SCOTTISH POLICY GROUP
BRITISH ECOLOGICAL SOCIETY

Stakeholder questionnaire from the Grouse Moor Management Group

A response from the British Ecological Society Scottish Policy Group to the stakeholder questionnaire.

19 September 2018

The British Ecological Society: 'A world inspired, informed and influenced by ecology'

Founded in 1913, we are the world's oldest ecological society, with over 6,400 members worldwide. As the voice of the UK's ecological community, we communicate the value of ecological knowledge to policymakers and promote evidence-informed solutions.

The Scottish Policy Group (SPG) is a group of British Ecological Society (BES) members promoting the use of ecological knowledge in Scotland. We act as a focal point to provide robust ecological evidence to the Scottish Government, Scottish Parliament and wider society.

The BES Scottish Policy Group welcomes the opportunity to contribute to the Grouse Moor Management Group's invitation to respond to the stakeholder questionnaire. Our approach to the questionnaire is in line with the BES position: *to make the best scientific evidence accessible to decision-makers* and is based on the expertise of our membership. As such, we have responded to a select number of questions where our answers can be supported by evidence. For some questions we received a substantial amount of information and papers, therefore some of the responses to the questions are longer than the suggested 400 words. It should also be noted that this response has been approved by the BES Policy Committee and signed off by the BES Scottish Policy Group Committee.

Raptor conservation and predation management

1: Do you consider that illegal killing of raptors is seriously affecting their conservation in Scotland? Is this connected with grouse moor management? Please supply the evidence supporting your view.

Key points:
Circumstantial evidence suggests that illegal killing of raptors is ongoing and appears to be especially prevalent on grouse moorlands which undertake management activities that are strongly associated with driven grouse shooting. Illegal killing appears to be affecting the distribution and abundance of several raptors such as golden eagle, red kite and hen harrier.

Illegal behaviour is hard to quantify. However, there is circumstantial evidence to suggest that this activity is ongoing and, at least for certain raptor species, appears to be especially prevalent on grouse moorlands which undertake management activities that are strongly associated with driven grouse shooting. As to whether this is "seriously affecting their conservation", that depends on what this phrase actually means. Illegal killing appears to be affecting the distribution and abundance of several raptors such as golden eagle, red kite and hen harrier. Current use of satellite tagging systems may help provide better estimates of illegal activity – for instance, in the recent publication by Whitfield and Fielding (2017) on golden eagles.

In support of this statement we have provided evidence highlighting key points as appropriate for four raptor species. For brevity we have listed additional scientific papers as well as those mentioned in each section to help support the above statement.

Hen harrier

Several scientific studies (Sim et al. 2007; Fielding et al. 2011; Hayhow et al. 2013) have found that breeding hen harrier numbers in the UK are lower in areas associated with the management of grouse moors (e.g. in southern and eastern Scotland and the north of England) and these studies infer that this is due to illegal killing of hen harriers. Etheridge et al. (1997) study focussed on the illegal killing of hen harriers in Scotland and they suggested that the low productivity and survival of hen harriers on grouse moors compared to other habitats was attributed to illegal human interference.

Although the hen harrier conservation status in England is thought of as being much worse than in Scotland it is important to note that there are very few hen harriers breeding on Scotland's grouse moors, and in this respect, Scotland presents a similar pattern to that found on England's grouse moors. For instance, in the 1990s the annual survival rates of female hen harriers breeding on grouse moors in Scotland was about half that of females breeding on other moorland (Etheridge et al. 1997). National surveys (Wotton et al. 2016) continue to show that declines in hen harriers have been most acute on areas that are intensively managed for grouse across the UK, including Scotland. Wotton et al. (2016) found that hen harrier numbers on grouse moors in Scotland declined significantly by 57% between 2010 and 2016 although numbers on other heather moors remained stable. Redpath et al (2010) have commented for UK grouse moors: *"The absence of breeding hen harriers from many grouse moors suggests that some, possibly many, grouse moor managers will not tolerate even one pair of hen harriers on their land".* According to modelling analysis they estimated that driven grouse moors across the UK (in the absence of persecution), should support about 500 successful hen harrier pairs in total each year". However, in 2008 there were just five successful pairs of hen harrier on driven grouse moors in the whole of the UK (Redpath et al. 2010).

Scotland is the stronghold for hen harriers in the UK because it has a larger proportion of suitable habitat *outwith* grouse moors and these areas generally support a higher number of hen harrier young per nest compared to grouse moors (Fielding et al. 2011). Even so, the hen harrier population in Scotland has not reached its full potential. Fielding et al (2011) estimated that the hen harrier population could reach 1467–1790 pairs based on the distribution of suitable habitat and the average breeding density of this species. This compares to the recent national hen harrier survey (Wotton et al 2016), which produced an estimate of 460 (confidence interval: 359–573) territorial pairs in Scotland.

Papers:

- Etheridge, B., Summers, R.W. and Green, R.E., (1997). The effects of illegal killing and destruction of nests by humans on the population dynamics of the hen harrier *Circus cyaneus* in Scotland. Journal of Applied Ecology. pp. 1081-1105.
- Fielding, A., Haworth, P., Whitfield, P., McLeod, D. and Riley, H., (2011). A Conservation Framework for Hen Harriers in the United Kingdom. JNCC Report, no. 441.
- Hayhow, D. B., Eaton M. A., Bladwell, S., Etheridge B., Ewing, S., Ruddock, M., Saunders, R., Sharpe, C., Sim I. M. W., Stevenson, A. (2013).The status of the Hen Harrier, *Circus cyaneus*, in the UK and Isle of Man in 2010. Bird Study. 60 pp. 446-458.
- Natural England (2008). A future for the hen harrier in England? Natural England, Sheffield.
- Rebecca, G., Cosnette, B., Craib, J., Duncan, A., Etheridge, B., Francis, I., Hardey, J., Pout, A., Steele, L. (2016). The past, current and potential status of breeding Hen Harriers in North-east Scotland. British Birds. 109 pp. 77-95.
- Redpath, S.M., Amar, A., Smith, A., Thompson, D.B. and Thirgood, S., (2010). People and nature in conflict: can we reconcile hen harrier conservation and game management. Species Management: Challenges and Solutions for the 21st Century. pp. 335-350.
- Sim I. M.W., Dillon I. A., Eaton M. A., Etheridge B., Lindley P., Riley H., Saunders R., Sharpe C., Tickner M. (2007). Status of the Hen Harrier *Circus cyaneus* in the UK and Isle of Man in 2004, and a comparison with the 1988/89 and 1998 surveys. Bird Study. 54 pp. 256-267.

- Wotton S. R., Bladwell, S., Mattingley W., Morris, N. G., Raw, D., Ruddock, M., Stevenson, A., Eaton, M. A. (2016) Status of the Hen Harrier *Circus cyaneus* in the UK and Isle of Man in 2016. Bird Study. 65 pp. 145-160.

