bird and habitat conservation has attracted considerable recent attention from both Welsh and UK Governments. European and UK funding for practical moorland restoration works have been made available for key sites in North and mid-Wales, including Berwyn, whilst the Berwyn study itself was used as an example of what could happen to wildlife in the absence of a grouse interest in a much publicised parliamentary debate in 2016 over the future of driven grouse shooting.

Changes in moorland birds already seen in Wales are likely to be mirrored in South West Scotland, where some of the greatest Scottish declines are likely to have occurred (Sim *et al.* 2005; Balmer *et al.* 2013). Several national and regional datasets exist, which this study reviews to help Scottish Government and associated statutory conservation bodies focus on the plight of key moorland species. By raising awareness of declining birds and possible impacting mechanisms, we aim to encourage adoption of mitigating conservation actions through collective funding schemes.

2. Objectives

The study aimed to describe and quantify changes in numbers of ground-nesting moorland birds, in particular breeding waders, in South West Scotland over the last 40 years and compare these rates to those in Scotland as a whole. We aimed to address what happens to moorland birds of conservation interest when the intensity of grouse moor management is either reduced or stopped altogether. The study included consideration of national (Scottish) and regional (South West Scotland) trends, and compared them with trends from two more detailed case studies in the region.

3. Methods

The study largely relied on the compilation and analysis of existing data sources and hence was essentially a desk-based review. However, some new field data were collected in spring and summer 2017 to complement existing data from one of the case studies, within the Muirkirk and North Lowther Uplands SPA. Unless otherwise stated, the geographical extent of this study is South West Scotland (Fig. 1), defined as Ayrshire, Dumfriesshire, Kirkcudbrightshire, Lanarkshire, Renfrewshire, Wigtownshire.

Bird species included in this study, data availability permitting, are: red grouse, black grouse *Lyrurus tetrix*, oystercatcher *Haematopus ostralegus*, golden plover, lapwing, dunlin *Calidris alpina*, snipe *Gallinago gallinago*, curlew, redshank *Tringa totanus*, common sandpiper *Actitis hypoluecos*, hen harrier *Circus cyaneus*, merlin *Falco columbarius* and carrion crow.

3.1 Desk-based collation and review of national and regional datasets

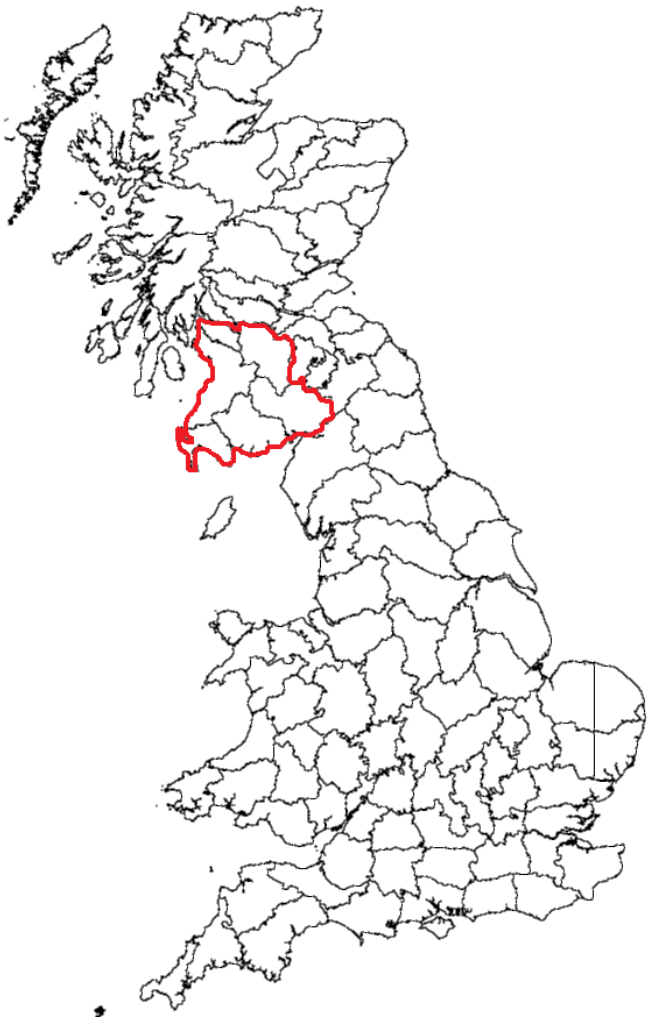
A desk-based study gathered existing moorland bird and mammal data from both published and unpublished sources from within GWCT's own databases and those available from other organizations.

3.1.1. National trends in breeding bird populations

Long term changes in population size – the Breeding Bird Survey (BBS)

The Breeding Bird Survey is run by the British Trust for Ornithology (BTO) and is a UK-wide volunteer participation line-transect survey based on 1-km grid squares. Squares are chosen through stratified random sampling, with more squares in areas with more potential volunteers. BBS volunteers make two early-morning visits to their square during the April-June survey period, recording all birds encountered whilst walking two 1-km transects across their square. In interpreting the data, BTO correct counts by excluding non-breeding flocks. The BBS provides reliable population trends for a large proportion of UK breeding species. Where sufficient data exist (any given species has to be recorded in a minimum of 30 squares), trends have also been produced just for Scotland; insufficient data exist to allow trends to be calculated for regions within Scotland. To calculate trends, BTO take the higher count from the two visits for each species. Only squares that have been surveyed in at least two years are included in the analyses. Population changes are estimated using a log-linear model with Poisson error terms. Counts are modelled as a function of year and site effects, weighted to account for differences in sampling densities across the UK / Scotland, with standard errors adjusted for over-dispersion. Changes in bird abundances for Scotland between 1995 (when the BBS started) and 2015 were available from the most recent BBS annual report (Harris *et al.* 2017) for red grouse, oystercatcher, golden plover, lapwing, curlew, common sandpiper, snipe and carrion crow.

Figure 1: Boundary of South West Scotland study area (unless otherwise stated)



Long-term changes in breeding bird distribution and abundance - Bird Atlas 1968-2011

The BTO's Bird Atlas 2007-11 (Balmer *et al.* 2013) reports on the results of a four-year survey of the distribution and relative abundance of all bird species breeding in the UK. Two complementary field methods were used, one providing systematic data for assessing relative abundance and change ('Timed Tetrad Visits'), and the other for collecting basic distribution records ('Roving Records'). For the Timed Tetrad Visits, the Atlas survey aimed to collect data from at least eight tetrads in every 10-km square in Britain and Ireland during the period of the survey. Surveyors were asked to make two visits to each tetrad, spending 1-2 hours during each visit and to walk around that tetrad recording every species seen and heard, noting any evidence of breeding. Roving Records aimed to capture all kinds of distribution records, with anyone being able to submit any records of birds seen, contributing to the Atlas aim of having species lists that are as complete as possible for every 10-km square in Britain and Ireland.

The resulting maps produced in the Atlas show relative abundance for all species throughout Britain and Ireland, and also show changes in distribution since the previous two Atlases in 1968-72 (Sharrock 1976) and 1988-91 (Gibbons *et al.* 1993). The published results in the Atlas are descriptive only, and therefore changes described here are similarly not quantitative. Findings are described for both South West Scotland and Scotland as a whole for all species being considered in this study.

3.1.2 Shooting bag records – National Game-bag Census (NGC)

The National Gamebag Census (NGC) is a voluntary scheme, coordinated by the Game & Wildlife Conservation Trust (GWCT), which collates game-bag statistics from over 800 estates, throughout the UK, using postal questionnaires (Tapper 1992). Questionnaires record number of quarry species shot, number of gamekeepers employed and, in the uplands, total area of heather moorland and total area of forest cover per land holding.

Red grouse

Annual bag records were available from 272 estates, across nine British regions, managed for red grouse from 1860. Robertson *et al.* (2017) used these data to examine long-terms trends from 1860 to 2010. Indices of annual change in number of grouse shot were calculated from 1860-2010 and percentage change was considered during four discrete 30-year periods; 1890-1920, 1920-1950, 1950-1980 and 1980-2010. The nine British regions were assigned using definitions within the NGC (Tapper 1992) and previous analyses (Barnes 1987), but within Scotland were modified from two to four regions: North East (NE), North West (NW), South East (SE) and South West (SW). For details of the data analysis see Robertson *et al.* (2017).

Black grouse

Baines & Hudson (1995) sourced evidence of the long-term black grouse decline from a collation of shooting bag data for the period 1890-1989. This included data from 161 moors in Scotland, of which 13 moors were in the South West. Data were split into four periods: pre-1914, 1918-39, 1948-75 and 1976-89. The mean number of black grouse shot per moor each 5-year interval between 1890 and 1990 was expressed as a proportion of the mean number shot per moor in the first 5 years (1890-94).

Warren *et al.* (2014) extracted long-term (1900 – 2012) trends in numbers of black grouse shot from NGC data from 31 moors across Southern Scotland (from Glasgow/Edinburgh central belt to English border). Due to an incomplete data series, and therefore the number of sample moors varying between years, they expressed annual bags as the mean number of birds shot per km^2 of heather moorland.

For the present study, we revisited NGC data and updated information on numbers of black grouse shot for the period 1980 to 2016 just for South West Scotland (NGC regions 10.2 and 10.3, 19 estates in total).

3.1.3 Black grouse – displaying males

National surveys

To complement their analyses of long-term bag data, Baines & Hudson (1995) conducted counts of males attending their display grounds or leks in 47 10-km grid squares in Scotland and Northern England between 1989 and 1993. Survey squares were chosen for their proximity to observers. Counts made at the same leks each year provided short-term indications of current population trends. Numbers of displaying males were converted into densities by measuring the amount of ground in each square that occurred within preferred altitudinal bands. Further details of methods are given in Robinson *et al.* (1993).

The first full UK survey was conducted in 1995-96 (Hancock *et al.* 1999), repeated in 2005 (Sim et al. 2008), with coverage extended in both of those surveys to include the remaining black grouse range in England and Scotland. The 2005 survey method followed that used in 1995-96, with coverage in Scotland based on 5-km grid squares within the species' range. This range was defined as all 10-km squares with records of black grouse since 1968, using the 1968-72 and 1988-91 Breeding Bird Atlases (Sharrock 1976, Gibbons *et al.* 1993), the 1981-84 Winter Bird Atlas (Lack 1987), and the Royal Society for Protection of Birds (RSPB) database of black grouse records, including data from the 1995-96 survey. In Scotland, considerable survey coverage was achieved from volunteers in Black Grouse Study Groups, site managers and recovery project staff, who surveyed specified 5-km squares as part of existing work programmes. These 'core' squares were likely to hold good numbers of black grouse and be regularly monitored. The remaining squares from within the defined range were then divided into two strata. Stratum one contained all squares known to be occupied by black grouse since 1988, while stratum two contained all squares known to be occupied during 1968-87, but in which the species had since not been recorded. In Scotland, 80 core, 100 out of 1414 randomly selected stratum one and 13 out of 542 randomly selected stratum two, sample 5-km squares were surveyed. Of these, 109 (36 in North, 23 in North East, 38 in South West and 12 in South East Scotland) were surveyed in both 1995-6 and 2005. Their definition of South West Scotland included Stirlingshire, West Perthshire, the southern part of Argyll, Dunbartonshire, Clyde Isles, Kintyre and South Ebudes. Within the area of South West Scotland as defined in this study, there were seven core, 15 stratum one and two stratum two sample squares.

Fieldwork methods in 2005 were as in 1995-96 (Hancock *et al.* 1999). Fieldwork was carried out between late-March and mid-May. Surveyors were instructed to arrive at vantage points one hour before dawn and count all male black grouse (whether displaying or not) every 15 minutes, for one hour either side of dawn. Counts were not carried out in poor weather (e.g. persistent heavy rain or snow, low cloud, fog) and were usually made from vantage points to avoid disturbance. In rare instances with no vantage point, birds had to be flushed to make accurate counts. Display sites were marked onto 1:25 000 Ordnance Survey (OS) maps and number of both males and females recorded, together with date, time, and the six-figure grid reference.

For calculation of population estimates and trends the maximum count was used where a display site was counted more than once, maintaining consistency with the 1995-96 survey (Hancock *et al.* 1999). Any non-simultaneous counts of leks or solo-displaying males that were within 200 m or 500 m of each other were treated as repeat counts of the same males. Details of the statistical treatment of data to produce population estimates are given in Sim *et al.* (2008).

Repeat surveys in Southern Scotland

Warren *et al.* (2014) explored temporal changes in numbers of displaying male black grouse from a sample of sites across Southern Scotland surveyed between 1989-99 and 2006-12. From that study, we extracted the data from those sites within South West Scotland, namely Muirkirk, Garpel and Douglas, and Cairnsmore of Fleet, for which lek counts (including single birds) were provided, but no information on size of each survey area. At Muirkirk, Garpel and Douglas, initial GWCT surveys were undertaken in 1992-97, and repeated in 2007 by SNH (Zisman *et al.* 2009). Cairnsmore of Fleet was first surveyed by GWCT in 1992 & 93, and surveyed again by Forestry Commission Scotland in 2011 & 12. Count methodology was similar across areas, being undertaken in accordance with the standardized methodology for lek counting (Baines 1996; Hancock *et al.*, 1999; Sim *et al.* 2008). Two visits were made to favored habitats for leks (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. Warren *et al.* (2014) also assessed the number of males recorded at 197 leks throughout Southern Scotland during 2006-12 in relation to habitat composition and moorland management.

