

Review article

Killing of raptors on grouse moors: evidence and effects

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Owing to the intensity of game management in Britain, managers of grouse moors have illegally killed raptors to increase the numbers of Red Grouse *Lagopus l. scotica* available for shooting. This paper summarizes evidence for the recent scale of illegal raptor killing on grouse moors and its effects on populations. It provides insights into how raptors themselves respond demographically to different levels of killing. Over Britain as a whole, most raptors have increased and expanded considerably since the 1970s, in response to reduced killing and nest destruction, and the diminished impacts of organochlorine pesticides; however, in recent decades the populations of some species have declined on and around grouse moors. This is widely evident in Hen Harrier *Circus cyaneus*, Peregrine Falcon *Falco peregrinus* and Golden Eagle *Aquila chrysaetos* populations and in more restricted areas also in Northern Goshawk *Accipiter gentilis* and Red Kite *Milvus milvus* populations, in all of which illegal killing has been sufficient to affect numbers over wider areas. The evidence consists mainly of: (1) greater disappearance of nesting pairs, lower breeding densities or reduced occupancy of apparently suitable traditional territories on grouse moors compared with other areas; (2) reduced nest success compared with other areas; (3) reduced adult survival compared with other areas; (4) reduced age of first breeding, reflecting the removal of adults from nesting territories and their replacement by birds in immature plumage; (5) greater levels of disappearance of satellite-tracked birds on grouse moors than elsewhere; and (6) the finding of poisoned baits and traps, and shot or poisoned carcasses of raptors. Not all these types of evidence are available for every species, and other types of evidence are available for some. The Common Buzzard *Buteo buteo* is currently the most numerous raptor in Britain and also seems to be killed in the greatest numbers. Other raptor species, including Merlin *Falco columbarius*, Common Kestrel *Falco tinnunculus* and Eurasian Sparrowhawk *Accipiter nisus* which nest on or near grouse moors, have little or no significant impact on grouse and are killed less often or not at all. In the absence of illegal killing, some raptor species breed as well or better on grouse moors than in other habitats. Merlins, in particular, seem to thrive on grouse moors, benefiting from the management involved (including predator control). Other aspects of illegal raptor killing are discussed, including suggestions for ways in which it might be reduced.

Keywords: Buzzard, Golden Eagle, Goshawk, heather moor, Hen Harrier, Peregrine, persecution, population decline, raptor killing, Red Grouse, Red Kite.

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Since the 19th century, game-rearing in Britain has been carried out intensively, with major emphasis placed on the numbers of game animals

that can be shot each year ('bag sizes') while maintaining the breeding stock. This management has long involved the manipulation of habitat to favour the species of interest, and the control of diseases and predators, all aimed at producing as large a post-breeding population as possible, ready for the start of the shooting season. On low ground, because of changes in agricultural practices, particularly pesticide use, it is difficult now to produce enough wild Grey Partridges *Perdix perdix* and wild (non-native) Common Pheasants *Phasianus colchicus* to sustain shooting, and so in most of Britain, Red-legged Partridges *Alectoris rufa* and Pheasants are now reared artificially and released to satisfy recreational demand. However, in upland areas unsuitable for agriculture, the main game species is the Red Grouse *Lagopus lagopus scotica* (the subspecies of Willow Ptarmigan *Lagopus lagopus* that is endemic to Britain and Ireland), which cannot easily be raised in captivity. For this species, areas of open moorland are managed to provide a plant community dominated by heather (chiefly *Calluna vulgaris*, the main food plant of the species), parasites are controlled mainly by chemical means, and predators are systematically killed (Hudson 1992, Watson & Moss 2008, Werriety 2019, Newton 2020). A crucial aspect of habitat management is the rotational and patchy burning of heather to produce mixed age stands, the patches of short young heather providing good feeding areas for grouse and the long older heather providing good cover and shelter. Grouse are shot either by groups of shooters walking over a moor with dogs to flush the grouse (called 'walked-up' shooting), or by stationary shooters ensconced in a line of butts firing at grouse driven over them by a line of 'beaters' walking over the moor (called 'driven' shooting). On sporting websites, costs of walked-up shooting quoted on 25 July 2020 varied from UK£350 to £600 per gun per day with bag limits of 60 grouse (i.e. 30 'brace'), whereas prices for driven shooting varied from £1488 to £6750 (mean about £4000) per gun per day, with up to eight 'guns' (shooters) at a time, and bag limits of 200–300 grouse (100–150 'brace'). Only driven shooting can cover the costs of management but it requires much greater densities of grouse than walked-up shooting. In fact, the capital value of a 'grouse moor' is influenced mainly by the number of grouse that can be shot there each year, with each brace of grouse supposedly worth up to £5000 in capital terms (Thomson *et al.*, 2018).

Management that aims to maximize the numbers of grouse available for shooting entails removing not only those predators that can be legally controlled (chiefly Red Foxes *Vulpes vulpes*, small mustelids and some corvids) but also on many moors those legally protected raptor species that eat grouse. Legislation intended to protect raptors came into operation in Britain with the Protection of Birds Act (1954) and was strengthened in the Wildlife & Countryside Act (1981), yet these birds are still killed illegally and their nest contents destroyed. This paper, based primarily on the scientific literature, summarizes evidence on the scale of this killing on grouse moors and its effects on raptor populations in Britain. It does not discuss the impact of raptors on grouse numbers (for which see Redpath & Thirgood 1997, Park *et al.* 2008, Newton 2013, 2020, Roos *et al.* 2018, Francksen *et al.* 2019). In an international context, this persistent killing of raptors may seem like a localized conservation issue resulting from the sheer intensity of game management in Britain, and the emphasis on bag sizes. But the ways in which illicit raptor killing has been studied scientifically, and its various impacts on the demography of raptor populations, are of wider interest.

HISTORY OF RAPTOR KILLING IN BRITAIN

In attempts to protect domestic livestock, the killing of large raptors has long been widespread in Britain and as early as the 16th century it was officially encouraged by payment of bounties (Newton 1979, 2013). These payments seem to have been sporadic, however, and in the absence of relevant information, it is hard to judge what impacts frequent killing had on raptor population levels. Nevertheless, Golden Eagles *Aquila chrysaetos*, White-tailed Eagles *Haliaeetus albicilla* and Western Ospreys *Pandion haliaetus* ('Ospreys') had apparently gone from most of their former range in Britain by the end of the 18th century, remaining only in some remote areas. Other species were still widespread, even if reduced in numbers.

From the mid-19th century, when small-game shooting became fashionable, the killing of raptors became more widespread and systematic, and spread to smaller species. It was conducted mainly by 'gamekeepers' employed by land-owners primarily for predator control, together with other aspects of game management. Much of the killing

occurred in the breeding season, when birds were present at traditional nesting sites. In time, five species were apparently eliminated altogether from Britain, namely, the Northern Goshawk *Accipiter gentilis* ('Goshawk') (last recorded nesting attempt 1893), Western Marsh Harrier *Circus aeruginosus* ('Marsh Harrier') (1898), European Honey Buzzard *Pernis apivorus* ('Honey Buzzard') (1911), Osprey (1916) and White-tailed Eagle (1916) (Newton 1979).