Golden Eagle
Whitfield et al. (2004) used data from two national censuses of golden eagle populations in Scotland (1982 and 1992) as well as data on poisoning incidents from 1982-2001 to model the effects of illegal persecution on the population dynamics of the golden eagle in Scotland. The results of modelling showed golden eagle persecution associated with illegal poisoning and strongly linked with actively managed grouse moors (Whitfield 2003), led to a reduction in the age of first breeding, increased territory vacancies, and an increased use of territories by non-breeding immature golden eagles. In areas of grouse moors this persecution created 'black holes' or 'ecological traps' where immature adults moved in to unoccupied territories increasing mortality rates amongst young birds, and adversely affecting golden eagle population dynamics over a much wider area. They concluded that persecution, associated with grouse moor management may be having a major impact on the golden eagle population of Scotland.

Their findings are further supported by Whitfield and Fielding's study (2017) investigating the fate of satellite tracked young golden eagles in Scotland from 2004-2016. Their analysis showed there was a pattern in the sudden failure to transmit for many tagged young eagles, and that corroborative information pointed to the perpetrators of the persecution of tagged young eagles being associated with some grouse moors in the central and eastern Highlands of Scotland. They concluded that the illegal persecution of young golden eagles on some grouse moors, largely in the central and eastern Highlands, was a major reason why Scotland's golden eagle population is artificially restricted in these areas. Such illegal killing potentially has consequences for the future golden eagle population's growth within mainland Scotland.

Papers:

- Watson, J., Whitfield, P. (2002). A conservation framework for the golden eagle *Aquila chrysaetos* in Scotland. Journal of Raptor Research. 36 (1 Suppl.), pp. 41-49.
- Whitfield, D.P., Fielding, A.H., McLeod, D.R.A. Haworth, P.F. (2004). The effects of persecution on age of breeding and territory occupation in golden eagles in Scotland. Biological Conservation. 118, 2, pp. 249-259.
- Whitfield, D.P., Fielding A.H., McLeod D.R.A., Haworth P.F. (2004). "Modelling the effects of persecution on the population dynamics of golden eagles in Scotland." Biological Conservation 119, 3, pp. 319-333.
- Whitfield, D.P., Fielding A.H., McLeod D.R.A., Haworth P.F., Watson J. (2006). "A conservation framework for the golden eagle in Scotland: refining condition targets and assessment of constraint influences." Biological Conservation. 130, 4, pp. 465-480.
- Whitfield, D. P. and Fielding, A.H. (2017). Analyses of the fates of satellite tracked golden eagles in Scotland. SNH commissioned report 982.

Red Kite
Smart et al. (2017), using data from 708 tagged red kite chicks collected from 1989 (when red kites were reintroduced to the north of Scotland) to 2006, found there was a lower than expected survival rate of dispersing red kites from the north of Scotland population, and this low survival rate was the main cause of the lack of population growth of red kites in this area. Illegal killing was the main cause of mortality with 55% of red kites (where cause of death could be determined) being killed illegally, mainly by direct poisoning. Coupled with this, the predicted population growth of the red kite population in this area since they were first released in 1989 (> 100 by 2007; Evans et al. 1999) has never materialised. The population growth rate is only half of what was expected, compared to other red kite reintroduction areas in the UK such as the Chilterns, which saw the red kite population achieve its predicted potential (> 100) by 1998 (Evans et al. 1999). The authors of the paper note that the reintroduction area in the north of Scotland is surrounded by grouse moors and it appears that the young birds succumb to illegal persecution as they disperse into these areas. They go on to state that if this killing is not reduced or eliminated, this northern population of red kite will at best only increase slowly.

Papers:

- Evans, I.M., Summers, R.W., O'Toole, L., Orr-Ewing, D.C., Evans, R., Snell, N., Smith, J. (1999). Evaluating the success of translocating Red Kites *Milvus milvus* to the UK. Bird Study. 46, pp. 129-144.

- Smart, J., Amar, A., Sim, I.M., Etheridge, B., Cameron, D., Christie, G. and Wilson, J.D. (2010). Illegal killing slows population recovery of a re-introduced raptor of high conservation concern–the red kite *Milvus milvus*. Biological Conservation. 143, 5, pp. 1278-1286.

Peregrine falcon
Amar et al. (2012) tested whether breeding performance of peregrine falcons differed between grouse moor and non-grouse moor habitats across all of the uplands of northern England, excluding the Lake District. They analysed data collected between 1980 and 2006 from 1081 peregrine nest histories, combined with remotely sensed mapping of grouse moor management across this area. They found that productivity of peregrines on grouse moors was far lower than that recorded on non-grouse moors and these differences were consistent across almost all of the regions within their study area. The low productivity was similar to that found during the era of organo-chlorine pesticides use. There has not been such a large-scale study conducted in Scotland, but at a local level, similar patterns of low peregrine productivity associated with upland grouse moor habitats, compared to other habitats (e.g. coastal, lowland farmland and deer forest) were described in north east Scotland using peregrine survey data collected in 2014 (North East Scotland Raptor Study Group 2015).

Papers:
- Amar, A., Davison, M., Downing, S., Grimshaw, T., Pickford, T. and Raw, D. (2012). Linking nest histories, remotely sensed land use data and wildlife crime records to explore the impact of grouse moor management on peregrine falcon populations. Biological Conservation. 145, 1, pp.86-94.
- North East Scotland Raptor Study Group (2015). Peregrines in North-East Scotland in 2014 – further decline in the uplands. Scottish Birds. 35, 3 pp. 202-206.

2: How might the illegal killing of raptors be reduced?

Key points:
Various approaches have been suggested to reduce the illegal killing of raptors. Focussing solely on coercion may work, but it may also be problematic risking non-compliance; whilst more collaborative strategies would require careful set-up, strong leadership, long-term resources and the commitment from Government to support actions arising.

Various approaches have been suggested in the literature/ peer reviewed publications and by environmental organisations regarding changing the behaviour of those involved in illegal killing of raptors including:

- Banning of certain types of shooting (e.g. Raptor Persecution UK[1])
- Licencing of grouse moors (e.g. RSPB Scotland and Scottish Wildlife Trust position, Scottish Raptor Study Group[2])
- Technical solutions to reduce impact of raptors on game (e.g. Thirgood et al. 2000; Redpath et al. 2001) (See also answer to Question 4 below.)

In England, Defra (2016) have developed a management plan for hen harriers with key stakeholder groups that includes more monitoring, feeding, reintroductions and the brood management scheme (Elston et al. 2014).

A sole focus on coercion through, for example, licensing may work, but it may also be problematic, potentially leading to risks of non-compliance. An alternative approach is to focus on developing more collaborative strategies (Redpath et al. 2013, 2017; Pooley & Redpath 2018). Dialogue would require careful set-up, strong leadership, long-term resources and the commitment from government to support actions arising (Thirgood and Redpath 2008). It may also be hard to bring stakeholders to the table, given the lack of success in England.