3.1.4 Hen harrier and merlin

National surveys

Hen harrier: Methods for the most recent survey in 2016 are, as yet, unpublished, but the 2010 survey followed very closely the design of previous surveys. Survey coverage in Scotland was of a three tier design. Overall, 135 10-km squares from the species' occupied range were selected non-randomly by Scottish Raptor Study Group members, and the remaining 446 squares were allocated to one of two strata. Stratum one comprised 104 10-km squares located in areas expected to hold relatively high densities of hen harriers, of which 45 were randomly selected for survey. Stratum two consisted of the remaining 342 squares within the known range, of which 40 were selected. Regional population estimates and trends in Scotland were calculated for each of five regions: Hebrides, North Highlands, Southern Uplands, East Highlands and West Highlands.

Merlin: The breeding status of the Scottish merlin population has been assessed three times, each time as part of a UK-wide survey. The first survey was in 1983-84 (Bibby & Natrass 1986), the second in 1993-94 (Rebecca & Bainbridge 1998) and the most recent in 2008 (Ewing *et al.* 2011). These surveys comprised two elements of sampling, including complete coverage of selected 10-km squares where there is existing knowledge of breeding merlin, complemented by a random selection of 10-km squares covering their remaining breeding range. This approach was adopted in Scotland for the 2008 survey, with full coverage of 139 10-km squares (of which nine were in South West Scotland) by existing raptor surveyors, and a further 46 randomly selected squares (of which five were in South West Scotland) covered by RSPB staff and volunteers.

Scottish Raptor Monitoring Scheme (SRMS)

The Scottish Raptor Monitoring Scheme was established in 2002 to improve partnership working between organisations (Scottish Raptor Study Group (SRSG), BTO, RSPB Scotland, Scottish Natural Heritage (SNH), Joint Nature Conservation Committee (JNCC), Rare Breeding Birds

Panel (RBBP), Scottish Ornithologists' Club (SOC) and Forestry Commission Scotland (FCS)) involved in raptor monitoring in Scotland. The SRMS currently focuses primarily on the annual monitoring of the abundance, distribution and breeding success of diurnal birds of prey and owls native to Scotland. The annual reports provide no detail of survey methods used, other than reporting that surveyors are encouraged to follow best practice as set out in Hardey *et al.* (2013). Survey coverage is not complete, therefore it is not possible to use these data to comment on absolute population size. Instead, demographic trends are based on a sample of the total population, with the size and representativeness of that sample varying between species and between survey areas.

Data for hen harrier and merlin were extracted from SRMS Annual Reports for Scotland, and for South West Scotland (comprising the two regions of Dumfries & Galloway and South Strathclyde) for the period 2003-2015. A data request was also submitted to the SRMS for any data they hold on number of pairs, and associated productivity, for hen harrier and merlin within the three SPAs within South West Scotland of which these two species are classified features (Muirkirk and North Lowther Uplands SPA, Langholm - Newcastleton Hills SPA and Glen App - Galloway Moors SPA). These data were requested at a tetrad or 5-km square resolution for all years (from 2003) for which data are available.

Changes in the number of territories occupied by breeding hen harriers and merlin in each year during the period 2003-15 were in turn analysed by linear regression with pairs as the response variable and year as a co-variate. Trends over time for each species were compared between returns for Scotland as a whole, those within the South West region and, where data allowed, those within each of the three SPAs. Breeding success for each species was also compared at the same three levels, national, regional and within region at the individual SPA level. Analyses for fledglings per pair and brood size were conducted by Poisson regression with a log link within generalized linear models, with chicks fledged as the response variable for both, but with $\log_e$ pairs as the offset for the former and $\log_e$ successful pairs for the latter. The percentage of pairs that successfully bred rearing one or more chicks was analysed by binomial regression with a logit link, the number of successful pairs as the response variable and the number of breeding pairs as the denominator. Analyses were adjusted for over-dispersion.

3.1.5 Other datasets

South West Scotland Environmental Information Centre (SWEIC)

A data request was submitted to South West Environmental Information Centre, asking for any upland bird surveys, particularly repeat surveys, that they may hold for the period of this study. SWEIC confirmed that their data holdings were predominantly from Wigtownshire, Kirkcudbrightshire and Dumfriesshire, as they have only just started to include Ayrshire in their area of interest and their records were very limited, and that they didn't hold any information on Lanarkshire or Renfrewshire. They also confirmed that most of the information stemmed from casual recording (from county bird records, and was only available for some years from 2006 onwards). The only upland survey data they had was a one-off survey in parts of Dumfries and Galloway as part of their Biodiversity Audit, but with no comparable data from visits in subsequent years, so it was not possible to extract any trend information.

Mountain hare data

Numbers of mountain hares *Lepus timidus* shot were extracted from the NGC database for South West Scotland (UK bag regions 10.2 and 10.3) for the period 1980 to 2016. Changes in the distribution of mountain hares throughout Scotland between 1995-96 and 2006-07 were assessed by two questionnaire surveys conducted by Tapper (1996) and Patton *et al.* (2010), respectively, and we extracted data from these surveys for South West Scotland. Between-year variation in bag data showed no significant positive or negative trend, other than showing two peaks in density (in the late 1980s and around 2005), which may accord with abundance cycles observed in 45% of mountain hare populations that were sampled from across the species' N European range (Newey *et al.* 2007). Examining data from the two questionnaire surveys (Tapper 1996, Patton *et al.* 2010) found there to be insufficient coverage of South West Scotland during both survey periods to comment on distribution change. Therefore, these mountain hare datasets were not considered further in this study.

4. Results

4.1 Red grouse

4.1.1. National surveys – BBS and Atlas

BBS data showed no significant change in numbers of red grouse. In Scotland between 1995 and 2015 (Harris *et al.* 2017). However, although red grouse remained widespread through much of Scotland, there have been significant losses between the two Atlas periods of 1968-72 and 2007-11 in East, South and West Scotland, particularly along the moorland edge (Balmer *et al.* 2013). In South West Scotland, the Atlas distribution change maps indicated greater declines in distribution during the first Atlas interval of 1968-72 to 1988-91, than during the second interval between 1988-91 to 2007-11.

4.1.2 Shooting bag records - NGC

The analysis of NGC bag data conducted by Robertson *et al.* (2017) showed that, with the exception of South East Scotland, bags were highest throughout Scotland in the earliest time period of 1890 – 1920, and have declined in each of the following three time periods thereafter in all three other regions (Table 1). Within South West Scotland, the biggest declines between time periods occurred post-1950, with a 34% reduction between the second and third time periods of the study (1920-1950 and 1950-1980), and a 42% reduction between the time periods of 1950-1980 and 1980-2010. Although by 1980-2010, this region still retained marginally higher densities of red grouse shot than North West and North East Scotland, the number of participating moors was by far the lowest, indicating that grouse shooting has probably ceased on more moors in the South-West than in any other Scottish region.

4.2 Black grouse

4.2.1 National surveys – BBS and Atlas

A BBS trend in Scotland could not be calculated for black grouse due to an insufficient number of survey squares in which the species was recorded (Harris *et al.* 2017), but there was adequate survey coverage to allow for the species' inclusion within all three Atlases. In 1968-72 black grouse were widespread through large parts of Scotland (Sharrock 1976). Occupied range in Southern Scotland was contiguous with birds in the Scottish Highlands and with those in Northern England. By 1988-91 separation from birds to the north and fragmentation with those to the south was evident (Gibbons *et al.* 1993). However, range in Southern Scotland has since contracted by 48% by 2007-11 (Warren *et al.* 2014, 2015). This has now resulted in black grouse in Southern Scotland becoming isolated from birds to the north and to the south, with an estimated 34 km gap between the nearest meta-populations. This isolation has been confirmed genetically (Hoglund *et al.* 2011).

4.2.2 Shooting bag records - NGC

When bag data from 97 moors across Scotland and Northern England with 100 year runs of bag records between 1890 and 1989 were considered, the number of black grouse shot declined by

93 ± 2% se, from almost 2300 birds per annum, before the First World War, to 130 per annum (Baines and Hudson 1995). The greatest rates of decline across this geographical range were in the period 1918-1938, although since then declines have largely continued through the species' Scottish range (Table 2). Before the First World War, the largest regional bag was a mean of 5.5 birds shot per km^2 in South West Scotland. This was more than three times greater than the regions with the next highest mean, West and East Scotland where, on average, 1.5 birds per km^2 were shot (Baines and Hudson 1995). Accordingly, South West Scotland has seen bigger rates of decline than in the rest of Scotland between 1918 and 1990 (Table 2).

Updating NGC data for South West Scotland (UK bag regions 10.2 and 10.3) showed a 100% decline from 28 birds shot to zero between 1980 and 2016, with just two birds shot since 2002 (one in 2007 and one in 2011).

4.2.3 Displaying males

In the period 1989–1993, Baines and Hudson (1995) found that the mean number of displaying males per 10-km grid square differed five-fold between Scottish regions ($F_{5,41} = 3.75$, $P < 0.01$). The greatest numbers were found in eastern regions of Scotland, and varied from a mean of 30 males per 10-km grid square in North East Scotland (0.30 males km^{-2}) to 72 males in E Scotland (0.72 males km^{-2}). Numbers were consistently lower in the West, with only 14 to 15 males per 10 km grid square (0.14 males km^{-2}). Annual counts of displaying males over the five-year period of survey showed declines in four of the regions between each year within that survey period, but insufficient data were available from sites in West Scotland to allow their inclusion in that analysis.

The next national survey in 1995-96 estimated the Scottish population of black grouse at 4960 displaying males (95% Confidence Intervals (CI): 3000-7,300) (Hancock *et al.* 1999), subsequently revised to 4719 (95% CI 3774-5774) (Table 3). The following national survey in 2005, estimated a Scottish population of 3344 males (95% CI 2580-2171), representing a decline of 29% since 1995-96 (Sim *et al.* 2008). A regional breakdown for both surveys gave estimates of 1586 (95% CI 1135-2086) and 807 (95% CI 516-1176) in 1995-96 and 2005 respectively in South West Scotland, with the more recent estimate representing 24% of the Scottish population.

In their Southern Scotland study, Warren *et al.* (2014) reported an overall decline of 80% in numbers of black grouse attending leks at the two South West Scotland study areas (Cairnsmore of Fleet, and Muirkirk, Garpel and Douglas) between 1992-93 and 2011-12 (Cairnsmore of Fleet), and 1992-97 and 2007 (Muirkirk, Garpel & Douglas) (Table 4). Assessing the number of males recorded at the 197 leks across all four of their Southern Scotland study areas in relation to levels of moorland management, they found that 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 (Warren *et al.* 2014). The results of this study that are derived from the Muirkirk, Garpel & Douglas area should also be considered in relation to our Muirkirk and North Lowther Uplands SPA case study (see Section 5.1).

4.3 Breeding waders

4.3.1 National surveys – BBS and Atlas

Of those species for which there is sufficient BBS coverage (minimum of 30 squares) to calculate a Scottish trend, oystercatcher, golden plover, lapwing and curlew all showed significant declines between 1995 and 2015, with no change for common sandpiper or snipe (Table 5) (Harris *et al.* 2017).

Atlas distribution maps indicated mixed fortunes for the suite of breeding wader species, but showed a general theme of declining distribution for several species:

Oystercatcher: In all three atlases, breeding oystercatchers have been almost ubiquitous in Scotland, except for some North West upland areas, with high densities associated with the upland margins in East Scotland. Since the 1968-72 Atlas there have been some losses at inland sites in North West Scotland but the South West Scotland population has remained largely stable, mirroring wider stability in the rest of the Scottish population.

Golden plover: Comparison of distribution between Atlas survey periods shows some suggestion of apparent gains around the Western and Northern fringes of Scotland, which could have resulted from increased coverage. Within the core of the species' Scottish breeding range, highest densities occur on the Outer Hebrides, Shetland and the flows of Caithness and Sutherland. Losses have been greatest in the Southern Uplands, with declines observed throughout South West Scotland.

Lapwing: Although absent from much of the North West mainland, lapwings are present throughout most of the rest of Scotland. However, declines in Western regions are reflected in much greater relative abundance in the mainland East. Over the period of 1968-72 to 2007-11, there were no increases reported in any 10-km square within South West Scotland; conversely, declines were recorded in 21 10-km squares.

Dunlin: During April & May there is a large movement of dunlin throughout Britain & Ireland en route to their arctic breeding grounds, with a return movement starting in mid-July. This has resulted in many breeding season records of passage birds and an exaggerated impression of breeding abundance in parts of North and West Scotland. The species UK strongholds are all within Scotland, in the Northern Isles and Outer Hebrides, the flow country of Caithness and Sutherland, the hills of the North West Highlands, and the Grampian Mountains. The breeding change map shows losses in marginal upland areas of Southern Scotland. Distribution within South West Scotland is very restricted, with declines in occurrence reported between both previous Atlas periods.

