



Forestry England

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# Golden Eagle recovery feasibility in England

Work Packages 1-3: D. Philip Whitfield & Alan H. Fielding  
Work Package 4: Greg Counsell



# Executive Summary

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<sup>3</sup>Roy Dennis Wildlife Foundation

<sup>4</sup>Natural England

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### Background

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Our planet faces dual and inextricably linked nature and climate crises. The UK has lost more biodiversity than many other countries in the world. Alongside biodiversity, bioabundance is critical to the health and resilience of an ecosystem, enabling different trophic levels to interact and function. The absence of species, or entire groups of species performing a comparable role, can cause cascading impacts on bioabundance elsewhere, leaving ecosystems unbalanced and dysfunctional.

The UK Government's [25 Year Environment Plan](#) (2018) aims to '*...protect threatened species and wildlife habitats. It calls for an approach to agriculture, forestry, land use and fishing that puts the environment first*'. The plan discusses opportunities to restore, recover and reintroduce species, including intention to develop a reintroduction code building on the [IUCN Guidelines for Reintroductions and Other Conservation Translocations \(2013\)](#). This has since been published, in 2021 (updated in 2024): [Reintroductions and other conservation translocations: code and guidance for England](#).

Forestry England have set out ambitions that 'the nation's forests provide the most valuable places for wildlife to thrive and expand in England'. The national [Biodiversity Plan 2022-26](#) identifies five areas they seek to focus efforts, aligned with the Lawton Review principles of creating habitats that are bigger, better and more joined-up (Lawton, 2010). One of these focus areas is 'Restoring species' and Forestry England are a sector lead in species reintroductions. These have historically ranged from Pool Frogs, to White-faced Darter dragonflies, to Pine Martens. Under the new Forest Wilding Programme, Forestry England are focusing population restoration efforts on 'influential species', such as ecosystem engineers and keystone species; those whose positive effect greatly surpasses their restoration alone.

There are numerous different approaches to support and expedite species recovery. These include, but are not limited to: targeting causes of population decline; improving habitat and connectivity; enhancing genetic resilience; engaging stakeholders and communities directly in recovery efforts; conservation translocations; and supporting a species through challenging stages in its lifecycle (e.g. providing denning and nesting opportunities). The species recovery 'toolbox' is being called upon in increasing frequency to preserve, conserve and restore at scale and with speed.

The loss of apex predators in ecosystems results in extensive negative cascading effects, with shifts in this top-down forcing leading to both direct and indirect consequences for natural process and function (Estes, J.A. *et al.* 2011). In the UK, our present day apex predators amount to just two, avian, species: the White-tailed Eagle *Haliaeetus albicilla* and the Golden Eagle *Aquila chrysaetos*. Following virtual extinction of both species in England around the turn of the 19<sup>th</sup> Century, predominantly through persecution, the White-tailed or 'Sea' Eagle has been the subject of reintroduction endeavours in southern England since 2019 by [Roy Dennis Wildlife Foundation](#) and [Forestry England](#). It has also previously been reintroduced to Scotland, with efforts beginning in 1975 by the Nature

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Conservancy Council (now [NatureScot](#)) and [RSPB](#). Despite also suffering significant losses, Golden Eagles have remained extant in Scotland throughout and now number well over 1000 individuals. However, their dwindling population south of the Central Belt has led to concerted reinforcement efforts by the [South of Scotland Golden Eagle Project](#) (SSGEP), beginning in 2018. England is not currently home to any breeding pairs of Golden Eagle.

Restoration efforts for raptors in England have been met with success for a number of species. This includes the recent White-tailed Eagle reintroduction to the south coast, which saw the first wild-hatched chick in 240 years fledging in 2023, to be followed by two siblings in 2024. Osprey, Hen Harrier and Red Kite have also undergone significant recovery and reintroduction efforts. For the latter, success has been so great we have come full circle and [facilitated recovery of Red Kites through translocation back to Spain](#), from whence our own reintroduced populations originated thirty years ago.

## Purpose of this report

In the light of national nature recovery ambitions and the recent exploratory behaviour of young Golden Eagles from Southern Scotland into Northern England, it is timely to undertake an assessment of England's capacity to support Golden Eagles nationally, as well as help identify approaches that may best expedite its recovery. These might include encouraging settlement of naturally recolonising young Eagles; engaging the public and stakeholders in restoration efforts; and/or proactive reinforcement and reintroduction.

This report is intended to gather existing evidence, analyse appropriate data, and draw on a wealth of expertise and research to understand the current English landscape's capacity to support a viable population of Golden Eagles, in both an ecosystem and societal context. It is intended to help inform and guide next steps for regional feasibility for those who are pursuing, or may in the near future pursue, recovery plans and efforts for this species in England. It is not a definitive blueprint to recovery approaches or intended to reflect the limitations of what might be possible. But, rather its purpose is as a decision-support tool, or springboard, for future projects. Modelling outputs only ever reflect data input and species responses and behaviours at both the individual and population levels are never entirely predictable; our understanding is growing all the time especially with increased availability of technology such as satellite tracking.

Localised recovery efforts going forward should follow appropriate legislation and guidance, such as the [IUCN Guidelines](#) and the [Defra Code & Guidance for England](#).

## Report Summary

As with any assessment of the feasibility of species recovery, there must be biological, ecological and social considerations. This feasibility addresses these through four work packages, split into two commissioned reports.

The aims of the overarching report are:

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1. To determine where in England is biologically and ecologically capable of supporting a viable population of Golden Eagle and consider social acceptability of population recovery.
2. To advise the most appropriate tool(s) and approaches for Golden Eagle recovery in England.

Work Packages 1-3 consider biological and ecological feasibility; they are supported by a 'Data Dictionary'. These were led by D. Philip Whitfield and Alan H. Fielding at Natural Research Ltd.

Work Package 4 considers social feasibility and was led by Greg Counsell at Forest Research.

A summary of each work package's key findings follows below.

## **Work Package 1: Background and Habitat Suitability including the 'risk landscape'**

Key findings and recommendations:

1. Golden Eagles are a native species to England, with historical evidence recorded within upland English habitats.

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2. Golden Eagles that formerly inhabited England are probably most genetically akin to those in Scotland. There is debate over whether the Scottish population is diminished in genetic diversity. If so, it empirically has not prevented considerable expansion of the Scottish population in recent decades.
3. Analysis considers 28 Potential Recovery Zones (PRZs) for Golden Eagles in England. These consist of i) PRZs combining results from a SDM (Species Distribution Model) and GET (Golden Eagle Topography) model; and ii) PRZs combining National Landscapes, National Parks and SPA boundaries, with a 1km buffer, as discrete areas of countryside with more nature-focused remit that may assist with future practical management.
4. Sixteen variables, inclusive of land cover, climate, topography and potential disturbance, were considered in relation to three datasets of Scottish Golden Eagle home ranges across the 28 PRZs.
5. The report highlights eight PRZs that, based on this evidence and analysis, are most likely to contribute to recovery of Golden Eagle in England. These are: Cheviots, North Pennines, Lakes, Yorkshire Dales, Bowland, South Pennines, North York Moors, and the South West. Former use of these areas by Golden Eagles is confirmed by historical records and movements of GPS-tagged Southern Scotland eagles.
6. The PRZs, core areas for recovery potential, have been identified as able to support an upper limit of 92 home ranges just within their defined boundaries. This may be revised to 45 when subjectively considering potential risk factors.
7. The report describes Scotland as the best-placed source of Golden Eagles for translocation efforts to England. It suggests apparent incomparability between English lowland habitats and those lowland habitats where the species persists in Europe, as well as the vulnerability of these populations to act as source populations.

Work Package 1 considers the existing and near-term areas of high suitability within the English landscape to support Golden Eagles originating from Scotland (be that through natural recolonisation or translocation). As is discussed, within their European range Golden Eagles are found in a wider variety of habitats and elevations than in Britain and Ireland, each with its nuance. Potential utilisation of lower lying landscapes by Golden Eagles (e.g. for foraging and dispersal, if not breeding), particularly on the fringe of core optimal habitats, should be acknowledged. This particularly considers ambitions for nature in England and the individual differences within a population that lead to some individuals having higher tolerances for disturbance.

## Work Package 2: Population Viability Analysis

Key findings and recommendations:

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1. If natural expansion were enabled, a notional carrying capacity of 80 Golden Eagle pairs across Southern Scotland and England over 40 years (likely an overestimate) requires a fledging rate close to 0.5 for both sexes.
  - Given juvenile dispersal distances and probable expansion routes from Southern Scotland, Golden Eagles could be seen across Northern England PRZs and as far south as the South Pennines within 10 years. It will take much longer for breeding pairs to be established across these areas.
  - Most probable routes of natural recolonisation from Southern Scotland are south through the Cheviots PRZ, into the North Pennines and Lake District. Once reached, the North Pennines and Yorkshire Dales are critical routes to recolonisation of the remaining northern PRZs. It could take two decades for any successful breeding in the Dales, but if this occurs, it may enable more rapid multi-directional population expansion.
2. If reinforcement were undertaken, a reasonable probability of success (considered herein as a population larger than that post-release) would require a moderate to high release strategy, survival rates like those in Southern Scotland, alongside good productivity.
  - Sourcing at least five individuals per year for five years, or preferably more, is required.
  - Individuals should be satellite-tagged and the population monitored for at least ten years post-release.
  - A comprehensive survey of prey should be undertaken prior to releases.
3. Natural recolonisation of the isolated South West PRZ is highly unlikely and any proposals for active translocation there would have to strongly consider this isolation at the regional scale, including dispersing birds' survival.
4. Continued monitoring of Southern Scotland Golden Eagles using satellite trackers is identified as essential. The behaviour and movement of these birds will enable documentation of Eagle recovery and increase the evidence-base for any future release programme.

## Work Package 3: A review of prey availability

### Key findings and recommendations:

1. The novel presence of Golden Eagles in England may result in impacts on distribution and abundance of mesopredators through direct and indirect means. This is less certain for mammalian species but may be the case for smaller raptors - although in turn, suppression across these species also suppresses competition between them. Exact effects are situation-specific and complex.
  - The authors note that mesopredator suppression effects pale in comparison to any effects of sustained persecution on these species.

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2. Restoration of apex predators has frequently been associated with significantly beneficial knock-on effects on biodiversity; the opposite is rarely, if ever, shown. Breeding Golden Eagles in England will at best be beneficial to biodiversity, at worst neutral.
3. No birds of conservation concern, notably Black Grouse, Merlin and Hen Harrier, should be additionally adversely affected by Golden Eagle recovery.
4. No mammals of conservation concern should be adversely affected by Golden Eagle recovery, with Red Squirrel and Pine Marten being particularly considered.
5. Non-native gamebirds Common Pheasant and Red-legged Partridge are traditionally released in the lowlands, but increasingly so in the uplands. Golden Eagles are not averse to predating on these species and where they may be more abundant at release locations that overlap with eagle habitat, they may be subject to localised predation. However, it is unlikely that this would have a large effect on stock available for shooting, especially considering timings of gamebird releases.
6. Golden Eagles depredate Red Grouse, a species of economic interest. Red Grouse numbers are deliberately elevated for driven shoots in a number of the PRZs identified. SSGEP has worked very effectively with landowners, managers and conservation groups to find ways of accommodating the expanding Golden Eagle population in Southern Scotland. Comparable sustained and interactive efforts would be required in any English recovery attempts.
7. The review considers results on Sheep (lamb) depredation from both Golden Eagle and White-tailed Eagle releases and concludes that both species have no effect, or only negligible economic effect. Likely concerns and perceptions to the contrary will, however, require addressing prior to recovery efforts (see WP4).
8. Golden Eagles can take a broad range of foods, although there may be preferences. Prey availability and abundance are impossible to quantify and only the latter possible to describe qualitatively and comparatively (doing so at any regional level was beyond the scope of this report).
9. Golden Eagle breeding productivity appears dependent on abundance of potential prey sources. Qualitative evaluation of prey abundance is therefore the most appropriate, and an essential, element of regional feasibility for Golden Eagle recovery in England.

## **Work package 4: A review of social approaches to Golden Eagle and White-tailed Eagle recovery and population restoration in the UK and Europe**

### Key findings and recommendations:

1. This work package utilises a combined literature (academic and grey) review and targeted practitioner interviews to identify the challenges and best approaches to Golden Eagle and White-tailed Eagle recovery in Britain and Europe.

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2. Key stakeholders and stakeholder groups will hold a range of views and perceptions on the recovery and reintroduction of Golden Eagles. Consultation and engagement should be considerate of this and seek to understand and address any concerns and opportunities raised.
3. Support from the general public for reintroduction of Golden Eagles is likely to be high and such support in any proposed region for recovery would be greatly advantageous.
4. Social perception research, both online and face-to-face, should measure: species knowledge, reintroduction knowledge, attitudes to the species, level of support for recovery/reintroduction, demographic data. Such information can directly inform subsequent outreach and engagement.
5. Consultation should consider:
  - Stakeholder mapping, including key groups: landowners, land managers, gamekeepers, farmers, local and national farming groups and associations, local and regional government, tourism, wildlife conservation, forestry.
  - Where possible, partnerships or steering groups should be formed with key stakeholders whose interests may pose challenges to Golden Eagle recovery.
  - Local organisations and individuals may likely hold differing views from their national counterparts.
  - Public and stakeholder consultations should run smaller events that encourage one-on-one discussion, rather than “town hall”-style meetings. In the first instance, these should be walk-in sessions and webinars, alongside informal semi-structured interviews with representatives from key stakeholder groups. Single-stakeholder group meetings should follow, with support from counterparts in areas with Golden Eagle populations. Financial cover for people’s expenses is recommended.
  - Evidence suggests avoiding compensation schemes as potential mitigation measures. Instead, conversation should be focused on evidence and lived experience elsewhere, with other mitigation measures proposed e.g. a dedicated channel for raising concerns.
6. Engagement methodologies throughout the research should consider:
  - Recruiting a longstanding Project Officer as early as possible, ideally local and with a background working in or with land-based business. Consistency of this individual, where possible, is key. This role is considered a key determinant in successful community and stakeholder engagement.
  - Forming a steering group, inclusive of individuals from key stakeholder groups.
  - A programme of community outreach, connecting the community to the project, including e.g. schools, local businesses, eco-tourism businesses.
  - Communications and utilising local and national media as an ally. Provide press releases to ensure accuracy in reporting. Maintain online presence and social media to keep people informed.

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- Seeking to reassure stakeholders of long-term project intentions. Creating a steering group with local stakeholders and maintaining an engaged community will ensure the longevity of support beyond the project duration and help optimise long-term success.

## Concluding remarks

England has the capacity to support Golden Eagles and eight Potential Recovery Zones are identified nationally as being core areas of the most suitable habitat. Seven of these are based in Northern England, one in the South West. Approaches to recovery are quantified through Population Viability Analyses, namely through i) supporting and enabling natural recolonisation (with probable expansion routes identified), or ii) proactively enhancing this through reinforcement or reintroduction (the latter being the only likely option for the South West).