The answer to this question also partly depends on the goal. If the goal is to find ways that raptor conservation and grouse management can coexist in the absence of illegal killing, then it seems likely that the best approach

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[1] See: Raptor Persecution UK website: https://raptorpersecutionscotland.wordpress.com/
[2] See: Scottish Wildlife Trust Living Landscapes in the Scottish Uplands Policy; Scottish Raptor Study Group petition: State regulated licensing system for gamebird hunting in Scotland https://www.parliament.scot/GettingInvolved/Petitions/PE01615; RSPB Scotland press release (24/11/2017): https://www.rspb.org.uk/about-the-rspb/about-us/media-centre/press-releases/rspb-and-srsg-welcome-announcement-of-grouse-moor-enquiry/

will have to involve dialogue, and the building of trust and relationships (Madden and McQuinn 2014). The development of an adaptive co-management approach has worked well in other conflicts (Butler et al. 2008, 2015), but this does require the active involvement of all parties including the Government maintaining a strong and consistent role throughout the process (Butler et al. 2015).

In the specific case of hen harriers, licencing of grouse moors may help reduce illegal killing, but may also prove hard to police. A brood management scheme (Elston et al. 2014) may be more acceptable to grouse moor managers, because allowing harriers to breed on their land under such a scheme will not result in high densities and the loss of their grouse shooting. However, brood management is controversial and will not be accepted by some stakeholders.

It should also be noted that the above question is one which criminologists and social scientists may be well placed to help answer (Wellsmith 20011; Gibbs et al. 2010; Gore 2011). For instance, Gore (2011) states, regarding human behaviour, that: "*Conservation criminology offers a framework for effectively dissecting the criminological aspects of the human-environment interface through integration of the three traditionally disparate fields of criminology and criminal justice (historically focused on understanding human behaviour and crime control), natural resource conservation and management (traditionally focused on understanding natural systems and their interactions), and formal risk and decision sciences (originally concentrated on expert, technical, and systematic approaches to characterizing risks".*

Papers:

- Butler, J.R., Middlemas, S.J., McKelvey, S.A., McMyn, I., Leyshon, B., Walker, I., Thompson, P.M., Boyd, I.L., Duck, C., Armstrong, J.D. and Graham, I.M. (2008). The Moray Firth Seal Management Plan: an adaptive framework for balancing the conservation of seals, salmon, fisheries and wildlife tourism in the UK. Aquatic Conservation: Marine and Freshwater Ecosystems. 18, 6 pp. 1025-1038.
- Butler, J.R.A., Young, J.C., McMyn, I.A.G., Leyshon, B., Graham, I.M., Walker, I., Baxter, J.M., Dodd, J. and Warburton, C. (2015). Evaluating adaptive co-management as conservation conflict resolution: learning from seals and salmon. Journal of environmental management. 160, pp. 212-225.
- Defra (2016) Joint action plan to increase the English hen harrier population. https://www.gov.uk/government/publications/increasing-hen-harrier-populations-in-england-action-plan
- Elston, D.A., Spezia, L., Baines, D., Redpath, S.M. (2014). Working with stakeholders to reduce conflict–modelling the impact of varying hen harrier Circus cyaneus densities on red grouse Lagopus populations. Journal of applied ecology. 51, 5, pp. 1236-1245.
- Gibbs, C., Gore, M. L., McGarrell, E. F., & Rivers, L. (2010). Introducing Conservation Criminology; Towards interdisciplinary scholarship on environmental crimes and risks. British Journal of Criminology. 50, 1 pp. 124-44.
- Gore M. L. (2011). The Science of Conservation Crime. Conservation Biology. 25, 4, pp. 659-661.
- Madden, F. and McQuinn, B. (2014). Conservation's blind spot: the case for conflict transformation in wildlife conservation. Biological Conservation. 178, pp. 97-106.
- Pooley, S. and Redpath, S. (2018). Speaking up for collaboration in conservation: A response to Vucetich et al.(2018) Just conservation: What is it and should we pursue it?. Biological Conservation. 223, pp. 186-187.
- Redpath, S.M., Linnell, J.D., Festa‐Bianchet, M., Boitani, L., Bunnefeld, N., Dickman, A., Gutiérrez, R.J., Irvine, R.J., Johansson, M., Majić, A. and McMahon, B.J. (2017). Don't forget to look down–collaborative approaches to predator conservation. Biological Reviews. 92, 4, pp. 2157-2163.
- Redpath, S.M., Thirgood, S.J. and Leckie, F.M. (2001). Does supplementary feeding reduce predation of red grouse by hen harriers? Journal of Applied Ecology. 38 (6), pp. 1157-1168.
- Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D., Watt, A. and Gutierrez, R.J. (2013). Understanding and managing conservation conflicts. Trends in ecology & evolution. 28, 2, pp. 100-109.
- Thirgood, S., Redpath, S., Newton, I. and Hudson, P. (2000). Raptors and red grouse: conservation conflicts and management solutions. Conservation Biology. 14, 1, pp. 95-104.
- Thirgood, S. and Redpath, S. (2008). Hen harriers and red grouse: science, politics and human–wildlife conflict. Journal of Applied Ecology. 45, 5 pp. 1550-1554.

- Wellsmith, M. (2011) Wildlife Crime: The Problems of Enforcement. European Journal of Criminal Policy Research. 17, pp. 125-148. https://doi.org/10.1007/s10610-011-9140-4

4: What actions/principles might reduce the impact of raptor predation on grouse?

Various studies have explored non-lethal approaches (Thirgood et al. 2000; Redpath et al. 2010; Elston et al. 2014). These vary from reducing raptor density (Elston et al. 2014), reducing predation rate (Redpath et al. 2001), or managing habitat to reduce encounter rate (Redpath et al. 2001).

Diversionary feeding is the only technique that has been experimentally tested (Redpath et al. 2001), and it has been shown to be effective at reducing predation rate of hen harriers on grouse chicks (but see answer to Question 8).

Papers:

- Elston, D.A., Spezia, L., Baines, D. and Redpath, S.M. (2014). Working with stakeholders to reduce conflict–modelling the impact of varying hen harrier Circus cyaneus densities on red grouse Lagopus populations. Journal of Applied Ecology. 51, 5, pp. 1236-1245.
- Redpath, S.M., Thirgood, S.J. and Leckie, F.M. (2001). Does supplementary feeding reduce predation of red grouse by hen harriers? Journal of Applied Ecology. 38, 6 pp. 1157-1168.
- Redpath, S.M., Amar, A., Smith, A., Thompson, D.B. and Thirgood, S. (2010). People and nature in conflict: can we reconcile hen harrier conservation and game management. Species Management: Challenges and Solutions for the 21st Century. pp. 335-350.
- Thirgood, S., Redpath, S., Newton, I. and Hudson, P. (2000). Raptors and red grouse: conservation conflicts and management solutions. Conservation Biology. 14, 1, pp. 95-104.

***5: Which predator species do you regard as most important in limiting grouse? Please supply the evidence supporting your named species*.**

Key points:
Research shows the main species involved in limiting grouse populations are red foxes and crows; in certain conditions hen harriers and peregrine falcons can also limit grouse populations. However, more research is needed using long term studies, before the above question can be definitively answered.