Snipe: The snipe is one of the most widespread breeding wader species in Scotland. However, since the 1968-72 Atlas, a significant population decline has taken place, mostly in lowland areas, leading to a range contraction towards the uplands. Scotland remains one of the foci for current UK breeding range and highest abundances. As with the rest of the species' range, within South West Scotland, declines have been largely restricted to lowland areas, and have mostly occurred between the two more recent Atlas periods.

Curlew: The loss of breeding curlew from parts of West Scotland over the last 40 years is a key finding of the 2007-11 Atlas, with highest breeding concentrations remaining in East Scotland. Even in southern and eastern Scotland, fewer tetrads were occupied in 2007-11 than in 1988-91. In spite of these observed declines, curlew remain widely distributed throughout South West Scotland, with fewer losses from 10-km squares than might be expected from population declines reported in other surveys, emphasizing that the species is still retaining some of its former range, albeit now at much lower densities.

Redshank: There has been a 44% contraction of breeding range across Britain & Ireland since the 1968-72 Atlas, much of which occurred since 1988-91. This contraction is particularly apparent in Scotland, with reductions in abundance also apparent in core areas. While redshank remain present as a breeding species in parts of South West Scotland, declines have been observed throughout the region since 1988-91 as well as since the earlier Atlas in 1968-72.

Common sandpiper: Common sandpiper is present as a breeding species throughout most of Scotland, where densities are the highest in the UK, particularly in the far North West. However, there have been losses, particularly in lower ground adjacent to the uplands. Relative abundance changes have been apparent even in Southern Scotland where range loss has so far been minimal. In South West Scotland, although the species remains widespread through the region, observed declines in the most recent Atlas period are apparent.

4.4 Carrion crow

4.4.1 National surveys – BBS and Atlas

The BBS data showed no significant change in carrion crow abundance over the period 1995-2015 (Harris et al. 2017). Widely distributed in South and East Scotland, this species is replaced by hooded crow *Corvus comix* in North West Scotland. Between the first Atlas in 1968-72 and the most recent Atlas in 2007-11, carrion crows have shown some range expansion in the North West; elsewhere there have been few changes in distribution, with the species showing no change in South West Scotland.

4.5 Hen harrier and merlin

4.5.1 National surveys

Hen harrier: The Scottish survey of hen harriers in 1988-89 estimated the population at 479 pairs (95% CI 350-622) (Table 6), 90% of the UK population (Bibby & Etheridge 1993). The second survey in 1998 located 436 pairs (95% CI 365-806) in Scotland, 84% of the UK population (Sim *et al.* 2001), followed by an increase to 633 (95% CI 563-717) pairs in Scotland, 85% of the UK population in the third survey in 2004 (Sim *et al.* 2007). This increase in Scotland was confined to the West and far North, with numbers of breeding pairs in the East and South declining. The fourth survey, in 2010, recorded 505 (95% CI 417-612) territorial pairs, 80% of the UK population and a 20% decline from the 2004 survey (Hayhow *et al.* 2013). As in previous surveys, the 2010 survey found the largest proportion of the Scottish population in the West Highlands. Comparing those 10-km squares surveyed in both 2004 and 2010, there was evidence of decreases of territorial pairs in the Southern Uplands. The national population estimate was updated again following a further survey in 2016, although to date only summary results have been published

(RSPB 2017). This survey reported a Scottish population of 460 pairs, 84% of the UK population, and a decline of 9% since the 2010 survey.

Merlin: The first national survey in 1983-84, which achieved only partial coverage of the species' known range, confirmed 168 breeding pairs in the first year, and 173 pairs in the second year (Bibby & Natrass 1986). This figure increased markedly to 785 breeding pairs in 1993-94 (Rebecca & Bainbridge 1998). Authors of that survey claim that the observed increase between survey periods may be explained in part by improvements in sampling protocol and geographic coverage. However, in all areas where robust comparisons could be made, regional populations had either increased or remained relatively stable, indicating that some increases were genuine (Rebecca & Bainbridge 1998). The most recent survey in 2008 (Ewing *et al.* 2011) found 733 breeding pairs (63% of total UK population). This represented a non-significant decline of 7% since the last survey in 1993-94. Although this suggests an overall stable population, there are some indications from local studies of a drop in breeding pairs in some areas, including parts of Southern Scotland (Scottish Raptor Study Group website, 2017).

4.5.2 Occupied territories (SRMS data)

Hen harrier: In Scotland as a whole, the number of territories checked by Raptor Study Group workers that have been occupied has declined between 2003 and 2015 at a rate of -2.3% (±1.0 se) per annum (t_{11} = -2.36, P = 0.038) (Table 7) and has fluctuated between a high of 417 in 2004 to a low of 240 in 2010. In South West Scotland, the number of occupied territories has also fluctuated between years, but shown no significant trend over time, with significant increases at Langholm (t_{12} = -3.04, P = 0.01), contrasting with a collective decline at Glen App and Muirkirk at a combined rate of -7.7% (±2.9) per annum (t_{12} = -2.66, P = 0.021).

Merlin: Occupied territories of merlin also declined in Scotland generally, at a rate of -2.4% (+1.0) per annum over the same period, but again showed no decline over time in the South West (Table 7). Within the South West region, no occupied merlin territories were found at Glen App after 2010 but, in contrast, the number of pairs breeding at Langholm increased from one in 2008 to a peak of 10 in 2015 (Table 8).

4.5.3 Breeding success (SRMS data)

Hen harrier: Overall breeding success, expressed as fledglings per pair for monitored breeding attempts, varied between years over the period 2003-16, but did not differ between Scotland as a whole and the South West region, averaging 1.5 chicks fledged per pair. There was no trend in breeding success over time, either in Scotland or the South West region. Within South West Scotland, harrier breeding success, whilst showing a three-fold level of variation between years, ranging from 0.8 to 2.4 fledglings per pair, also varied between the three SPAs. Mean breeding success across the period was more than twice as high at Langholm (2.7 chicks per pair) than at either Muirkirk (1.2) or Glen App (1.0) ($F_{2,26}$ = 7.89, P = 0.002) (Table 9). Breeding success increased over time within the study period at Langholm (t_{12} = 2.26, P = 0.043), with higher breeding success occurring post-2008 when keepering was restored, but did not change at either Muirkirk or Glen App.

When overall breeding success was divided into its constituent components of successful pairs (the proportion of breeding pairs that raised one or more fledglings) and brood size (fledglings per successful nest), the percentage of successful pairs varied between sites. It was approximately

twice as high at Langholm (70%) as at either Muirkirk or Glen App (37% and 31% respectively) ($F_{2,26}$ = 6.32, P = 0.006). Brood size did not differ between sites and averaged 3.5 chicks.

Merlin: Overall breeding success did not differ between Scotland as a whole and the South West region and averaged 2.2 chicks fledged per breeding pair. Within the three SPAs in South West Scotland, breeding success did not differ between sites.

5. Case Studies

5.1 Muirkirk and North Lowther Uplands Special Protection Area (SPA)

5.1.1 Site description

Spanning the counties of East Ayrshire and South Lanarkshire, the Muirkirk and North Lowther Uplands SPA is situated both to the North and South of the town of Muirkirk (Fig. 2). Covering approximately 263 km^2, the SPA includes areas of semi-natural blanket bog, acid grassland and heath. The current study encompassed moors on six privately owned estates located within the SPA boundary, covering a total of 221 km^2 (range per moor 16 – 97 km^2). In 1992, when the study was initiated, four of the moors had an active red grouse shooting interest and employed gamekeepers either solely or partially to manage the moors for red grouse. On three of the four moors driven shooting occurred, with the fourth having largely walked-up shooting. The remaining two sites were managed primarily as sheep farms and had no grouse shooting interest. In 2004, keepering stopped on one of the moors, which was later sold, with one part of the moor reverting to sheep farming and the other to shooting of released red-legged partridge *Alectoris rufa*. The grouse interest on a further moor, which had previously had walked-up shooting, stopped shortly afterwards. By 2017, only a single gamekeeper on one of the moors remained and here the chief sporting interest was in released pheasants *Phasianus colchicus* away from the moor itself. The SPA was classified in 2003 for its internationally important populations of breeding golden plover, hen harrier, merlin, peregrine *Falco peregrinus* and short-eared owl *Asio flammeus*, as well as for its wintering population of hen harrier. The underpinning Sites of Special Scientific Interest (SSSIs), comprising Muirkirk Uplands SSSI and North Lowther Uplands SSSI are also noted for their 'outstanding assemblage' of upland breeding birds including, in addition to those species already mentioned in the SPA citation, curlew, dunlin, raven, red grouse, redshank, snipe, teal *Anas crecca*, wheatear *Oenanthe oenanthe* and whinchat *Saxicola rubetra* (SNH 2003).

Figure 2: Locations of Muirkirk & North Lowther Uplands SPA and Langholm – Newcastleton Hills SPA.

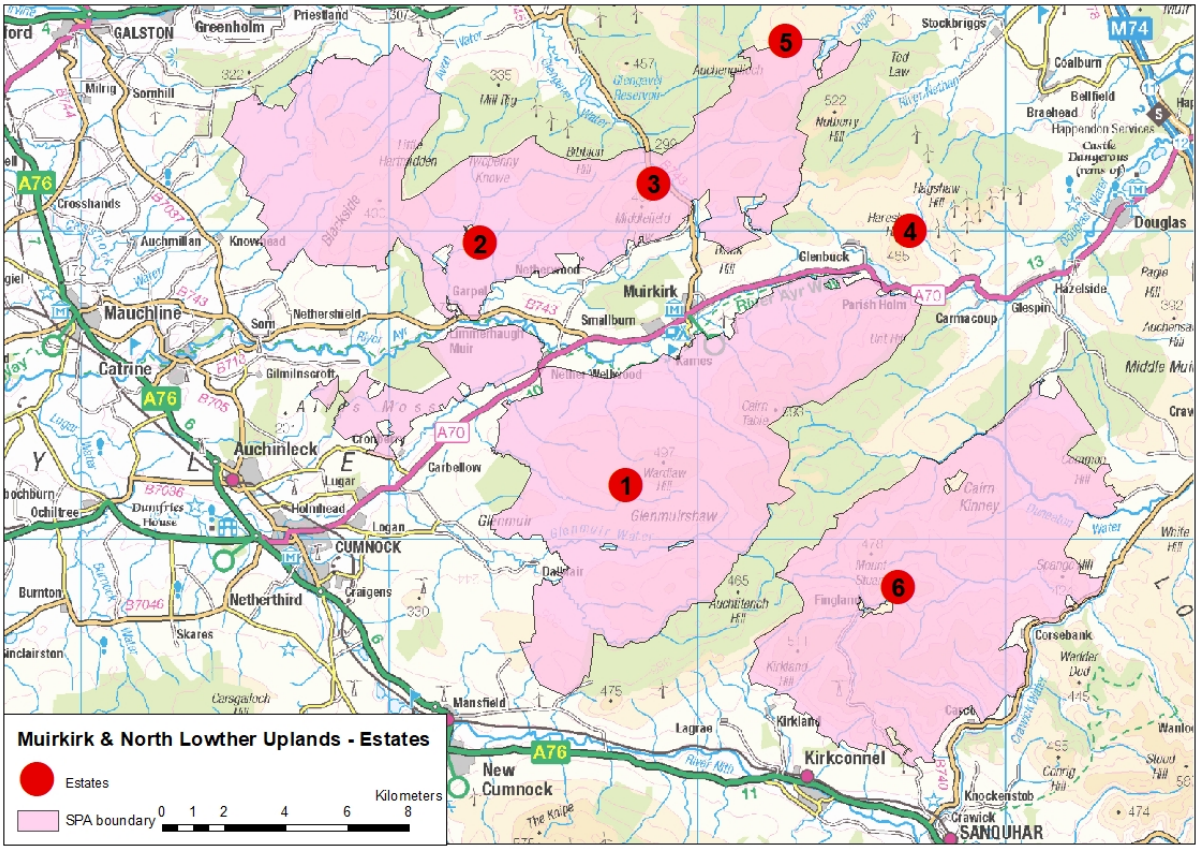
5.1.2 Methods

Long term trends in red grouse

Red grouse were surveyed within 16 discrete count areas varying in size from 0.8 to 4.0 km^2 across six privately owned moors between 1992 & 2017 (Table 10; Figure 3). Count areas were surveyed using pointing dogs and typically occurred either within blocks of ground of 0.8 to 1.1 km^2, when the observer walked six parallel transects spaced 150 m apart, whilst the dog searched for grouse either side of the transect lines. On one moor (Dumfries House) grouse were surveyed within tetrads (2 x 2 km grid-squares along four East to West transects at 500 m spacings, i.e. on a total of 8 km of transect. Grouse were surveyed either in March prior to

breeding, in July post-breeding when flushed birds where both sexed and aged to give estimates of breeding success, or in both March and July.