Over the same period, several other previously widespread species were eradicated from most of their range in Britain. The Common Buzzard *Buteo buteo* ('Buzzard') remained chiefly in some northern and western hill districts, the Hen Harrier *Circus cyaneus* on the Outer Hebrides and Orkney, and the Red Kite *Milvus milvus* in a small part of central Wales where game preservation did not take hold (Witherby *et al.* 1940, Newton 1979). Peregrine Falcons *Falco peregrinus* ('Peregrine') remained widespread through upland districts and coastal cliffs but were usually killed on grouse moors (Ratcliffe 1993). Only the Common Kestrel *Falco tinnunculus* ('Kestrel') and Eurasian Sparrowhawk *Accipiter nisus* ('Sparrowhawk') remained widespread across Britain and the Merlin *Falco columbarius* in uplands areas. These species had large populations living partly away from game-shooting areas, their small size marked them as less of a threat, and their high reproductive rates enabled them to compensate better than larger species for the extra mortality inflicted (Newton 1979).

Some have doubted that so many species could have been eliminated from Britain or large parts of Britain by gamekeepers when some areas remained free of intensive game management. But in the 19th and early 20th centuries, many farmers and other people also habitually killed predators. In any case, to eradicate a species it was not necessary to kill every individual. All that was required was for more individuals to be killed each year than could be replaced by annual breeding or immigration. Providing this level of killing was sustained over enough years (related to the longevity of the species), regional extinction would inevitably follow. Moreover, young raptors would have repeatedly wandered outside safe areas, and any individuals lingering for a time on game-shooting estates would have been at risk. With their

abundance of prey, including game and other native species, game-shooting estates are likely always to have attracted raptors, but more so in recent years as the wider farmed countryside has become increasingly bereft of wild bird species that could serve as prey (Newton 2017).

NATIONAL RECOVERIES IN RAPTOR POPULATIONS

Beginning in the 20th century, declines in gamekeeper numbers, changes in public attitudes, abolition of bounty schemes, enactment of protective legislation from 1954, and state-run re-afforestation programmes enabled raptors to increase and spread, especially from around 1970. Recoveries occurred despite several species (notably Sparrowhawk, Peregrine and Merlin) being reduced in the 1950–1960s by organochlorine pesticide poisoning (Newton & Haas 1984, Ratcliffe 1993, Newton 1998).

Systematic monitoring of bird populations in Britain started in the 1960s and has continued since, with increasing survey effort and statistical refinement of trend estimation. Over the 40-year period from around 1970 to around 2010, centred on the first and third British Trust for Ornithology (BTO) Atlas projects (Sharrock 1976, Balmer *et al.* 2013), almost all raptor species in Britain expanded in numbers and range, some massively so (Fig. 1). Those which increased by the biggest percentage had shown the lowest numbers around 1970, and some were supplemented by releases of continental birds during reintroduction programmes (notably Red Kite and White-tailed Eagle). All these observed increases could more appropriately be regarded as 'recoveries' from past persecution and organo-chlorine pesticide impacts. For most species, vacant habitat still exists, available to be recolonized (see maps in Balmer *et al.* 2013). However, in contrast to all other species, the Kestrel declined in numbers by 44% over this period and in distribution (as recorded by presence or absence in 10-km squares) by 6% (Balmer *et al.* 2013). Nevertheless, the main messages are that the period 1970–2010 saw a general recovery in the numbers and distributions of raptors nesting in Britain, but that for most species, vacant habitat still exists to support further population growth. It is against this background of generally increasing

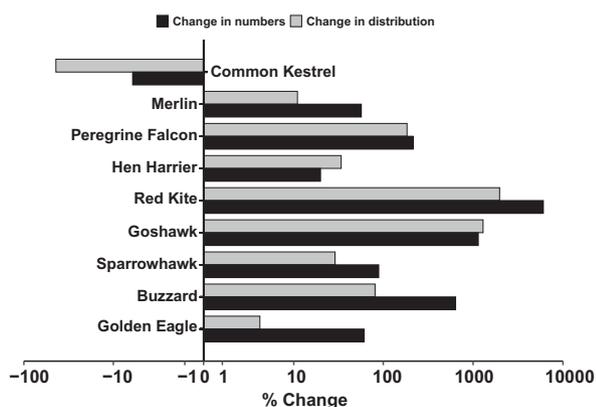


Figure 1. Increase in the numbers and distributions of raptors in Britain over a roughly 40-year period (1970–2010), corresponding with the first and third BTO Atlases (from which the distributional data were taken). Distributional change is recorded as the percentage change in the number of 10-km squares recorded as occupied around 1970 and around 2010. Numerical change is recorded as the percentage change in pair numbers recorded between the time of the first BTO Atlas and Musgrove *et al.* (2013). Percentages are on a log scale. The Common Kestrel is the only species whose numbers declined in Britain over the period concerned. Sources: three BTO Atlases (Sharrock 1976, Gibbons *et al.* 1993, Balmer *et al.* 2012), and Musgrove *et al.* (2013).

populations that findings on grouse moors for a smaller number of species should be viewed.

Numerical increases have continued, and the most recent population estimates were given by Woodward *et al.* (2020) as follows: Osprey 240 pairs, Honey Buzzard 33–69 pairs, Golden Eagle 510 pairs, Sparrowhawk 28 500 pairs, Goshawk 620 pairs, Marsh Harrier 590–695 females, Hen Harrier 500 females, Montagu's Harrier *Circus pygargus* 8 females, Red Kite 4350 pairs, White-tailed Eagle 122 pairs, Common Buzzard 61 500–85 000 pairs, Kestrel 30 000 pairs, Merlin 1150 pairs, Eurasian Hobby *Falco subbuteo* 2050 pairs and Peregrine 4650 pairs. Even accepting estimation errors, these figures give meaningful orders of magnitude. The numbers refer to pairs on nesting territories, except for harriers in which, owing to frequent polygyny, numbers are expressed as nesting females. However, for each species there are in addition an unknown number of non-breeding (including immature) individuals. These unattached birds cannot usually be counted reliably (but for local exceptions involving the large-scale use of radiotags see Kenward *et al.* 1999, Kenward 2006, Walls & Kenward 2020).

CONTINUED ILLEGAL RAPTOR KILLING

One of the methods used to kill raptors is shooting, and because most species are difficult to approach closely, this is most easily accomplished by lying in wait near the nest and shooting the birds as they arrive or leave. Another frequent method involves the laying of poisoned meat baits in the open or on frequently used perches. Typically, the poison is smeared on carcasses of rabbits or some other animal, or injected into chicken eggs, and these baits are then placed out on the moor. This practice is indiscriminate, as it kills a wide range of predatory and scavenging species, including domestic dogs (RSPB 2015). Hundreds of poisoned baits have been discovered and reported in recent decades, many with dead raptors or corvids lying nearby (RSPB 2001–18). Analyses of birds found dead usually identified the chemicals involved – in recent decades mainly pesticides such as carbofuran (RSPB 2015). Because the chance of anyone detecting these baits is considered low, it is likely that the numbers of baits and poisoned birds found represent a small fraction of the totals. A study of Red Kites in northern Scotland highlighted this low probability of detection (Smart *et al.* 2010). Using field data and population modelling, the authors calculated that a total of 166 Red Kites had probably been illegally poisoned in this region between 1999 and 2006, but only 41 poisoned carcasses were found and reported. Sometimes such baits kill several birds, one after another, and on several occasions in the last two decades more than a dozen dead raptors or Northern Ravens *Corvus corax* ('Raven') have been picked up on particular estates at one time (for examples see Lovegrove 2007, RSPB 2015, Sansom *et al.* 2016). Recent recorded poisoning incidents were widely spread through Britain but were particularly common on grouse moors. This was not necessarily because poisoning had increased there but because it had probably declined in lowland areas (Whitfield *et al.* 2003). Those raptor species which habitually feed on carrion (Golden Eagle, White-tailed Eagle, Buzzard, Red Kite) are the most vulnerable to poisoned baits, but others can also be killed in this way, especially if the poison is placed on a carcass at the nest, on a regular feeding perch or on a carcass from which a bird has been flushed.