Golden Eagles take a broad range of foods and breeding success appears dependent on prey abundance. No species of conservation concern should be additionally adversely affected by the recovery of Golden Eagles. Evidence points to no, or negligible, economic risk to Sheep (lambs). Sustained and interactive efforts would be required in any English recovery attempts to work effectively with landowners, managers and conservation groups to find ways to accommodate Golden Eagles with relation to driven shoots, as SSGEP have done so effectively. Public support for the recovery of Golden Eagles is likely to be high.

Approaches to social feasibility and engagement at a regional level should ensure appropriate engagement and outreach across all stakeholders from the beginning of a project and inclusion of key stakeholders in partnerships or steering groups. There is no evidence that compensation schemes are required as a mitigation measure; instead, sharing evidence and lived experience amongst stakeholder groups is key. The value of a longstanding dedicated Project Officer for recovery projects cannot be understated.

## References

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# Golden Eagle Recovery Feasibility in England

A report to Forestry England on Work  
Packages 1-3

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Natural Research, Banchory

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# 1. Background and Work Package 1

## 1.1 Background and Introduction

*The aims of the overarching project are:*

i) *To determine where in England is biologically and ecologically capable of supporting a viable population of Golden Eagle [and consider social acceptability of population recovery<sup>1</sup>].*

ii) *To advise the most appropriate tool(s) and approaches for Golden Eagle recovery in England.*

### **Work Package 1**

*Habitat suitability modelling (using Maxent or similar) for the Golden Eagle in England, incorporating species records from the British Isles and NW Europe, to highlight priority regions capable of supporting a Golden Eagle population.*

*Considerations for models:*

- *appropriate land cover, terrain and climatic variables*
- *the 'risk landscape' to Golden Eagles, e.g. windfarms, human activity/disturbance, climate change.*

## 1.2 A brief history of the Golden Eagle in England, Britain and Ireland

Currently there are no breeding pairs of Golden Eagles in England. The most recent “English” pair nested in a territory around the border with Scotland, first occupied in the mid-1970s (D. Anderson *pers. comm.*). Occupying pair(s) raised several fledglings. The last record of a pair was in 2005 (both birds present) or 2006 (the year the male disappeared, possibly killed after being caught in a crow trap in the English Cheviots). These final records involved a female ringed in 1991 as a nestling in the same territory. This ringed female laid infertile eggs in 2007 (with no male present), and in 2008 she moved to a breeding site in the Scottish Borders, raising a chick there (D. Anderson *pers. comm.*). In 2009 after rearing another fledgling she was poisoned. Afterwards her (currently 20 years+ old) ringed male partner was joined at this Scottish Borders breeding site by a GPS-tagged female originating from south Scotland and they have subsequently produced fledglings regularly (R. Dennis & LBRSG *unpublished data*, D. Anderson *pers. comm.*, J. Wright *pers. comm.*).

A second Cheviots pair was established by the early 1970s but did not survive long before being killed by the local gamekeeper (D. Anderson *pers. comm.*). This territory has not been reoccupied since.

In the Lake District, preceded by a few years of sightings and nest building by Golden Eagles, in 1969 a breeding attempt was confirmed, after an absence of 200 years. Two pairs were documented later, the second pair being present for a relatively short period

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<sup>1</sup> The bracketed aim is not relevant to this report's brief.

(Walker 1990). In 2004 the female of the sole remaining pair died leaving her male partner alone for 12 years before he died in 2016.

Aside from a few breeding pairs in recent decades, previously the Golden Eagle became extinct in England in the 19<sup>th</sup> Century (Dennis *et al.* 1984). Reconstruction of the distribution of Golden Eagles over time suggests that by the beginning of the 19<sup>th</sup> century (1800 CE) they were almost extinct (one record in Cheviots), with breeding in the Lake District until the latter part of the 18<sup>th</sup> century (Evans *et al.* 2012). As any locations of remnant breeding sites may have been protected the final year of extirpation may have been later, or not recorded (Evans *et al.* 2012, a potential bias echoed by Fryer 1987). The “1850s” is repeatedly noted in several internet sources (without references), which coincides with the species’ extirpation from Wales (Williams 2021).

Fryer (1987), however, presents persuasive evidence that it was present in 1851 in Derbyshire while also noting: “*In England it bred in the Lake District until towards the end of the eighteenth century, and of course has persistently done so again in recent years. In the Cheviots it bred until well into the nineteenth century, and it did so in close proximity to the probable Yorkshire sites in the seventeenth and possibly eighteenth centuries.*” Incidentally, none of the information on prior distribution collated by Fryer (1987) across several centuries cites historical Golden Eagle records in England away from the uplands, in keeping with Evans *et al.* (2012) and Holloway (1996).

Hence, there is no evidence that the Golden Eagle occupied lowland habitats of England in recorded history. With a richer history through greater abundance of the species this same result is in many Scottish accounts (e.g. Baxter & Tintoul 1953). In the consistent absence of Golden Eagles in the lowlands from historical information in Britain it is also noteworthy that most naturalists collating such information with an interest in doing so, probably lived in the lowlands (albeit obviously with sources in or personal visits to the uplands). It is logical to surmise that if these many authors knew of lowland breeding records, these would have been more likely to have been documented. But there are none.

The historical record for the Golden Eagle is in stark contrast to contemporaneous accounts of the White-tailed Eagle *Haliaeetus albicilla*, for which there is a substantial information showing a former distribution across much of lowland England before it became extinct (e.g. Evans *et al.* 2012, Dennis *et al.* 2019)<sup>2</sup>. The tendency for segregation between Golden and White-tailed Eagles’ distributions is also consistent with modern studies of habitat preference, with White-tailed Eagles preferring lower altitudes and greater proximity to aquatic habitats (e.g. Whitfield *et al.* 2002, 2013, Evans *et al.* 2010). Therefore, this is another strand of evidence that Golden Eagles were not missed in the lowlands by historical authors, but that they were not there.

Currently, there is also no evidence that Scottish Golden Eagles use lowland habitats (Fielding *et al.* 2024a), or breed there despite a population now numbering several hundreds of pairs (Hayhow *et al.* 2017). Rather, lowland habitats can act as a barrier to dispersal and population spread (Fielding *et al.* 2024a).

Regardless of an accurate historical extinction date from England, before a temporary recolonisation started in the late 1960s and the 1970s, the Golden Eagle had been absent as a breeding species in England for at least 100 years, and much longer in most regions. Centuries before, in 500 CE, reconstructions suggest that England was part of a

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<sup>2</sup> Of relevance, and confirmatory on the value of historical records, areas used by recently reintroduced White-tailed Eagles to the south coast of England have substantially aligned (T. Allard *pers. comm.*).

widespread distribution extending across much of Scotland, regions of north England (and even southwest England) and Wales, and many parts of Ireland (Evans *et al.* 2012). The last Golden Eagle in Ireland, prior to later reintroduction, was recorded in 1912 (O’Toole *et al.* 2002).

By 1920 this formerly widespread distribution had shrunk predominantly to parts of the Scottish Highlands and a smaller remnant on the Outer Hebrides (Love 1983, Evans *et al.* 2012, 2013). These refuges typically shared land management aligned to shooting Red Deer *Cervus elaphus*, away from intense persecution associated with egg and specimen collecting, contemporarily antithetical sheep husbandry, and the Victorian intensification of killing perceived ‘vermin’ to maximize bags from driven shoots of Red Grouse *Lagopus lagopus scotica* (Love 1983, Watson 2010, Evans *et al.* 2012, 2013).

Subsequently, for several reasons (notably relaxation of persecution) these refuges have served as sources for the considerable expansion of the Golden Eagle in Scotland (and temporarily in the recent past, likely from there, into England: see later) (Watson 2010). This expansion is despite persecution associated with intensive management for shooting Red Grouse remaining a constraint in some parts of the east Highlands, despite decades-old legal protection of eagles (Whitfield & Fielding 2017). Whereas in other parts of the Highlands the recent cessation of persecution has seen an increase in the number of productive breeding pairs (Benn & Whitfield 2023).

### 1.2.1 Genetic studies of the historical British and Irish population(s)

Against the ecological backdrop of Golden Eagle historical distributions, genetic analyses of the current Scottish population show that it has been isolated from the European mainland for thousands of years (Sato *et al.* 2020, 2023). Separate analyses have also consistently found distinct genetic separation of Scottish birds from several populations sampled elsewhere in Europe and beyond (Nebel *et al.* 2015<sup>3</sup>, 2019, 2023).

This strongly suggests that the genetic heritage of historically more widespread but now extinct native English Golden Eagles shared greatest affinity with birds recently sampled in Scotland. In other words, the current birds in Scotland are the most representative remnant of a once-wider population which extended across Britain and Ireland. This Scottish remnant is possibly currently diminished from former genetic diversity (Bourke 2007, Sato *et al.* 2023) although contrarily it has been argued that genetic diversity has not been substantially diminished (Nebel *et al.* 2019). This group of birds was already long isolated from other Golden Eagles before humans took their toll on numbers and distribution (including before their extirpation from England), but there was no suggestion that this caused a bottleneck on genetic diversity (Nebel *et al.* 2019).

Ideally, definitive confirmation of historical relatedness could be achieved by extraction of DNA from historical specimens with confirmed English provenance and comparison to samples from other parts of the previously wider distribution (Bourke 2007).

Unfortunately, this has not been possible to date. Bourke (2007: page 71) notes:

*“Given the large breeding ranges maintained by the species (up to 100 km<sup>2</sup>) and the relatively localised records for England and Wales since the 17<sup>th</sup> century, it is likely that English and Welsh breeding was sustained in more recent centuries (if at all) by individuals from Scotland and Ireland. Extirpation in these English and Welsh edge*

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<sup>3</sup> Note that the Scottish samples in Nebel *et al.* (2015) were dated 1904-1997 and came from “museum collections and private collectors”.

*populations was unlikely to have had a major impact on genetic diversity within the large Scottish population. Only when large declines occurred in the Scottish range was there likely to be a significant loss in genetic diversity. Unfortunately, few historical specimens with reliable English and Welsh provenance exist, and so the genetic basis of this theory can not be tested.”*

Historical DNA samples were obtained from Ireland and Scotland, nevertheless, and Irish genetic profiles were found to be most like Scottish birds (compared to other European profiles) but there was differentiation (Bourke 2007). The differences were attributed to (despite) some possible slight connectivity through dispersal, geographical isolation probably creating a substantial degree of separation between Irish and Scottish birds (Bourke 2007). It was concluded, nonetheless that the Scottish population is the most closely related extant population to the former Irish population<sup>4</sup>.

These findings reflect another study using recent DNA samples from Scotland. The current sub-population on the Outer Hebrides, isolated from the rest of Scotland by geographical barriers to dispersal (Fielding *et al.* 2024a), is essentially a genetic subset of the larger sub-population in the Highlands and Inner Hebrides (Ogden *et al.* 2015)<sup>5</sup>. The initial separation probably came about several hundreds of years ago, if not longer, and was possibly exacerbated because of fewer remnant birds still surviving on the Outer Hebrides at the nadir of all Scottish sub-populations in the late 19<sup>th</sup> and early 20<sup>th</sup> centuries (Evans *et al.* 2013).

### 1.2.2 The source of recent temporary recolonisations in England

With Golden Eagles that: a) have been isolated from mainland Europe for thousands of years (e.g. Sato *et al.* 2020, 2023), b) the species' history in Britain and Ireland, c) recent data on Scottish birds' movements during dispersal and geographical barriers they are apparently reluctant to cross (Fielding *et al.* 2024a), and d) the relatively close proximity to Scotland of the recolonising English pairs in the 20<sup>th</sup> and 21<sup>st</sup> centuries, it may be superfluous to emphasise the logical conclusion that the recent temporary recolonisations of England must have come from Scotland.

In addition, the timing of these English recolonisations may be related to the earlier recolonisation of southwest Scotland. Marquiss *et al.* (1985) notes:

*“Golden Eagles Aquila chrysaetos recolonised southwest Scotland in the early 1940s. By 1966 four pairs were established and breeding success was good. In the early 1970s, coincident with large-scale afforestation, two pairs ceased to breed and a third pair rarely produced young.”*

What is perhaps more curious (with a Scottish source seemingly indisputable) is the route behind the temporary recolonisation of the Lake District in the late 1960s, and the comparable apparent (if slightly later) timing of recolonisation in the Cheviots. By 1966 the small southwestern Scotland group of breeding birds were at their zenith (Marquiss *et al.* 1985). On a linear distance, this part of Scotland is closest to the Lake District.

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<sup>4</sup> Hence Bourke (2007) also concluded that despite not conducting any formal genetic analysis, the Irish reintroduction project (O'Toole *et al.* 2002) was justified in choosing Scottish birds as the most suitable donor stock because they were from the most closely related extant population, as per 1996 IUCN reintroduction criteria on genetics (subsequently updated: IUCN/SSC 2013).

<sup>5</sup> This was not realised by Bourke (2007) and Bourke *et al.* (2010) because this research combined samples from the Outer Hebrides and parts of the Inner Hebrides (Ogden *et al.* 2015).

Yet recent research on dispersal movements of Scottish birds, and the effects on movements through geographical barriers (Fielding *et al.* 2024a) show that this direct route, including the Solway Firth, would be close to the limit of unsuitable habitat Golden Eagles are prepared to cross. Moreover, thanks to a recently burgeoning south Scotland sub-population and satellite tracking (substantially through the South of Scotland Golden Eagle Project begun in 2019: SSGEP 2024), this study recorded movements during dispersal going into England in the Cheviots and for some, through to the North Pennines and, for two birds briefly, thereafter into the Lakes (Fielding *et al.* 2024a, *unpublished data*), with all returning to Scotland.

As has been emphasised (Fielding *et al.* 2024a), the distances covered by movements during natal (juvenile) dispersal are greater than those described by Natal Dispersal Distance (NDD: Whitfield *et al.* 2024). NDD, the distance between a bird's natal site and the subsequent first breeding site, is most relevant to gene flow and population connectivity. Raw NDD median estimates for Scottish birds were 30 km for males and 59 km for females, with maximums of 82 km and 87 km respectively (Whitfield *et al.* 2024).

## **BOX 1.1**

### **An interim summary**

So far as future options for Golden Eagle recovery in England, historical and genetic sources are pertinent:

1. The historical ecological affinity is with birds from Scotland, including information from the few English pairs in the 20<sup>th</sup> and 21<sup>st</sup> centuries.
2. The genetic affinity of English birds in the historical past is probably most aligned on relatedness with birds from Scotland.
3. There is no ecological evidence that historically, or currently, the Golden Eagle in Britain or Ireland (including England) is a species which has or does exploit lowland habitats (never mind breeding there).
4. All evidence indicates that the past and present gene pool of British Golden Eagles was and is adapted to exploiting upland habitats.