Figure 3. Map indicating the location of the estates within which red grouse surveys were undertaken between 1992 – 2017, within and adjacent to the Muirkirk and North Lowther Uplands SPA (1 – Dumfries House, 2 – Garpel, 3 – Muirkirk, 4 – Glenbuck, 5 – Logan & 6 - Sanquhar).



Grouse data were available from 201 counts (118 post-breeding in July and 83 pre-breeding in March or early-April) on 16 sites within six moors under different ownership between 1992 and 2017 (Table 10). Adult densities in July were closely correlated with estimates from earlier that year during counts in spring (July count = 0.714 grouse counted in spring + 1.21, t_{67} = 19.26, P<0.001). July counts also estimated breeding success (expressed as young per adult) and thus were used in preference to spring counts. The relationship between July and spring counts was used to estimate a further six July densities where counts had not been conducted that year, thus bringing the number of counts upon which further analyses were based up to 124.

Analyses involving trends in grouse abundance over time had count nested within moor as factors in the model to account for the lack of independence between counts within the same moor and also to account for the fact that not all counts were conducted in all years. These were fitted with year as a further factor into a generalized linear model (GLM) using a Poisson distribution and log link with log size (km^2) of area counted as an off-set. Based on this model, an annual index of grouse abundance, adjusted for the remaining factors, was obtained by exponentiating the year coefficients (index values relative to 1992 = 1) for each moor-year when counts had been conducted. The overall population change for each moor was calculated by subtracting the year coefficient in the last year of survey from that in the first and then dividing by the first. Annual

rates of change in grouse abundance were calculated using the annual indices of abundance generated from the GLM regressed against year, both as a linear coefficient and a quadratic coefficient.

Differences in grouse breeding success (young reared per female) between moors and changes over time were analysed within a GLM with the number of young grouse counted as the response variable in a Poisson regression (log link) with the log of the number of adult females counted as the off-set (equivalent to young per female). Time period (two-levels: 1992-99 and 2004-08, 2017), together with moor were included as factors. A further factor; keeper (presence/absence) in each moor-year was included in a second model together with period.

Long term trends in breeding waders

Moorland surveys:
Muirkirk and Garpel moors were sample surveyed by observers walking 17 transects placed within the SPA area. Each transect varied from 1-2 km in length and was visited once in May, annually from 1994 to 1999 and then repeated in 2009 and 2017. Surveys were undertaken between 08:30 and 18:00 hours BST to avoid the main periods of rapidly changing bird activity (Reed *et al.* 1985). Waders were recorded if they were seen or heard and locations of recordings were marked on a 1:25,000 map (Brown & Shepherd 1993).

The numbers of each species of wader observed were summed for each transect within each of the three Muirkirk beats: Dippal, Middlefield and Priesthill, and for Limmerhaugh at Garpel. Of the six species of waders recorded, curlew was the only one where there were sufficient observations to allow statistical analysis. For curlew the total number of birds seen per beat per year was the response variable in a GLM with a Poisson distribution and log link, with the log transect length surveyed as an off-set, i.e. equivalent to birds km^{-2}. Rather than being surveyed annually throughout the study period, waders were only surveyed annually from 1994-99, with repeat surveys in 2009 and 2017. Thus changes in curlew abundance over time were considered in relation to these two periods; 1994-99 and 2009/2017, which, together with beat, were entered as factors into the model, with a beat-period interaction. For the other wader species observed, encounters were simply summed at the level of moor-period and expressed as the abundance of each species per km of transect.

Farmland (in-bye field) surveys:
A total of 30 enclosed (in-bye) fields, each varying in size from 2 - 25 hectares, were surveyed in 1995, 1999, 2009 and 2017 (Table 11). The number of in-bye fields surveyed varied (13 – 30) between years. Fields were surveyed in May and the total numbers of lapwing and redshank were recorded for each field. Most fields were visible from the roadside and could be surveyed from a vehicle using binoculars and a telescope. However, some fields were entered on foot if they could not be seen from the roadside or if vegetation prevented accurate observation. Numbers of lapwing and redshank were summed for all of the field surveyed in each of the four years, with insufficient data to allow analyses for the other species. To account for an incomplete survey in 1995, values were corrected in that year for the area of ground surveyed and expressed as birds observed per km^2 for each species.

'Repeat Upland Bird Surveys'

Sim *et al.* (2005) reported on results of re-surveys of 13 areas of the British Uplands which had previously been surveyed between 1980 and 1991. The report included repeat surveys that fell

wholly ('South West Scotland' repeat survey) or partly ('South Scotland' repeat survey) within Muirkirk and North Lowther SPA.

South Scotland:
Original surveys of 12 upland plots in Southern Scotland were undertaken in 1980-82 (Easterbee & Pitkin 1984), of which six plots were within South West Scotland. Of those six, three fell within the SPA and two adjacent to it. Surveys of these six plots were repeated in 1998 (Smith & Green 2000). Both surveys involved four complete visits on each plot between April and July, with each plot covered by walking 200m-spaced parallel transects.

South West Scotland:
Original surveys were undertaken within what would become the Muirkirk and North Lowther Uplands SPA in 1989 (Brown & Shepherd 1989), and repeated in 1999 (Shepherd 1999), both surveys using the Brown & Shepherd (1993) upland bird survey method. The repeat survey in 1999 was of a random sample of 31 tetrads (2 x 2 km squares) from an original study area of 290 km^2. Of those 31 tetrads, 20 were surveyed in both 1989 and 1999.

Data from these repeat upland bird surveys were available for eight species of waders. Four species, golden plover, curlew, lapwing and snipe were sufficiently abundant for statistical analysis, together with the abundance of all wader species summed. Data for oystercatcher, dunlin, redshank and common sandpiper are presented and summarized, but not included in formal analyses. Differences in wader abundance between repeated survey visits in each of the two studies were analysed within GLMs with count of each wader species in turn, and waders collectively, as the response variable with a Poisson distribution and log link function. Plot (12 plots) nested within Study (2 areas: South and South West Scotland) and Survey (2; first and second) were included in the model as factors, together with Study*Survey as a first-order interaction. Models were corrected wherever appropriate for over-dispersion.

In 2015, Scottish Natural Heritage (SNH) commissioned a full survey of the breeding waders and passerines within the SPA (Starling Learning 2015). Total survey area, which included the SPA and other 'suggested areas' was 285 km^2 and was covered by a survey based on Brown and Shepherd (1993) methodology, with two visits between 20 April and 30 June. The location and activity of all waders was recorded on 1:25000 maps, which were then combined to produce final visit maps for each round. Final species maps were derived using the data from both visits. The surveys described previously (Brown and Shepherd 1989, Shepherd 1999) occurred within this wider survey area covered in 2015.

Other data sources

Calladine *et al.* (2014) compared bird population trends at a 9.5 km^2 managed moorland site within the Muirkirk and North Lowther Uplands SPA, with wider site background trends. Bird abundances were considered over a ten-year period (2002 – 2011), during which the managed site was subjected to compensatory habitat management to offset the loss of 99 ha of adjacent designated land to surface coal extraction. Three survey methods were used annually to estimate breeding bird densities within the managed mitigation area:

1) Constant effort search surveys: four survey visits in April – June to derive annual estimates for occupied territories by breeding waders and some passerines;

2) Transect sampling surveys: two surveys from parallel transects (500 m apart) undertaken in May and June recording the most commonly occurring passerines within distance bands of 0-25 m and 25-100 m.
3) Post-breeding population estimates of red grouse: red grouse were sampled from the same transect as in (2) above but in late July – early August using pointer dogs to search out birds and to provide an estimate of post-breeding density.

5.1.3 Results

Red grouse

Trends in July adult grouse abundance between 1992 and 2017 differed between moors (moor*year: $F_{6,109} = 5.52$, $P<0.001$) (Table 12). Grouse abundance showed significant declines on four of the six moors and no trend at the remaining two. Those moors where no trend was observed were however monitored for a shorter time period, eight consecutive years 1992-99 on Glenbuck and the same period plus 2004 for Logan, hence coinciding with when the adjacent Muirkirk Estate had grouse keepers. Excluding these two moors and thus examining the longer trend in grouse abundance (1992-2017 for Dumfries House, Garpel and Muirkirk, and 1992-2007 for Sanquhar) continued to show differences between moors over time ($F_{4,94} = 7.64$, $P<0.001$). This was explained by all moors except Muirkirk exhibiting broadly linear declines over time, whilst Muirkirk showed a quadratic relationship in grouse abundance over time. Initial grouse increases of 27% ($\pm$ 4.5 se) per annum at Muirkirk over the period 1992-98 ($t_5 = 6.02$, $P = 0.002$) were associated with the on-set of grouse keepering and the development of a driven grouse shoot, whilst subsequent declines of 4% ($\pm$ 1) per annum over the period of 1999-2017 ($t_6 = -3.35$, $P = 0.015$) were linked to the cessation of grouse moor management in 2004. Declines at Sanquhar and Dumfries House were also linked to loss of gamekeepers, but declines at Garpel occurred despite a full-time gamekeeper remaining, albeit chiefly focused on released pheasant shooting.

Grouse breeding success (young reared per female) differed between time periods ($F_{1,102} = 24.61$ $P < 0.001$) and between moors ($F_{5,102} = 8.44$, $P < 0.001$), being consistently higher in the 1990s and at Garpel and Muirkirk, lowest at Glenbuck and Logan and intermediate at Dumfries House and Sanquhar (Table 13). Inclusion of whether or not a moor was keepered was an important explanatory factor in grouse breeding success, with over twice as many young per hen (5.0 $\pm$ 0.2) on the 62 counts when the areas concerned were keepered than when they were not (2.3 $\pm$ 0.2) ($F_{1,102} = 33.97$, $P < 0.001$). The inclusion of keepering explained most of the variation in breeding success previously explained by "time period", which was no longer significant ($F_{1,102}= 1.78$, $P = 0.19$).

Grouse breeding success was highly positively correlated with post-breeding grouse density (adults and juveniles combined) ($F_{1,107} = 90.12$, $P < 0.001$) and thus also varied in relation to time period, being on average four-fold higher at 93 grouse km^{-2} in the earlier than in the later period ($F_{1,106} = 10.02$, $P = 0.002$), and to keepering, being three-fold higher at 104 grouse km^{-2} when a moor was keepered ($F_{1,106} = 14.81$, $P < 0.001$).

Breeding waders

Moorland transect surveys:
Curlew abundance (birds km^{-1}) declined by 38% between time-periods in a consistent manner across the four moorland beats (period.beat: $F_{3,21} = 1.52$, $P = 0.24$). Abundance varied between

periods and beats, with curlew being twice as abundant in the earlier period as in the later period ($F_{1,24}$ = 5.54, P = 0.027) and three times more numerous on Garpel as on Dippal, with intermediate values on Middlefield and Priesthill ($F_{3,24}$ = 4.62, P = 0.011) (Table 14). Declines between periods were associated with the cessation of grouse keepering on Muirkirk. This occurred between the two periods of time being compared. Golden plover and redshank were no longer found at Muirkirk in the later period of observations, whilst the frequency of lapwing and snipe observations were approximately halved (Table 14). At Garpel, repeat surveys in the later period, failed to find any waders.

Farmland (in-bye field) surveys:
Lapwing showed an overall decline of 85% between 1995 and 2017, with the greatest rate of change occurring between the 1999 and 2009 surveys (Table 15). The picture was similar with the rarer redshank which was not found in either the 2009 or 2017 surveys.

'Repeat Upland Bird Surveys'

Analysis of these combined data (six plots from the South Scotland surveys and all plots from the South West Scotland survey) found differences in wader changes between studies (study*survey interaction). Wader abundance as a whole ($F_{1,10}$ = 11.01, P = 0.008) and that of individual species for golden plover ($F_{1,10}$ = 5.29, P = 0.044) and lapwing ($F_{1,10}$ = 12.32, P = 0.006) declined most in the South Scotland study, with a weak tendency for curlew ($F_{1,10}$ = 3.55, P = 0.09) and snipe ($F_{1,10}$ = 2.87, P = 0.12) to do the same, but not significantly. These between study differences are not surprising as the interval between repeat surveys averaged 18 years for the plots in South Scotland, but was only 10 years in South West Scotland. Given the difference in wader change between studies, data at the plot level were analysed for each study separately.

For the whole of South Scotland, Smith & Green (2000) reported significant declines for golden plover (-81%), lapwing (-87%), snipe (-56%) and curlew (-57%) between the two survey periods in 1980-82 and 1998. This pattern is reflected in the percentage changes in the six plots that were within the SW part of that South Scotland survey; golden plover (-82%), lapwing (-94%), snipe (-79%) and curlew (-67%) (Table 16 and Table 17).

The slightly later surveys just within South West Scotland showed overall smaller declines between 1989 and 1999 (Table 17 and Table 18), with significant declines of -33% for golden plover, -64% for lapwing, a tendency for reduced curlew (-25%) and a non-significant halving of snipe abundance.

