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Viewpoint

Environmental impacts of high-output driven shooting of Red Grouse *Lagopus lagopus scotica*

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Recreational hunting of game birds and mammals is globally widespread (Loveridge *et al.* 2009). Habitat and predator management is sometimes undertaken to increase game abundance and hunting bags (e.g. Hudson 1992, Arroyo *et al.* 2012). This can have environmental benefits such as creation and maintenance of wildlife-rich habitat (Potts 1986, Loveridge *et al.* 2009), but may conflict with delivering other ecosystem services and public benefits from the same landscapes (Côté *et al.* 2004). For these reasons, regulations to ensure responsible management and monitoring of game populations are widely recommended (Loveridge *et al.* 2009, Caro *et al.* 2014).

Here we consider management for recreational shooting of Red Grouse *Lagopus lagopus scotica*, a subspecies of Willow Ptarmigan *Lagopus lagopus* that is endemic to submontane heathlands in the United Kingdom. The non-lekking, monogamous, highly territorial Willow Ptarmigan has a circumpolar distribution typically occurring at low breeding densities (0.1–10 pairs per km^2) across northern Europe, northern Eurasia and North America (Watson & Moss 2008). However, in the UK intensive habitat management, predator control and medication are used to secure exceptionally high (150–500 birds per km^2) post-breeding densities of Red Grouse, which are then driven (flushed) over static lines of shooters (Hudson 2008). This high-input, high-output management is practised in a regulatory environment in which landowners set their own bag limits and establish the management to deliver these, with the state only regulating quarry species, hunting season and permitted hunting methods. There is no statutory requirement for hunters to report their bags, although records are collected by a non-profit organization, the Game & Wildlife Conservation Trust (GWCT). This combination of intensive shooting practice with weak regulation is almost unique (Mustin *et al.* 2012), and offers general insights into the environmental impacts of intensive game management when managers operate without much of the regulation recommended by Loveridge *et al.* (2009). There is growing public debate about these impacts (Thompson *et al.* 2009, Avery 2015, Wightman & Tingay 2015), part of a wider trend of public engagement in hunting policy (Minnis 1998). For example, the recent near-extirpation of the Hen Harrier *Circus cyaneus* as a breeding bird in England (Redpath *et al.* 2010) and claims of mass culls of Mountain Hares *Lepus timidus* in Scotland by grouse moor managers (Anon 2014) has prompted three UK public petitions to license or ban driven grouse shooting, one for the introduction of vicarious liability (whereby the rights-holder is held responsible for the actions of an employee) and one for stronger legal protection of Scottish Mountain Hares, collectively amassing over 85 000 signatures by 29 January 2016. To date, however, wider environmental impacts of driven grouse management have received little public scrutiny, despite an increasing evidence base to inform a debate. Here we assess environmental impacts of driven grouse management and consider current regulation and policy in the context of the objective of securing legal and environmentally sustainable outcomes.

THE ECOSYSTEM SERVICES OF MOORLAND HABITATS

Red Grouse depend on moorland habitats comprising blanket bog and heath beyond the altitudinal and climatic limits of enclosed agriculture (Watson & Moss 2008). These habitats and the breeding bird assemblages they support in the UK are of international conservation importance (Thompson *et al.* 1995), with large areas protected under national and international law. Moorlands also provide regulatory and cultural ecosystem services. The UK uplands are landscapes that inspire millions of people, with associated benefits for local economies, health and well-being. They provide 70% of drinking water in Britain, and support peatlands in England and Scotland that are the largest carbon store in the UK, amounting to almost 1800 Mt (Bonn *et al.* 2009, Chapman *et al.* 2009, Alonso *et al.* 2012).

RED GROUSE SHOOTING

Driven shooting of Red Grouse on moorlands managed for the purpose is the economically dominant and most

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prestigious form of gamebird shooting in the UK (Hudson 1992, Sotherton *et al.* 2009). Grouse are driven by lines of 'beaters' to fly over a row of shooters who expect to kill more grouse in a day (30–40 each) than on a 'walked-up' shoot, where hunters walk in line using dogs to flush grouse. Most of this shooting takes place on private land.