Results from research at Otterburn (Northumberland, England) and Langholm (southern Scotland) strongly suggest that the main species involved in limiting grouse populations are red foxes and crows (Fletcher et al. 2010). In certain conditions hen harriers and peregrine falcons can also limit grouse populations (Redpath & Thirgood 1999; Thirgood et al. 2000). Many other species take grouse, but evidence for them having a strong limiting effect on grouse populations is not clear and more research is needed using long term studies, before this question can be definitively answered. For example, Francksen (2015) examined buzzard predation on red grouse at Langholm Moor over four years (which the researcher acknowledged was a short time period - length of his PhD - and limited some of the study's findings). It was found that buzzard predation of grouse appeared to be driven by changes in vole abundance which affected the relative attractiveness of heather moorland to foraging buzzards. The author acknowledged that more research was needed to investigate the effectiveness of diverting buzzards away from grouse habitats, either by making these habitats less attractive or by providing alternative habitats and food resources away from grouse habitats.

Papers:

- Fletcher, K., Aebischer, N.J., Baines, D., Foster, R. and Hoodless, A.N. (2010). Changes in breeding success and abundance of ground-nesting moorland birds in relation to the experimental deployment of legal predator control. Journal of Applied Ecology. 4, 2 pp. 263-272.
- Francksen, R.M. (2015). Exploring the impact of common buzzard *Buteo* predation on red grouse *Lagopus scotica*. Unpublished PhD thesis. Newcastle University. Available at https://theses.ncl.ac.uk/dspace/bitstream/10443/3365/1/Francksen%2c%20R%202016.pdf
- Francksen, R.F., Whittingham, M.J., Ludwig, S.C., Roos, S., Baines, D. (2017). Numerical and functional responses of common buzzard *Buteo* on a Scottish grouse moor. Ibis. 159, pp. 541-553.

- Redpath, S.M. and Thirgood, S.J. (1999). Numerical and functional responses in generalist predators: hen harriers and peregrines on Scottish grouse moors. Journal of Animal Ecology, 68, 5, pp.879-892.
- Thirgood, S.J., Redpath, S.M., Rothery, P. and Aebischer, N.J. (2000). Raptor predation and population limitation in red grouse. Journal of Animal Ecology. 69, 3, pp. 504-516.

8: Is 'diversionary feeding' (providing alternative food at raptor nests for broods) to reduce raptor predation on grouse a workable method?

Key point:
This depends on what is meant by a 'workable' method'. Diversionary feeding has been shown to increase grouse chick numbers, but the resulting increase in grouse density may not be sufficient to make driven grouse shooting economically viable.

The Langholm demonstration project, which has been providing diversionary feeding for hen harriers for ten years and other forms of management for 23 years, has not resulted in a sufficient rate of grouse recovery (current recovery has seen a 2-3-fold increase in the number of grouse chicks when the moorland is actively managed) to a density of grouse that makes driven grouse shooting economically viable[3]. This is because costs incurred per year to manage the moorland are high and include habitat management, diversionary feeding, generalist predator control, fencing, laying new tracks and heather reseeding. The rate of grouse recovery may also be compounded by other avian predators being present on the moorland that predate on grouse. However, it is acknowledged that it is difficult to separate signs of the different raptor species predation (Thirgood et al. 1998) so, the relative impact of individual raptor species on grouse is unknown. The most recent report from the Langholm project (Ludwig et al. 2017) concluded that an adequate solution to resolving the existing conservation conflict still remains to be found, and on-going analyses will consider which factors are most important in preventing full grouse recovery.

References:

- Langholm demonstration project http://www.langholmproject.com/index.html
- Ludwig S.C., Roos S., Bubb D., Baines D. (2017). Long-term trends in abundance and breeding success of red grouse and hen harriers in relation to changing management of a Scottish grouse moor. Wildlife Biology doi: 10.2981/wlb.00246.
- Redpath, S.M., Thirgood, S.J. and Leckie, F.M. (2001). Does supplementary feeding reduce predation of red grouse by hen harriers? Journal of Applied Ecology. 38, 6 pp. 1157-1168.
- Thirgood, S.J., Redpath, S.M., Hudson, P.J., Donelly, E. (1998). Estimating the cause and rate of mortality in red grouse *Lagopus lagopus scoticus*. Wildlife Biology. 4,2 pp. 68-71.

9: Do you have any evidence that the presence of golden eagles nesting on a moor limit or reduce the number of smaller, grouse-eating raptors which occur there (such as hen harriers or peregrines)?

Key point:
There is neither strong evidence to support or reject the hypothesis regarding golden eagles limiting or reducing numbers of smaller raptors.

Currently there is neither strong evidence to support or reject this hypothesis regarding golden eagles. Thompson et al. (2009) have suggested more research is needed to assess whether recovery of golden eagle populations could assist in limiting predatory impacts of hen harriers on grouse populations. However, there is evidence of intraguild predation (the killing/eating of potential competitors) for other species and the evidence is outlined below; anecdotal evidence from observations in Scotland regarding golden eagle interactions with other raptor species is also provided.

There are several studies which demonstrate that larger species can restrict the distribution and/or productivity of some smaller raptors because of intraguild predation. For instance, Sergio et al. (2003) found that eagle owls

[3] For explanation of economic differences between driven vs walked up grouse shooting see: Sotherton, N., Tapper, S., and Smith, A., (2009) Hen harriers and red grouse: economic aspects of red grouse shooting and the implications for moorland conservation. Journal of Applied Ecology. 46, pp. 955–96

preyed on both adult and nestling black kites, especially when kites nested within 2 km of an owl nest. Overall, kites responded to predation risk by owls through avoidance and it was found that the abandonment of kite territories increased near owl nests. However, the two species did still coexist in some places; black kites established new territories in areas of high predation risk and high food abundance – in areas that function as ecological traps (or 'black holes') for the black kite. Sergio et al. (2004) found that where suitable habitat was present, peregrines selected sites near ravens[4] and far from elevations associated with golden eagle nests to avoid predation. Brambillo et al. (2006) found that peregrine productivity was reduced in cliff nesting peregrines that were in close proximity with eagle owl nesting sites.

Fielding et al. (2011) state that golden eagles are known to take hen harriers and other smaller raptors. Their cited examples include: a golden eagle being observed predating a hen harrier nest on Jura in 2005, a hen harrier chick being seen in a golden eagle nest on Mull in 2008 and male hen harrier feathers being found in the prey remains of a golden eagle close to an eyrie in Perthshire in 2005; during monitoring of the Beinn an Tuirc wind farm in Argyll, an adult hen harrier was predated by one of the resident golden eagles. On the Uists, hen harriers and other raptor species were found to show significant avoidance of areas within 2 km of golden eagle nests (Haworth et al. 2010 cited in Fielding et al. 2011) .