Data from the more recent survey in 2015, commissioned by SNH, are presented in Table 19. When expressed as densities, to control for differences in survey area, and compared with the findings from the South West repeat surveys in 1989 (Brown and Shepherd 1989) and 1999 (Shepherd 1999), the data show continued declines in golden plover (-84%), lapwing (-88%) and curlew (-61%).

Other data sources:

Calladine *et al.* (2014) found that breeding numbers of most moorland bird species showed either a more negative trend at the managed site (red grouse) or no significant difference was detected (golden plover, curlew, snipe) when compared to the wider site background trends. Carrion crows increased, despite being actively removed as part of predation control measures.

5.2 Langholm - Newcastleton Hills SPA

5.2.1 Site description

The Langholm - Newcastleton Hills SSSI and SPA comprises approximately 7,600 hectares of heather and grass-dominated moorland between the towns of Langholm and Newcastleton (Fig. 2). The site is partly in the Scottish Borders and partly in Dumfries and Galloway. The vegetation is dominated by blanket mire, heather, and species-poor acidic grassland, with some small areas of broad-leaved wood associated with streams. The hen harrier is the SPA qualifying feature, while the SSSI features include the assemblage of upland habitats, upland breeding bird assemblage as well as geology.

Langholm Moor has a long history as a moor managed for driven grouse shooting. Since 1992, the moor has hosted two major studies which aimed to help resolve raptor-grouse conflicts. The Joint Raptor Study (JRS), which ran from 1992-1997, set out to measure the scale of raptor predation on grouse and to work out the likely effect this would have on shooting and subsequent breeding stocks of grouse (Redpath & Thirgood 1997; 1999; Thirgood *et al.* 2000a). The subsequent increase in harrier abundance on the moor contributed to increased raptor predation on grouse until shooting became unviable and ceased in 1996 (Redpath and Thirgood 1997). In an attempt to reduce predation of grouse chicks by harriers, half of the harrier nests were supplied with diversionary food in 1998-1999 (Redpath *et al.* 2001) as a two-year "bolt-on" to the original Joint Raptor Study. Predation of grouse by raptors prevented the recovery of grouse densities (Thirgood *et al.* 2000b) and, as a result, active grouse moor management was abandoned in 1999, resulting in the loss of four grouse keeper jobs.

Grouse moor management at Langholm was resumed in 2008 at the inception of the 10-year Langholm Moor Demonstration Project (LMDP) (2008-2017), a partnership between Scottish Natural Heritage, Buccleuch Estates, GWCT, RSPB and Natural England to test whether sustainable driven grouse shooting could be restored in the presence of a viable harrier population. This management comprised heather burning and cutting, sheep grazing reductions, heather re-seeding, legal control of generalist predators, use of medicated grit to control grouse parasites (Hudson *et al.* 1998, Newborn & Foster 2002) and diversionary feeding of harrier broods (Redpath et al. 2001). In the period between the JRS and the LMDP (2000-2007), the moor was no longer managed for grouse shooting. Sheep grazing was the primary land-use and generalist predators were no longer routinely controlled, although some limited heather burning and legal predator control took place (Baines *et al.* 2008).

During the course of these projects at Langholm, a range of data have been collected, analysed and reported. Results, and some new analyses, from long-term monitoring of bird and predator populations are reported in this study.

5.2.2 Methods

<u>Long-term trends in abundance and breeding success of red grouse, hen harriers and predators</u>

Ludwig et al (2017) used the findings from all phases of study to consider how cessation and subsequent restoration of grouse moor management affected the abundance and breeding success of red grouse and hen harrier, as well as the abundance of their perceived key predators: red fox and carrion crow. Monitoring of red grouse was achieved through twice yearly counts on ten 0.5 km^2 count areas (Fig. 4), in March/early April to estimate pre-breeding densities (birds

km^{-2}) and in July/early August to estimate post-breeding densities (birds km^{-2}) and breeding success (mean young per adult). Within each count area, the observer walked along parallel transects 150 m apart, whilst a pointing dog quartered the ground on either side of the transect. Spring counts were not conducted in 2001 due to foot and mouth disease in livestock, which prevented access to the moor.

Hen harrier nests were located in April-June by observing displaying birds, nest-building, prey transports and food passes (Hardey *et al.* 2013). All nests were visited at least three times: during incubation to record clutch size, within a week after hatching to record the number of chicks hatched, and shortly before fledging to record the number of chicks reared.

From 2003 onwards, an index of red fox *Vulpes vulpes* activity was estimated annually from surveys of scats along up to five transects, each approximately 10 km long. Scats were surveyed and collected four times per annum, during a clear-up round in March, followed by three repeat surveys at monthly internals. From 2013 onwards, only one repeat survey was conducted in May. Number of transects varied between years and data analyses took account of variation in total transect length and interval between consecutive surveys. Indices were presented as the average number of scats / km / 10 days. For details of statistical treatment of the data, see Ludwig *et al.* (2017).

Long-term trends in moorland bird abundance

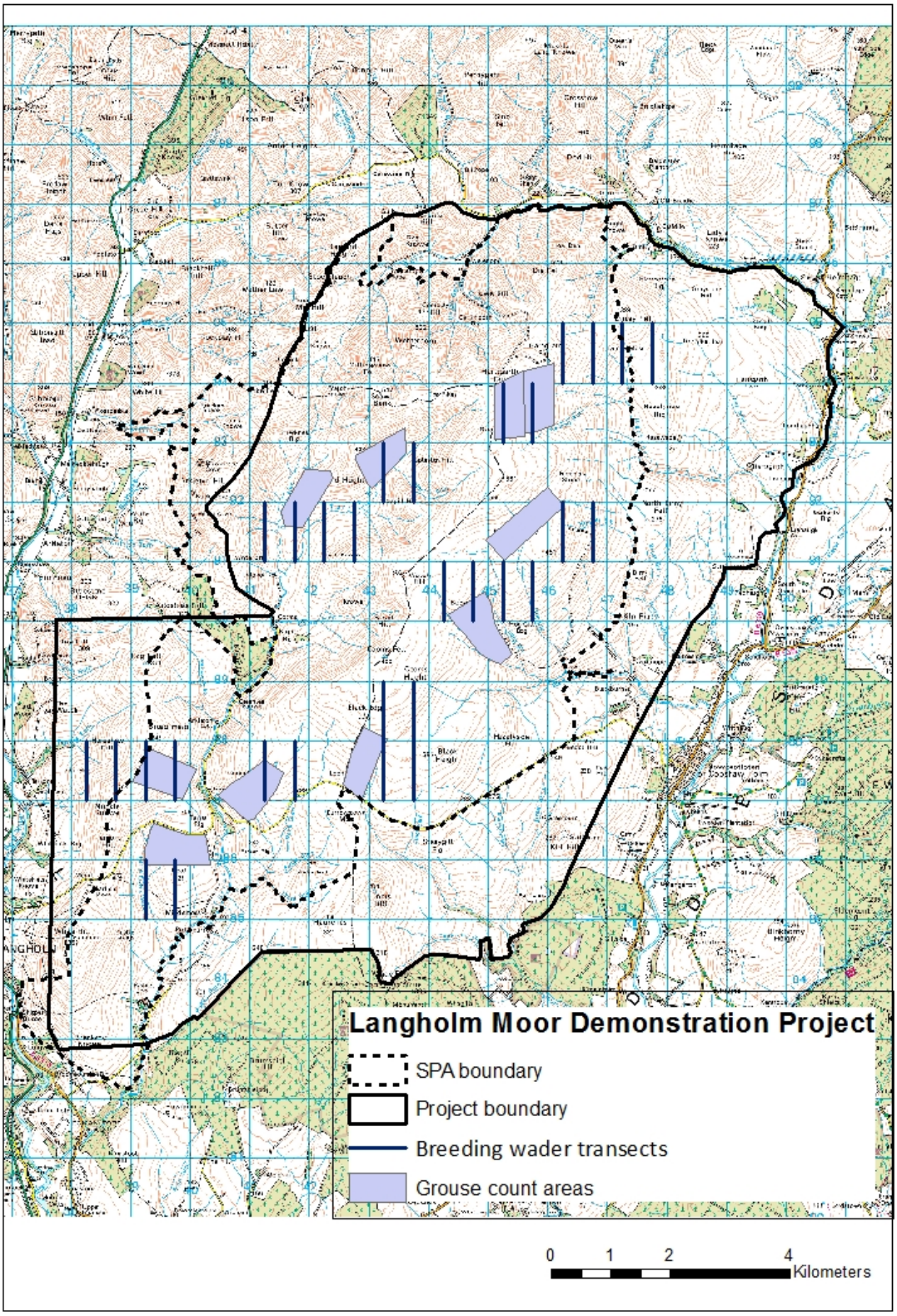
From 1992 to 2016, annual bird surveys were conducted within each of the five management areas or 'beats' within which grouse shooting and associated management occurred. The survey method approximated to that of the subsequent BBS. Counts were made in 15 1-km grid squares (Fig. 4), with three squares randomly located within each beat. Within each square, two parallel transects were surveyed on foot, each 250 m in from the edge of the square in a north-south orientation, separated by 500 m. A single count was undertaken annually in each square between 1992 and 2002, with seasonal timing of the count varying from 27 May to 17 July. From 2003 until 2017, squares were counted twice, the first time between mid-April and mid-May and then repeated between mid-May and mid-June. Data gathered on waders, together with those on carrion crow along the same transect lines are considered here.

We examined trends in wader abundance from 1992 – 2016, using the maximum count from the two visits for 2003 onwards, when squares were surveyed twice. Trends in abundance of each of four wader species; curlew, golden plover, snipe and lapwing, were analysed for three time periods: 1992-1999 when the moor was keepered, 2000-2008 when the moor was not keepered and 2009-16 when keepering resumed as part of the Langholm Moor Demonstration Project. Although the LMDP keepers commenced in spring 2008, 2008 was categorized as an unkeepered year because many waders had already returned to the moor to breed before management recommenced that spring. Despite BBS surveys commencing within a further five 1-km grid squares from 2008 onwards, analyses were restricted for consistency over time to the original 15 squares only.

Analyses of the wader data were conducted at the level of the moor by summing observations for each species in turn from each survey square. To account for two years when not all squares were surveyed, annual totals for each wader species were made comparable by expressing results as the mean number of birds observed per km of transect within a regression involving a normal distribution, the equivalent of using a Poisson regression and log transect length as an offset. Using one value per wader species per annum, we tested for differences in trend in numbers between

the three periods (year*period: with year as a covariate and period as a three-level factor; 1992-99 keepered in JRS, 2000-2008 unkeepered and 2009-16 keepered in LMDP. If the year*period interaction was significant, then we next tested for trends within each period, or if not significant, we considered the trend over the whole time period of the study, i.e. 1992 to 2016.

Figure 4. Location of Langholm Moor Demonstration Project boundary in relation to the boundary of the Langholm – Newcastleton Hills SPA; together with locations of the 10 red grouse count areas and the 15 1-km grid squares used for wader surveys.



5.2.3 Results

Numbers and breeding success of red grouse, hen harriers and predators:

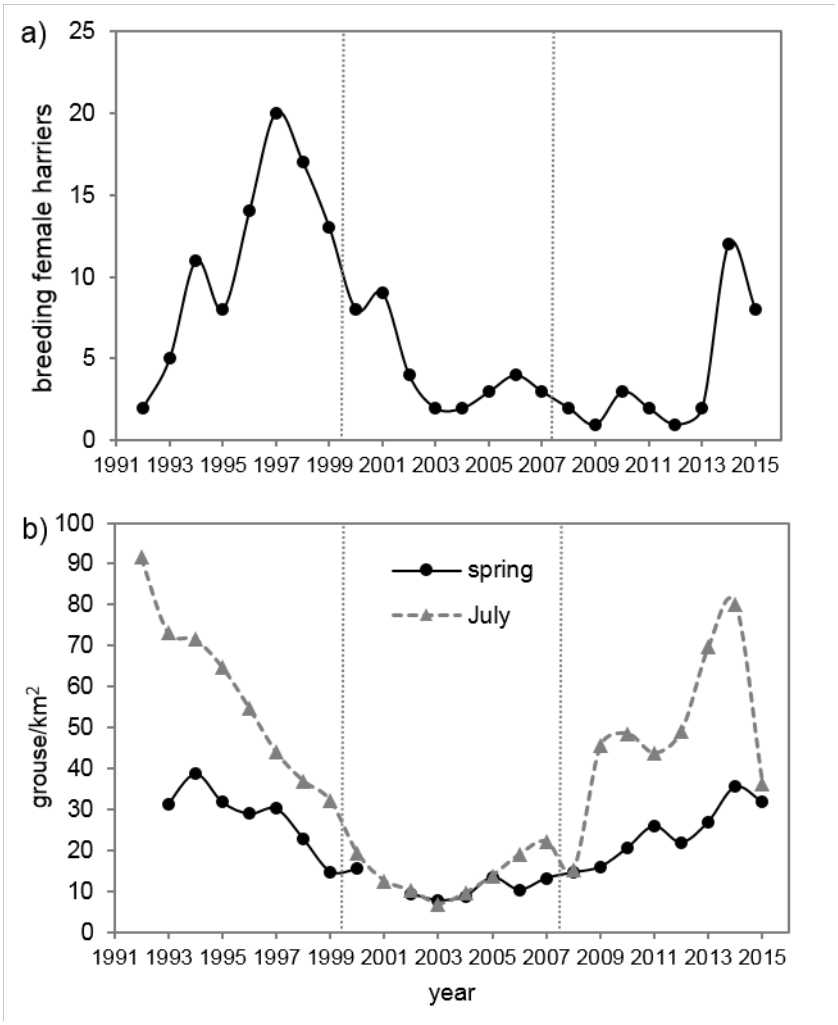
Ludwig et al. (2017) found that between 1992 and 1999, the number of breeding female harriers increased by 10 ± 3% per annum ($F_{1,6}$ = 12.36, P = 0.013), peaking at 20 females in 1997 (Fig 5a). During the same period, grouse densities declined by 8 ± 2% per annum in spring ($F_{1,5}$ = 12.39, P = 0.017) and by 9 ± 1% per annum in July ($F_{1,6}$ = 242.43, P = 0.001) (Fig. 5b), in spite of gamekeepers removing on average 187 ± 20 foxes and 308 ± 18 carrion crows per annum during this period (Fig 6).