## **1.3 Identifying regions where Golden Eagles may settle**

The aim of this section is to define discrete regions which can then be assessed for their potential to support dispersing birds and/or breeding pairs plus any constraints which reduce their potential. The present feasibility study under Work Package 1 included a brief to consider habitat suitability modelling for the Golden Eagle in England, incorporating species records from “the British Isles and NW Europe”, to highlight priority regions capable of supporting a Golden Eagle population. Considerations for models were to include appropriate land cover, terrain and climatic variables. Given the conclusions from section 1.2 we have not involved “records...from NW Europe” in defining potential regions where recovery may occur.

Despite the conclusions of section 1.2 that the Golden Eagle in the British Isles was historically and is currently an occupant of ‘upland’ habitats, in the forthcoming analyses we nevertheless retain the possibility that some lowland areas of England could be suitable.

This issue is considered further in section 1.5, with an emphasis on where any birds released into England should be sourced, given the brief: “*To advise the most appropriate tool(s) and approaches for Golden Eagle recovery in England*” and that reintroduction/reinforcement is obviously an appropriate tool via translocations. The possibility of translocations is also considered explicitly in Work Package 2 (section 2), so far as essential underlying requirements and prospects for population increase.

### 1.3.1 Terminology

The discrete regions are **Potential Recovery Zones (PRZs)**. Including recovery in the name does not imply a known historical regional population, rather it is a general term relating to England, i.e. areas which may contribute to a recovery of the English Golden Eagle population.

### 1.3.2 Criteria used to identify PRZs

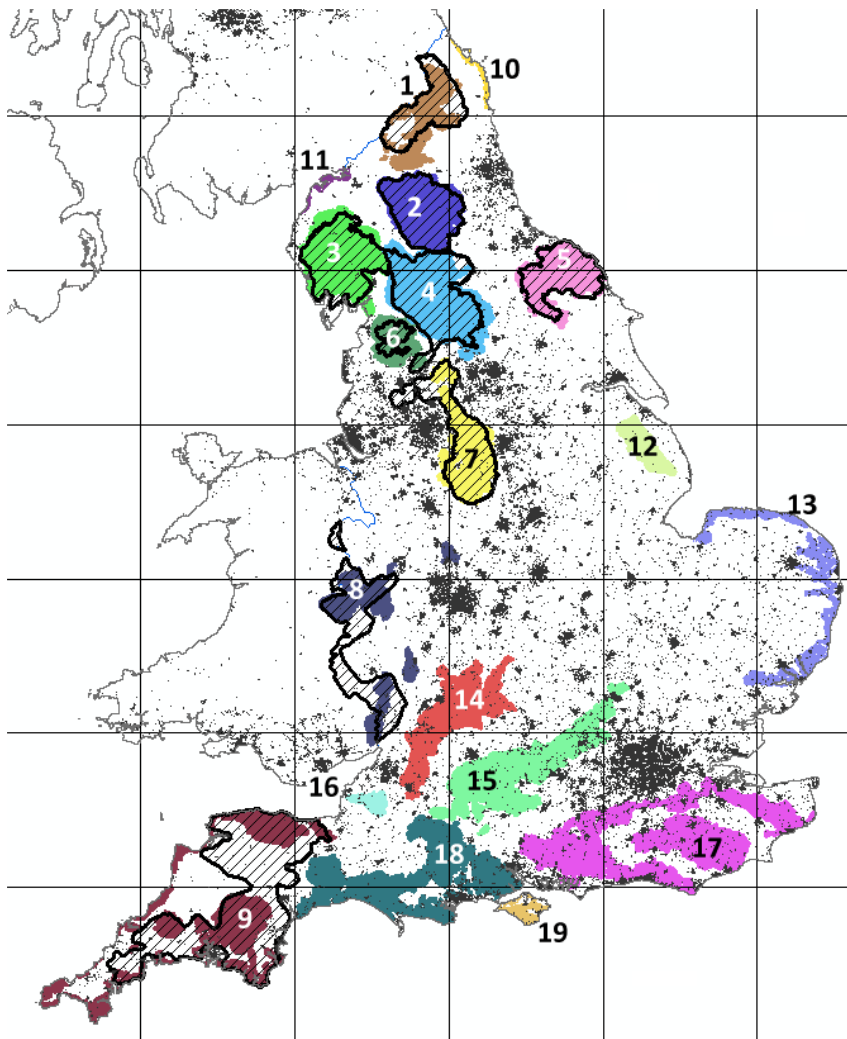
A dual approach was used to identify two groups of PRZs, A & B, which cover a large area of England. There is considerable overlap between some A and B zones.

1. Six PRZ A zones were identified by combining results from the SDM and GET models (Data Dictionary). PRZ boundaries were defined subjectively, based on patterns in the SDM and GET model, mainly using significant landscape features, such as rivers or major roads. Despite its contiguity, given some possible ecological differences within the largest zone (Lakes and North Pennines) it was split into four zones: Lakes; Yorkshire Dales; North Pennines; and Bowland.
2. Identifying the PRZ B zones is less evidence based but the boundaries are less subjective. The PRZ B zones use landscape designations which define discrete areas of ‘countryside’ and may assist with future practical management. The 16 PRZ B zones were a merger of National Landscape (formerly Areas of Outstanding Natural Beauty), National Park and SPA boundaries (buffered outwards by 1km to avoid creating small ‘islands’). The National Landscapes, National Parks and SPA boundaries often overlap. As above, the largest block was split into four.

There is considerable overlap between six of the PRZ A and PRZ B zones (Borders, Cheviots, Lakes, N. Pennines, Yorkshire Dales, North York Moors & South Pennines; Figure 1.1). The remaining 10 PRZ B zones (Cotswolds, Dorset - Wiltshire, Downs, East Anglia, Isle of Wight, Lincolnshire, Mendips, NE Coast, Solway coast & Wessex - Chilterns) do not overlap with PRZ A zones. Table 1.1 lists the PRZ A and PRZ B zones and their areas.

**Table 1.1. Potential Recovery Zones and their areas (km<sup>2</sup>).**

<b>ID</b>	<b>PRZ Name</b>	<b>PRZ A</b>	<b>PRZ B</b>
1	Cheviots	1527.6	1593.7
2	North Pennines	1868.2	2105.0
3	Lakes	2103.0	2637.9
4	York Dales	2745.6	3293.1
5	North York Moors	1542.6	1900.9
6	Bowland	328.1	944.0
7	South Pennines	2155.8	2056.8
8	Borders	2321.1	1839.1
9	South West	6330.4	4266.1
10	NE Coast		157.9
11	Solway		183.7
12	Lincolnshire		693.3
13	East Anglia		1837.2
14	Cotswolds		2521.0
15	Wessex-Chilterns		3471.9
16	Mendips		281.9
17	South Downs		5680.0
18	Dorset - Wiltshire		4170.7
19	Isle of Wight		298.6



**Figure 1.1.** PRZ A (hatched) and PRZ B (filled) recovery zones. See Table 1.4 for zone names. The map background shows urban areas (>20 ha) from an OS data set. The grid is 100 km. Contains Ordnance Survey data © Crown copyright and database right 2020.

### 1.3.2.1 Selecting the most promising PRZs

It was inevitable that not all PRZs would be suitable for Golden Eagle breeding. In this section an objective approach is used to reduce the 28 putative PRZs to a smaller subset which are the PRZ most likely to contribute to a recovery of the Golden Eagle in England.

An exploratory multivariate statistical approach (non-metric multidimensional scaling, NMDS) was used to look for similarities across a set of predictor variables (covering climate, land cover, topography and potential disturbance) to identify the most promising PRZs from the 28 candidate PRZs. The most promising PRZs were identified by comparing the 28 PRZs with predictor values in three groups of Scottish Golden Eagle home ranges.

1. New home ranges in the South of Scotland (from Fielding *et al.* 2024b).
2. A cluster of ranges immediately south west of Stornoway on the Isle of Lewis (these have ‘atypical’, flatter and lower topography than most Golden Eagle home ranges (from Fielding *et al.* 2024b).

3. Land around all of the known Scottish Golden Eagle ranges. This dataset was used for the original South of Scotland Golden Eagle species distribution model (Fielding & Haworth 2014).

Note that maps of the range boundaries are not shown to protect the ranges.

### 1.3.2.2 Mapping Benefits and Constraints

There were 16 predictors: Less Favoured Areas (LFA 1 - disadvantaged; LFA 2 severely disadvantaged); Growing Degree Days baselines 1 & 2 (GDD\_1; GDD\_2); Windspeed (at 45 m agl); Rainfall (spring mean 1997-2006); GET6+ Proportion; Corine land cover (Human; Arable; Pasture; Broad Leaf; Conifer; Moor-Heath; Peatland); Road density; and Urban distance. **Full descriptions of these predictors are in the Data Dictionary.**

Information was extracted for each Golden Eagle region and the 28 candidate PRZs and summarised, typically by the median of each predictor.

#### *Computational Note*

The most efficient way of extracting areas of interest for regions such as the PRZs or the Golden Eagle home ranges, was using simple raster arithmetic. PRZs were converted to raster images from vector shape files and coded in increments of 200 (for example: Cheviots 200; North Pennines 400, North York Moors 600, etc). Some layers of interest were already in a raster format others had to be converted. When converting from a vector to a raster file a 50 m pixel size was used.

As an example, the Open GET image has values ranging from 0 to 10 for each 50 m pixel. If this is added to a rasterised PRZ image the GET values in the summed image range from 200 to 210 for the Cheviots and 600 to 610 for the North York Moors, thus allowing the GET profile for each zone to be extracted.

NMDS analyses the similarity between samples (PRZs and eagle areas in this analysis) based on multiple predictor variables (climate, land cover, etc). A distance matrix plots the relative positions of the samples in a reduced 2-dimensional space. Samples close together in this reduced space share similar values across the predictors. The positions of the predictors, relative to the samples, is also plotted enabling an interpretation of the environmental gradients. Consequently, the main aim of the NMDS is to recognize and interpret patterns and find gradients that represent underlying ecological gradients (see Box 1.2 for a more technical description of NMDS).

#### **BOX 1.2.** From Fielding (2006)

A NMDS analysis starts with the lower triangle of a distance matrix, which need not be Euclidean. The aim is to transform these distances into a set of Euclidean distances in a low dimensional space. In NMDS the rank order of the original distances is assumed to contain the necessary information. The analysis tries to reproduce the rank order of the distances, from the original distance matrix, in the final Euclidean distance matrix. A non-statistical example would be to use a map of inter-city distances to reconstruct a map of the UK based only on distances between cities.

NMDS is iterative, using monotone regression to calculate pseudo-distances. Differences between real and corresponding pseudo-distances are an index of how far the distances

between cases depart from the value required to preserve the original distance rank order.

The overall measure of how badly the distances in the reduced spaces fit the original data is called the stress. The raw stress score is usually normalized to range from 0 (perfect fit) to 1 (worst fit). Normalization makes the stress score independent of the size or scale of the configuration and allows the appropriate solution dimensionality to be identified. It is normal to have stress values greater >0 but this only occurs when the solution has insufficient dimensions. Increasing the number of dimensions, e.g. from 2 to 3, may reduce the stress but it can never increase it. However, since the aim is to reduce dimensionality, it is normal to accept some distortion (a stress value >0). Usually the greatest distortions (at least proportionally) are in the smallest distances. This is because the goodness of fit measures place greater emphasis on larger dissimilarities.

Note that the NMDS axis order is arbitrary, axis 1 is not, by default, the most important.

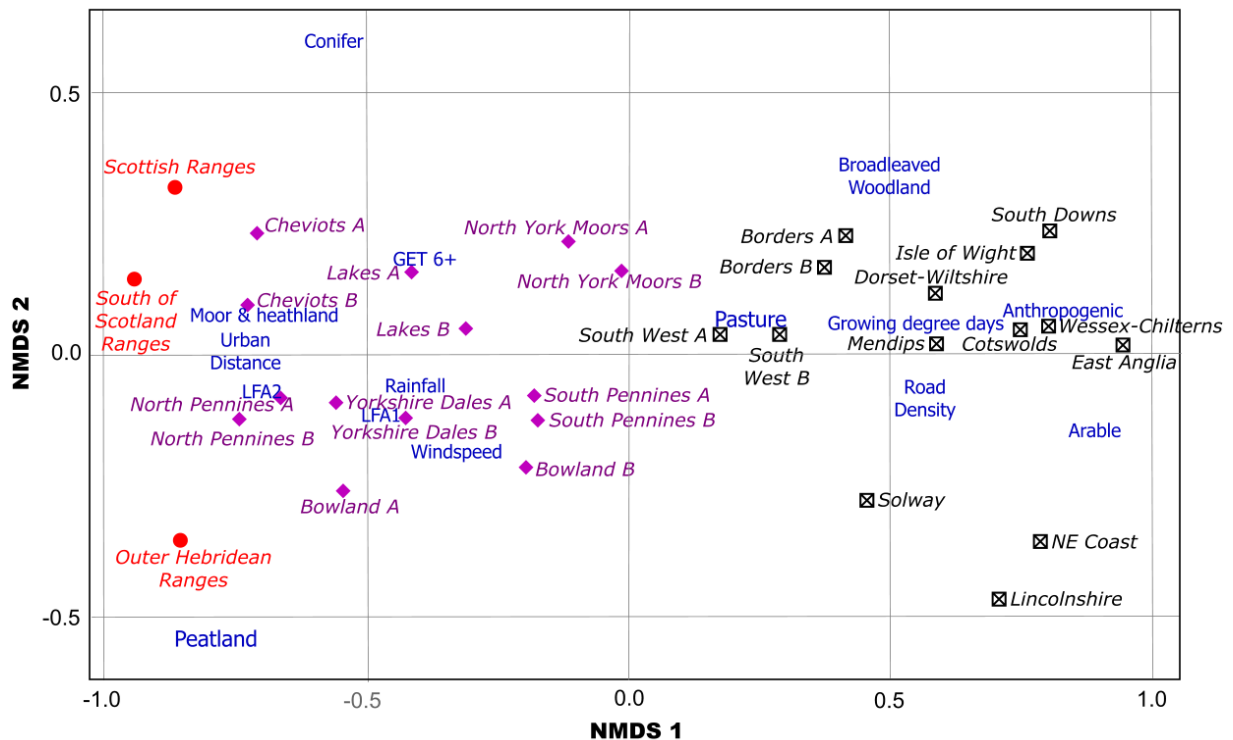
### 1.3.2.3 The NMDS Analysis

As predictors were on different scales, they were first re-scaled to have values between 0 and 1. Normal standardisation (mean = 0 and sd = 1) is not possible as negative predictor values are not allowed in the distance calculations.

The stress value of the NMDS was 0.078 which is close to 0 suggesting a very good fit.

The NMDS analysis produces scores on two axes for both the predictors and the samples. Although these can be jointly plotted the resulting graph (Figure 1.2) can be difficult to interpret.