Papers:

- Brambilla M., Rubolini, D., Guidali, F. (2006). Eagle Owl *Bubo* proximity can lower productivity of cliff-nesting Peregrines *Falco peregrinus.* Ornis Fennica. 83 pp. 20-26.
- Fielding, A., Haworth, P., Whitfield, P., McLeod, D. and Riley, H. (2011). A Conservation Framework for Hen Harriers in the United Kingdom. JNCC Report, no. 441.
- Haworth, P. F., Fielding, A. H., and Reid R. (2010). Numbers, distribution and productivity of key raptor species breeding in Benbecula, Barra and Uists. Report to Scottish Natural Heritage, contract no. 26711. Haworth Conservation, Mull.
- Sergio, F., Marchesi, L., Pedrini, P. (2003). Spatial refugia and the coexistence of a diurnal raptor with its intraguild owl predator. Journal of Anima Ecology. 72 pp. 232-245.
- Sergio, F., Rizzolli, F., Marchesi, L. & Pedrini, P. (2004). The importance of interspecific interactions for breeding-site selection: peregrine falcons seek proximity to raven nests. Ecography. 27 pp. 818-826.
- Thompson, P.S., Amar, A., Hoccom, D.G., Knott, J., Wilson, J.D. (2009). Resolving the conflict between driven-grouse shooting and conservation of hen harriers Journal of Applied Ecology. 46, pp. 950–954

Muirburn

10: In your experience has the frequency of moorland management fires increased or decreased in recent years? Please supply the evidence supporting your view.

Key point:
The frequency of fires on moorlands managed for grouse has increased in recent years.

A recent study (detailed below) shows the frequency of fires on moorlands managed for grouse has increased in recent years.

Douglas et al. (2015) investigated the frequency of fires on moorlands managed for grouse covering Scotland, Wales and England. Using remotely sensed data (at a 1 km resolution) they mapped burning on moorlands managed for grouse across c 45000 km^2 of the UK. The pattern of strip burning was readily visible on high resolution aerial and satellite images, which allowed fine-scale repeatable mapping over large areas. The heat generated by the fires (muirburn) was detectable by fire monitoring satellites (although an unknown proportion of fires remained undetected because of cloudy days – therefore the authors' estimates of number of fires were conservative). The researchers were also able to assess the extent of burning on deep peat and on protected nature conservation sites.

[4] Sergio et al. (2004) suggested a number of reasons for this behaviour including (1) the fact that ravens are extremely aggressive near their nest towards potential terrestrial and aerial predators and will chase them with calls which can be heard from very far away, potentially alerting peregrines of incoming danger (2) Peregrines often use raven nests for laying and as ravens build many alternative nests, a raven pair nearby may provide peregrines with many alternative, high-quality nest-sites.

It was found that the annual number of burning events on moorlands managed for grouse had increased significantly from 2001 to 2011 at a rate of c 11% per annum across the UK. There were no significant difference in annual burn trends between the three countries. They also found that nearly a third of burning in Scotland was on peat ≥ 0.5 m in depth (i.e. deep peat). Across the UK, burning was detected within 55% of Special Areas of Conservation and 63% of Special Protection Areas that were assessed, and the proportion of moorland burned was significantly higher inside sites than on comparable squares outside protected areas. The annual numbers of total burns increased from 2001 to 2011 irrespective of peat depth.

Paper:

- Douglas, D.J., Buchanan, G.M., Thompson, P., Amar, A., Fielding, D.A., Redpath, S.M., Wilson, J.D. (2015). Vegetation burning for game management in the UK uplands is increasing and overlaps spatially with soil carbon and protected areas. Biological Conservation. 191, pp. 243-250.

12: If you are involved in muirburn, what intensity of burn is necessary for successful heather regeneration? What proportion of muirburn burns affects the moss/litter layer as well as heather. What difference does this make to vegetation recovery?

See answer to Question 13 below regarding effects of burning on *Sphagnum* spp.

13: What are the relative merits of burning versus cutting on grouse moors? Please supply the evidence supporting your view.

Key point:
Decisions regarding whether to burn or cut heather to achieve sporting objectives on moorlands managed for grouse should not be considered in isolation, as burning on peatlands has been shown to have a number of negative environmental impacts.

Decisions regarding whether to burn or cut heather to achieve sporting objectives on moorlands managed for grouse should not be considered in isolation. Rather, the long-term environmental effects should be viewed more widely, particularly in areas of moorland with peatland cover that fall within a rotational burning regime. Burning on peatlands (which is discouraged in the Muirburn Code[5]) has been shown to have a number of negative environmental impacts which may lead to undesirable ecological outcomes occurring locally, at the catchment scale or globally if there is an increase in greenhouse gas emissions.

Evidence in support of this statement is given below.

Changes in peatland stream ecosystems
Brown et al. (2013) and Ramchunder et al. (2013) investigated stream macroinvertebrate communities from ten headwater peatland catchments in northern England as part of a major NERC-funded project (EMBER) on muirburn, at the University of Leeds. They sampled from five streams with no burning regime on the peatland sites in the catchment and from five streams which were in a catchment that was subject to rotational burning as part of moorland management. It was found that the streams within the catchments that underwent rotational burning had significantly greater dissolved organic matter, sulphate, nitrate, fine particulate organic matter (FPOM) and suspended sediments concentration (SSC) compared to those that had no burning in the catchment. Coupled with this, they found significant differences in stream macroinvertebrate richness, diversity and dominance, and community composition between burned and intact catchments, suggesting that burning management had an effect on aquatic ecosystems. Stream macroinvertebrate diversity was reduced in burned sites. For example, increased SSC and FPOM in burned catchments were both associated with lower abundance of some species of mayfly, stonefly, and caddis-fly and elevated abundance of some Diptera larvae. Grazer and collector-gatherer feeding groups were also significantly less abundant in rivers draining burned catchments. These biotic changes were associated with lower pH and higher silicon, manganese, iron and aluminium in burned systems.

[5] Muirburn Code currently states: *Burning should not take place on peatland, except as part of a habitat restoration plan, approved by SNH and Areas with peat hags, bare peat or erosion should not be burnt.*

Changes in blanket peat hydrology
Holden et al. (2015) investigated peatland hydrology from ten headwater catchments in northern England (using the same comparative sites described above). They found that those peatland sites subjected to prescribed vegetation burning had significantly deeper water tables compared to those that had no burning. Brown et al. (2014) suggested that a deeper water table could lead to peat degradation and loss of carbon to the atmosphere. In terms of river flow in catchments where burning has taken place, it appears to be slightly more prone to higher flow peaks (flooding) during heavy rain. Other work by the University of Leeds team (e.g. Holden et al. 2008; Gao et al. 2016) has shown that dense *Sphagnum* cover is very effective at slowing flow and reducing river flow peaks and so peatland ecology and hydrological response are directly connected.