After keepering was stopped in 2000, grouse densities in spring and July remained low, but stable (spring: –0.7 ± 3% change per annum, $F_{1,5}$ = 0.05, P = 0.838; July: 4 ± 4% per annum, $F_{1,6}$ = 0.84, P = 0.396) (Fig 5b). In contrast, the number of female harriers declined sharply from 2001 to 2002, then remained fairly stable for the remaining six years (–8 ± 4% per annum, $F_{1,6}$ = 5.40, P = 0.059) (Fig 5a). During this period without management, these respective reductions of 60% and 76% in spring and July grouse, and 61% fewer breeding female harriers were associated with higher crow and fox indices (Fig 6).

After management was resumed in 2008 as part of LMDP, grouse density in spring increased until 2014, then fell sharply in 2015, resulting in an overall population increase of 8 ± 1% per annum between 2008 and 2015 ($F_{1,6}$ = 39.17, P = 0.001) (Fig 5b). Post-breeding density followed the same pattern, but on a lower level (2008–2015: 6 ± 3%, $F_{1,6}$ = 2.91, P = 0.139). In contrast, the number of breeding hen harrier females remained low at 1-3 until 2014, when they increased to 12 (Fig 5a). During this period of resumed keepering, gamekeepers removed 189 ± 22 foxes and 260 ± 22 carrion crows per annum.

Overall, Ludwig *et al.* (2017) found that when the moor was managed for red grouse and generalist predators were routinely controlled, grouse and harrier breeding success was two- to three-fold higher than when the moor was not managed. When managed, about three-quarters of harrier breeding attempts fledged chicks, compared to only 39% when unmanaged. Correspondingly, carrion crow abundance and the fox index were three times higher during the unmanaged period than in managed periods (Table 20), although crows showed a high level of annual fluctuation throughout the study period.

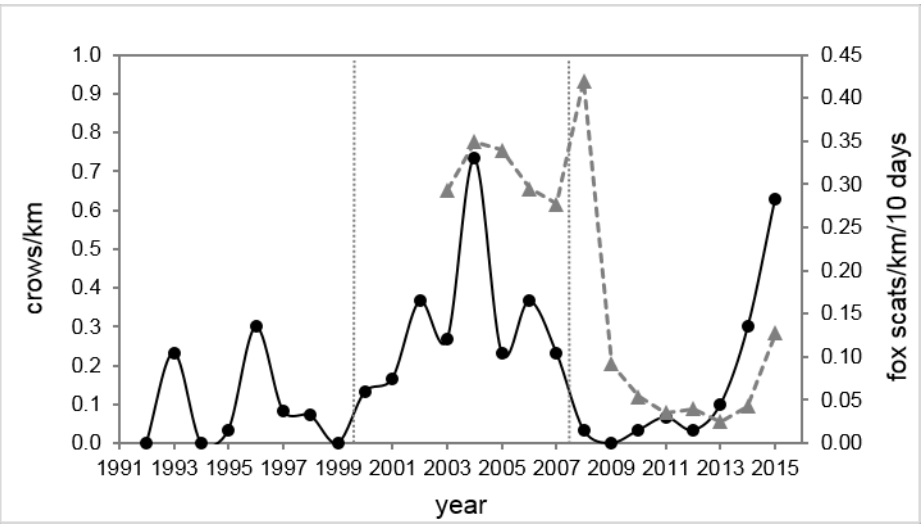
Figure 5. Annual variation in (a) the number of female hen harriers and (b) red grouse densities in spring (black solid line) and July (grey dashed line) on Langholm Moor between 1991 and 2015. The dotted vertical lines separate the three periods (managed-unmanaged-managed) (Ludwig et al. 2017).



Waders:

None of the four wader species showed differences in rates of change between the three periods of observation, therefore changes in abundance were considered over the whole study period. Three species; curlew, golden plover and lapwing showed significant rates of annual decline from 1992 to 2016 (Table 21), with curlew numbers more than halving, golden plover halving and lapwing showing an approximate seven-fold reduction between periods (Table 22). Hence, although these species were more numerous in the first period of keepering and were less numerous after keepering stopped in the second period, resumption of keepering in the third period failed to restore numbers and in general on-going declines continued. In contrast, the fourth species, snipe, increased over time, with five-fold higher numbers observed in the unkeepered period relative to the first keepered period, with numbers being maintained within the second period of keepering (LMDP).

Figure 6. Annual variation in abundance of carrion crows (black solid line, left axis) and fox scat index (grey dashed line, right axis) on Langholm Moor between 1992 and 2015. The dotted vertical lines separate the three periods (managed – unmanaged – managed).



6. Discussion

Declines in some key moorland bird species, particularly breeding waders, previously reported by Sim *et al.* (2005) are supported by similar negative trends apparent from examination of other datasets in this study, and mirror downward trends seen in other parts of the UK (Warren and Baines 2014; Colhoun *et al.* 2015). These declines have been attributed to large-scale changes in upland land-use (Douglas *et al.* 2013). Sim *et al.* (2005) have previously identified that some of the most widespread and severe wader declines have occurred in southern Scotland. Here, significant afforestation since the 1920s has led to replacement of open ground with conifer woodland, and an estimated loss of 5000 curlew pairs in the region since the 1939-1945 war (Ratcliffe 2007). Such afforestation has also been implicated in the decline of golden plover and dunlin in this and other regions (Gibbons *et al.* 1993, Thompson *et al.* 1995).

Where land hasn't been planted with trees, historical intensification of land-use was instead often manifested through increased sheep grazing (Fuller & Gough 1999), leading to loss of vegetation structure and diversity. More recently, there have been reductions in livestock numbers. In their review of changing livestock numbers in UK Less Favoured Areas (LFA) in relation to biodiversity implications, Silcock *et al.* (2012) highlighted the UK-wide effects of the 2001 Foot and Mouth Disease outbreak, resulting in significant stock reductions in some areas, and an associated breakdown of hefted sheep flocks. This was followed in 2005 by decoupling of agricultural subsidies, which saw a switch from subsidy payments based on number of livestock to ones based on the land area of the holding. The authors of that review reported for the period 1995 – 2011 an overall reduction in stocking density of -15% for Ayrshire LFA and -9% for Dumfries & Galloway LFA. While some grazing reduction can be beneficial, if grazing is reduced too much this can lead to lower structural diversity of the sward as it becomes taller and can lead to scrub encroachment (Fuller 1996). Consequent changes in the composition and structure of moorland vegetation may affect bird abundance, with changes in structure and heterogeneity rather than changes from heather to graminoid dominance having greatest direct effects on bird abundance (Pearce-Higgins & Grant 2006).

Afforestation and changes in livestock farming practice are just part of the picture. Barnes (1987) reported Scotland-wide declines in grouse bags during the 1939-45 war, followed by further, steep declines in South West Scotland (and Central Highlands) between the mid-1970s and 1983. Robertson *et al.* (2017) demonstrated that long-term trends in red grouse abundance coincided with changes in intensity of moor management, as represented by keeper density on grouse moors. Downward trends in grouse moor management have also been associated with negative trends in many other upland bird species (Tharme *et al.* 2001) with the role of keepering, and associated reduction in predator density, being experimentally demonstrated to result in increased wader breeding success (Fletcher *et al.* 2010). The effect on increased predator numbers, resulting from a decrease in the number the of grouse moors and game keepers in recent decades (Barnes 1987, Tapper 1992), will have been exacerbated by increases in tree planting, which has led to habitat fragmentation, woodland edge effects and creation of a landscape that is more favourable for predators (Douglas *et al.* 2013).

All of these factors have been implicated in the decline not only of waders, but also both red and black grouse. Warren *et al.* (2015) concluded that black grouse in Southern Scotland are in long term decline, with further reductions in numbers and range contraction considered likely. In the same area of Scotland, shooting bag records illustrate that red grouse bags have also declined, with 42% of 31 moors now no longer shooting red grouse. Warren *et al.* (2015) acknowledge the significant land use changes that have happened throughout southern Scotland in the past

100 years, recognizing the same issues of afforestation, changes in livestock grazing and a loss of grouse moor management. These conclusions are particularly pertinent to our Muirkirk case study; for this part of South West Scotland, Warren et al. (2015) observed declines in black grouse which reflected the similar patterns of decline illustrated in other moorland bird species.

Our case studies both provide clear illustrations of the likely consequences of changes in land use. At Muirkirk, densities and breeding success of red grouse were closely allied to levels of keepering. The change in land-use in that part of South West Scotland, with the evident decline in active grouse moor management, has happened in tandem with significant declines in the suite of ground-nesting moorland birds, including hen harriers, at all three mainland SPAs when grouse moor management was either reduced or ceased.

On their study area within the Muirkirk and North Lowther Uplands SPA, Calladine *et al.* (2014) considered changes in vegetation, the effectiveness of predation control and influences of disturbance to attempt to identify potential mechanisms for observed changes in bird abundance. No general change in the vegetation was detected and no reasonable habitat-based cause for the observed declines in some species was apparent. There was also no convincing evidence for a negative effect on moorland birds of disturbance from a nearby open cast coal mine. As crow control failed to stem their increase and with supportive evidence for a decline in the breeding success of red grouse, the authors suggested that the control of predation was ineffective and may have contributed to some species decline.

The parlous state of many of the species within the SPA is highlighted in the 2015 survey of the site commissioned by SNH (Starling Learning 2015), who report a sharp decline in the number of golden plover, a classified feature of the SPA. Our comparison of the observed breeding densities with those of surveys from a sub-set of the SPA in 1989 and 1999 show ongoing, marked declines in golden plover, lapwing and curlew. The authors of the 2015 report observe that many of the areas within the SPA are no longer suitable for breeding waders, much of it being under-grazed, hence promoting rank vegetation unsuitable for waders, together with the proximity of extensive conifer plantings. They also report that much of the site no longer benefits from keepering, noting evidence of a high fox population, in the form of prevalent fox scats, and several predated golden plover and curlew eggs.

The long term study at Langholm has demonstrated how grouse moor management can have a positive effect on abundance and breeding success of hen harriers (Ludwig *et al.* 2017). Data from SRMS showed that numbers of occupied hen harrier and merlin territories have both increased at Langholm during the period of the Demonstration Project (2008 onwards), when keepering was introduced. This contrasts with trends seen in the rest of Scotland. Similarly, breeding success for hen harrier was significantly higher at Langholm than at the other SPAs, a success rate that increased during the period of keepering, and which demonstrated the benefits that keepering can potentially have for breeding hen harrier (Baines & Richardson 2013).

Baines *et al.* (2008) showed that golden plover, lapwing, curlew, red grouse and hen harrier were all more abundant when Langholm Moor was managed for grouse. However, our analyses of wader abundance which included data from the most recent management period have highlighted a lack of wader population response to reintroduction of keepering at Langholm. This highlights the importance of the scale at which management is implemented. Langholm is now an isolated moor, with no keepering on the surrounding estates. Therefore, any benefits of predator control will be diluted by the proximity of predator populations that are not subject to any control. Furthermore, with wader densities now at such low levels, compared to historical

densities, birds may be more inclined to disperse to adjacent areas of land which offer good quality habitat for breeding, but where the risk of nesting failure due to predation may be higher. These results from Langholm therefore highlight the need not only for a comprehensive package of management for waders that includes both habitat management and predator control, such as can be delivered through grouse moor management, but also for that management to be implemented at an appropriately large, landscape scale.

The decline of breeding curlew across the UK is now the most high-profile of the breeding wader declines, and is gaining an increasing public profile. Having been categorized as 'the most pressing bird conservation priority in the UK' (Brown *et al.* 2015), there has followed a significant amount of activity in terms of regional and national workshops, action groups and actions plans. If collective discussions within these fora lead to meaningful and sustainable conservation action, it will not only benefit curlew, but other ground-nesting bird species too. In the meantime, the evidence of long-term sustained declines in populations of many of our upland ground-nesting birds is irrefutable, with observed patterns of decline in South West Scotland following closely on the heels of those already catalogued in Ireland and Wales.