Fewer Red Grouse are now shot over a smaller land area than in the heyday of driven grouse shooting in the early 20th century (Hudson 1992). However, grouse shooting still takes place over approximately 850 000 ha (Douglas *et al.* 2015), with the intensity of management (number of gamekeepers employed, vegetation burning and grouse medication) increasing over the last 20–30 years (Natural England 2009, Clutterbuck & Yallop 2010). This reflects an industry choosing to intensify further to meet perceived market demands, with economic returns apparently reliant on producing ever more grouse (Osborne 2013). Annual monitoring of post-breeding Red Grouse densities by the GWCT on a sample of moors shows a 90% increase from 171 per km^2 (1990–1994) to 325 per km^2 (2010–2014) in England and a 74% increase from 81 to 141 per km^2 over the same period in Scotland, with the rapid increase attributed to higher strengths of medicated grit to combat strongyle worm infections in grouse (Game & Wildlife Conservation Trust 2015). In places, Red Grouse are now more abundant than at any time since the 1930s (Osborne 2013).

GROUSE MANAGEMENT PRACTICES

Predator control

Gamekeepers kill predators of grouse to maximize the shootable surplus. Red Foxes *Vulpes vulpes*, Stoats *Mustela erminea*, Weasels *Mustela nivalis* and some corvid *Corvus* species are legally shot and trapped. However, illegal trapping, shooting and poisoning of protected birds of prey and mammalian predators also takes place and limits the national range and population size of some species (Whitfield *et al.* 2003, Redpath *et al.* 2010, Amar *et al.* 2012).

Managed burning, grazing and vegetation control

Red Grouse feed mainly on young, nutritious Heather *Calluna vulgaris* shoot tips and use older, deeper Heather for nesting and protective cover. Vegetation is burned on rotation (every 10–30 years) to create and maintain a mosaic of different ages of Heather and other dwarf shrubs to benefit grouse (Hudson 1992). Managed burning also maintains open habitats by inhibiting woodland regeneration. Reductions in grazing densities of sheep and deer and control of Bracken *Pteridium aquilinum* by herbicide spraying are also used to maintain Heather dominance (Grant *et al.* 2012).

Treatment of grouse disease

Red Grouse are vulnerable to strongylosis, a disease caused by the gastrointestinal nematode *Trichostrongylus tenuis* which depresses body condition, may cause death, and can reduce brood sizes and population densities (Redpath *et al.* 2006). Following trials (Newborn & Foster 2002), Red Grouse are now routinely treated with anti-worming drugs (flubendazole) by medication of grit, which the birds take to aid digestion of Heather. This medicated grit, including 'super-strength' varieties (Osborne 2013), is dispensed from boxes typically located 100–200 m apart across the moor (i.e. one box per territory). Red Grouse are also susceptible to louping-ill, a virus causing encephalomyelitis in sheep that is also carried by wild mammals such as hares and deer, and is transmitted by the tick *Ixodes ricinus* (Watson & Moss 2008). To reduce the infection risk from louping-ill, some gamekeepers treat sheep with acaricides which can reduce tick burdens by 90% and also shoot Mountain Hares and Red Deer *Cervus elaphus* (Watson & Moss 2008, Newborn & Baines 2012).

ENVIRONMENTAL IMPACTS OF MANAGEMENT PRACTICES

Predator control

Control of corvids, foxes and mustelids can increase the breeding success and abundance of other ground-nesting birds, including Northern Lapwing *Vanellus vanellus*, European Golden Plover *Pluvialis apricaria* and Eurasian Curlew *Numenius arquata* (e.g. Tharme *et al.* 2001, Fletcher *et al.* 2010), as well as Red Grouse. However, protected raptors, mammalian predators such as Wildcats *Felis silvestris*, Badgers *Meles meles*, Pine Martens *Martes martes* and even domestic cats are regularly killed illegally (Harris & Yalden 2008, RSPB 2015). The impacts on raptors have received the most attention. For example,