In order to simplify the interpretation, the axis scores were used as inputs to hierarchical clustering analyses (Figure 1.3).



**Figure 1.2.** NMDS of the 28 PRZs and three Golden Eagle home range data sets with 16 predictors. PRZs from the second, B group, are labelled with a terminal B.

The three Golden Eagle home range blocks are positioned close to each other on the far left of the NMDS 1 axis in Figure 1.2, although they are separated along the NMDS 2 axis, primarily by the amount of peatland. The Outer Hebridean home ranges have a 75% peatland cover compared with 13% in the South of Scotland home ranges and 6%, on average, in all Scottish ranges. The Bowland PRZ has the largest cover of peatland (53%) which explains its proximity to Peatland in Figure 1.2.

Because of overlapping labels, it is quite difficult to interpret the relationships between the PRZ and between the PRZ and the predictor variables. In order to simplify the interpretation, NMDS 1 & 2 coordinates were used as inputs into a hierarchical cluster analysis using complete linkage and a Euclidean distance measure (Figure 1.3).

A cluster analysis is an approach which always finds structure in data by identifying natural groupings (clusters). Unfortunately, ‘natural groupings’ is not well defined and it is usual to have more than one natural grouping for any collection of data (Fielding, 2006). (As an analogy, consider the ways in which a deck of playing cards can be clustered: colours; suites; face non-face, etc). The appearance of the dendrogram is determined by the choice of distance measure and the algorithm used to join clusters. The complete linkage method tends to produce very tight clusters of similar cases and performs well when cases form distinct clusters. Interpretation of the dendrograms should be linked to the NMDS plot.

Interpretation of the dendrograms (Figure 1.3) should be linked to the NMDS plot (Figure 1.2).

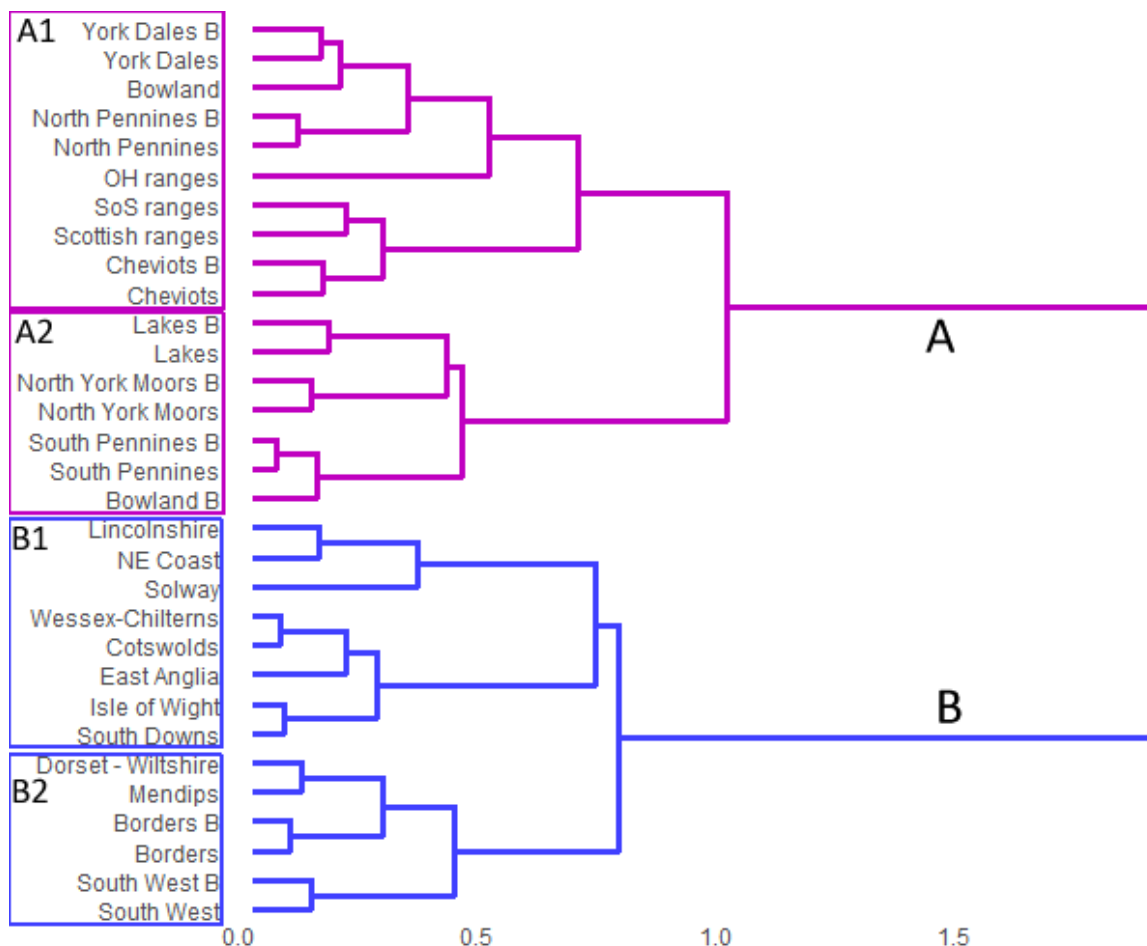
Figure 1.3 shows the dendrogram for the clusters formed using the 16 predictors and 28 PRZs. There is a very clear split into two clusters (A & B) with the PRZ split equally between the two.

Cluster A contains the three Golden Eagle home range areas and these are in a sub-group (A1) which includes the Cheviot, North Pennine, Bowland and Yorkshire Dales PRZs.

Cluster A2 is made up of the Lakes, North York Moors, South Pennines and the broader Bowland PRZ.

Cluster B has the remaining 14 PRZ, split into two heterogeneous clusters (B1 & B2). Cluster B1 has the more coastal PRZs.

All PRZs, with membership of both PRZ classes, except Bowland, are clustered together suggesting it makes little difference which one of the pair of PRZs is used in subsequent analyses.



**Figure 1.3.** Hierarchical cluster analysis of 28 PRZ and three Golden Eagle home range groups.

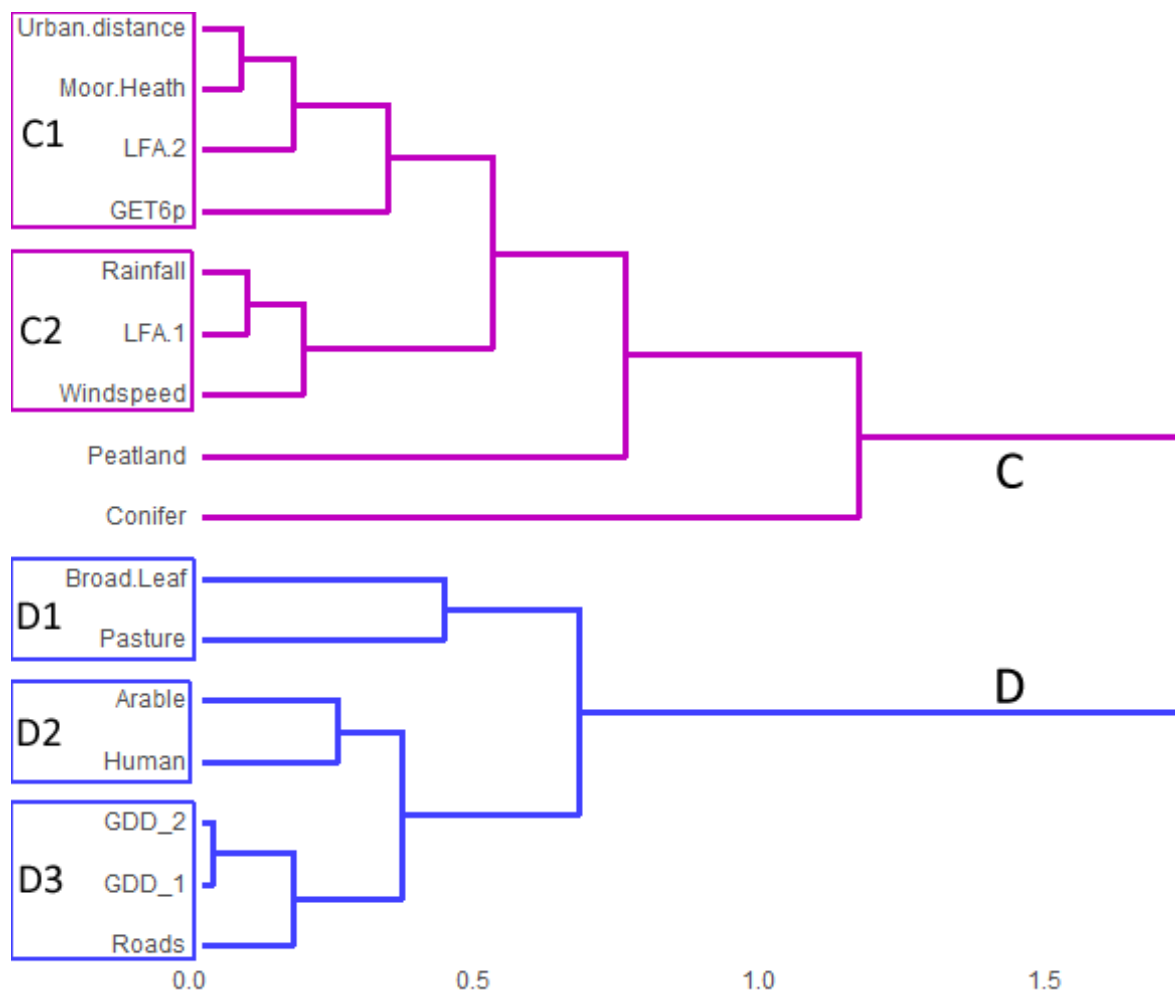
Figure 1.4 is a cluster analysis of the 16 predictors used in the first NMDS analysis and, as with the PRZ, the clustering splits the predictors into two clear groups reflecting their positions in the NMDS plot (Figure 1.2).

Cluster C has two obvious clusters (C1 & C2) plus two more isolated predictors.

Cluster C1 combines distance to urban areas, the extent of moor and heathland (Corine land cover class), the severely disadvantaged less favoured agricultural land and the proportion of GET 6+ topographic habitats. Large values for all of these are associated with the Golden Eagle home range areas.

Cluster C2 comprises mean spring rainfall (1997-2006) with the extent of disadvantaged agricultural land and mean annual wind speed. As with C1, large values for the predictors in C2 are associated with the Golden Eagle range areas. The same is true for the isolated predictors in cluster C.

Cluster D has three sub-clusters and large values for any of these predictors are associated with the absence of Golden Eagle ranges.



**Figure 1.4.** Hierarchical cluster analysis of the 16 predictor variables.

Based on the results of the NMDS analysis and the subsequent cluster analyses it is possible to broadly categorise areas where Golden Eagles breed in Scotland and hence where they might be expected to breed in England assuming there is no gross change in their habitat preferences (Table 1.2).

**Table 1.2.** Broad categorisation of areas where Golden Eagles breed in Scotland.

Associated with breeding Golden Eagles	No evidence for breeding Golden Eagles
A long way from urban areas	High road density
Extensive moor-heathland or peatland	Large proportion of anthropogenic land cover (human)
A less favoured agricultural classification	Larger areas of broadleaf woodland and pasture
Higher annual wind speeds	High number of growing degree days
High spring rainfall	Low spring rainfall
A high proportion of GET 6+ topography	
Extensive conifer plantations	

While Scottish Golden Eagles may often breed in areas with extensive conifer plantations (Table 1.5) this does not mean that such land management is net beneficial (Whitfield *et al.* 2007, 2008, Fielding *et al.* 2024b). This ‘presence-only’, if not necessarily beneficial, is also implied by the position of ‘Conifer’ in the hierarchical cluster analysis of Figure 1.4.

### 1.3.3 Pruning the PRZs

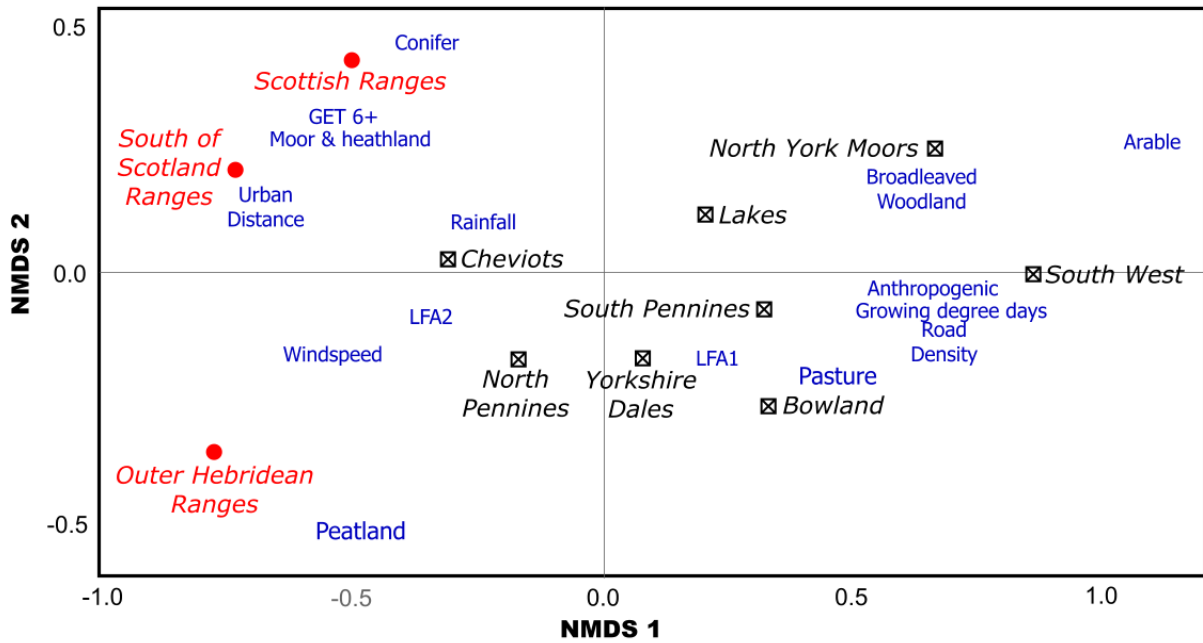
Based on the clear split in Figure 1.3, less clearly in Figure 1.2, subsequent analyses are restricted to those PRZ in Cluster A but with one exception. Although the South West PRZs are placed far from the Golden Eagle home ranges in Figure 1.3 they are more intermediate in Figure 1.2, adjacent to the North York Moors PRZs, which were retained.

Cluster A contains the A and B PRZs for most regions with both designations. As the boundaries for the class B PRZ were not constructed subjectively by the authors the class B PRZ are retained except for Bowland. This is because the class A Bowland PRZ was more closely associated with the Golden Eagle home range areas.