Carrion and Hooded Crows (*Corvus corone* and *Corvus cornix*) prey upon the eggs of grouse and other birds, and their numbers can be reduced legally on grouse moors. But the legal use of cage traps to catch crows also leads to the capture of raptors, especially Buzzards and Goshawks (RSPB 2001-18). Each trap usually contains a live decoy crow, supplied with food and water, which attracts in wild crows which cannot then escape. Some of the traps are small ('Larsen traps') and can catch only one or two crows at a time, but others are large cages, with a laddered funnel entrance on top, enabling bigger numbers to be caught. The raptors are attracted in by the live crows as potential prey, and can then be killed along with any crows when the trap is next inspected. Golden Eagles are also vulnerable to the large multiple-catch funnel traps. In 2018, the RSPB recorded a total of 87 confirmed incidents of raptor persecution in Britain, uplands and lowlands combined. These included 41 cases of shooting, 28 of poisoning, 16 of trapping and two others (RSPB 2018).

In recent years, night-viewing equipment has become used to aid killing of raptors. Powerful spotlights from vehicles were first used to find and shoot foxes and cats at night, but are now allegedly used to search cliff faces at night to find roosting raptors, or to search ground-roosting sites for Hen Harriers. Heat-detecting equipment is used for the same purpose, enabling roosting birds to be detected and shot. These activities can take place in remote terrain on any night of the year and so are difficult to detect. One would not expect to find these methods described in the scientific literature but they seem widely acknowledged among those familiar with grouse moor management (Werritty 2019). However, one product of modern technology has also been useful to the raptor conservation side, namely the satellite-based tracking of birds which can reveal the locations of individual birds, and crucially their last known locations. For the two raptors on which tagging has been applied on a large scale in Britain, Golden Eagle and Hen Harrier, findings have revealed that birds disappear on grouse moors in far greater proportion per unit time than in any other habitat (Whitfield & Fielding 2017, Murgatroyd *et al.* 2019; see below). While this information points to high mortality of these species on grouse moors, it rarely incriminates individuals (which is necessary in British law to secure a conviction).

In the sections that follow, discussion is limited to the nine raptor species regularly associated with grouse moors. Species are discussed in order of their claimed impacts on grouse management. In addition to raptors, comments are also made on some other legally protected species which are recorded as killed on grouse moors, namely Raven and Short-eared Owl *Asio flammeus* (RSPB 2015). Unless stated otherwise, all such species are non-migratory in Britain, which rules out conditions in other countries as influencing their population levels.

HEN HARRIER

This ground-nesting bird of the open uplands feeds mainly on voles and small birds including chicks of grouse and waders; however, the larger female can also kill full-grown grouse, Rabbits *Oryctolagus cuniculus* and young hares (Watson 1977, Redpath & Thirgood 1997). The species was apparently almost eliminated as a breeder from mainland Britain in the 19th century but, as mentioned above, survived in the Hebrides and Orkney islands. It successfully recolonized mainland areas from around 1939, the start of the Second World War, when gamekeeping was reduced and from when new forestry plantations in their early years of growth provided safe nesting habitat (Blake 1976, Watson 1977, Bibby & Etheridge 1993). By the end of the war, the Hen Harrier was found nesting again in every Highland county, but as gamekeepers returned after the war, persecution resumed (Blake 1976).

Hen Harriers nest among rank vegetation, mainly heather, but also rough grass or rushes, and young growing trees until canopy closure at 10–15 years. In Britain, they favour moorland where patches of heather are intermixed with patches of grass, supporting good numbers of pipits and voles as prey. On six Scottish moorland areas where Hen Harriers were left undisturbed, their mean nesting densities were found to vary with the abundance of Meadow Pipits *Anthus pratensis*, but in addition fluctuated from year to year according to the abundance of Field Voles *Microtus agrestis* (Redpath & Thirgood 1997). Their nesting densities were not related to concurrent densities of Red Grouse eaten abundantly later in the season (Redpath & Thirgood 1999).

The Hen Harriers that breed in Britain are partial migrants. Some winter near their breeding

areas and others move further south, reaching southern England or even France and Spain (Wernham *et al.* 2002). As the females are able to take grouse and rabbits, many can stay in the uplands year-round, but the smaller males mostly follow their small-bird prey to lower ground for the winter. In general, then, males move longer distances between breeding and wintering localities than females, but there is no obvious difference in this respect between first-year and older birds (Marquiss 1980, Etheridge & Summers 2006).

Five national surveys of Hen Harriers in Britain gave estimated totals of around 639 nesting females in 1988–1989, 483 in 1998, 697 in 2004, 574 in 2010 and 499 in 2016 (Bibby & Etheridge 1993, Sim *et al.* 2001, 2007, Hayhow *et al.* 2013, Wotton *et al.* 2018). From the peak in 2004, the birds had declined by about 28% in 2016. This decline was apparent in all regions, but was more marked on grouse moors than in other habitats. The suggested explanation for the decline was an increase in killing by gamekeepers, mainly in the breeding season, but also outside the breeding season, including at communal roosts. The many harriers raised in Scotland that spend their winters in England visit grouse moors or lowland game-rearing areas (Wernham *et al.* 2002, Murgatroyd *et al.* 2019) and the same may be true for birds from Northern Ireland and the Isle of Man (as yet unconfirmed by ring recoveries or other means).

In the first survey of Hen Harriers in 1988–1989, persecution was widespread. Only 14% of nests on grouse moors produced young, compared with 40% of nests in other heather areas and 66% of nests in young conifer plantations (Bibby & Etheridge 1993), even though foxes – the main nest predators – were controlled on grouse moors but generally not in the other habitats. At 18 nests on grouse moors the shot bodies of one or both adults were found nearby.

Further information accumulated during 1988–1995 gave similar results, but also revealed the annual survival of tagged females from re-sightings in subsequent years (Etheridge *et al.* 1997). Signs of human interference were recorded at nests on more than half of grouse moors studied but were much less frequent elsewhere. Annual survival of females nesting on grouse moors (at about 40%) was about half that of females breeding on other moors (78%). More yearling males bred on grouse moors than elsewhere, presumably filling vacancies left by the killing of their predecessors. The

authors calculated that: (1) numbers of harriers nesting on grouse moors would decline rapidly without continuing immigration from other habitats; (2) grouse moors receive two-thirds of their recruits from other habitats; and (3) without the killing and nest destruction, harriers could, on the figures available, increase at 13% per year until reaching a new, but unknown, equilibrium level as all nesting habitat became occupied.

Subsequent studies of Hen Harriers in England gave similar results, with many nesting adults disappearing during the breeding season. Known numbers in England declined from 19 nesting females in 1998 to only one in 2012 and two (both unsuccessful) in 2013 (Avery 2015). Satellite-tracking in England and southern Scotland revealed that 42 of 58 birds tagged as chicks disappeared in their first few months of life. Disappearance rates were about 10 times greater in areas dominated by grouse moors than in areas without grouse moors. Survival through the first year of these tagged birds was only 17%, compared with estimates of 36–54% from other harrier studies elsewhere, also based on tagged birds (Murgatroyd *et al.* 2019). Based on annual survival estimates of 36% for first-year birds and 78% for older birds away from grouse moors, at least one young per pair per year would be needed to maintain a stable population (Fielding *et al.* 2011). But wherever the adult survival rate is lowered through the shooting of breeders, much greater breeding output would be needed from remaining birds to keep the overall population from declining.