(1) illegal use of poisons to kill predators is associated with land actively managed for grouse shooting (Whitfield *et al.* 2003);
(2) Hen Harriers are almost entirely absent from driven grouse moors across the UK, yet estimates based on habitat area indicated there was sufficient habitat to support almost 500 pairs on driven grouse moors (Redpath *et al.* 2010);
(3) illegal killing of Golden Eagles *Aquila chrysaetos* and Red Kites *Milvus milvus* in Scotland, predominantly in areas managed for grouse shooting, has prevented

populations achieving favourable condition (Whitfield *et al.* 2006, 2007, Smart *et al.* 2010);

(4) breeding performance of Peregrines *Falco peregrinus* is lower on grouse moors than other habitats, with only one-third of pairs on grouse moor territories producing any young, even though clutch and brood sizes of successful nests do not differ between grouse moor and other habitats (Amar *et al.* 2012).

Managed burning

Managed burning has helped to protect dwarf-shrub heath from increasing grazing pressure and afforestation (Robertson *et al.* 2001), and can provide good habitat for some birds of high conservation importance, including Eurasian Curlew and European Golden Plover (Thompson *et al.* 1995, Tharme *et al.* 2001). However, burning reduces availability of nesting cover for species using deep Heather (e.g. Merlin *Falco columbarius*, Hen Harrier and Short-eared Owl *Asio flammeus*) and dominant Heather cover disfavours species associated with grassy moorland such as Skylark *Alauda arvensis* and Meadow Pipit *Anthus pratensis* (Tharme *et al.* 2001, Pearce-Higgins & Grant 2006), and prevents successional recovery of scrub and woodland and its associated biodiversity (Watson & Moss 2008).

On grouse moors, burning rotations are becoming shorter, the number of annual burns is increasing, and moorlands overlying deep peat soils that often support blanket bog and wet heath are routinely burned (Yallop *et al.* 2006, Douglas *et al.* 2015). This occurs on protected areas, despite government regulation to prevent damage to mire and woodland habitat, soils and water (e.g. Scottish Government 2011; see Appendix S1), and the fact that repeated burning of blanket bog is inconsistent with international responsibilities to maintain and restore blanket bog to favourable conservation status. As a result, only 14% of UK upland peatland habitats are in favourable condition (Committee on Climate Change 2015) because burning of blanket bog and wet heath can lead to long-term loss of bog-forming *Sphagnum* mosses in favour of Heather or grass and sedge cover, especially when combined with stressors such as grazing and atmospheric pollution (Glaves *et al.* 2013). The result is degradation or loss of peat formation and carbon sink conditions (Garnett *et al.* 2000, Ward *et al.* 2007). The long-term effect of burning on below-ground carbon processes remains unclear. On Heather-dominated peatlands, vigorous re-growth of young Heather after burning may yield increased net uptake of carbon, but more carbon is stored in the peat than in the vegetation, thus favouring the restoration of *Calluna*-dominated ecosystems back to their original, *Sphagnum*-dominated, peat-forming state (Clay *et al.* 2015). Peatland restoration may also be a more sustainable long-term means to achieving another often-claimed benefit of prescribed burning on grouse moors: the reduction of wildfire risk (e.g. McMorrow *et al.* 2009). Increasingly, evidence suggests that many wildfires have impacts not much different from those of prescribed burns, with many wildfires arising from prescribed burns (reviewed by Werritty *et al.* 2015).

Burning also has hydrological impacts with associated economic consequences. It can cause elevated dissolved organic carbon (DOC) and water discoloration, whose remedial treatment costs are then borne by water companies and their customers (Grayson *et al.* 2012). The removal of surface vegetation also increases runoff so that in the most intense rainfall events flow peaks downstream are exacerbated (Holden *et al.* 2015). In the long term, temperature-driven drying and wetting cycles near the surface of burned and exposed peat increase the potential of DOC leaching for up to 10–20 years (Holden *et al.* 2014, Brown *et al.* 2015), and macro-invertebrate diversity of rivers can be reduced in burned catchments (Brown *et al.* 2013).