As observed by Johnstone & Bladwell (2016), in their assessment of Welsh bird conservation priorities, 'birds are being added to the red list faster than our collective ability to deliver conservation actions to improve their status'. This is reflected at the UK level, with five upland bird species, including curlew and merlin, being added to the red list (the highest level of conservation priority) in the last update of Birds of Conservation Concern (Eaton *et al.* 2015), in addition to those upland species already on the red list (black grouse, hen harrier, lapwing, whinchat).

The on-going declines of breeding waders on SPAs featured in this study are happening in spite of those sites' national and international conservation designations. Similarly, the average or below average number of successful hen harrier and merlin territories on sites for which they are regarded as being of international significance is of concern. Langholm is the exception to this observation, but is the only one of the three SPAs to have retained active grouse moor management for the period in which these species of raptor appear to have thrived. It is of note that keepering stopped at Langholm Moor in spring 2016 as the active management component of the Langholm Moor Demonstration Project was brought to a close. As a consequence, we predict further declines in waders as a result, together with impacts on the restored harrier numbers, and their breeding success, as fox and crow numbers increase again.

Red-listing of these moorland bird species and their inclusion on legal schedules seems merely to be a means of formally cataloguing their demise rather than facilitating effective mechanisms to halt and reverse their population declines. Current mechanisms to secure management for these species at an appropriate scale are clearly not working. Urgent implementation of measures, which include both habitat management and predator control at an appropriate scale and intensity are needed to prevent further declines and possible local or regional extinctions of ground-nesting moorland bird species.

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Appendix 1: Tables

Table 1: Mean ± se number of red grouse shot km^{-2} and number of moors (n) included in analyses of temporal and regional variation in red grouse abundance for each of nine UK regions and for four time periods (Robertson *et al.* 2017).

	SW Scotland	SE Scotland	NW Scotland	NE Scotland
1890-1920	32.4 ± 1.4 n=17	33.9 ± 2.1 n=22	28.9 ± 1.0 n=61	55.6 ± 1.5 n=67
1920-1950	29.2 ± 1.5 n=24	58.7 ± 5.6 n=29	23.0 ± 0.7 n=93	49.5 ± 1.2 n=89
1950-1980	19.2 ± 1.1 n=27	39.6 ± 1.5 n=27	9.6 ± 0.3 n=104	32.8 ± 0.7 n=118
1980-2010	11.1 ± 1.5 n=24	40.1 ± 3.5 n=35	6.7 ± 0.3 n=112	10.9 ± 0.3 n=129

Table 2: Mean percentage changes in the number of black grouse shot km^{-2} per annum in Scotland and northern England between four different periods: pre-1914 (period 1), 1918-1938 (period 2), 1948-1975 (period 3) and 1976-1990 (period 4) (Baines and Hudson 1995).

Region	Mean % change per annum ± se			
	Pre-1914 to 1918-38	1918-38 to 1948-75	1948-75 to 1976-90	Overall decline
N England	0.6 ± 0.6	-7.7 ± 0.5	0.8 ± 0.8	-2.1 ± 0.3
SW Scotland	-4.0 ± 0.6	-9.7 ± 0.9	-3.8 ± 0.9	-5.5 ± 0.3
SE Scotland	0.3 ± 0.1	-9.0 ± 0.9	1.1 ± 0.9	-2.2 ± 0.3
W Scotland	-2.2 ± 0.5	-9.7 ± 1.9	-2.5 ± 1.1	-4.5 ± 0.3
E Scotland	-1.2 ± 0.4	-4.2 ± 0.5	-0.4 ± 0.4	-1.7 ± 0.2
NW Scotland	-6.7 ± 0.7	-7.0 ± 1.6	0.0 ± 2.4	-4.2 ± 0.4
NE Scotland	-3.8 ± 0.5	-6.6 ± 0.6	-2.2 ± 0.7	-3.9 ± 0.2

Table 3: Comparison of the number of displaying male black grouse (with upper and lower confidence intervals) in 1995-6 and 2005 in different regions of Scotland. For this survey, SW Scotland included Stirlingshire, West Perthshire, the southern part of Argyll, Dunbartonshire, Clyde Isles, Kintyre and South Ebudes (Sim *et al.* 2008).

Region	Number of displaying males			
	1995-96	2005	Change (%)	Significance
N Scotland	912 (548-1327)	770 (423-1142)	-16	ns
NE Scotland	1644 (891-2572)	1499 (1001-2145)	-9	ns
SW Scotland	1586 (1135-2086)	807 (516-1176)	-49	P = 0.003
SE Scotland	820 (386-1293)	257 (45-577)	-69	P = 0.019
Total	4719 (3774-5774)	3344 (2580-4171)	-29	P = 0.024

Table 4: Number of male black grouse (and number of leks) in each of two time periods in two areas of south west Scotland (Warren *et al.* 2014). Period 1 = 1992-97 (Muirkirk, Garpel & Douglas) and 1992 & 93 (Cairnsmore of Fleet); Period 2 = 2007 (Muirkirk, Garpel & Douglas) and 2011 & 2012 (Cairnsmore of Fleet).

Area	Total number of males at leks (number of leks)	
	Period 1	Period 2
East Ayrshire (Muirkirk, Garpel and Douglas)	53 (13)	12 (4)
Galloway (Cairnsmore of Fleet)	17 (5)	2 (1)
Total	**70 (18)**	**14 (5)**

Table 5: Scottish trends in bird populations surveyed by the Breeding Bird Survey. Trends are only produced for those species which have been recorded in a minimum of 30 squares (Harris *et al.* 2017).

Species	Number of survey squares	1995-2015 % change
Red grouse	55	8
Oystercatcher	139	-37*
Golden plover	38	-31*
Lapwing	88	-58*
Curlew	128	-59*
Common sandpiper	35	-13
Snipe	62	22
Carrion crow	212	-6

*denotes a statistically significant ($P < 0.05$) trend

Table 6: Numbers of territorial pairs (95% confidence intervals, CI) of hen harriers in UK and in Scotland in 1988/89, 1998, 2004, 2010 and 2016 (Bibby & Etheridge 1993, Sim *et al.* 2001, Sim *et al.* 2007, Hayhow *et al.* 2013, RSPB 2017).

Year of survey	Number of territorial pairs (95% CI)		Percentage change between consecutive surveys	
	Scotland	UK	Scotland	UK
1988/99	479 (350-622)	534 (405-677)	-	-
1998	436 (365-806)	521 (450-591)	-9	-2
2004	633 (563-717)	749 (675-832)	45	44
2010	505 (417-612)	633 (547-741)	-20	-15
2016	460 (not available)	545 (not available)	-9	-14

Table 7: Number of hen harrier home ranges known to be occupied, number monitored, number of pairs successfully fledging young, and minimum number of young fledged in Scotland, South West Scotland (comprising Scottish Raptor Monitoring Scheme regions of Dumfries & Galloway and South Strathclyde); Muirkirk and North Lowther Uplands SPA; Langholm – Newcastleton Hills SPA; and Glen App – Galloway Moors SPA for 2003 – 2016 (Scottish Natural Heritage; Scottish Raptor Monitoring Scheme Annual Reports and data; Langholm Moor Demonstration Project).

Year	Scotland				SW Scotland				Muirkirk			Langholm			Glen App		
	Occupied home ranges	Pairs monitored	Pairs known to fledge young	Min. number young fledged	Occupied home ranges*	Pairs monitored	Pairs known to fledge young	Min. number fledging	Occupied home ranges*	Pairs known to fledge young	Min. number fledging	Occupied home ranges*	Pairs known to fledge young	Min. number fledging	Occupied home ranges*	Pairs known to fledge young	Min. number fledging
2003	335	303	171	529	56	56	33	71	16	5	17	1	1	1	3	1	3
2004	417	359	219	630	66	65	25	84	23	13	53	2	1	3	9	2	5
2005	342	310	175	466	33	29	17	65	21	8	35	4	2	5	11	7	25
2006	355	278	144	381	43	32	8	24	20	3	10	8	2	5	9	3	8
2007	298	253	147	432	38	35	12	43	12	3	11	4	0	0	7	3	8
2008	311	311	128	370	25	23	9	40	8	3	10	1	1	4	8	2	12
2009	232	208	108	326	30	28	12	39	14	7	17	1	1	5	7	2	8
2010	240	222	108	303	30	30	9	35	11	4	13	3	1	6	7	1	3
2011	267	246	111	291	24	23	6	25	8	1	3	2	2	10	8	2	8
2012	259	217	107	275	10	10	3	9	2	1	3	1	1	4	3	0	0
2013	278	247	109	294	25	23	16	56	9	7	22	2	2	10	4	2	5
2014	314	293	177	579	60	55	39	101	11	6	15	12	10	47	5	1	4
2015	303	276	120	309	Data unavailable				3	1	4	8	6	17	4	1	2
2016	Data unavailable								4	0	0	7	7	25	2	1	3

*****Number of home ranges that were occupied and subsequently monitored, but does not assume comprehensive survey coverage of area

Table 8: Number of merlin home ranges known to be occupied, number monitored, number of pairs successfully fledging young, and minimum number of young fledged in Scotland, South West Scotland (comprising Scottish Raptor Monitoring Scheme regions of Dumfries & Galloway and South Strathclyde); Muirkirk and North Lowther Uplands SPA; Langholm – Newcastleton Hills SPA; and Glen App – Galloway Moors SPA for 2003 – 2016 (Scottish Natural Heritage; Scottish Raptor Monitoring Scheme Annual Reports and data; Langholm Moor Demonstration Project).

Year	Scotland				SW Scotland				Muirkirk			Langholm			Glen App		
	Occupied home ranges	Pairs monitored	Pairs known to fledge young	Min. number young fledged	Occupied home ranges*	Pairs monitored	Pairs known to fledge young	Min. number fledging	Occupied home ranges*	Pairs known to fledge young	Min. number fledging	Occupied home ranges*	Pairs known to fledge young	Min. number fledging	Occupied home ranges*	Pairs known to fledge young	Min. number fledging
2003	242	190	171	476	20	20	9	9	3	2	6						
2004	254	175	219	319	24	24	15	15	4	3	7				1	1	1
2005	290	189	175	500	22	22	12	12	5	3	11				1	1	3
2006	285	189	144	402	18	13	7	7	2	0	0				1	0	
2007	262	168	147	403	26	16	12	12	2	2	9	2	1	4	1	0	
2008	314	209	128	433	24	17	9	9	3	1	4	1	1	5			
2009	204	145	108	353	21	13	9	9	5	0	0	1	1	5	1	0	
2010	201	133	108	335	23	15	14	14	4	2	7	4	2	8	1	0	
2011	202	137	111	324	24	20	17	17	4	4	11	5	4	11			
2012	211	145	107	287	16	13	9	9	3	2	5	2	1	5			
2013	205	133	109	302	23	21	20	20	1	1	3	5	5	16			
2014	221	150	177	366	20	19	16	16	1	1	3	4	3	11			
2015	225	125	123	279	Data unavailable				3	1	3	10	4	5			
2016	Data unavailable											6	3	12			

*****Number of home ranges that were occupied and subsequently monitored, but does not assume comprehensive survey coverage of area

Table 9. Three measures of hen harrier breeding success within the three SPAs in South-West Scotland. Values are the mean (se) of annual means for the period 2003-16, i.e. n = 14 years. Sample sizes varied within years; for the whole period they were 88 breeding attempts at Glen App, 52 at Langholm and 162 at Muirkirk (Scottish Raptor Monitoring Scheme data).

SPA	Fledglings / pair	% successful pairs	Fledglings / successful nest
Glen App	1.0 (0.2)	0.31 (0.04)	3.3 (0.3)
Langholm	2.7 (0.5)	0.70 (0.09)	3.8 (0.4)
Muirkirk	1.2 (0.2)	0.37 (0.05)	3.4 (0.2)

Table 10: Count areas within Muirkirk and North Lowther Uplands SPA surveyed for red grouse between 1992-2017; x = count undertaken.

	Dumfries House								Garpel								Glen-buck		Logan		Muirkirk								Sanquhar			
	Cairn Table		Cairn Hill		Gass Water		Wardlaw Hill		Upper Whitehaugh		Limmerhaugh Muir		Over River		Greenock		Wedder Hill		Grouse Hill		Dippal		Lunch Hut		Middlefield		Priesthill		Blackgannoch		Leftshaw	
	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July	March	July
1992	x	x			x	x				x								x		x		x		x		x		x				x
1993	x	x			x				x	x		x					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1994	x	x			x				x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
1995									x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
1996									x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
1997									x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x				
1998									x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x				
1999									x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				
2004		x		x				x												x	x	x	x	x								
2005		x		x				x														x		x								
2006																						x		x								
2007										x												x		x						x		x
2008		x		x																		x		x		x		x				
2012	x		x						x												x		x		x				x		x	
2017		x		x					x	x		x										x	x	x								

Table 11: In-bye fields with Muirkirk and North Lowther Uplands SPA surveyed for waders between 1995-2017. X = survey undertaken and the area of each field surveyed is given in hectares.