The history of the Hen Harrier on the Isle of Man is testimony to the speed with which a large population can become established when conditions are suitable (apparent absence of illegal killing and absence of foxes). From a single nest found in 1977, numbers increased to reach about 57 breeding pairs by 2004 (Wotton *et al.* 2018). It is this ability to increase rapidly in local areas, partly because of semi-colonial nesting, that worries gamekeepers if they leave any pairs to nest undisturbed.

In the absence of persecution, grouse moors provide excellent habitat for Hen Harriers. Older heather is selected for nesting and, through control of generalist predators (such as foxes and crows), availability of some prey species for harriers is increased, while natural predation on harrier nests is reduced (Redpath *et al.* 2002, Baines & Richardson 2013, Ludwig *et al.* 2017). However, these

positive influences may be of no value if the harriers themselves are shot there or elsewhere before they can reproduce. During 1990–2007, the density of recorded Hen Harrier persecution incidents in different regions of Scotland was directly proportional to the percentage of grouse moor in those regions, and to the proportions of nests recorded as failing (Fielding *et al.* 2011).

Land cover maps indicate that 47% of the surface area of Scotland offers suitable nesting habitat for Hen Harriers, as does 21% of the whole UK (Fielding *et al.* 2011). On the basis of these figures, and density estimates from places where harriers were undisturbed, Scotland alone could hold 1467–1790 pairs. This compares with the estimated 460 pairs present in 2016, about one-quarter of potential numbers. The whole UK could hold 2514–2653 pairs, compared with 575 pairs in 2016, less than one-quarter of potential numbers (Fielding *et al.* 2011). These figures indicate the extent to which the numbers of Hen Harriers are currently below their potential level, with birds breeding over only one-third of their potential range in Britain. They exclude the possibility that, if Hen Harriers were more abundant, they might also occupy more lowland habitats, including cropland of the kind used in parts of continental Europe (Millon *et al.* 2002).

Experimental attempts to reduce predation by Hen Harriers on grouse have involved providing alternative food to nesting pairs to reduce their need to hunt. The provision of dead domestic cockerel chicks and laboratory rats to particular pairs resulted in a big reduction in the number of grouse chicks taken, compared with unfed pairs (Redpath *et al.* 2001, Ludwig *et al.* 2018). However, such ‘diversionary feeding’ has not been taken up by moor managers, partly because of the large amount of work involved, and also because of the fear that it could lead to even more harriers on the moor in later years (Werritty 2019). Another suggestion to resolve the problem of harrier predation was that a trial should be undertaken, taking steps to cap the numbers nesting on a grouse moor once they had reached a level beyond which driven shooting would become impossible. If moor managers could accept this compromise rather than attempting to kill every pair that settles, this could lead to more harriers on moorland in total than occurs at present, but not the maximum that the moors could hold. Capping the numbers could involve destroying or

removing eggs or chicks from some nests, rather than killing adults (Thirgood & Redpath 2008). This idea has been widely discussed at various levels from social media to government departments. It gained support from some conservation bodies but not others, and from some moor owners but not others, and the main issues involved were discussed by Sotherton *et al.* (2009) and Thompson *et al.* (2009). Now, more than 20 years after the idea was first mooted (Potts 1998), a modified version of the idea, termed ‘brood management’, is being trialled in England. At the request of the moor owner, the brood of any Hen Harrier above a certain number (two or more within 10 km of one another) can be removed, reared in captivity centrally for subsequent release into similar habitat (naturalengland.blog.gov.uk/2020/05/22/hen-harrier-brood-management-trial). This has the same effect for the moor owner as the destruction of harrier broods, because it reduces the number of young grouse taken. In 2019, the first year of the scheme, one brood of five young was taken, reared successfully, and tagged for satellite tracking after release.

PEREGRINE FALCON

Peregrines nest primarily on cliffs, but also increasingly now on buildings (Ratcliffe 1993, Wilson *et al.* 2018). They hunt over open land and take mainly medium-sized birds, such as pigeons and grouse. Catching their prey on the wing and feeding largely on both free-living Feral Pigeons *Columba livia var. domestica* and those released for pigeon racing, Peregrine densities and breeding success are in some regions only partly dependent on wild prey produced within the nesting habitat. It may be this abundant supplementary food which has enabled Peregrines to achieve high nesting densities in some upland areas of southern Scotland, northern England and Wales which offer relatively few natural prey, except for transient birds passing through. In all these areas, in the latter decades of the 20th century, Feral and racing Pigeons formed one half or more of all prey remains found near nesting sites (Mearns 1983, Ratcliffe 1993). This proportion would have constituted around 70% or more of the diet by mass, more than in most other areas with lower Peregrine densities (Ratcliffe 1993).

In earlier centuries, as now, Peregrines probably bred in every county of Britain which offered cliffs

as nesting sites, but from the mid-19th century their numbers were reduced in areas managed for game shooting (Ratcliffe 1993). In addition, they disappeared from many southern and eastern districts and declined elsewhere in the mid-20th century, when newly introduced organo-chlorine pesticides reduced their breeding and survival rates (as in some other raptors, Newton 1979, 1998). However, as these pesticides were progressively phased out during the 1960s–1980s, Peregrines gradually recovered and spread back over their former range (Ratcliffe 1993, Horne & Fielding 2002).

Six national surveys have been made of Peregrine breeding numbers in Britain, at intervals of a decade or more. They gave estimates of occupied territories of 554 in 1961–1962, 445 in 1971, 751 in 1981, 1187 in 1991, 1325 in 2002 and 1628 in 2014 (Ratcliffe 1993, Crick & Ratcliffe 1995, Banks *et al.* 2010, Wilson *et al.* 2018). During the first two surveys, numbers were still declining in association with organo-chlorine impacts. The initial increase that followed accompanied the phasing out of these pesticides but later also reflected a behavioural change in the population. From the late 1990s, Peregrines in Britain took increasingly to nesting on buildings, enabling them to spread through the lowlands into areas lacking natural cliffs that were previously unoccupied. However, despite this general expansion in Britain, which made Peregrines more numerous and widely distributed than at any other time since records began, between the surveys of 2002 and 2014 numbers declined over most of upland Scotland and northern England (Wilson *et al.* 2018).

In a wide-ranging study in northern England over the period 1980–2006, involving 1081 Peregrine nesting attempts, breeding productivity on grouse moors was only half that recorded in the remaining upland habitat (Amar *et al.* 2012). Clutch and brood-sizes in successful nests did not differ between habitats, and the difference was mainly due to increased complete nest failures on grouse moors. Analysis of wildlife crime records for the region confirmed that persecution was much greater on grouse moors than elsewhere. During the study period, Peregrine breeding numbers in most of northern England increased, whereas on grouse moors they decreased. Population modelling confirmed that, at the prevailing levels of loss, Peregrines could not sustain themselves on grouse moors without continual

immigration. Where Peregrines were left undisturbed on grouse moors, they bred just as well as Peregrines elsewhere. Similar reduction in nesting success on grouse moors compared with other habitats was recorded in parts of Scotland during 1991–2000 (Hardey *et al.* 2003), and a marked reduction in occupancy of territories on grouse moors was recorded in another study in northern Scotland in 2014, where only 7% of 28 traditional territories on grouse moors were occupied, compared with 51% of 81 territories in other habitats (NE Scotland Raptor Study Group 2015). Declining numbers and nest success were also documented in another part of northern England (the Dark Peak of Derbyshire) during 1995–2015 (Melling *et al.* 2018). On grouse moors, the regular ‘replacement’ of territorial adult Peregrines by immature birds, often during the breeding season, became ‘another indicator of the routine removal of adult birds’ (RSPB 2015). Despite the many records of Peregrines found shot or poisoned on grouse moors, to my knowledge, no comparison has been made of their survival rates between grouse moors and other upland areas, where annual survival has been estimated at 81–90% (Mearns & Newton 1984, Smith *et al.* 2015).