Grouse disease and treatment

Treatment of Red Grouse with anthelminthics via medicated grit or direct dosing is routine (Newborn & Foster 2002). However, there is no clear evidence that culling Mountain Hares increases Red Grouse densities and both ticks and louping-ill virus persist even when tick hosts occur at very low densities (Gilbert *et al.* 2001, Harrison *et al.* 2010), so the scientific case for culling Mountain Hares is weak (Werritty *et al.* 2015). The impacts of these practices on Mountain Hare populations and the wider environmental impacts of acaricides and anthelminthic treatments remain unknown. However, laboratory studies show that aquatic toxicities of benzimidazole anthelminthics, including flubendazole, to bacteria and invertebrates are sufficient to indicate potential wider environmental problems (Oh *et al.* 2006), thus reflecting broader concerns about the environmental impacts and weak regulation of veterinary pharmaceuticals (Margalida *et al.* 2014). These impacts can in some circumstances be severe, as shown by the recent catastrophic declines of *Gyps* vulture populations across the Indian subcontinent, caused by toxicity of a non-steroidal anti-inflammtory drug, diclofenac, in the tissues of the cattle on which the vultures fed (Green *et al.* 2004).

Lastly, the incidence of a new disease in Red Grouse, respiratory cryptosporidiosis, caused by *Cryptosporidium baileyi*, has increased markedly since it was first observed in northern England in 2010, and may now have started to affect Black Grouse *Tetrao tetrix* (Baines *et al.* 2014), a species of conservation concern. The spread of cryptosporidiosis in grouse may be a consequence of high population densities, increased risk of crossinfection at grit-feeding stations or infected birds being driven over several kilometres across lines of shooters (Osborne 2013, Baines *et al.* 2014).

CONCLUSIONS

Red Grouse shooting as currently practised has some environmental benefits, notably for maintenance of Heather moorland and some ground-nesting birds, especially waders. However, there is growing evidence of negative environmental impacts and societal costs associated with increasingly intensive management practices, many of which are not usually factored in to studies (e.g. Sotherton *et al.* 2009) of the economics of driven grouse management.

Overall, there is increasing evidence that driven grouse shooting is incompatible with requirements for the hunting of Annex II species (e.g. Red Grouse) under Article 7 of the EU Birds Directive, including the principles of wise use and requirement not to jeopardize conservation efforts. This principle is defined for wetlands, including peatlands, as 'the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development' (Ramsar Convention Secretariat 2007). Following these principles, land use and management, including those for Red Grouse shooting, would need to deliver a range of ecosystem services and help biodiversity recover and adapt to climate change. Grouse moor management could contribute by developing and promoting alternative shooting styles and cultures (e.g. walked-up shooting or driven shooting of smaller bags) which integrate more readily with wider environmental and societal objectives for sustainable moorland management. For this to happen, a fundamental shift in behaviours and practices would be needed, informed by evidence, supported by public policy, and led by landowners committed to a sustainable future for grouse shooting.

In the 1930s, Aldo Leopold, a founding father of the science of wildlife management, observed that game management for recreational shooting should 'grow natural species in an environment not greatly altered for the purpose in hand, relying on partial control of a few factors to enhance the yield above what unguided nature would produce… controls are barely visible; an observer, unless he were an expert, could see no difference between managed and unmanaged terrain', and concluded that 'the recreational value of a head of game is inverse to the artificiality of its origin, and hence to the intensiveness of the system of game management which produced it' (Leopold 1933). Driven grouse moor management has diverged far from these principles, but they would serve well as principles of environmentally sustainable grouse moor management.