Greater peat temperature extremes
Brown et al. (2015) monitored the soil thermal regime across 12 burned peatland plots over an 18-month period with the aim of quantifying thermal dynamics between burned plots of different ages (from < 2 to 15 years post burning). They found that recently burned plots (< 2 - 4 years) showed a greater range of soil temperature extremes, with the greatest effects being at the soil surface, compared to those plots that had been burnt 15 years ago. Their findings led them to calls for further research to better understand the impacts of such long-term temperature change on soil ecology, carbon processing and release, and hydrological processes, in these peatlands.

Changes in vegetation composition
Noble et al. (2018) investigated how muirburn, atmospheric pollution and grazing affected vegetation communities and cover of four key taxa (*Sphagnum* spp., *Calluna vulgaris, Eriophorum vaginatum* and *Campylopus introflexus*) using two datasets from a total of 2,013 plots across 95 peatland sites, which were subject to prescribed burning or no burning and various levels of grazing and atmospheric pollution. They found at a national scale, burned sites had less *Sphagnum spp*. cover (a peat forming moss)*;* this has been found to be related to changes in hydrological properties of the peat (see above) and greater *C. vulgaris* cover. On a regional scale, plots burned between two and ten years ago had greater cover of the invasive moss *C. introflexus* and less *E. vaginatum* than unburned sites. Livestock presence was associated with less *Sphagnum* and *C. vulgaris*, while atmospheric pollution was associated with less *Sphagnum*, but greater *C. introflexus* cover. The authors concluded that to promote a cover of peat-forming species (such as *Sphagnum spp.* and *E. vaginatum*), peatlands should not be routinely burned or heavily grazed. Noble et al. (2017) suggested that bulk density increases caused by fire or drainage can limit *Sphagnum* establishment and growth, potentially threatening peatland function. They also showed that ash inputs from muirburn may have direct benefits for some *Sphagnum* species but are also likely to increase competition from other bryophytes and vascular plants which may offset positive effects. Forthcoming papers (not yet published) have investigated the impact of fire temperature on moss damage by measuring cell death. It has been found that even the 'coolest' muirburn temperatures kill moss cells. In addition, another paper, not yet published, concludes that the idea of conservation burning to remove dense heather to promote *Sphagnum* is not scientifically supported (*Pers. comm*. Professor Joseph Holden, Pro-Dean of Research, Faculty of Environment, University of Leeds).

Some results from a small number of experimental burned plots have contradicted the suggestion that burning is detrimental to peat forming *Sphagnum* species (Lee et al. 2013). However, Brown et al. (2014) suggested that the discrepancy between experimental plot studies and wider studies can be explained by the fact that burning on the wider moorland is subject to less stringent controls regarding burning than in experimental plots and the frequency of fires (see also answer to Question 10 above) as well as the effect of fire penetration into the peat mass may make it difficult for *Sphagnum spp*. to recover in the wider moorland (Thacker et al. 2014).

Papers:

- Brown, L.E., Holden, J., Palmer, S.M., Johnston, K., Ramchunder, S.J., Grayson, R. (2015). Effects of fire on the hydrology, biogeochemistry, and ecology of peatland river systems. Freshwater Science. 34, 4, pp. 1406-1425
- Brown, L.E., Johnston, K.L., Palmer, S., Aspray, K.L., Holden, J**.** (2013) River ecosystem response to prescribed vegetation burning on blanket peatland. PLoS ONE 8 (11): e81023. doi:10.1371/journal.pone.0081023
- Brown, L.E., Holden, J. Palmer, S.M. (2014). Effects of Moorland Burning on the Ecohydrology of River basins. Key findings from the EMBER project. University of Leeds.

- Brown, L. E., Palmer, S.M., Johnston, K., Holden, J. (2015) Vegetation management with fire modifies peatland soil thermal regime. Journal of Environmental Management. 154 pp 166-176.
- Douglas, D.J., Buchanan, G.M., Thompson, P., Amar, A., Fielding, D.A., Redpath, S.M., Wilson, J.D. (2015). Vegetation burning for game management in the UK uplands is increasing and overlaps spatially with soil carbon and protected areas. Biological Conservation. 191 pp.243-250.
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- Gao, J., Holden, J., Kirkby, M.J. (2016). The impact of land-cover change on flood peaks in peatland basins. Water Resources Research**.** 52, 3477-3492.
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- Holden, J., Kirkby, M.J., Lane, S.N., Milledge, D.J., Brookes, C.J., Holden, V., McDonald, A.T. (2008). Factors affecting overland flow velocity in peatlands. Water Resources Research. 44. W06415, doi: 10.1029/2007WR006052.
- Lee, H., Alday, J.G., Rose, R.J., O'Reilly, J., Marrs, R.H. (2013). Long-term effects of rotational prescribed burning and low-intensity sheep grazing on blanket-bog plant communities. Journal of Applied Ecology. 50, pp. 625-635.
- Noble, A., Palmer, S.M., Glaves, D.J., Crowle, A., Holden, J. (2018) Prescribed burning, atmospheric pollution and grazing effects on peatland vegetation composition. Journal of Applied Ecology. 55, 559-569
- Ramchunder, S.J., Brown, L.E., Holden, J. (2013). Rotational vegetation burning effects on peatland stream ecosystems. Journal of Applied Ecology. 50, 3, pp. 636-648
- Thacker, J., Yallop, A. R., Clutterbuck. B. (2014). Burning in the English uplands: a review, reconciliation and comparison of results of Natural England's burn monitoring: 2005-2014. Natural England, Peterborough, UK.
- Worrall, F., Clay, G.D., Marrs, R., Reed, M. S. (2010). Impacts of burning management on peatlands. Report to International Union for the Conservation of Nature, UK Peatland Programme, Edinburgh, Scotland. (Available from: http://randd.defra.gov.uk/Document.aspx?Document=SP0567_9953_FRP.pdf)

3. Mountain Hares

15: Based on your experience of a particular area, have mountain hares increased or decreased in your area? Please provide the associated location and timescale.

Key points:
There has been no mandatory monitoring of mountain hare in Scotland and the current population density is unknow. The most recent survey in the eastern Highlands of Scotland shows a long-term decline in mountain hare density where the survey was carried out, whilst two other surveys show no significant decline in mountain hare abundance at the UK/Scotland level. In all instances there are some potential problems with the methodologies used.

We have not answered this question based on our own experience of a particular area as we do not own or manage land in Scotland. Instead, we describe some of the most relevant and recent results of monitoring that have been carried out in Scotland (and as part of a UK study). It is important to note that there is no mandatory monitoring of mountain hare in Scotland and the current population density is unknown (Newey et al. 2018).

Massimino et al. (2018) modelled mountain hare data collected during the British Trust for Ornithology's Breeding Bird Survey (BBS)[6,7]. In the analysis[8] they compared changes in abundance of mountain hare between 1995-99

[6] Using the British Trust for Ornithology's Breeding Bird Survey (BBS) incidental mammal sightings data.
[7] For BBS methodology see: https://www.bto.org/volunteer-surveys/bbs/research-conservation/methodology
[8] The researchers followed an approach already successfully applied to bird count data from the breeding bird survey to derive maps of relative abundance and change.

and 2011-15 in terms of having increased, decreased, or not changing significantly in randomly chosen 1-km squares that had been surveyed as part of the BBS (see also Harris et al. 2016 for methodology). They did not find a statistically significant decline in mountain hare abundance across the UK.