GOLDEN EAGLE

Centuries ago, Golden Eagles probably bred in all the open uplands of Britain, and possibly also in open lowlands, nesting on crags or in trees (Evans *et al.* 2012). Throughout their current range, they feed mainly on medium-sized birds and mammals, including grouse and hares, and the young and dead of larger mammals such as deer (Watson 2010). In Britain they were persecuted for centuries as predators of lambs and other small livestock, and at least since the mid-19th century also as predators of grouse (Watson 2010). By the end of the 18th century, they had apparently gone altogether from England and Wales, and by 1920 they had been reduced to an estimated 100–200 pairs, all in northern Scotland (Evans *et al.* 2012). Traditionally, they were killed chiefly by trapping, but now most of the emphasis seems to be on poisoning, although some are caught and killed in large crow traps, and others are shot at their nests or roosts (Whitfield *et al.* 2007, 2008).

Four national surveys of Golden Eagles in Britain gave estimates of around 424 pairs in 1982–1983, 422 and 442 pairs in 1992 and 2003,

respectively, increasing to around 508 pairs in 2015, with almost all these birds in Scotland (Dennis *et al.* 1984, Green 1996, Eaton *et al.* 2007, Hayhow *et al.* 2017b). Despite steady or increasing overall numbers, large regional variations in trends were apparent between surveys. Broadly speaking, over the 12 years from 2003, Golden Eagles increased in numbers mainly in some western districts but declined in eastern areas where more of the land is managed for grouse shooting. Decline in the central and eastern Scottish Highlands was evident between 1992 and 2003 and further to 2015, as increasingly large areas became devoid of breeding pairs. In some places, more than 60% of known territories had become vacant by 2003, although the old nests still remained intact. No evidence was found that factors other than illegal killing were involved (Whitfield *et al.* 2007).

In the absence of human interference, it is rare to find Golden Eagles in sub-adult plumage occupying nesting territories (Watson 2010). When a breeding adult dies, it is usually replaced by another, previously unpaired, non-breeding adult. But in Scotland, when adult Golden Eagles disappear from a territory, they are often replaced by younger birds in sub-adult plumage. Over 11 different regions of Scotland, the proportion of sub-adult birds at nests was found to correlate with the number of proven poisoning incidents. In the regions with the most poisoning incidents, the proportions of sub-adults seen on nesting territories stood at more than 20% (Whitfield *et al.* 2004). This indicated an unusually high mortality and turnover of breeding birds in these areas, inferred as resulting from illegal killing.

In the most recent national survey (2015), the proportion of known territories that were occupied varied greatly between regions and was especially low in the eastern Scottish Highlands (Hayhow *et al.* 2017b). The proportions of occupied territories with one or both members of the pair in sub-adult plumage were highest in the eastern Highlands and the south-central Highlands, both regions with relatively abundant grouse moors. But sub-adults were recorded in varying proportions at nesting sites in all regions, which could be taken to indicate a generally depressed population. Several factors are known to influence the breeding of eagles, including not only persecution but also poor food supply and poor weather (Watson 2010). Reproductive rates in 2015 varied widely

between regions, with no clear association in this year with grouse moors (Hayhow *et al.* 2017b).

The fact that eagles eat carrion makes them especially vulnerable to poisoning, and analysis of illegal poisoning incidents in the Scottish uplands showed a concentration in areas of managed grouse moor (Whitfield *et al.* 2008). Where eagles are allowed to breed on grouse moors, over a period of years their reproductive rates tend to be higher than in other habitats, presumably because of the greater food supply that grouse moors offer, in the form of Red Grouse and Mountain Hares *Lepus timidus* (Whitfield *et al.* 2008, Watson 2010). However, in many grouse moor areas, Mountain Hares have declined markedly in the last two decades in association with large-scale culling in attempts to reduce the spread of louping ill disease to Red Grouse (Watson & Wilson 2018).

Some 1500 years ago, the range of Golden Eagles extended as far south as Dartmoor in south-west England, with an overall British population probably in the order of 1000–1500 pairs, some two to three times higher than present numbers (Evans *et al.* 2012). The habitat currently available in Scotland is thought to be capable of holding around 700 pairs, against the 508 found, so there is considerable scope for further expansion within Scotland (Hayhow *et al.* 2017b). If one also includes the open uplands of England and Wales as suitable habitat, then less than half the potential habitat in Britain is currently occupied.

The movements and fates of tagged Scottish Golden Eagles that were tracked from satellites during 2004–2016 were particularly revealing (Whitfield & Fielding 2017). In their early years of life, the eagles wandered over large parts of Scotland, most over areas spanning more than 100 km across, and some more than 200 km across. But of 131 young eagles tracked, as many as 41 (31%) disappeared (presumably died) under suspicious circumstances in places where there were other independent records of illegal persecution. These disappearances occurred mainly in six areas of the Scottish Highlands (chiefly in the central and eastern Highlands) which held grouse moors. Some other grouse moor areas elsewhere in Scotland showed few or no suspicious disappearances. The relatively high proportions of young eagles which disappeared on some grouse moors would be expected to suppress Golden Eagle densities in the central and eastern Highlands, and hamper recovery of the overall Scottish population from

historical persecution. Those losses, regarded as suspicious, roughly halved the survival rate of eagles in their first 3 years of life (88% in the absence of human killing to 44% with human killing at its prevailing level). Interestingly, no known eagle deaths occurred at wind farms, and very few tagged young were recorded near turbines.

Operations associated with tagging had no discernible adverse effects on the welfare, behaviour or survival of the birds (Whitfield & Fielding 2017). These data thus gave further evidence of the likely illegal killing of eagles on grouse moors, and its role in preventing overall population recovery, and shows that the problem extends to wandering sub-adult eagles, as well as breeding adults. With young birds passing through, persistent law-breaking on a small number of estates could have a significant impact on eagle numbers over much wider areas, and hence on the overall national population.

GOSHAWK

Goshawks nest primarily in forests but also hunt on open land. They take mainly medium-sized birds and mammals, including corvids, pigeons and game birds, rabbits and hares (Kenward 2006). After the original British population was eliminated in the 19th century, the species was later imported for falconry, leading to occasional escapes and releases. During the 1960s and 1970s, Goshawks started nesting in at least 13 widely separated regions in Britain, with five leading to established breeding populations (Marquiss & Newton 1982). By 1980, overall breeding numbers in Britain were estimated at around 60 pairs, but imports were then restricted and subsequent population growth varied according to the annual productivity and killing of established birds (Marquiss *et al.* 2003). In some areas, breeding production was reduced by half due to the destruction of breeders or the removal of eggs and young (Marquiss & Newton 1982). Nevertheless, most nesting occurred in the seclusion of large upland forest plantations, enabling numbers to increase gradually, despite the killing on lower ground. The overall population was estimated at around 400 pairs in the 1990s, a time when illegal killing provided 42% of all ring recoveries (Petty 1996). More recently, national numbers were estimated at around 620 pairs (Woodward *et al.* 2020), but

given the size and remoteness of some large forest plantations, this is likely to be an under-estimate.