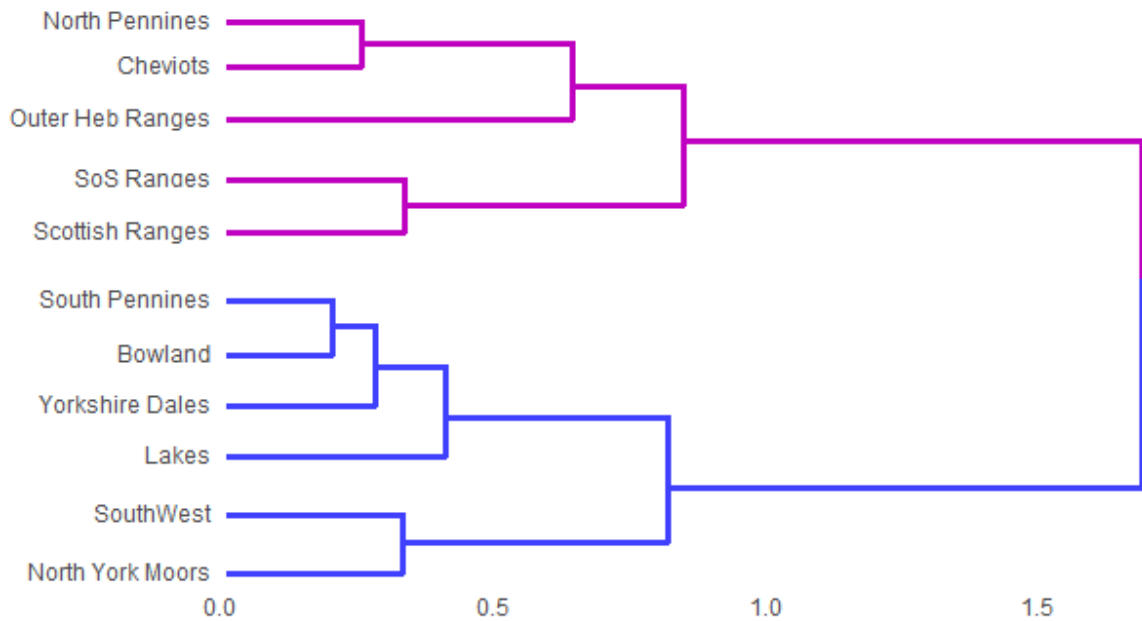
**The eight retained PRZs are: Cheviots; North Pennines; Lakes; Yorkshire Dales; Bowland; South Pennines; North York Moors; and the South West. It is notable that the first six are essentially one spatial block which is important for connectivity, eagle movements and population modelling.**

The North York Moors and the South West are isolated from these six and may require different recovery strategies which are investigated later.

The reduced set of PRZs were subjected to the same NMDS analysis. The cluster plot of the predictors is not shown as it was identical to Figure 1.4. Figure 1.5 again has Golden Eagle home ranges on the extreme left of NMDS 1. The Cheviots, North Pennines and Yorkshire Dales are the closest of the remaining PRZs. The Lakes, South Pennines and Bowland are a little further from the home ranges. This shown clearly in the cluster plot (Figure 1.6).



**Figure 1.5.** NMDS of the eight PRZs and three Golden Eagle home range data sets with 16 predictors.



**Figure 1.6.** Hierarchical cluster analysis of the eight PRZs and three Golden Eagle home range groups.

### 1.3.3.1 Validation of the eight PRZs

There are two data sets which can be used as an initial validation of these eight PRZs. First is the historic record set of Evans *et al.* (2012) and second are the ongoing locations of satellite tracked Golden Eagles associated with the SSGEP (Fielding *et al.* 2024a).

All but one of the Evans *et al.* (2012) place names in England are in a PRZ or very close to a PRZ boundary (Figure 1.7). The one outside of a PRZ is below Darwen Hill, on the outskirts of Darwen in Lancashire. This is a very popular walking area, and it is difficult to believe that this site would ever be reoccupied.

The remaining 27 are split into two in the Cheviots, three in the North Pennines, five in the Yorkshire Dales, 11 in the Lakes, five in the South Pennines and one each in the North York Moors and the South West (Figure 1.7).

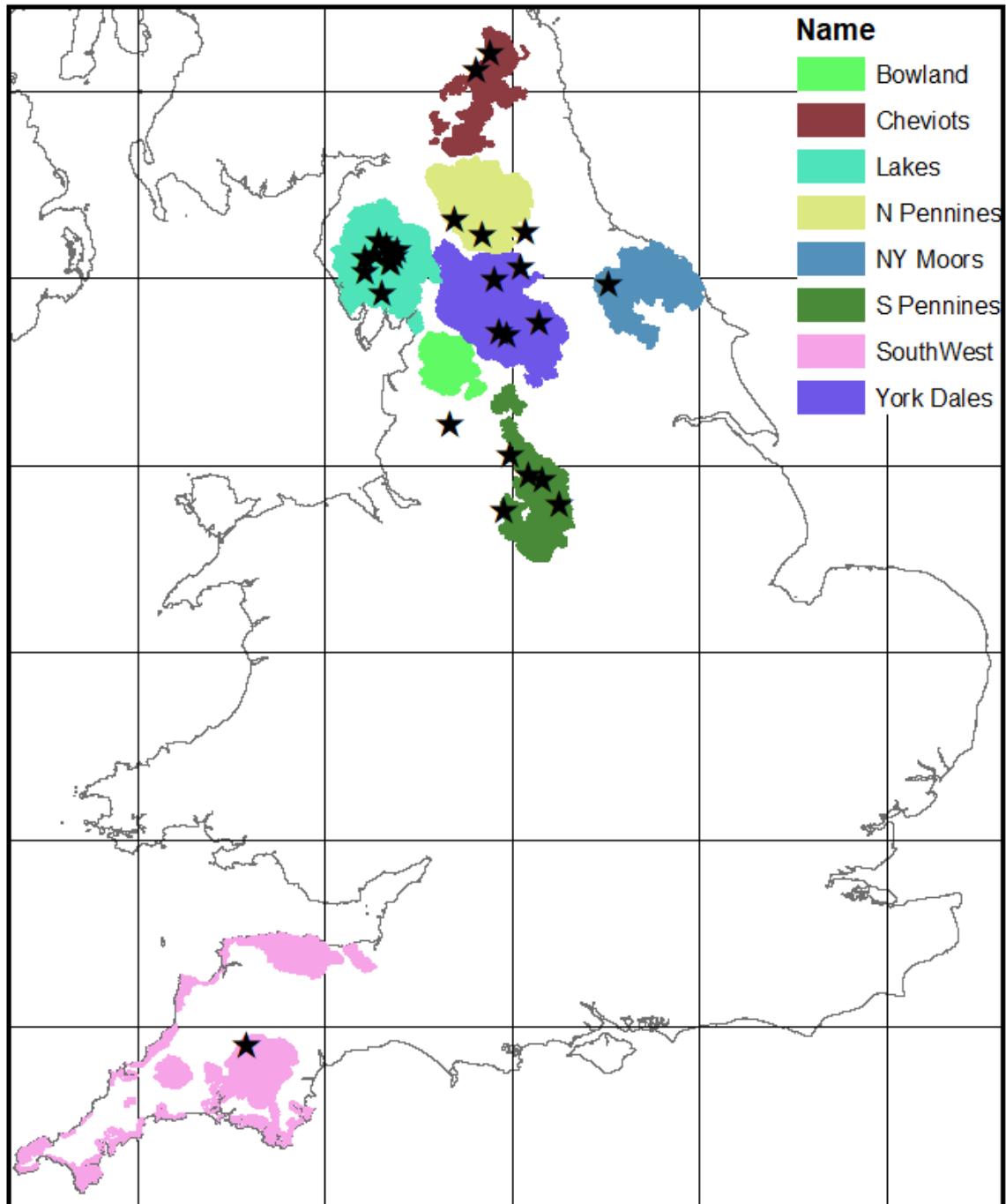
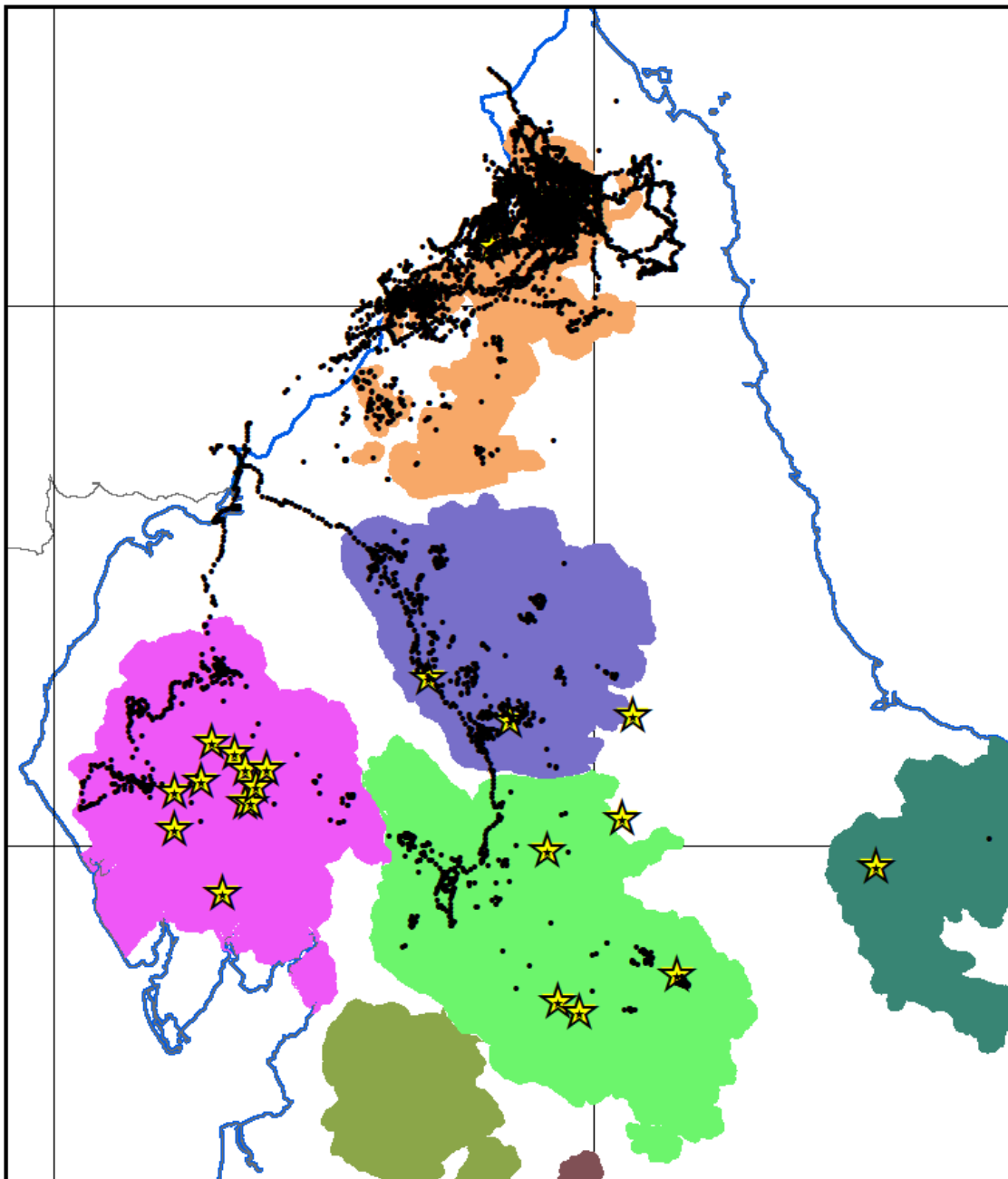


Figure 1.7. Evans *et al.* (2012) historic Golden Eagle sites and the retained PRZs.

The majority of Golden Eagle tag records are within 10 km of The Cheviot. 30,878 of the 32,524 records (94.9 %) in England are in the Cheviots PRZ (Figure 1.8). There are clusters of records around the two historic nest sites in Evans *et al* (2012). There were 847 records in the North Pennines PRZ with several records close to the historic site on Mickle Fell which is just outside of the Warcop MoD zone. The Yorkshire Dales PRZ has the next highest total with 519 records. The records furthest south were 9 km north east of Grassington in the Yorkshire Dales. There were 433 records in the Lakes PRZ, mainly in the north and west. Perhaps significantly there was a single record in the North York Moors PRZ. Unfortunately, given the frequency of records there is no indication of the route taken into and out of the North York Moors.



**Figure 1.8.** SSGEP tag records in England in relation to the PRZs and historic Golden Eagle sites.

Tag 1271, a translocated bird from the Outer Hebrides, crossed apparently unsuitable land to and from Scotland, passing either side of Carlisle (Figure 1.8). Some caution is needed when extrapolating from the behaviour of these translocated subadult individuals as, soon after their release, they often undertook long exploratory flights before mainly returning to the north of Scotland. Tag 1271 could yet prove to be an important individual for an English recovery as she settled into a new range north east of Langholm within 10 km of the border and less than 20 km from the relatively recently occupied G/EO4 range (the 4<sup>th</sup> labelled English range in National Survey records).

## 1.4 How many Golden Eagle home ranges could each PRZ support?

Using information from the study of Scotland’s home ranges (Fielding *et al.* 2024b) it is assumed that in England a new home range will be 10,000 ha with at least 7,000 ha of GET 6+ habitat. This places a theoretical upper threshold on the number of home ranges each PRZ could support (Table 1.3). It is important to understand that this is a theoretical upper limit and the actual upper limit will be considerably lower after taking account of, for example, landscape configurations.

**Table 1.3.** *Theoretical upper limit on the number of Golden Eagle home ranges assuming a planar home range size of 10,000 ha (100 km<sup>2</sup>) or a GET 6+ limit of 7,000 ha.*

PRZ Name	Area (km <sup>2</sup> )		Number of home ranges	
	Planar	GET 6+ area	Planar	GET 6+ area
Cheviots	1,593.7	387.5	16	5
North Pennines	2,105.0	764.1	21	11
Lakes	2,637.9	1,222.6	26	17
York Dales	3,293.1	1,165.1	33	17
North York Moors	1,900.9	425.3	19	6
Bowland	328.1	131.8	3	2
South Pennines	2,056.8	837.2	20	12
South West	4,266.1	1,550.0	43	22
All	18,181.6	6,483.6	181	92

In Table 1.3 the South West has the largest upper limit of 22 home ranges. However, as can be seen in Figure 1.7, the South West PRZ is split into distinct patches many of which will be too small to support a Golden Eagle range.

Each PRZ was next subjected to a detailed study using expert knowledge gained from a combined total of more than 40 years of Golden Eagle research and incorporation of several ‘risk factors’ (constraints) to identify a more realistic upper limit for the number of ranges (Table 1.4).

A breakdown of several risk factors according to PRZs is in Appendix 1: Potential Recovery Zone Summaries. More information on risk factors can also be found in the Data Dictionary.