Data collected by the Game and Wildlife Conservation Trust (National Game Census (NGC) data - mountain hare game bags recording numbers shot), which is a voluntary scheme whereby estates submit records of the number of hares killed each year, showed there were no significant long-term trends in decline[9] in game bag numbers for mountain hares (Aebischer et al. 2011). The most recent report (Aebischer 2014) suggests an increase in mountain hares over the five-year period 2010 to 2014, which the author suggests is due to natural population cycling - whereby the mountain hare has been in an 'up phase' of the cycle (for further information regarding the cyclic dynamics of mountain hare see: Newey et al. 2007). It is important to note that the data collected reflects shooting effort of mountain hare and any variation in number of hares shot may reflect different management objectives and priorities of a given estate, changes in the sport shooting industry, or hunting legislation rather than changes in local populations.

Commenting on the above two research results, Newey et al. (2018). state that caution is needed when interpreting indices of population abundance, as the link between the numbers of hares reported killed in the NGC and hares seen during the BBS, and the actual number of mountain hares is unknown.

The recently published Watson and Wilson paper (2018) found long-term declines in mountain hare densities that increased in severity of decline after 1999. Watson and Wilson (2018) propose this decline is associated with an increased effort by some estates managing moorlands - with a primary interest in driven grouse shooting in the eastern Highlands of Scotland - to lower mountain hare densities in an effort to decrease disease in grouse (see below) on moorlands. Their results are based on long term monitoring (just over 70 years) across 100 sites. It should be noted that the sites were not randomly chosen and the surveying was carried out in daylight rather than at night. Newey et al. (2018) suggest that counts of mountain hares during daylight walked transect surveys are unlikely to provide a reliable or repeatable population index.

In detail, the Watson and Wilson (2018) analysis revealed there was a long-term decline in mountain hare density index that occurred between 1954-1999; the population decreased by 80% in these 45 years which was likely caused by a number of factors including loss of managed heather moorland due to afforestation, sheep grazing and abandonment of grouse shooting, with the subsequent loss of heather burning and heather cover in moorland areas (mountain hare benefit from actively managed moorland where there is rotational burning of heather and predator control).

From 1999 onwards, there was an increased rate of decline in mountain hare density that was strongly associated with grouse moors. The authors hypothesised that this coincided with an increased effort by some grouse moor owners and managers to lower mountain hare densities as part of an effort to control tick and Louping Ill virus (LIV) (Newey et al. 2008; see also Game and Wildlife Conservation Trust webpage on mountain hare management relating to grouse populations[10]; see also answer to Question 16). They argued that the decline after 1999 could not wholly be explained by mountain hare population cycling as described by Newey et al. (2007) causing population crashes, as the amplitude of the declines exceeded those that would be 'expected' as part of natural cycling. However, they were comparing the amplitude of change found in their study with the amplitude of change found from game bag counts (which were used in the analysis of mountain hare cycling by Newey et al. 2007), so it may not be correct to say 'expected' as they are not comparing counts of the same things. In addition, it is likely that the amplitude of change for game bags is much smaller than for counts of hares because mountain hares are not usually shot when the population is at low density, plus the National Game Census game bag data does not include zero values. The declines in mountain hare on the arctic/alpine sites that were also sampled remained within the historic range. This was attributed by the authors to the lack of mountain hare shooting - for LIV control - in arctic/alpine habitats because there are little or no red grouse found at these elevations.

[9] Non-statistically significant decline of 40% in the number of mountain hares reportedly killed by estates in the period 1995 to 2009
[10] The Game and Wildlife Conservation Trust state: "*Where grouse suffer from tick and the tick-borne louping-ill virus, hares can sustain high levels of these parasites and help perpetuate the disease. As there is no alternative form of treatment, in these cases hare numbers may need to be temporarily reduced to suppress the disease*." https://www.gwct.org.uk/research/species/mammals/mountain-hare/
Accessed 30/08/2018

Watson and Wilson (2018) noted that results found in this part of Scotland, where the overall declines in the mountain hare density index were in excess of 99% on moorland sites in the study area, suggesting that mountain hare populations were not in favourable conservation status in the study sites. As the study sites were not a random sample, it is not possible to infer anything about what might be happening to hare numbers anywhere else in Scotland or the rest of the UK.

Papers:

- Aebischer, N.J., Davey, P.D., Kingdon, N.G. (2011). National Gamebag Census: Mammal Trends to 2009. Game & Wildlife Conservation Trust, Fordingbridge (http://www.gwct.org.uk/ngcmammals).
- Aebischer, N.J. (2014) National Gamebag Census: Grouse, snipe and hares. pp. 38–41, In: The Game Conservancy Trust Review of 2014. The Game & Wildlife Conservation Trust.
- Harris, S.J., Massimino, S., Newson, S.E., Eaton, M.A., Marchant, J.H., Balmer, D.E., Noble, D.G., Gillings, S., Procter, D., Pearce-Higgins, J.W, (2016). The Breeding Bird Survey 2015. BTO Res. Rep. 687.
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- Newey, S., Iason, G., & Raynor, R. (2008). The conservation status and management of mountain hares. Scottish Natural Heritage Commissioned Report No. 287, Battleby.
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- Newey, S., Fletcher, K., Potts, J., Iason, G. (2018) *Developing a Counting Methodology for Mountain Hares (Lepus Timidus) in Scotland. Scottish Natural Heritage Research Report No. 1022.* Inverness, Scotland.
- Watson, A., Wilson, J.D., (2018) Seven decades of mountain hare counts show severe declines where high-yield recreational game bird hunting is practised. Journal of Applied Ecology. pp 1–10.

***16: Are mountain hares controlled in your area and if so, do you know what the main purposes are? What information or experience guides the number of hares culled? If disease is a control purpose, please specify which disease(s) and what evidence you are using to inform your assessmen*t.**

Key point:
It is generally recognised that some estates managing moorlands for driven grouse shooting, carry out intensive population control of mountain hares to try to control ticks and Louping Ill virus. There is no compelling scientific evidence to suggest culling mountain hares might increase red grouse densities.

Although we cannot answer this question for a particular area, it is generally recognised that some estates managing moorlands for driven grouse shooting, carry out intensive population control of mountain hares to try to control ticks and LIV (Gilbert 2016; Watson and Wilson 2018). For example, a recent survey (Patton et al. 2010) asked respondents why they killed mountain hares. The survey found that respondents killed mountain hares for tick control (50%) above all other reasons (e.g. sport interests 40% and forestry or crop protection 10%). The view that killing mountain hares is necessary to control ticks and LIV in grouse is endorsed[11] by the Game and Wildlife Conservation Trust who state on their website (accessed 30/8/2018) that " *where grouse suffer from tick and the tick-borne louping-ill virus, hares can sustain high levels of these parasites and help perpetuate the disease. As there is no alternative form of treatment, in these cases hare numbers may need to be temporarily reduced to suppress the disease*." However, the Game and Wildlife Conservation Trust (GWCT) have signed up to the joint Scottish Natural Heritage-GWCT-Scottish Land and Estates position statement calling for restraint on killing hares for tick/LIV control[12].