A pioneering example of an attempt to deliver a wider range of ecosystem benefits from a former grouse moor is the Langholm Moor Demonstration Project in southwest Scotland, a partnership between the landowner, conservation charities and statutory organizations. After 8 years, this project has reduced grazing pressures, halted Heather loss, seen increases in populations of Black Grouse and Hen Harriers, and restored Red Grouse densities to those that last supported grouse shooting (Langholm Moor Demonstration Project 2014). It has also successfully adopted diversionary feeding of nesting Hen Harriers (Redpath *et al.* 2001) to reduce predatory impacts on grouse. But such initiatives remain the exception. For example, the recently published action plan for Hen Harriers in England (Defra 2016) focuses on the conflict with driven grouse shooting rather than addressing the underlying environmental impacts of driven grouse management.

In a recent review, Werritty *et al.* (2015) found strong evidence of deterioration of moorland habitats and urged the need for a shared vision to tackle these problems. The range and abundance declines of many upland breeding birds in the UK revealed by the recent *Bird Atlas* (Balmer *et al.* 2013) are examples of the severity of the challenge. Reforms of grouse moor management could be central to this vision, but inability or unwillingness to self-regulate, especially in regard to the evidence of killing of protected raptors and burning on deep peat, is driving increasingly vocal and publicly supported calls to ban driven grouse shooting (e.g. Avery 2015). Statutory regulation and effective legislative deterrence of illegal management could catalyse more fundamental reform, and this would need to be accompanied by further research to tackle remaining evidence needs. These include (i) the wider environmental impacts of acaricides and anthelminthics, and lead shot (Group of Scientists 2014) currently used on grouse moors, (ii) the long-term impacts of repeated rotational burning of above-ground vegetation on the peat carbon cycle, and on riparian biodiversity, (iii) analyses of the economic contribution of driven grouse management which take full account of externalized environmental costs, and (iv) understanding the effects of land use patterns and loss of apex predators on populations of bird and mammal predators of Red Grouse.

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REFERENCES

Alonso, I., Weston, K., Gregg, R. & Morecroft, M. 2012. *Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon* *stores and sources*. Peterborough: Natural England Research Report NERR043.

Amar, A., Court, I.R., Davison, M., Downing, S., Grimshaw, T., Pickford, T. & 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. *Biol. Conserv.* **145**: 86–94.

Anon. 2014. Outrage over mountain hare "massacre". *Sunday Herald*, 28 September 2014. Available at http://www.heraldscotland.com/news/home-news/outrage-over-mountain-hare-massacre.25442597 (accessed 29 January 2016).

Arroyo, B., Delibes-Mateos, M., Diaz-Fernandez, S. & Viñuela, J. 2012. Hunting management in relation to profitability aims: red-legged partridge hunting in central Spain. *Eur. J. Wild. Res.* **58**: 847–855.

Avery, M. 2015. *Inglorious – Conflict in the Uplands*. London: Bloomsbury.

Baines, D., Newborn, D. & Richardson, M. 2014. Spread of *Cryptosporidium baileyi* in red grouse (*Lagopus lagopus scoticus*). *Vet. Rec.* **175**: 149.

Balmer, D.E., Gillings, S., Caffrey, B.J., Swann, R.L., Downie, I.S. & Fuller, R.J. 2013. *Bird Atlas 2007–11: The Breeding and Wintering Birds of Britain and Ireland*. Thetford: BTO Books.

Bonn, A., Rebane, M. & Reid, C. 2009. Ecosystem services - A new rationale for conservation of upland environments. In Bonn, A., Allott, T., Hubacek, K. & Stewart, J. (eds) *Drivers of Environmental Change in Uplands*: 448–474. London: Routledge.

Brown, L.E., Johnston, K., Palmer, S.M., Aspray, K.L. & Holden, J. 2013. River ecosystem response to prescribed vegetation burning on blanket peatland. *PLoS One* **8**: e81023.

Brown, L.E., Palmer, S.M., Johnston, K. & Holden, J. 2015. Vegetation management with fire modifies peatland soil thermal regime. *J. Environ. Manage.* **154**: 166–176.