Perhaps more than any other raptor, Goshawks are attracted to Pheasant-rearing pens. Many are killed around such pens, and others after entering Larsen crow traps, attracted by the decoy bird (RSPB 2001-18, RSPB 2015). The impact of this killing away from nest-sites was inferred from a comparison of population growth in two regions: the Scottish Borders, where Goshawks lived in large state-owned forests remote from game interests, and Deeside in northeast Scotland, where many of the birds nested in privately owned woods close to Pheasant-rearing sites (Marquiss *et al.* 2003). In both regions, Goshawk breeding performance was little affected by the killing, and production was similarly good at nearly 2.5 young per nest, on average. However, in Deeside, there was ample evidence of Goshawks being shot and trapped at Pheasant release sites. The population growth rate in Deeside was less than half of that in the Borders, and three types of evidence suggested higher mortality in Deeside leading to a relative lack of recruits to the breeding population. First, on average only 70% of known breeding sites were occupied each year in Deeside compared with virtually complete occupancy each year in the Borders. Secondly, breeding numbers in Deeside increased or decreased from one year to the next according to the number of young produced 2 years earlier (most Goshawks first breed at 2 years of age). Finally, the birds in Deeside bred at a younger mean age, with 13% of nesting females being in their first year, compared with none in the Border forests, where all individuals began breeding in their second or a later year. Both populations became established in the early 1970s, but by 1996 the Deeside area held 17 breeding pairs, compared with at least 87 pairs in the Borders.

Although much of the killing occurs on Pheasant-rearing estates on low ground, other killing occurs on upland grouse moors. Some evidence derives from northern England (Peak District National Park), covering the period 1995–2015 (Melling *et al.* 2018). The Dark Peak is an area of intensive grouse moor management, where recovering numbers of Goshawks and Peregrines first settled, and from where they later colonized the White Peak to the south, where grouse management was less intensive. Initially these raptors were

left alone, but eventually killing became rife in the Dark Peak. Over the 20-year period, as the numbers of both species declined in the Dark Peak, they increased in the White Peak, where persecution had not become widespread. Among pairs that survived to lay eggs, the probability of success was much lower in the Dark Peak than in the White Peak.

Two main lessons emerge from the recent history of the Goshawk in Britain. Following its largely unauthorized 'reintroduction', the success of the species in re-establishing itself was almost certainly due to the presence in many upland regions of large state-owned forests, where pairs could nest largely free of persecution. Secondly, much of the killing occurred in late summer and autumn, away from nesting sites, and involved mainly young birds, rather than breeding adults at their nests (which are difficult for gamekeepers to find in large forests). Much of the recent killing has therefore occurred at the time each year when numbers were near their seasonal peak. Calculations based on data from Swedish ringing, supplemented by radiotracking, suggested that a loss of up to 35% of all young Goshawks might be sustained without leading to a decline in breeding numbers (Kenward *et al.* 1991). In contrast, the shooting of nesting birds can have more significant impacts, soon leading to population decline. Several studies in continental Europe showed how the persistent killing of a proportion of adult birds at nests lowered the mean age of the breeding population, as killed birds were replaced by youngsters (Rutz *et al.* 2006). With so many young birds nesting, overall productivity declined, ultimately reducing breeding density. In a long-term study in northern Germany, a marked drop in breeding numbers followed a change in hunting law, legalizing the killing of Goshawks; but after legal protection was reinstated, numbers increased again to their previous level (Looft 2000). These and other studies in various regions show clear relationships between the timing and intensity of killing and Goshawk population trends (Bijlsma 1991, Rutz *et al.* 2006).

RED KITE

Red Kites nest in trees in woods and hunt over open land, taking a wide range of prey from earthworms to young rabbits, and carrion of various kinds. Full-grown game birds are too big for Red

Kites to kill, at least in normal circumstances, but unfledged chicks of various birds are frequently taken. The Red Kite was almost eliminated from Britain, but survived in mid-Wales where, despite protection, the increase was very slow, partly owing to continued use of poisoned baits against foxes and corvids (Davis & Newton 1981). From the 1990s, birds from Europe were released in several areas to re-establish local Kite populations from which the whole of Britain might eventually be recolonized (Evans *et al.* 1997, 1999).

Subsequent population growth varied between the different release areas. It was exceptionally slow in northern Scotland (centred on the Black Isle), where reproduction was at least as good as in other areas, but annual survival rates were much lower (Smart *et al.* 2010). At least 40% of 103 Red Kites found dead in northern Scotland had been killed, mainly by poisoning. The annual survival rates of marked first-year, second-year and older birds were measured as 0.37, 0.72 and 0.87, respectively, but in the absence of illegal killing, these rates could have become 0.54, 0.78 and 0.92. In a mathematical model, the observed demographic rates gave a calculated population trend similar to that observed in the wild population, but without the illegal deaths, this Scottish population could have grown as rapidly as the fastest growing (Chiltern) population in south-east England in which persecution was negligible. It was therefore concluded that the growth of this reintroduced population in northern Scotland was being constrained by killing, again mainly on grouse moors. This situation persisted beyond the end of the study, and in 2014 the north Scottish population held only 64 known pairs, whereas the Chilterns population, introduced at the same time using the same methods and the same number of founding birds, had reached more than 1000 pairs (Sansom *et al.* 2016). Such was the impact of inferred persecution in northern Scotland.

Illegal killing is not restricted to the population in northern Scotland. In England, 32 of 110 Red Kites found dead during 1989–2007 had been poisoned, 19 by rodenticides ingested in the bodies of rodents, six by lead shot ingested in the bodies of other prey, and nine by other pesticides (two birds were categorized as containing both lead and pesticide, Molenaar *et al.* 2017). The poisonings resulting from ingestion of rodenticides and lead ammunition were presumably unintentional, but the others involved chemicals (aldicarb, alpha-

chlorolose, bendiocarb, carbofuran, mevinphops and strychnine) frequently used on poisoned baits.

BUZZARD

Buzzards now occur throughout Britain, nesting on cliffs or in trees, and gaining most of their food from open land. They take a wide range of prey, from earthworms to medium-sized birds and mammals, including chicks and occasionally adult grouse (Francksen *et al.* 2016a, 2016b, 2017, 2019). Some of their food is taken as carrion. In most parts of Britain where studies have been made, voles or rabbits form the bulk of the diet and have most influence on Buzzard densities and nest success (Newton 1979, Graham *et al.* 1995, Walls & Kenward 2020).

Historically, Buzzards were heavily persecuted by gamekeepers, and were eliminated from most of Britain, surviving chiefly in western hill districts, as mentioned above. Their spectacular expansion in recent decades marks a decline in persecution from the higher levels of the past. By 2009, they had reoccupied the whole of Britain, uplands and lowlands, and total breeding numbers were estimated at 56 000–77 000 pairs, making the Buzzard by far the commonest raptor in Britain (Musgrove *et al.* 2013). A more recent assessment has pushed the estimate up to 61 500–85 000 pairs (Woodward *et al.* 2020). There is now constant pressure from some in the game industry to have legal protection removed from Buzzards, and in recent years small numbers of licences to remove Buzzards to protect raised Pheasants have been granted by the relevant authority for England (naturalengland.blog.gov.uk/2019/04/08/latest-update-wild-bird-licencing-2). Buzzards are more conspicuous and visible than most other raptors, carrion-feeding makes them vulnerable to poisoning and they often enter Larsen traps containing decoy crows. So, it is perhaps not surprising that the Buzzard is now the raptor most often found illegally killed in Britain, forming about 60% of the total casualties reported in Scotland during 1994–2014 (RSPB 2001–18, RSPB 2015).