**The revised number of 45 home ranges (Table 1.4) assumes that there will be no intentional interference which prevents a home range from being established. This risk**

factor (persecution) could be especially influential, especially in PRZs dominated by management for driven grouse shoots (e.g. Amar *et al.* 2009, Melling *et al.* 2018, Ewing *et al.* 2023, Peak District National Park Authority 2023, Yorkshire Dales National Park Authority 2024). Unintentional disturbance (recreation) will also be influential as proxied by several measures (Data Dictionary).

**Table 1.4.** Potential number of Golden Eagle home ranges (HR) based on expert knowledge and considerations of ‘risk factor’ constraints.

PRZ Name	Upper HR limit	Constraints reducing the number of HRs	Revised HR limit
Cheviots	5	Much of the suitable habitat is restricted to the north and the border. Beyond those areas the habitat is patchy.	4
North Pennines	11	There is extensive suitable habitat with not too much fragmentation. Much of the PRZ is grouse moor so success here depends on having a good working relationship with the land owners. Nest sites are likely to be limiting given the topography and shortage of large trees.	5
Lakes	17	There is extensive suitable habitat but levels of recreation are likely to restrict nesting opportunities in the core around Ambleside and Keswick. There is scope in the Eastern and Western Fells. Prey may be a constraint on productivity.	8
York Dales	17	There is again extensive suitable habitat but nest sites are likely to be a constraint. As in the North Pennines, there is extensive grouse moor so success here depends on having a good working relationship with the land owners.	7
North York Moors	6	Most of the suitable habitat is away from the coast. Extensive forests in the south east may provide secluded nesting opportunities. Isolation from other breeding areas is likely to be a significant constraint if recruitment is difficult.	5
Bowland	2	There is sufficient habitat either side of the Trough of Bowland to support two home ranges. There is unlikely to be significant recreational pressure but, as in the North Pennines and Yorkshire Dales, there is extensive grouse moor so success here depends on having a good working relationship with the land owners.	2
South Pennines	12	Optimistically, there is potential for eight home ranges but it is likely that recreational pressures will lead to poor breeding success and/or range abandonment. Even if the South Pennines have no breeding pairs they have the	8

PRZ Name	Upper HR limit	Constraints reducing the number of HRs	Revised HR limit
South West	22	potential to be an important area for dispersing young birds from further north. This is a large area but suitable habitat is fragmented and split, approximately, into northern and southern sections. In the south the most extensive habitat is associated with Dartmoor. There is probably sufficient habitat to support dispersing young birds both within the PRZ but also in other PRZs which have been discounted as likely places for Golden Eagle breeding. Clearly, the biggest challenge is the isolation from the main body of a recovering population. Birds are unlikely to get there by themselves and it is doubtful if a population of less than 10 pairs could be self-sustaining. Any initial intervention, such as planned releases, may need to followed up indefinitely.	6
All	92		45

The revised upper limits for the number of pairs in Table 1.4 are optimistic and any population in the South West would have to be considered to be a special case, leaving a core population of up to 40 pairs plus another 15 in the South of Scotland.

A more realistic and achievable total would exclude the South Pennines, the South West and possibly the North Yorkshire Moors, suggesting a population of 20 - 25 pairs plus ~15 in the South of Scotland.

## 1.5 The biology of ‘lowland’ birds in NW Europe and as potential donors to England

As concluded earlier (section 1.2), English eagles historically did not appear to use lowland habitats pre-extirpation, and the most closely aligned British representative (Scotland) of a formerly connected group of birds, definitively does not use lowland habitats. Rather, antithetically, the lowlands can be a barrier to movement. This issue was considered from another perspective on identification of prospective Potential Recovery Zones (PRZs) in section 1.3 and ‘lowland regions’ were again rejected on suitability by other evidence.

Despite this evidence, given the alternative argument that the Golden Eagle should be able to occupy lowland habitats in the British Isles (including England), we examine this issue further. The prospect for occupation of predominantly farmland (arable) habitats/regions in England (lowland) seems to rest on the possibility of translocations via reintroduction/reinforcement, rather than any natural recolonisation from Scotland. Reintroduction/reinforcement through translocations is one of the tools available to a recovery of Golden Eagles in England and is implicitly part of the overarching project goals

and, hence, this report's objectives: *"To advise the most appropriate tool(s) and approaches for Golden Eagle recovery in England.* Hence, IUCN Guidelines (IUCN/SSC 2013) on such possible translocations become relevant. These Guidelines are also relevant to evaluations of Population Viability Analysis (PVA) which are covered under Work Package 2 for a translocation with release prospect.

### 1.5.1 IUCN Guidelines

The IUCN Guidelines for Reintroductions and Other Conservation Translocations (IUCN/SSC 2013) provide a road map which should be responsibly followed in any translocation project (e.g. Dennis *et al.* 2019) and is a *de facto* requirement in UK conservation translocations. Under the present report's brief, it would be premature to go into every aspect of the guidelines for any translocation of Golden Eagles to England.

However, there are some features that are relevant at this stage, because translocation is patently a tool in possible *"approaches for Golden Eagle recovery in England"*. This prospect also reverberates in Work Package 2 (Population Viability Analysis). Early examination on some prospects concerning lowland region recipients (in addition to analyses in section 1.3) and potential NW European donor sources, can be a rehearsal for any future formal English reintroduction/reinforcement initiative.

Section 2 of the Guidelines define a population restoration as any conservation translocation to within an indigenous range, on which England qualifies for the Golden Eagle. Translocations may comprise two activities: a) **Reinforcement**, the intentional movement and release of an organism into an existing population of conspecifics; b) **Reintroduction**, the intentional movement and release of an organism inside its indigenous range from which it has disappeared.

Any possible translocation project for England could obviously only occur in the future and by then it is likely, via the SSGEP, there may already be a recolonisation of northern England (section 2). Hence, a reinforcement definition would most likely apply, and in justifications via IUCN Guidelines, this is less onerous. An overarching principle is in Section 3 of the Guidelines (Deciding when translocation is an acceptable option)<sup>6</sup>:

*"...justifying a conservation introduction requires an especially high level of confidence over the organisms' performance after release, including over the long-term..."*.

Additional relevant requirements are as follows:

**1. There should be suitable habitats of sufficient extent to which the species can be translocated.** This is crucial, with the guidelines noting in Section 3: *"...with reassurance on its acceptability [the conservation introduction] from the perspective of the release area's ecology..."*.

**2. Ensure no adverse impact on the donor population.** Meeting this requirement should involve an analysis of the population dynamics of the donor population and the impact of removing sufficient donor nestlings for release, to ensure a new self-sustaining population in the release region (e.g. O'Toole *et al.* 2002, Dennis *et al.* 2019, Wilson-Parr *et al.* 2020). While several demographic metrics such as survival and reproductive rates are needed for such, in judging this, a simplistic first tier metric can be the size of the donor population, together with the number of birds needing extraction from the donor population for release (Table 1.5). Typically, at least 60 birds are deemed necessary for

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<sup>6</sup> Our emboldening.

extraction and release (usually over 5+ years) from a donor population numbering in the hundreds (Table 1.5).

**Table 1.5.** Some examples of reintroduction/reinforcement translocation projects of large raptors, with an illustration of the number of birds needing to be extracted from a donor population, and the abundance of the donor population(s).

Species	Recipient region	Number of (proposed) released birds	Donor country	Donor population size (pairs)	Reference
Osprey	Ireland	60(+)	Scotland	c 300	Wilson-Parr <i>et al.</i> (2020)
Osprey	Poole, England	60	Scotland	250+	Wilson-Parr <i>et al.</i> (2020)
Osprey	Rutland, England	73	Scotland	250+	Wilson-Parr <i>et al.</i> (2020)
Osprey	Basque, Spain	48	Scotland	200+	Wilson-Parr <i>et al.</i> (2020)
Osprey	Andalusia, Spain	164	Scotland, Finland, Germany	Thousands	Wilson-Parr <i>et al.</i> (2020)
White-tailed Eagle	East Scotland	85	Norway	Thousands	RSPB (unpublished data)
White-tailed Eagle	Isle of Wight, England	60	Scotland	c 150+	Dennis <i>et al.</i> (2019)
Golden Eagle	Ireland	≤75 <sup>7</sup>	Scotland	450+	O'Toole <i>et al.</i> (2002)
Golden Eagle	South Scotland	60	Scotland	500+	SSGEP (2024)

### 3. Donor birds should be the closest genetically to the former indigenous population.

With the wide range of possible cases which the IUCN guidelines are designed to cover, the guidelines' sections on genetics are especially circumspect and caveated. They do emphasise, however, the need to source donor birds that are genetically suited to the former indigenous population and the destination conditions. This has been a critical guideline followed in all (explicitly or implicitly) of the examples for large raptor translocations in Table 1.5. The guidelines also guard against the possible genetic incompatibilities of using a mixture of donor populations.

On the other hand, the guidelines also recognise that in some cases sourcing multiple founder populations may beneficially maximise diversity in the recipient (release) area and should consider possible inbreeding depression.

These contrasting prospects should be justified on a case-by-case basis. We will return later to this specific subject.

<sup>7</sup> 63 released in practice, 2001-2012 (Golden Eagle Trust).

Against this background of relevant IUCN requirements, we next consider three regions of northern Europe where there are representative breeding groups of lowland Golden Eagles. These sub-sections briefly review available information on abundance, habitat use, diet, and genetic relationships. They are geared towards addressing appropriate IUCN guidelines for a possible conservation translocation to England.

### 1.5.2 Denmark

After an absence of about 150 years, the Golden Eagle became re-established as a breeding bird in Denmark in 1998 (Ehmsen *et al.* 2021). Despite producing at least 53 fledglings after establishment, since 2005 the population has remained small at 3 - 5 pairs (Tøttrup *et al.* 2023)<sup>8</sup>. GPS-tagging of nine GPS-nestlings found a year-after-tagging mortality rate of 44 % (4/9), ascribed death in three due to infection (1) and starvation (2) (Tøttrup *et al.* 2023). This mortality rate is comparable with results from Norway (Nygård *et al.* 2016) but higher than estimated from a much larger Scottish dataset, in the absence of persecution (Whitfield & Fielding 2017), and preliminary results from the recently reinforced south Scotland sub-population (SSGEP *unpublished data*).

By geography the Danish birds are likely linked with a similarly small number of breeding eagles in the southern tip of mainland Sweden (predominantly Skåne). In Skåne, lowland birds became (re-)established from the late 1980s onwards (Bengtsson 1999). These southern limits of Scandinavia are dominated by farmland with patches of boreo-nemoral forest (Näsman 2018). At least for nest sites such forest patches appear important. According to Ehmsen *et al.* (2011), in Denmark: “*The first two of the breeding sites were in private preserves with old deciduous forests, closed to the public and with **nearby extensive moorland***”. The next two breeding sites were in private forest, with public access limited to tracks and roads during daytime hours.”

On diet, Ehmsen *et al.* (2011) remarked that waterbirds were common as a potential source of prey near to breeding birds’ locations. At one of the first breeding sites, the main prey was waterbirds together with 21 % mammals (n = 103) (Nielsen 2009). However, at another of the first breeding sites Pheasants *Phasianus colchicus* were released for hunting and made up 73 % of 154 identified prey items (Nielsen 2009).

A stagnant stable small number of Danish breeding pairs is probably incompatible with the prospect of a large expanse of suitable habitat to support more, and when the national landscape is dominated by farmland. The relatively low survival of dispersing birds (Tøttrup *et al.* 2023) may be a contributory factor to the lack of expansion, although the recorded breeding productivity would suggest, on the availability of birds for new breeding pairs, this is not the sole reason. On the other hand, the survival rate estimate during dispersal may be another sign that there is relatively little suitable habitat for the species nationally, with farmland being widespread and by far the most common national habitat class.

Hence, the distribution of breeding birds and areas used by dispersing birds in Denmark (Tøttrup *et al.* 2023) do not suggest that farmland is a favoured habitat. Apart from anything else given its extensive availability, if it was favoured or even of some utility, then on demographic metrics the population should be greater than it is.

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<sup>8</sup> Three according to the Danish Golden Eagle Project <https://rc.ku.dk/projekter/goldeneagle/> Accessed 20 May 2024.

<sup>9</sup> Our emphasis in bold.

With very few Danish birds (and similarly few in Skåne, southern Sweden), Golden Eagle DNA has seldom been sourced from these birds and understandably, when it has, in a robust sample. Näsman (2018) included five in an analysis involving 95 across Fennoscandia. Some caution is needed, therefore, on any conclusions on any relatedness and genetic convergence/divergence. With this caveat in mind, no apparent differences in genetic structure were found between Denmark/Skåne, Finnmark (arctic Norway, c. 1700 km away) or samples from geographically intermediate locations (Näsman 2018).

### 1.5.3 Gotland, Sweden

Covering about 3000 km<sup>2</sup>, dominated by farmland, heaths and pine forest on calcareous soil (Näsman 2018), the island of Gotland in south Sweden hosts one of the densest populations of Golden Eagles worldwide with nest sites often just 3 km apart (Tjernberg 2015). In 2021 there were 65 pairs, with the population apparently being “full up” (Sveriges Radio 2023).

Nest sites are usually in old Scots Pine *Pinus sylvestris* (93 % of 84, mean pine tree age 145 years) (Wiss 2008). Despite the old age of 83 tree nest sites, they were not especially tall (mean 16 m, mean distance 10 m from bottom of nest to ground), and small weak trees could be used. They were also often not far from roads (mean 374 m, range 2-1800 m) but were further away from a permanent human residence (mean 1300 m). The woodland areas used for nesting was 1200 km<sup>2</sup>, so about 40 % of the island (Wiss 2008)<sup>10</sup>. Wiss (2008) adds:

*“The forest is rather dense and this is perhaps a reason why I often found some type of open areas near the nesting-trees. The distances between alternative nests ranged from some tens of meters up to some kilometers. The location of territories depended mainly on the supply of prey. Forests in combination with seashores or ditched mires were good areas”*. According to Högström & Wiss (1992) eagles’ hunting areas consist of pine forests with many small fens and clearings, and open seashores and treeless pastures<sup>11</sup>.

On diet, Gotland Golden Eagles are well-known for depredating European Hedgehogs *Erinaceus europaeus* (Watson 2010). The reference study (Högström & Wiss 1992) found Hedgehogs dominated numerically, followed by Rabbits *Oryctolagus cuniculus*, ducks (and other Anatidae), and hares (*Lepus* spp.)<sup>12</sup> (652 food items, obtained 1978-1983). By biomass these four groups contributed 88 % to the estimated diet, with a more equitable distribution of importance across these four prey classes than shown by numbers (Högström & Wiss 1992).