Caro, J., Delibes-Mateos, M., Vicente, J. & Arroyo, B. 2014. A quantitative assessment of the release of farm-reared red-legged partridges (*Alectoris rufa*) for shooting in central Spain. *Eur. J. Wild. Res.* **60**: 919–926.

Chapman, S.J., Bell, J., Donnelly, D. & Lilly, A. 2009. Carbon stocks in Scottish peatlands. *Soil Use Manage.* **25**: 105–112.

Clay, G.D., Worrall, F. & Aebischer, N.J. 2015. Carbon stocks and carbon fluxes from a 10-year prescribed chronosequence on a UK blanket peat. *Soil Use Manage.* **31**: 39–51.

Clutterbuck, B. & Yallop, A.R. 2010. Land management as a factor controlling dissolved organic carbon release from upland peat soils 2: changes in DOC productivity over four decades. *Sci. Total Environ.* **408**: 6179–6191.

Committee on Climate Change 2015. *Reducing emissions and preparing for climate change: 2015 Progress Report to Parliament. Summary and Recommendations*. London: Committee on Climate Change.

Côté, S.D., Rooney, T.P., Tremblay, J.-P., Dussault, C. & Waller, D.M. 2004. Ecological impacts of deer overabundance. *Annu. Rev. Ecol. Evol. Syst.* **35**: 113–147.

Defra. 2016. *Joint action plan to increase the English Hen Harrier population*. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/491818/hen-harrier-action-plan-england-2016.pdf (accessed 29 January 2016).

Douglas, D.J.T., Buchanan, G.M., Thompson, P.S., 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. *Biol. Conserv.* **191**: 243–250.

Fletcher, K., Aebischer, N.J., Baines, D., Foster, R. & 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. *J. Appl. Ecol.* **47**: 263–272.

Game & Wildlife Conservation Trust 2015. *Review of 2014*. Fordingbridge: Game & Wildlife Conservation Trust.

Garnett, M.H., Ineson, P. & Stevenson, A.C. 2000. Effects of burning and grazing on carbon sequestration in a Pennine blanket bog, UK. *Holocene* **10**: 729–736.

Gilbert, L., Norman, R.A., Laurenson, M.K., 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. *J. Anim. Ecol.* **70**: 1053–1061.

Glaves, D., Morecroft, M., Fitzgibbon, C., Owen, M., Phillips, S. & Leppitt, P. 2013. *The effects of managed burning on upland peatland biodiversity, carbon and water*. Peterborough: Natural England Upland Evidence Review NEER004.

Grant, M.C., Mallord, J., Stephen, L. & Thompson, P.S. 2012. *The costs and benefits of grouse moor management to biodiversity and aspects of the wider environment: a review*. RSPB Research Report 43. Sandy: RSPB.

Grayson, R., Kay, P., Foulger, M. & Gledhill, S. 2012. A GIS based MCE model for identifying water colour generation potential in UK upland drinking water supply catchments. *J. Hydrol.* **420–421**: 37–45.

Green, R.E., Newton, I., Schultz, S., Cunningham, A.A., Gilbert, M., Pain, D.J. & Prakash, V. 2004. Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. *J. Appl. Ecol.* **41**: 793–800.

Group of Scientists 2014. *Wildlife and Human Health Risks from Lead-Based Ammunition in Europe: A Consensus Statement by Scientists*. Available at http://www.zoo.cam.ac.uk/departments/conservation-science/European-Statement (accessed 29 January 2016).

Harris, S. & Yalden, D.W. 2008. *Mammals of the British Isles. Handbook*, 4th edn. Southampton: Mammal Society.

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. *J. Appl. Ecol.* **47**: 926–930.

Holden, J., Wearing, C., Palmer, S., Jackson, B., Johnston, I.K. & Brown, L.E. 2014. Fire decreases near-surface hydraulic conductivity and macropore flow in blanket peat. *Hydrol. Process.* **28**: 2868–2876.