OTHER AVIAN PREDATORS OF GROUSE MOORS

In the breeding season, Merlins are associated mainly with the open uplands, nesting either in trees – in the old stick nests of corvids – or on the

ground among heather and other rough vegetation, and eating mainly small birds. Unlike some larger raptors, they are not systematically killed on most grouse moors; although they take occasional small grouse chicks, this is unlikely to affect significantly the numbers of grouse available for shooting, as chicks formed no more than 0.2–1% of the breeding season diet in three studies, the last being on prime grouse moor (Newton *et al.* 1984, Bibby 1987, Heavisides *et al.* 1995). The Merlin has been surveyed nationally in three different years. The first in 1983–1984 suggested a population in Britain of 550–650 breeding pairs, whereas the second in 1993–1994 gave an estimate of 1291 breeding pairs, an increase that probably reflected a recovery from organo-chlorine pesticide impacts of earlier years (Bibby & Natrass 1986, Rebecca & Bainbridge 1998). In 2008, numbers were estimated again at 1128 pairs. This apparent overall decline of 13% since 1993–1994 was not statistically significant (Ewing *et al.* 2011). Analysis of BTO Atlas data for 1988–1991 and 2008–2011 showed that the proportion of 10-km grid squares on managed grouse moors occupied by breeding Merlins in England doubled from 40 to 80%, but on other open upland it fell from 55 to 20% (Rogers 2014). This shift in emphasis to grouse moors was partly associated with growth of new forest on former open land, making it unsuitable for Merlins.

In any case, Merlins seem to favour grouse moors as nesting habitat. Trees are few there, which may explain why most Merlins on grouse moors nest on the ground, presumably benefitting from predator control. In a study in Northumbria during the 1970s–1980s, greater proportions of known nesting territories were occupied each year on managed heather moors than on other upland habitats, and the success of ground nests was higher on managed moors (Newton *et al.* 1986). Overall, tree nests were more successful than ground nests on both types of habitat. A preference for grouse moors was also apparent among Merlins in Wales (Bibby 1986). In recent years, however, the increased intensity of management on grouse moors (especially heather burning) may have reduced the suitability of some moorland for Merlins, accounting for declines in some areas, such as the Lammermuirs in south Scotland (Ewing *et al.* 2011, Barker *et al.* 2017). Not only is heather burning more frequent than in the past, but deep heather is especially targeted to

discourage nesting by Hen Harriers, so Merlins may be incidentally affected, too (Thompson *et al.* 2016). Nevertheless, some of the highest densities of ground-nesting Merlins occur in parts of northern England (Balmer *et al.* 2013), where the management of grouse moors is intense. Sufficient tall Heather for nesting Merlins evidently remains, despite sward burning to benefit grouse. Conversely, in the Berwyn Special Protected Area of North Wales, where moorland management ceased in 1992, numbers of breeding Merlins declined from a peak of 14 pairs in 1992 to eight in 2000, and then to only two pairs in 2014 (Sotherton *et al.* 2017).

After breeding, most Merlins abandon their nesting areas and, like most of their small prey species, move to lower ground for the winter, some extending south into Europe (Wernham *et al.* 2002). They can be seen in coastal areas and almost anywhere on inland farmland but are generally sparsely distributed, despite their winter numbers in Britain being swollen by immigrants from Iceland.

The Kestrel is another small falcon that occurs commonly on heather moors, nesting on crags or in trees (cavities or stick nests of other species). It feeds mainly on voles, and its numbers and nest success fluctuate from year to year in line with vole cycles (Snow 1968, Village 1990). It also takes small birds, including occasional grouse chicks, but its impact on grouse populations is probably trivial or non-existent, and most gamekeepers leave Kestrels alone. These birds are partial migrants and, although they can be seen in the uplands year-round, many move to lower ground or further south for the winter. At this season they are also joined by immigrants from northern Europe (Wernham *et al.* 2002). The Kestrel is the only raptor which, at the national level, has decreased markedly over recent decades – by about 44% from 1970 to 2010 (as in Fig. 1), and further by 50% by 2015 (Hayhow *et al.* 2017a), for reasons that are not yet well understood.

Sparrowhawks nest in woodland and eat mainly small birds. They hunt over grouse moors in search of Meadow Pipits and other small prey. They can kill grouse of any age, from small chicks to full-grown, but not in significant numbers (Newton 1986). In winter their numbers are swollen by immigrants from northern Europe. Moorland gamekeepers are unlikely to kill Sparrowhawks in

numbers sufficient to affect their wider population levels, but little relevant information is available.

The only other legally protected birds known to be frequently killed on grouse moors are the Short-eared Owl and Raven (RSPB 2001-18, Avery 2015, RSPB 2015). Short-eared Owls nest regularly on grouse moors, but most numerous in years when voles are plentiful. They also take small birds, including grouse chicks. Nationally, their numbers and distribution have declined in recent decades, but so has their vole-rich habitat (Balmer *et al.* 2013), so it is impossible based on present data to assess the role of illegal killing. In addition, these owls are highly mobile, concentrating in different areas in different years, according to food supply, and some also move to lower latitudes for winter, whereas others move in from northern Europe (Newton 2013). In contrast, Ravens are resident within Britain and have increased greatly over recent decades (Balmer *et al.* 2013), apparently in recovery from past persecution. They are potential predators of the eggs and chicks of grouse and other ground-nesting birds. One study found no significant negative associations between Raven abundance and population changes in upland waders in different areas, although the near-significant negative associations found for Northern Lapwing *Vanellus vanellus* and Eurasian Curlew *Numenius arquata* merit further investigation (Amar *et al.* 2010). Ravens also kill some young lambs, and many recorded instances of illegal killing relate to upland sheep farms (e.g. Lovegrove 2007).

DISCUSSION

Since the mid-20th century, following declines in illegal killing and organo-chlorine pesticide use, population recoveries became apparent in most raptor species in Britain, and not only those associated with grouse moors. White-tailed Eagles and Goshawks which had been eradicated altogether were reintroduced, and Red Kites (which had persisted in very small numbers in central Wales) were obtained from various parts of Europe for release in several different areas. Ospreys recolonized naturally and became fairly widely established and were later released in further areas. By the end of the 20th century, Buzzards had spread naturally from the west eastwards, and were breeding abundantly again in every county.

Peregrines, Merlins, Sparrowhawks and Marsh Harriers had recovered from much-reduced population levels caused by organo-chlorine pesticides. However, apart from two or three territories in northern England, Golden Eagles had still not spread back through the uplands of England and Wales where they bred in earlier centuries and where suitable habitat and food remain available. Three summer visitors to Britain, namely the Honey Buzzard, Montagu's Harrier and Hobby, had increased and spread to varying extents, but remained mainly confined to lower ground. The Kestrel, formerly the most common raptor in Britain, is the only species which has declined greatly in recent decades, with potential causes including reduction in food supply, rodenticide use and predation by increasing numbers of larger raptors. Most of these species still do not occupy their full potential range in Britain (Balmer *et al.* 2013). Throughout this period of general increase, killing of raptors continued on many grouse moors and lowland game estates, and population recovery at the national scale would almost certainly have occurred more rapidly without it. During the present century, a resurgence in the demand for driven grouse shooting has coincided with declines of several raptor species on grouse moors, and the abandonment of many traditional nesting sites. Raptor killing on grouse moors is now sufficiently widespread and intense to be affecting population levels beyond the moors themselves, as evident for Hen Harrier, Golden Eagle and Peregrine, and in northern Scotland also for Red Kite, and in part of northern England for Goshawk.