Field	Area (ha)	Fields surveyed			
		1995	1999	2009	2017
1	8	X	X		X
2	4	X	X		X
3	3		X		X
4	9		X		X
5	4	X	X		X
6	4	X	X		X
7	3		X	X	X
8	2	X	X	X	X
9	5	X	X	X	X
10	11	X	X	X	X
11	3	X	X		X
12	5	X	X	X	X
13	8	X	X	X	X
14	4	X	X		X
15	6	X	X	X	X
16	3	X	X	X	X
17	4		X	X	X
18	25	X	X		X
19	7		X	X	X
20	5	X	X	X	X
21	6	X	X	X	X
22	5		X	X	X
23	9		X		X
24	7	X	X		X
25	4		X		X
26	11		X		X
27	4	X	X		X
28	5	X	X		X
29	6		X		X
30	6	X	X		X

Table 12: Annual mean (se) percentage rates of change and overall changes in adult red grouse abundance in July on six moors within the Muirkirk and North Lowther SPA between 1992 and 2017 (GWCT data).

Moor	Period	Years counted	% change	% Annual rate of change			
				Constant	Mean (se)	t	P
Dumfries Ho.	1992-2017	7	-86%	60.3	-3.0 (1.2)	-2.49	0.055
Garpel	1992-2017	10	-93%	61.1	-3.0 (0.8)	-3.68	0.006
Glenbuck	1992-1999	8	17%	-83.3	4.2 (4.2)	-1.02	0.35
Logan	1992-2004	9	-31%	-37.4	1.9 (3.1)	0.63	0.55
Muirkirk	1992-2017	14	-86%	134.9	-6.7 (2.3)	-2.96	0.012
Sanquhar	1992-2007	6	-68%	101.1	-3.7 (1.1)	-3.25	0.031

Table 13: Mean (se) breeding success (young/hen) and density (grouse km^{-2}) of red grouse in two time periods at six moors in the Muirkirk and North Lowther SPA. Count-years = the no of counts x no of years in which they were counted (GWCT data).

Moor	Period 1 (1992-97)			Period 2 (2004-08, 17)		
	Count-years	Young/hen	Density (grouse km^{-2})	Count-years	Young/hen	Density (grouse km^{-2})
Dumfries Ho.	4	3.9 (1.0)	76 (22)	10	2.0 (0.4)	30 (6)
Garpel	20	5.9 (0.4)	126 (22)	3	2.5 (1.9)	28 (23)
Glenbuck	8	2.6 (0.7)	48 (6)	0	-	-
Logan	8	2.8 (0.6)	52 (13)	1	2.4 (- -)	40 (--)
Muirkirk	32	4.8 (0.3)	107 (16)	14	1.9 (0.4)	18 (4)
Sanquhar	7	3.4 (0.5)	48 (8)	2	2.3 (0.3)	16 (2)

Table 14: The abundance and linear density (birds/km) of six species of waders in two time-periods on two moors within the Muirkirk and North Lowther Uplands SPA (GWCT data).

Species	Garpel-Limmerhaugh				Muirkirk				% change
	1992-1999 (n=9km)		2009,2017 (n=4.5km)		1992-1999 (n=187km)		2009,2017 (n=57 km)		
	No seen	No/km	No seen	No/km	No seen	No/km	No seen	No/km	
Lapwing	2	0.22	0	-	16	0.09	2	0.04	-56%
Golden plover	0	-	0	-	13	0.07	0	-	-100%
Snipe	1	0.11	0	-	26	0.14	4	0.07	-50%
Redshank	0	-	0	-	5	0.03	0	-	-100%
Oystercatcher	0	-	0	-	5	0.03	5	0.09	300%
Curlew	32	3.56	0	-	318	1.70	60	1.05	-38%

Table 15: The abundance and density of lapwing and redshank within 30 in-bye fields, in the Muirkirk and North Lowther SPA, surveyed in 1995, 1999, 2009 and 2017 (GWCT data).

Year	Area (km^2)	Lapwing	Lapwing /km^2	Redshank	Redshank/km^2
1995	1.26	49	38.8	2	1.6
1999	1.88	60	31.9	7	3.7
2009	1.88	19	10.1	0	0
2017	1.88	11	5.9	0	0
% change 1995-2017			-85%		-100%

Table 16: Numbers of individuals of oystercatcher (OC), golden plover (GP), lapwing (L), dunlin (DN), snipe (SN), curlew (CU), redshank (RK) and common sandpiper (CS) encountered in each of six survey plots in Southern Scotland bird surveys in 1980-82 and 1998, and plot mean percentage change for each species (Easterbee & Pitkin 1984, Smith & Green 2000).

Plot	10 km square	Number of encounters															
		OC		GP		L		DN		SN		CU		RK		CS	
		80-82	1998	80-82	1998	80-82	1998	80-82	1998	80-82	1998	80-82	1998	80-82	1998	80-82	1998
Stab Hill	**2157**	2	0	3	0	6	0	0	0	7	2	186	14	0	0	1	2
Baytes Mine (80-81 max)	**2662**	1	0	297	34	13	0	15	0	30	10	220	42	1	0	3	3
Wee Hill	**2762**	0	0	104	37	16	0	2	0	30	10	155	50	0	0	2	0
Middle Muir (80-82 max)	**2862**	4	0	207	54	264	15	10	4	97	17	453	120	47	1	0	0
Twenty Hill	**2860**	0	1	97	0	117	11	0	0	25	3	521	267	3	0	0	0
Cock Hill	**2860**	0	0	0	0	12	0	0	0	14	1	101	40	0	0	0	0
Mean % change			-33		-71		-98		-43		-78		-71		-50		-8

Table 17: Mean wader abundance (se) expressed as number of individuals (Southern Scotland plots) or number of pairs (SW Scotland plots) from six survey plots in each of the two areas, surveyed in two different time periods (Southern Scotland 1980-82 and 1998; SW Scotland 1989 & 1999) (Easterbee & Pitkin 1984, Brown & Shepherd, 1989, Shepherd 1999, Smith & Green 2000).

	Southern Scotland						SW Scotland					
	1980-82	1998	Survey		Plot		1989	1999	Survey		Plot	
	Mean individuals ± SE	Mean individuals ± SE	$F_{1,5}$	P	$F_{5,5}$	P	Mean pairs ± SE	Mean pairs ± SE	$F_{1,5}$	P	$F_{5,5}$	P
GP	118.0 ± 47.5	20.8 ± 9.7	39.62	<0.001	14.36	0.005	10.0 ± 4.7	6.7 ± 3.3	6.73	0.049	31.99	<0.001
CU	272.7 ± 70.2	88.8 ± 38.5	31.39	0.003	9.10	0.015	23.3 ± 8.2	17.5 ± 6.3	6.08	0.057	40.61	<0.001
L	71.3 ± 42.2	4.3 ± 2.8	294.2	<0.001	94.73	<0.001	8.8 ± 3.9	3.2 ± 1.7	6.43	0.052	5.47	0.043
SN	33.8 ± 13.2	7.2 ± 2.5	93.51	<0.001	24.88	0.002	5.7 ± 2.6	2.7 ± 1.5	2.91	0.15	4.94	0.052
OC	1.2 ± 0.7	0.2 ± 0.2					1.0 ± 0.8	2.0 ± 1.0				
DN	4.5 ± 2.6	0.7 ± 0.7					0.2 ± 0.2	0.3 ± 0.3				
CS	1.0 ± 0.5	0.8 ± 0.5					1.3 ± 0.8	1.8 ± 1.3				
Waders	511.0 ± 150.1	123.0 ± 41.9	84.29	<0.001	18.56	0.003	51.2 ± 18.8	34.5 ± 12.6	56.31	<0.001	221.05	<0.001

Table 18: Number of pairs of oystercatcher (OC), golden plover (GP), lapwing (L), dunlin (DN), snipe (SN), curlew (CU), redshank (RK) and common sandpiper (CS) in each survey plot (total area = 20 tetrads (2 x 2 km) visited in each of 1989 and 1999 within the SW Scotland bird surveys, and plot mean percentage change (Brown & Shepherd 1989, Shepherd 1999).

Plot	OC		GP		L		DN		SN		CU		RK		CS	
	1989	1999	1989	1999	1989	1999	1989	1999	1989	1999	1989	1999	1989	1999	1989	1999
1	1	1	12	5	23	11	0	0	7	5	24	26	2	2	1	1
2	0	0	2	3	1	4	1	0	0	1	17	10	0	0	0	0
3	0	6	32	22	15	2	0	0	11	9	54	40	3	0	2	2
4	0	1	1	1	1	1	0	0	0	0	6	2	0	0	0	0
5	0	0	4	1	0	0	0	0	1	0	1	2	0	0	0	0
6	5	4	9	8	13	1	0	2	15	1	38	25	0	0	5	8
Mean % change		30		-21		12		17		-23		-10		-17		16

Table 19: Density of wader pairs, derived from total survey area of 285km^2, of oystercatcher (OC), golden plover (GP), lapwing (L), dunlin (DN), snipe (SN), curlew (CU), redshank (RK) and common sandpiper (CS) recorded in Muirkirk and North Lowther Uplands SPA during complete survey of the site in 2015 (Starling Learning 2015), compared with densities recorded in 1989 and 1999 on a subset of 80km^2 within the same survey area (Brown & Shepherd 1989, Shepherd 1999).

Species	1989 density (pairs / km^2)	1999 density (pairs / km^2)	2015 density (pairs / km^2)	1989 density (pairs / km^2)	% change 1989 to 2015
OC	0.08	0.15	0.09	0.08	-11
GP	0.75	0.50	0.12	0.75	-84
L	0.66	0.24	0.08	0.66	-88
DN	0.01	0.03	0.03	0.01	-
SN	0.43	0.20	0.33	0.43	30
CU	1.75	1.31	0.69	1.75	-61
RK	-	-	0.02	-	-
CS	0.10	0.14	0.13	0.10	-23
RP	-	-	0.01	-	-

Table 20: Mean red grouse, hen harrier and predator (carrion crow and red fox) indices (± SE) during periods when Langholm moor was managed for grouse by gamekeepers and when it was unmanaged. N = number of years in each period. Calculation of abundance indices varied between species: [1] count data (grouse km^{-2}), [2] breeding female harriers, [3] crows km^{-1}, [4] scat index (scats/km/10 days). Note that grouse spring density in 2008 was assigned to the unmanaged period (Ludwig et al. 2017).

Species	1992-1999 (n) Managed	2000-2007 (n) Unmanaged	2008-2015 (n) Managed	
Grouse spring[1]	(7) 28.40 ± 2.88	(8) 11.65 ± 1.03	(7) 25.60 ± 2.55	$F_{2,19} = 17.11$, $p = 0.001$
Grouse July[1]	(8) 58.65 ± 7.20	(8) 14.22 ± 1.92	(8) 48.60 ± 6.99	$F_{2,21} = 15.60$, $p = 0.001$
Hen harrier[2]	(8) 11.25 ± 2.14	(8) 4.38 ± 0.94	(8) 3.88 ± 1.41	$F_{2,21} = 6.79$, $p = 0.005$
Carrion crow[3]	(8) 0.09 ± 0.04	(8) 0.31 ± 0.07	(8) 0.15 ± 0.08	$F_{2,21} = 3.36$, $p = 0.054$
Red fox[4]	N/A	(5) 0.31 ± 0.01	(8) 0.11 ± 0.05	$F_{1,11} = 14.73$, $p = 0.003$

Table 21: Mean annual change (se) in numbers of breeding waders estimated as change in birds per km of transect from 30 km of transect within 15 1-km grid squares at Langholm Moor over the period 1992-2016 (Baines *et al.* 2008, Langholm Moor Demonstration Project).

Species	Intercept (se)	Estimate (se)	$t_{(22)}$	P
Curlew	98.9 (30.9)	-0.049 (0.015)	-3.16	0.005
Golden plover	22.6 (6.7)	-0.011 (0.003)	-3.35	0.003
Snipe	-40.2 (9.9)	0.020 (0.005)	4.09	<0.001
Lapwing	30.2 (11.1)	-0.015 (0.006)	-2.69	0.013

Table 22: Mean wader abundance (se) expressed as birds per km of transect from 30 km of transect in 15 1-km grid squares within three defined time periods; 1992-99 when keepered, 2000-08 when keepering stopped and 2009-2016 when keepering was resumed as part of the Langholm Moor Demonstration Project (Baines *et al.* 2008, Langholm Moor Demonstration Project).

Species	Keepered 1992-99	Unkeepered 2000-08	Keepered 2009-16	Test of Period	
				$F_{2,22}$	P
Curlew	1.77 (0.20)	0.96 (0.19)	0.73 (0.13)	9.63	0.001
Golden plover	0.40 (0.04)	0.27 (0.05)	0.20 (0.03)	5.98	0.008
Snipe	0.06 (0.02)	0.32 (0.08)	0.37 (0.08)	6.24	0.007
Lapwing	0.38 (0.10)	0.02 (0.01)	0.05 (0.01)	12.73	<0.001