Holden, J., Palmer, S.M., Johnston, K., Wearing, C., Irvine, B. & Brown, L.E. 2015. Impact of prescribed burning on blanket peat hydrology. *Water Resour. Res.* **51**: 6472–6484.

Hudson, P.J. 1992. *Grouse in Space and Time. The Population Biology of a Managed Gamebird*. Fordingbridge: The Game Conservancy.

Hudson, D. 2008. *Grouse Shooting*. Shrewsbury, UK: Quiller Publishing.
Langholm Moor Demonstration Project 2014. *The Langholm Moor Demonstration Project: seven year review – December 2014*. Langholm Moor Demonstration Project Ltd.
Leopold, A. 1933. *Game Management*. New York: Charles Scribner's Sons.
Loveridge, A.J., Reynolds, J.C. & Milner-Gulland, E.J. 2009. Does sport hunting benefit conservation? In Macdonald, S. & Service, K. (eds) *Key Topics Conservation Biology*: 222–238. Oxford: Blackwell.
Margalida, A., Bogliani, G., Bowden, C.G.R., Donazar, J.A., Genero, M., Gilbert, W.B., Karesh, R., Kock, J., Lubroth, X., Manteca, V., Naidoo, A., Neimanis, J.A., Sanchez-Zapata, J.A., Taggart, M.A., Vaarten, J., Yon, L., Kuiken, T. & Green, R.E. 2014. One Health approach to use of veterinary pharmaceuticals. *Science* **346**: 1296–1298.
McMorrow, J., Lindley, S., Aylen, J., Cavan, G., Albertson, K. & Boys, D. 2009. Moorland wildfire risk, visitors and climate change: patterns, prevention and policy. In Bonn, A., Allott, T., Hubacek, K. & Stewart, J. (eds) *Drivers of Environmental Change in Uplands*: 404–431. London: Routledge.
Minnis, D.L. 1998. Wildlife policy-making by the electorate: an overview of citizen-sponsored ballot initiatives on hunting and trapping. *Wildlife Soc. B.* **26**: 75–83.
Mustin, K., Newey, S., Irvine, J., Arroyo, B. & Redpath, S. 2012. *Biodiversity Impacts of Game Bird Hunting and Associated Management Practices in Europe and North America*. Aberdeen: James Hutton Institute.
Natural England, 2009. *Mapping Values: The Vital Nature of Our Uplands*. Peterborough: Natural England.
Newborn, D. & Baines, D. 2012. Enhanced control of sheep ticks in upland sheep flocks: repercussions for red grouse co-hosts. *Med. Vet. Entomol.* **26**: 63–69.
Newborn, D. & Foster, R. 2002. Control of parasite burdens in wild red grouse *Lagopus lagopus scoticus* through the indirect application of anthelmintics. *J. Appl. Ecol.* **39**: 909–914.
Oh, S.J., Park, J., Lee, M.J., Park, S.Y., Lee, J.H. & Choi, K. 2006. Ecological hazard assessment of major veterinary benzimidazoles: acute and chronic toxicities to aquatic microbes and invertebrates. *Environ. Toxicol. Chem.* **25**: 2221–2226.
Osborne, M. 2013. Grouse, grit and grounds for concern. *The Field*, July 2013, 72–74.
Pearce-Higgins, J.W. & Grant, M.C. 2006. Relationships between bird abundance and the composition and structure of moorland vegetation. *Bird Study* **53**: 112–125.
Potts, G.R. 1986. *The Partridge. Pesticides, Predation and Conservation*. London: Collins.
Ramsar Convention Secretariat 2007. *Wise Use of Wetlands: A Conceptual Framework for the Wise Use of wetlands*. Ramsar handbooks for the wise use of wetlands, 3rd edn, Vol. 1. Gland, Switzerland: Ramsar Convention Secretariat.
Redpath, S.M., Thirgood, S.J. & Leckie, F.M. 2001. Does supplementary feeding reduce predation of red grouse by hen harriers? *J. Appl. Ecol.* **38**: 1157–1168.
Redpath, S.M., Mougeot, F., Leckie, F.M., Elston, D.A. & Hudson, P.J. 2006. Testing the role of parasites in driving the cyclic population dynamics of a gamebird. *Biol. Lett.* **9**: 410–418.