Högström & Wiss (1992) explicitly comment that before their study Rabbit abundance was far greater (during their study period only an estimated 3 % of 1962-63) and formerly were probably far more common as eagle prey. This may imply that a compensatory switch to other prey (including Hedgehogs) had occurred. Perhaps similarly, a long-term dietary study in the Strandzha Mountains of southeast Bulgaria found that collapse of Golden

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<sup>10</sup> In an earlier paper, island area of 3172 km<sup>2</sup> with 1381 km<sup>2</sup> of forests (44 %): Högström & Wiss (1992).

<sup>11</sup> Probably revelatory, no mention of agricultural farmland used for foraging by Högström & Wiss (1992) and Wiss (2008). As concluded earlier for Denmark by the present report.

<sup>12</sup> In the 30 remains that could be identified to species, 90 % were Mountain Hare *Lepus timidus* and only 10 % Brown Hare *L. europeus*, which is probably indicative of habitats (heaths and farmland respectively) used for hunting by eagles.

Eagles' usual tortoise prey (*Testudo* spp.) was associated with a shift to other prey, particularly the Northern White-breasted Hedgehog *Erinaceus roumanicus* (Milchev 2022).

A distinctively separate genetic structure in Gotland eagles compared to other parts of Fennoscandia makes a strong argument for limitations in gene flow for this insular population (Näsman 2018). Gotland is separated from mainland Sweden by 80 km of open sea, and such geographical isolation (Fielding *et al.* 2024a) makes the genetic finding of Näsman (2018) unsurprising and consistent.

#### 1.5.4 Estonia

A further breeding group of lowland (peatland) Golden Eagles occurs in Estonia typifying, in habitat use, fewer more scattered breeding sites in eastern Europe (including Latvia, Belarus and western Russia) (Sergio & Whitfield 2020, Sein & Väli 2024). Estonia, with 65 pairs estimated in 2013, stabilizing thereafter (Sein & Väli 2024), hosts the highest density of 'lowland peatland' Golden Eagles in eastern Europe (Sergio & Whitfield 2020). Historically, birds occupying this distinctive habitat were probably more widespread in several other European countries (Nebel *et al.* 2015) including south Finland (Kylmänen *et al.* 2023) and north Poland (Stój *et al.* 2024).

Estonian Golden Eagles are closely associated with peatlands, and predominantly forage on raised bogs, fens, transitional bogs, and occasionally on remote human-made grasslands or forest clear-cuts. Nest sites are in pine-dominated forests near bogs, or in isolated stands of trees within bogs, with an average distance of approximately 10 km between neighbouring pairs (Sein & Väli 2024).

Food remains (n = 2439) collected at Estonian nest sites in 2013-2021 consisted primarily of (in descending biomass importance) Black Grouse *Lyrurus tetrix*, followed by hares (the majority, Mountain Hares), Common Crane *Grus grus*, and Capercaillie *Tetrao urogallus*. These contributed 54 % to the estimated diet, with Mallard *Anas platyrhynchos* and Greater White-fronted Goose *Anser albifrons* adding a further 6.4 % and 6.3 % respectively (Sein & Väli 2024). The diet composition was broadly similar to other Golden Eagles in comparable lowland peatland ecotypes in central Finland, Latvia and Belarus (references cited by Sein & Väli 2024).

Nebel *et al.* (2019) obtained 24 DNA samples from southern Finland and Estonia (total n = 121). Broad structural analyses found three most prominent clusters in Europe: Scotland, a "northern" (Norway, southern Finland and Estonia) and a "southern" (Mediterranean and Alps) population. Estimates of gene flow found Scotland as isolated, even from Norway. Strongest genetic connectivity was between Mediterranean and Alpine birds, with reduced estimates between Norway and Finland/Estonia. Interestingly, only slightly lower was the estimated gene flow between Finland/Estonia and Mediterranean/Alpine<sup>13</sup> (Nebel *et al.* 2019). Further structural analyses of this dataset using mitochondrial haplogroups found Finland/Estonia as a single genetic cluster, most closely aligned with Norway, and Scotland again came out as separate.

#### 1.5.5 Additional genetic perspectives

Before we summarise the prospect of using lowland eagles from northern 'mainland' Europe in a translocation to England (incorporating pertinent information from three of

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<sup>13</sup> Despite "Mediterranean" birds classed as *A. c. homeyeri* and "Alpine" birds classed as *A. c. chrysaetos* (along with birds from Scotland, Norway, Finland and Estonia).

the characteristically lowland regions against IUCN guidelines), there are further genetic perspectives to be resolved thoroughly and/or re-emphasised.

As described earlier, the Golden Eagles in Scotland have consistently been found as distinct genetically from other birds in Europe (Nebel *et al.* 2015, 2019, 2023, Sato *et al.* 2020, 2023). So far this has not resulted in any calls for this isolated group of birds to be classified as a sub-species. This could be surprising when many studies have shown that it is genetically distinct, by different methods, and when there is greater genetic relatedness between other groups of birds classified as sub-species (Nebel *et al.* 2015, 2019, 2023, Sato *et al.* 2020, 2023). Scottish birds will be most closely aligned genetically to birds which recently recolonised England in the 20<sup>th</sup> century and, in all likelihood, earlier in the historical past.

Sato *et al.* (2023) found a relatively low genomic diversity of Scottish birds (*A. c. chrysaetos*, estimated > 1500 birds in the population) and another insular population in Japan (*A. c. japonica*, estimated 500 birds). This was in comparison to samples obtained from mainland Europe: Switzerland (n = 8), Spain (2), Norway (1) and Italy (1). According to Sato *et al.* (2023) through possible adverse inbreeding effects in insular populations, their results highlighted the need to consider genetic reinforcement of small isolated Golden Eagle populations (i.e. Scotland<sup>14</sup> and Japan) from neighbouring outbred populations. This was despite Sato *et al.* (2023) also noting that there was no veterinary or ecological evidence to indicate that island eagles were suffering from inbreeding depression. Moreover, Sato *et al.* (2023) were aware of the potential danger of such reinforcement translocations through outbreeding depression. This is when locally adapted birds meet translocated birds with a different adaptive origin and the meeting may cause a loss of fitness due to reproduction between birds that are adaptively divergent (Frankham *et al.* 2011). This danger is also highlighted by the IUCN guidelines (IUCN/SSC 2013).

Relatively low genetic diversity was also found for Scotland in another study, but this diversity was comparable to a much larger geographical swathe and eagle abundance across Fennoscandia (Nebel *et al.* 2015). Nebel *et al.* (2019) note that genetic diversity values did not differ substantially across Europe even if, largely using the same dataset as Nebel *et al.* (2015), Scotland was lowest.

Nebel *et al.* (2015) also remark: “...results suggest that genetic diversity in Golden Eagles [in Scotland] was largely retained, possibly due to the species’ long generation time...”. This study opined that the relatively low diversity was due to a founder effect (see also Ogden *et al.* 2015 for within Scotland) with the most likely source or shared lineage being Scandinavia through recolonisation after the Last Glacial Maximum when ice sheets receded (Nebel *et al.* 2015, see also Bourke *et al.* 2010). Nebel *et al.* (2019), however, found no evidence of gene flow between Scotland and Norway (or with S Finland/Estonia). There was also no evidence of a historical bottleneck creating the lower diversity in Scottish birds (*cf* unsubstantiated suggestion by Sato *et al.* 2023), or in other populations (Nebel *et al.* 2019).

The retention of genetic diversity, despite potential bottlenecks being created by (e.g.) persecution<sup>15</sup>, could well be due to the long generation time of large raptors acting as a buffer against the loss of (or more likely, intrinsically low) genetic diversity. This

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<sup>14</sup> Although the Scottish population can hardly be considered as “small”.

<sup>15</sup> Recall that Nebel *et al.* (2019) found no evidence for a historical bottleneck affecting genetic diversity in any of the European populations they examined, including Scotland.

conclusion was also reached for White-tailed Eagles in Scandinavia (Hailer *et al.* 2006). For both Golden and White-tailed Eagles, after reduction or removal of anthropogenic constraints, low genetic diversity in northwestern Europe has demonstrably not been an obstacle either to their numerical expansion or to the demographic health of the resultant more widespread populations.

Similarly, the Madagascar Fish-Eagle *Haliaeetus vociferoides* has an estimated total breeding population of 100-120 pairs. Low genetic diversity was observed in this endemic species compared to other surveyed *Haliaeetus* species (Johnson *et al.* 2009). Madagascar fish-eagles have maintained a small effective population size for hundreds to thousands of years and its low level of genetic diversity is not the result of a recent bottleneck. Therefore, the risk of extinction this endangered species faces is not through low genetic diversity, but maintenance of habitat requirements and reducing direct and indirect human persecution (Johnson *et al.* 2009).

To conclude, the suggestion by Sato *et al.* (2023) of translocating birds into the British population from other European sources to avoid genetic inbreeding depression has little justification or credence, for several reasons, and may actually be problematic. This is therefore not an issue we will consider further as any potential benefit for translocating birds sourced away from Scotland (e.g. Section 2).

### 1.5.6 Tabulation of the ecology and genetics of lowland European eagles against three IUCN guidelines as donors for translocations to lowland regions of England

**Table 1.6.** Summary consideration of using three potential donor “lowland” Golden Eagle populations for translocation to English regions dominated by arable/farmland against three IUCN guidelines for translocation projects.

Potential donor population	Ecologically suitable?	Adverse impact on donor population?	Genetic compatibility?
Denmark/Skåne	No <sup>1</sup>	Yes <sup>2,3</sup>	No <sup>4</sup>
Gotland	No <sup>5</sup>	Yes <sup>6</sup>	No <sup>4,7</sup>
Estonia	No <sup>8</sup>	Yes <sup>6</sup>	No <sup>4</sup>

<sup>1</sup> Danish birds do not use arable habitats to any substantial degree. Apart from other information described earlier, if they did, they would be far more common in Denmark.

<sup>2</sup> With a Danish population of around three pairs, clearly this could not provide a source for translocation to England, or anywhere else.

<sup>3</sup> Interestingly, Ehmsen *et al.* (2021) state that in Denmark “Introduction of eagles... is now directly forbidden by law”. While we haven’t researched any domestic legislation relating to taking birds from Denmark as donors for elsewhere (i.e. England), logically there may well be a similarly prohibitive legal restriction. This would be additional to the clear absence for any basis to do so under IUCN guidelines.

<sup>4</sup> Birds’ genetic lineage are not aligned with those from the formerly more widespread indigenous English population (most similarity is probably with Scottish birds), the recent recolonising birds (from Scotland), or the most likely source of any imminent new recolonisation through SSGEP (Scotland).

<sup>5</sup> Gotland eagles seem to have particular ecological requirements which do not rely much on the arable habitats on the island and are probably not replicated in arable-dominated habitats of eastern and southeastern England.

<sup>6</sup> With only 65 pairs, this population could probably not be a donor without potentially adverse impact (Table 1.5).

<sup>7</sup> Gotland eagles apparently have a distinct genetic profile, separate to other populations in Fennoscandia, never mind Britain (Scotland).

<sup>8</sup> Estonian eagles use a distinct lowland peatland ecotype. There is no adequate extent of such habitats in England (or even in Scotland, if slightly more widespread: section 1.3) comparable in ecology to the lowland peatlands of (e.g.) Estonia.

To summarise, with the onerous practicalities, and little or no support from IUCN guidelines (IUCN/SSC 2013), any eagle(s) translocated to England from such genetically and ecologically distant relatives from separate lowland populations in northern Europe would be a “Stranger in a Strange Land”<sup>16</sup>. Apart from the summation in Table 1.6, using details presented in earlier text, such translocation would clearly not pass the fundamental IUCN guideline on requiring “*an especially high level of confidence over the organisms’ performance after release*”.

## 1.6 Conclusions

1. There is substantial historical evidence that the Golden Eagle is a native species in England. There is clear justification for its restoration to England.
2. The genetic affinity of English birds in the historical past is probably most aligned on relatedness with birds in Scotland.
3. There is no ecological evidence that historically, or currently, the Golden Eagle in Britain or Ireland (including England) is a species which has or does exploit lowland habitats (never mind breeding there).
4. All historical evidence indicates that the past and present gene pool of British Golden Eagles was and is adapted to exploiting upland habitats. The historical ecological affinity is with birds in Scotland, including information from the few English pairs in the 20<sup>th</sup> and 21<sup>st</sup> centuries.
5. Analyses of Potential Recovery Zones (PRZs) considered 28 possible PRZs in England. Despite research results presented in earlier sections, these possibilities included several in lowland regions. Using a number of analytical tools and factors representing suitability for Golden Eagles, 20 possible PRZs were rejected as suitable. Rejected regions were largely in the lowlands. This re-affirmed other evidence on current ecology and distribution in Scotland.
6. The eight retained PRZs were: Cheviots; North Pennines; Lakes; Yorkshire Dales; Bowland; South Pennines; North York Moors; and the South West. These are all predominantly “upland” regions. The first six are essentially one spatial block which is important for connectivity, eagle movements and population modelling.
7. Historical records and recent movements of GPS-tagged birds from southern Scotland into northern England validated the eight retained PRZs.
8. The extent of the eight PRZs together with estimates of home range extent derived from southern Scotland provided for a theoretical upper limit of the number of pairs which England may be capable of supporting (92). However, after considering a number of potential ‘risk factors’/constraints and expert opinion this was deemed more likely to be closer to 45.

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<sup>16</sup> With posthumous apologies to Heinlein (1961) on incompatible context.

9. The revised number of 45 pairs also assumes that there will be no intentional interference which prevents a home range from being established. This risk factor (persecution) could be especially influential, especially in PRZs dominated by management for driven grouse shoots. Unintentional disturbance (recreation) will also be influential as proxied by several measures.
10. The revised upper limits for the number of pairs are still optimistic and any (sub)population in the South West would have to be considered to be a special case, leaving a core population of up to 40 pairs plus another 15 in the South of Scotland.
11. A more realistic and achievable total would exclude the South Pennines (including through recreation pressure), the South West (isolation) and possibly the North Yorkshire Moors, **suggesting a population of 20 - 25 pairs** plus ~15 in the South of Scotland. The South Pennines may serve as region which dispersing birds may use, if unsuitable through disturbance (of both forms) for breeding pairs. The South West is so isolated any natural recolonisation is highly unlikely and hence any active translocation there would have to be aware of this isolation (including impacts on dispersing birds' survival) and its marginal capacity for a self-sustaining subpopulation (see also section 2 Work Package 2).
12. There is no realistic prospect that Golden Eagles will naturally occupy lowland/arable farmland in England. While the obvious and evidentially reasoned source for any translocations is Scotland, releases of Scottish birds into lowland regions of England is not supported by several strands of evidence.
13. Golden Eagles in three 'lowland' populations of NW Europe (Denmark, Gotland and Estonia) share few similarities ecologically with lowland regions of Britain and Ireland and the habitats they exploit are extremely rare or non-existent in England (and Scotland, also). Their small populations also could not sustain being donors, since a successful translocation requires scores of birds (see also section 2 Work Package 2). Under three IUCN Guidelines on translocations this prospect would not occur.
14. Moreover, translocating birds into the British population from other European sources to avoid genetic inbreeding depression has little justification or credence, for several reasons, and may actually be problematic.
15. Any release sites in a possible reintroduction/reinforcement project should be in upland habitats, most likely in northern England, and involve Scottish birds.