Some general patterns

The main lines of evidence for the widespread killing of raptors on grouse moors to emerge from the

accounts above include: (1) greater disappearance of nesting pairs, lower breeding densities or reduced occupancy of apparently suitable traditional territories on grouse moors compared with other areas; (2) reduced nest success on grouse moors compared with other areas; (3) reduced adult survival on grouse moors compared with other areas; (4) reduced age of first breeding, reflecting the removal of adults from nesting territories and their replacement by birds in immature plumage; (5) greater disappearance of radiotagged birds on grouse moors than elsewhere; and (6) finding of poisoned baits and traps, and shot or poisoned carcasses of raptors (Table 1). Not all these types of evidence are available for every species, and for some species other types of evidence are also available, including occasional eyewitness accounts or prosecutions of gamekeepers (RSPB 2001-18, Avery 2015). It is notable that, in the absence of killing, most of these raptors breed as well or better on grouse moors than in other habitats, evidently benefitting from the other management involved (for Hen Harrier see Green & Etheridge 1999, Ludwig *et al.* 2017; for Peregrine see Amar *et al.* 2012; for Golden Eagle see Watson 2010; for Goshawk see Marquiss *et al.* 2003, Rutz *et al.* 2006; for Merlin see Newton *et al.* 1986).

Raptor killing on a proportion of estates could affect populations over a wider area, especially if numbers of wandering sub-adults were killed in addition to breeding pairs. For example, a single Golden Eagle pair, if left undisturbed, might occupy a territory for 10 or more years, but if the birds were killed every year, this same territory could absorb 10 or more pairs in the same period, with none of them producing young. This process, leading some estates to become 'ecological traps', clearly has the potential to impose a large drain on the overall regional population, in part because of

Table 1. Summary of available information from grouse moor areas on effects of persecution on large raptors. Dashes (–) indicate lack of data. See text for references.

Evidence	Golden Eagle	Hen Harrier	Peregrine	Red Kite	Goshawk
Reduced densities/decline	+	+	+	+	+
Reduced nest success	–	+	+	–	+
Reduced adult survival	+	+	–	+	–
More sub-adult breeding	+	+	+	–	+
Disappearance of tagged birds	+	+	–	–	–
Direct evidence of persecution	+	+	+	+	+

the habit of many raptors, in their pre-breeding years, of wandering over large areas and passing through multiple individual estates. The presence of grouse and hares makes grouse moors especially attractive to Golden Eagles, and the numbers of eagles killed on some moors were indicated by the study of satellite-tracked birds mentioned above. Persistent killing at the levels recorded could stop a depleted population from recovering, or tip it into further decline, at least regionally. This could happen while unmolested populations in more distant regions continue to thrive or even increase (Whitfield & Fielding 2017).

If the illegal killing of raptors on grouse moors was stopped, this would be unlikely to result in higher densities of all species. This is because larger raptors often prey upon smaller ones, or deter them from nesting nearby, and can thereby limit their densities (Petty *et al.* 2003, Sergio & Hiraldo 2008, Newton 2017a). Golden Eagles kill most of the smaller species and can probably reduce the breeding numbers of Hen Harriers, Buzzards and Peregrines, or at least influence where they nest and forage (Fielding *et al.* 2003). Although studied elsewhere, the impacts of intra-guild predation on raptor populations have yet to be examined in the context of grouse moor management in Britain.

Issues for the future

Some 86% of 49 people convicted of killing raptors during 1994–2014 in Scotland were gamekeepers (RSPB 2015). It is understandable that gamekeepers view raptors as a threat to their grouse stocks and hence to their jobs and associated housing. Many may also be acting under other employment-related pressures, including instructions from their employers or financial rewards ('tips') received from shooters in return for 'big bags' (Burnside & Pamment 2020). All these aspects of livelihood depend on delivering an abundance of game for shooting.

Three measures to reduce the illegal killing of raptors have been suggested:

- Make land-owners responsible for proven illegal activities (such as shooting or poisoning of protected birds) on their land by people they employ, but this still requires evidence sufficient for prosecution of an individual. Such vicarious liability became law in Scotland from 2012 (but not in England and Wales), and so far at least two people have been prosecuted under this legislation.
- License grouse shooting itself, with the threat of licence withdrawal if law-breaking is proven. This view has been advocated by RSPB and others, but it still requires information that will lead to the conviction of an individual. This measure has been recommended in Scotland if raptor populations on grouse moors do not improve within 5 years from 2019 (Werritty 2019).
- Ban driven grouse shooting altogether. This view was put forward in 2015 by Mark Avery who organized a petition to Parliament with more than 120 000 signatures in support. The Government of the day turned it down, but pressure on moor owners over raptor killing continues. Banning driven grouse shooting could incidentally lead to the loss of some other cherished ground-nesting species that benefit from the management involved, which maintains a low-predation open environment.

Although the banning of driven grouse shooting could remove the main current constraint on Hen Harrier and other raptor numbers in some regions, it might not translate into larger national populations in the longer term. If heather moors were no longer valued by their owners, they would most likely be converted to sheep pasture or forest plantation, the main alternative land-uses in the British uplands. This would diminish their value for harriers and other large raptors by destroying habitat or reducing prey populations. It would also lessen their value for many other ground-nesting birds besides grouse, including several wader species. For example, stopping routine grouse moor management on Langholm Moor in south-west Scotland was followed by a rapid rise in fox and crow numbers, and reduction in the numbers of nesting Hen Harriers and some other ground-nesting species, trends that were reversed when management was reinstated (Ludwig *et al.* 2017).

A different approach to resolving the raptor–grouse conflict involves attempts to achieve compromise, consensus and cooperation (Redpath *et al.* 2010). Law enforcement has proved extremely difficult, and for many moor-owners and gamekeepers the law is no longer a significant deterrent. Alternatives under continual discussion include: (1) better enforcement of existing law (difficult under present circumstances); (2) a move to less intensive

management, allowing more raptors to survive, but yielding fewer grouse to shoot and insufficient revenue to cover the costs of management (unless clients would pay more than hitherto for walked-up shooting, a change that would require a cultural shift among the grouse-shooting community); (3) intra-guild predation by Golden Eagles (see below); and (4) diversionary feeding or a Hen Harrier brood management scheme as discussed above. Progress requires continued dialogue between the main stakeholders and more understanding of the costs, acceptability, legality and feasibility of these different approaches, as well as their environmental, economic and social consequences.

Questions are often asked by those involved in game shooting as to why it is desirable to have so many raptors and why should their numbers not be reduced. In conservation terms, the long-term security of any species depends on its abundance and spatial extent. The more widely distributed is a species within its natural range, the more secure in the long term it is likely to remain. Large numbers and wide distributions tend also be associated with greater genetic diversity, an attribute thought to favour greater long-term resilience against other environmental pressures. As predators, raptors are naturally much less numerous than most other birds occupying similar habitats, and partly for this reason they are naturally more vulnerable, and can be more readily eliminated by human action (as shown by past events). Other arguments in favour of conservation are based on value judgements. They are concerned with the kinds and variety of wildlife prevalent in the countryside, and the pleasures derived by many people from regularly seeing different species. This is a source of pleasure that promotes tourism, boosting local economies in places that still have unusual or abundant wildlife to offer (for the economic impact of White-tailed Eagles on the economy of the Scottish island of Mull, see Molloy 2011, and for the wider impacts of various raptors in specific localities, see Dickie *et al.* 2006). Clearly, recreational shooting is not the only wildlife-based activity which brings revenue to local communities.

Raptor killing is the main issue that divides grouse moor managers and conservation organizations in Britain, which otherwise have much in common. It is difficult to see how to resolve this issue in a satisfactory manner, as both sides have reasoned arguments, both have taken entrenched positions, and legislation is extremely difficult to

enforce and is being increasingly ignored. Only dialogue, mutual understanding and compromise are likely to lessen this conflict.

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DATA AVAILABILITY STATEMENT

All the data quoted in this review are acknowledged to the references included in the text and reference list.

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