It is likely the research by Laurenson et al. (2003), which found that the prevalence of LIV in grouse declined dramatically when hare densities were reduced on one sporting estate in the central Highlands, has encouraged large scale killing of mountain hares amongst some grouse moor managers (Gilbert 2016). This is despite the fact that according to Harrison et al. (2010), there is no compelling scientific evidence to suggest culling mountain

[11] See also: Smith, A., 2009. The Game Conservancy Scottish Research Trust 25th anniversary report from trustees to supporters. Game & Wildlife Conservation Trust, Couston, Newtyle, Angus PH12 8UT
[12] See: https://www.snhpresscentre.com/news/snh-gwct-sle-position-on-large-scale-culls-of-mountain-hares-to-reduce-louping-ill

hares might increase red grouse densities. Cope et al. (2004) earlier critique of Laurenson et al. (2003) research states that it "*has failed to demonstrate that the removal of mountain hares has any effect on the potential harvest of red grouse, making their conclusions unreliable*". Harrison et al. (2010) thought the Laurenson et al. (2003) findings could not be widely applied for a number of reasons: firstly, the study site was unusual in having very high LIV levels in grouse, secondly there was an absence of red deer (which is unusual for grouse shooting estates in the Highlands, if not most of Scotland) and thirdly sheep were treated to act as 'tick mops' to reduce tick numbers. Therefore, it was not possible to separate the effects of hare culling and sheep management on changes in tick burdens, LIV prevalence and grouse density. In addition to the Harrison et al. (2010) investigation, a theoretical modelling study by Gilbert et al. (2001) showed that mountain hare culling would not be effective form of control for LIV if an alternative tick host, such as deer, were present and this is likely to be the case on most sporting estates.

Papers:

- Cope, D.R., Iason, G.R., Gordon, I.J. (2004). Disease reservoirs in complex systems: A comment on recent work by Laurenson et al. J. Anim. Ecol. https://doi.org/10.1111/j.0021-8790.2004.00850.x
- Gilbert, L., Norman, R., Laurenson, K. M., Reid, H. W,. Hudson P.J. (2001). Disease persistence and apparent competition in a three-host community: an empirical and analytical study of large-scale, wild populations. Journal of Applied Ecology. 70, pp. 1053-106.
- Gilbert, L. (2016) Louping ill virus in the UK: a review of the hosts, transmission and ecological consequences of control. Experimental Journal of Applied Acarology. (2016). 68, pp. 363-374.
- Harrison, A., Newey, S., Gilbert, L., Haydon, D.T., Thirgood, S. (2010). Culling wildlife hosts to control disease: mountain hares, red grouse and louping ill virus. Journal of Applied Ecology. 47, 4 pp. 926-930.
- Laurenson, M.K., Norman, R.A., Gilbert, L., Reid, H.W, Hudson, P.J. (2003). Identifying disease reservoirs in complex systems: mountain hares as reservoirs of ticks and louping-ill virus, pathogens of red grouse. Journal of Applied Ecology. 72, pp. 177-185.
- Patton, V., Smith, A.A., Newey, S., Iason, G.R., Thirgood, S.J. & Raynor, R. (2010). Distribution of mountain hares (*Lepus timidus*) in Scotland: results from a questionnaire survey. Mammal Review. 40, 4 pp. 313-32.

17: Does grouse moor management influence mountain hare numbers? If so, are there ecological consequences?

Key point:

Grouse moor management can have both positive and negative effects on mountain hare numbers. An increase in mountain hare numbers in a given location could have potential cascading effects on their predators and associated prey although the effects are not well researched.

Grouse moor management can have both positive and negative effects on mountain hare numbers. Some potential ecological consequences are described below.

Habitat management on grouse moors - such as rotational heather burning and general predator control - have been associated with high densities of both mountain hares and grouse (Hewson, 1984). After heather burning, short young heather is produced which is attractive to mountain hares both to forage and because the short heather also increases predator visibility to them (Hewson 1984). In addition, predators such as foxes and crows are also actively controlled as part of grouse moor management, this will favour both grouse and mountain hares.

In terms of ecological consequences, mountain hare densities are greater on managed grouse moors than anywhere else in Scotland; numbers can reach 30-70 km^{-2} and have even been found to be 200-250 km^{-2} (Iason, et al. 2008; Watson et al. 1973). Away from areas of grouse moors, mountain hares in Scotland generally occur at much lower densities of 0.5-3 km^{-2} (Watson et al. 1973).

Mountain hares are predated by fox, wild cat, stoat, weasel, buzzard, hen harrier and golden eagle; therefore an increase in mountain hare numbers in a given location could have potential cascading effects on their predators and associated prey (depending on levels of legal and/or illegal control of other species), although the effects are not well researched (Flux 1970; Hewson 1976; Watson et al. 1993; Watson 1997).

Mountain hares (and brown hares) can constitute over a third of a golden eagle's diet, and nearly 15 % of white-tailed eagle (Whitfield et al. 2013). Therefore, moorland areas that support high numbers of mountain hares (and grouse) may present attractive foraging sites for golden eagle and to a lesser extent white-tailed eagle. However, it is important to recognise that in terms of conservation management, there are individual differences in dietary preferences between golden eagles occupying different territories (Whitfield et al. 2009). A 'typical' Scottish golden eagle's diet is predominantly made up of red grouse and/or lagomorphs whereas in other 'specialist' pairs, seabirds dominate the diet (Watson 1997).

In terms of the ecological effects on local mountain hare populations, Harrison et al. (2010) state that little is known about the impact of harvesting or culling on mountain hare demography and population dynamics. However, they hypothesise that intensive, localized killing could potentially further fragment populations and if the resulting distance between subpopulations exceeds mountain hare dispersal distance, or if dispersing individuals are subject to greater mortality risk, dispersal rates and local population persistence may be reduced. That said, Harrison (2011 – Chapter 6 of thesis; not published in a peer reviewed journal) estimates that hare populations should be able to sustain up to 40% hunting mortality, although the model found the likelihood of extinction increased with decreasing population size and as harvesting became increasingly yearling (i.e. up to 18 months old) biased.

Papers:

- Flux, J.E.C. (1970). Life history of the Mountain hare (*Lepus timidus scoticus*) in north-east Scotland. Journal of Zoology. 161, pp. 75-123.
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- Harrison, A., Newey, S., Gilbert, L., Haydon, D.T., Thirgood, S. (2010). Culling wildlife hosts to control disease: mountain hares, red grouse and louping ill virus. Journal of Applied Ecology. 47, 4 pp. 926-930.