Redpath, S., Amar, A., Smith, A., Thompson, D.B.A. & Thirgood, S. 2010. People and nature in conflict: can we reconcile hen harrier conservation and game management? In Baxter, J.M. & Galbraith, C.A. (eds) *Species Management: Challenges and Solutions for the 21st Century*: 335–350. Edinburgh: The Stationery Office.
Robertson, P.A., Park, K.J. & Barton, A.F. 2001. Loss of heather *Calluna vulgaris* moorland in the Scottish uplands: the role of red grouse *Lagopus lagopus scoticus* management. *Wildlife Biol.* **7**: 11–16.
RSPB 2015. *Birdcrime 2014. Offences against wild bird legislation in the UK*. RSPB: Sandy.
Scottish Government 2011. *The Muirburn Code*. Edinburgh: The Scottish Government.
Smart, J., Amar, A., Sim, I.M.W., Etheridge, B., Cameron, D., Christie, G. & Wilson, J.D. 2010. Illegal killing slows population recovery of a re-introduced raptor of high conservation concern – The red kite *Milvus milvus*. *Biol. Conserv.* **143**: 1278–1286.
Sotherton, N., May, R., Ewald, J., Fletcher, K. & Newborn, D. 2009. Managing uplands for game and sporting interests – An industry perspective. In Bonn, A., Allott, T., Hubacek, K. & Stewart, J. (eds) *Drivers of Environmental Change in Uplands*: 241–260. London: Routledge.
Tharme, A.P., Green, R.E., Baines, D., Bainbridge, I.P. & O'Brien, M. 2001. The effect of management for red grouse shooting on the population density of breeding birds on heather-dominated moorland. *J. Appl. Ecol.* **38**: 439–457.
Thompson, D.B.A., MacDonald, A.J., Marsden, J.H. & Galbraith, C.A. 1995. Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation. *Biol. Conserv.* **71**: 163–178.
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. *J. Appl. Ecol.* **46**: 950–954.
Ward, S.E., Bardgett, R.D., McNamara, N.P., Adamson, J.K. & Ostle, N.J. 2007. Long-term consequences of grazing and burning on northern peatland carbon dynamics. *Ecosystems* **10**: 1069–1083.
Watson, A. & Moss, R. 2008. *Grouse*. London: Collins.
Werritty, A., Pakeman, R.J., Shedden, C., Smith, A. & Wilson, J.D. 2015. *A Review of Sustainable Moorland Management*. Battleby, UK: Report to the Scientific Advisory Committee of Scottish Natural Heritage.
Whitfield, D.P., McLeod, D.R.A., Watson, J., Fielding, A. & Haworth, P.F. 2003. The association of grouse moor in Scotland with the illegal use of poisons to control predators. *Biol. Conserv.* **114**: 157–163.
Whitfield, D.P., Fielding, A.H., McLeod, D.R.A., Haworth, P.F. & Watson, J. 2006. A conservation framework for golden eagle in Scotland: refining condition targets and assessment of constraint influences. *Biol. Conserv.* **130**: 465–480.
Whitfield, D.P., Fielding, A.H., McLeod, D.R.A., Morton, K., Stirling-Aird, P. & Eaton, M.A. 2007. Factors constraining the distribution of Golden Eagles *Aquila chrysaetos* in Scotland. *Bird Study* **54**: 199–211.

Wightman, A. & Tingay, R.E. 2015. *The Intensification of Grouse Moor Management in Scotland*. Commissioned and Published by the League Against Cruel Sports.

Yallop, A.R., Thacker, J.I., Thomas, G., Stephens, M., Clutterbuck, B., Brewer, T. & Sannier, C.A.D. 2006. The extent and intensity of management burning in the English uplands. *J. Appl. Ecol.* **43**: 1138–1148.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Regulation of heather and grass burning.