The fate of any such releases on population viability is covered in part of the next section.

## 1.7 References

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## Appendix 1: Potential Recovery Zone Summaries

**Table 1. PRZ and their areas (km<sup>2</sup>).**

<b>Id</b>	<b>PRZ Name</b>	<b>PRZ A</b>	<b>PRZ B</b>
1	Cheviots	1527.6	1593.7
2	North Pennines	1868.2	2105.0
3	Lakes	2103.0	2637.9
4	York Dales	2745.6	3293.1
5	North York Moors	1542.6	1900.9
6	Bowland	328.1	944.0
7	South Pennines	2155.8	2056.8
8	Borders	2321.1	1839.1
9	South West	6330.4	4266.1
10	NE Coast		157.9
11	Solway		183.7
12	Lincolnshire		693.3
13	East Anglia		1837.2
14	Cotswolds		2521.0
15	Wessex-Chilterns		3471.9
16	Mendips		281.9
17	South Downs		5680.0
18	Dorset - Wiltshire		4170.7
19	Isle of Wight		298.6

**Table 2. Open GET Habitat in PRZs and three Golden Eagle home range areas - proportion in each GET class.**

Region	GET SCORES										
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	6+
<b>PRZ A</b>											
Cheviots	0.19	0.04	0.24	0.11	0.11	0.08	0.07	0.08	0.05	0.01	0.30
North Pennines	0.16	0.02	0.17	0.12	0.13	0.11	0.10	0.10	0.06	0.03	0.41
Lakes	0.04	0.02	0.15	0.09	0.11	0.14	0.13	0.13	0.13	0.06	0.59
York Dales	0.08	0.03	0.21	0.13	0.14	0.11	0.11	0.11	0.07	0.02	0.42
North York Moors	0.19	0.06	0.27	0.11	0.10	0.08	0.09	0.07	0.04	0.00	0.28
Bowland	0.09	0.02	0.22	0.14	0.14	0.11	0.11	0.11	0.06	0.01	0.40
South Pennines	0.03	0.03	0.24	0.14	0.13	0.11	0.11	0.13	0.07	0.01	0.43
Borders	0.19	0.05	0.25	0.11	0.09	0.08	0.10	0.08	0.04	0.00	0.31
South West	0.10	0.03	0.25	0.11	0.11	0.11	0.13	0.11	0.04	0.00	0.39
<b>PRZ B</b>											
Cheviots	0.23	0.05	0.23	0.11	0.10	0.08	0.07	0.08	0.05	0.01	0.28
North Pennines	0.19	0.03	0.18	0.11	0.12	0.10	0.10	0.10	0.05	0.02	0.37
Lakes	0.10	0.03	0.18	0.09	0.10	0.12	0.11	0.11	0.10	0.05	0.50
York Dales	0.16	0.03	0.21	0.12	0.12	0.10	0.09	0.09	0.06	0.02	0.36
North York Moors	0.25	0.06	0.26	0.10	0.09	0.07	0.08	0.06	0.03	0.00	0.25
Bowland	0.26	0.05	0.25	0.11	0.09	0.07	0.07	0.06	0.03	0.00	0.24
South Pennines	0.04	0.03	0.23	0.14	0.13	0.11	0.11	0.13	0.07	0.01	0.42
Borders	0.20	0.05	0.25	0.11	0.09	0.08	0.09	0.08	0.04	0.00	0.31
South West	0.12	0.03	0.25	0.11	0.11	0.10	0.12	0.11	0.05	0.01	0.38
NE Coast	0.88	0.02	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02
Solway	0.97	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Lincolnshire	0.79	0.03	0.10	0.02	0.02	0.02	0.02	0.01	0.00	0.00	0.04
East Anglia	0.98	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cotswolds	0.52	0.05	0.17	0.06	0.05	0.04	0.05	0.04	0.01	0.00	0.15
Wessex-Chilterns	0.54	0.05	0.19	0.06	0.04	0.04	0.04	0.03	0.01	0.00	0.12
Mendips	0.26	0.10	0.27	0.08	0.08	0.06	0.07	0.05	0.03	0.00	0.21
South Downs	0.45	0.05	0.22	0.07	0.05	0.06	0.06	0.04	0.01	0.00	0.16
Dorset - Wiltshire	0.42	0.05	0.22	0.07	0.06	0.06	0.06	0.05	0.02	0.00	0.19
Isle of Wight	0.41	0.05	0.22	0.06	0.06	0.07	0.06	0.05	0.02	0.00	0.20
<b>Home ranges</b>											
Scotland	0.03	0.05	0.07	0.07	0.09	0.10	0.12	0.13	0.15	0.19	0.70
Outer Hebrides	0.07	0.15	0.13	0.13	0.14	0.08	0.13	0.09	0.06	0.01	0.38
South of Scotland	0.00	0.01	0.03	0.04	0.04	0.09	0.11	0.18	0.24	0.25	0.88

**Table 3. Species Distribution model - first and third quartiles plus median and mean scores.**

<b>Zone</b>	<b>Q1</b>	<b>Median</b>	<b>Mean</b>	<b>Q3</b>
<b>PRZ A</b>				
Cheviots	1	9	11.5	18
North Pennines	9	22	22.8	32
Lakes	12	26	28.6	44
York Dales	6	16	17.2	25
North York Moors	1	9	11.0	18
Bowland	4	13	13.7	20
South Pennines	6	13	13.6	20
Borders	0	6	8.7	14
South West	5	14	15.9	25
<b>PRZ B</b>				
Cheviots	1	10	10.3	20
North Pennines	4	20	20.6	31
Lakes	5	19	24.2	40
York Dales	1	12	14.3	23
North York Moors	0	6	9.5	17
Bowland	0	2	7.6	13
South Pennines	6	12	13.1	20
Borders	0	6	8.9	14
South West	5	14	17.5	28
NE Coast	0	0	3.3	5
Solway	1	3	4.2	6
Lincolnshire	0	0	2.0	0
East Anglia	0	2	3.3	5
Cotswolds	0	0	4.3	6
Wessex-Chilterns	0	0	3.4	3
Mendips	0	2	8.9	16
South Downs	0	1	7.3	13
Dorset - Wiltshire	0	3	7.5	13
Isle of Wight	0	5	12.2	23
<b>Home Range</b>				
South of Scotland HR	9	16	19.4	27

**Table 4. CORINE Land cover classes by PRZ and Golden Eagle home range area (percentage cover). Only classes with >5% cover are shown. The Anthropogenic class is the sum of the first 11 Corine land cover classes.**

	Anthropogenic	Non-irrigated arable	Pastures	Broad-leaved forest	Coniferous forest	Mixed forest	Natural grasslands	Moors and heathland	Transitional woodland-shrub	Sparsely vegetated areas	Peat bogs	Salt marshes
<b>PRZ A</b>												
Cheviots	0.3	8.7	15.1	0.3	18.0	1.1	16.5	17.3	9.4	0.4	12.0	0.0
North Pennines	0.4	0.0	18.3	0.3	1.6	0.7	18.4	28.5	0.7	6.3	24.3	0.0
Lakes	0.8	0.5	21.5	3.9	3.4	4.5	30.0	20.6	1.7	6.4	3.0	0.0
York Dales	0.6	0.0	24.3	0.7	0.9	0.2	21.8	20.2	0.7	2.3	27.7	0.0
North York												
Moors	0.7	19.2	27.4	5.4	11.6	1.3	1.2	11.2	1.7	0.0	19.0	0.0
Bowland	0.1	0.0	14.8	1.0	0.6	0.4	14.4	14.4	1.1	0.0	53.3	0.0
South Pennines	3.9	0.4	42.7	2.7	1.6	0.8	8.8	13.0	0.2	0.0	24.8	0.0
Borders	2.4	37.3	40.5	4.9	5.6	3.1	2.5	1.8	0.5	0.0	0.0	0.0
South West	3.4	31.6	41.6	4.4	2.6	2.3	4.7	5.4	0.4	0.0	2.5	0.0
<b>PRZ B</b>												
Cheviots	0.2	2.8	16.3	0.3	14.9	0.5	23.2	18.8	8.6	0.4	13.8	0.0
North Pennines	0.6	0.7	25.1	0.5	1.5	0.6	17.1	25.6	0.7	5.6	21.5	0.0
Lakes	1.3	1.0	32.7	3.7	2.7	4.2	25.0	16.6	1.7	5.1	2.4	0.2
York Dales	1.2	1.2	34.5	1.0	1.3	0.4	17.9	16.4	0.8	1.9	22.9	0.0
North York												
Moors	1.5	26.2	28.2	4.8	9.8	1.2	1.0	9.2	1.5	0.0	15.5	0.0
Bowland	1.0	0.7	57.8	1.5	1.6	1.1	7.1	7.8	1.2	0.0	19.5	0.0
South Pennines	3.1	0.6	48.6	2.8	1.8	0.6	6.6	12.2	0.2	0.0	22.2	0.0
Borders	4.2	30.5	42.3	6.2	5.1	2.9	3.4	3.2	0.5	0.0	0.0	0.0
South West	3.9	28.9	35.9	4.7	2.2	1.7	7.2	10.0	0.4	0.1	3.7	0.1
NE Coast	8.6	63.5	20.3	1.3	0.0	0.2	5.8	0.0	0.0	0.0	0.0	0.4
Solway	3.1	29.0	43.4	0.4	0.0	0.4	0.7	0.0	0.0	0.3	7.5	15.2
Lincolnshire	2.2	86.0	9.0	0.9	0.1	0.8	0.0	0.0	0.2	0.0	0.0	0.0
East Anglia	8.5	54.6	20.0	3.1	0.8	3.9	0.1	1.1	0.1	0.0	0.0	2.1
Cotswolds	7.4	50.9	32.6	5.0	0.1	1.7	0.2	0.1	0.1	0.0	0.0	0.0
Wessex-												
Chilterns	7.9	52.2	23.7	6.4	0.6	1.8	7.1	0.0	0.0	0.0	0.0	0.0
Mendips	6.1	19.6	59.4	4.2	0.7	2.5	0.0	2.3	1.7	0.0	0.0	0.0
South Downs	10.8	33.6	37.0	9.5	1.7	5.5	0.0	0.8	0.1	0.0	0.0	0.0
Dorset -												
Wiltshire	6.7	36.6	35.9	6.1	2.8	3.6	0.6	5.5	0.6	0.0	0.0	0.2
Isle of Wight	9.9	38.0	41.0	6.6	0.1	2.0	0.5	0.7	0.3	0.0	0.0	0.5

PRZ A	Anthropogenic	Non-irrigated arable	Pastures	Broad-leaved forest	Coniferous forest	Mixed forest	Natural grasslands	Moors and heathland	Transitional woodland-shrub	Sparsely vegetated areas	Peat bogs	Salt marshes
<b>Home ranges</b>												
Scotland	0.6	0.4	6.9	2.1	14.4	0.8	18.7	33.1	4.6	8.4	5.7	0.0
Outer Hebrides	0.0	0.0	4.7	0.0	0.0	0.0	2.4	10.1	0.3	0.0	75.4	0.0
South of Scotland	0.3	0.4	6.4	0.2	13.2	0.5	31.2	27.5	5.2	2.0	12.7	0.0

**Table 5. Percentage cover by Less Favoured Agricultural Areas: LFA 1 – Disadvantaged; LFA 2 – Severely disadvantaged (Scotland has no Moorland category).**

PRZ A	Moorland	FLA 1	FLA 2
<b>PRZ A</b>			
Cheviots	40.9	5.1	83.2
North Pennines	66.7	0.7	99.2
Lakes	56.0	7.7	89.7
York Dales	62.3	8.3	91.8
North York Moors	30.9	13.9	55.6
Bowland	75.3	4.0	97.7
South Pennines	41.8	9.8	90.2
Borders	2.3	10.3	22.9
South West	11.6	5.1	28.3
<b>PRZ B</b>			
Cheviots	43.8	91.3	93.8
North Pennines	59.3	94.5	97.9
Lakes	44.9	78.8	89.7
York Dales	51.3	79.8	93.6
North York Moors	25.3	46.0	58.6
Bowland	30.1	55.7	87.1
South Pennines	37.6	85.6	99.9
Borders	3.3	23.5	35.8
South West	18.3	40.5	49.4
NE Coast	0.0	0.0	0.0
Solway	0.0	13.5	0.0
Lincolnshire	0.0	0.0	0.0

	Moorland	FLA 1	FLA 2
<b>PRZ A</b>			
East Anglia	0.0	0.0	0.0
Cotswolds	0.0	0.0	0.0
Wessex-Chilterns	0.0	0.0	0.0
Mendips	0.0	0.0	0.0
South Downs	0.0	0.0	0.0
Dorset - Wiltshire	0.0	0.0	0.0
Isle of Wight	0.0	0.0	0.0
<b>Countries</b>			
England	5.9	4.9	13.4
Scotland		1.8	69.0
<b>Home ranges</b>			
Scotland		0.5	99.0
Outer Hebrides		0.0	99.9
South of Scotland		0.2	99.3

**Table 6. Wind speed (m/s) at 10 m and 45 m above ground level.**

	Wind speed m/s	
	10 m	45 m
<b>PRZ A</b>		
Cheviots	5.8	7.2
North Pennines	5.8	7.2
Lakes	5.6	6.7
York Dales	5.5	6.8
North York Moors	5.7	7.0
Bowland	6.0	7.3
South Pennines	5.6	6.9
Borders	5.0	6.2
South West	5.5	6.8
<b>PRZ B</b>		
Cheviots	6.0	7.3
North Pennines	5.7	7.0
Lakes	5.5	6.6
York Dales	5.3	6.6
North York Moors	5.6	6.9
Bowland	5.3	6.7
South Pennines	5.5	6.8
Borders	5.1	6.4
South West	5.8	7.1
NE Coast	5.7	7.1
Solway	5.6	7.0
Lincolnshire	5.4	6.7
East Anglia	5.1	6.4
Cotswolds	5.1	6.4

PRZ A	Wind speed m/s	
	10 m	45 m
Wessex-Chilterns	5.1	6.4
Mendips	5.3	6.6
South Downs	5.1	6.4
Dorset - Wiltshire	5.3	6.6
Isle of Wight	5.7	7.0
<b>Home ranges</b>		
Scotland	6.2	6.7
Outer Hebrides	6.3	7.8
South of Scotland	6.2	7.6

**Table 7. Growing Degree Days (GDD) with two baselines (1981 - 2000 & 2001 - 2020, a 0.51° rise) and three possible future global warming levels of 1.5°C, 2.0°C and 3.0°C above the pre-industrial (1850-1900) period. The percentage rise in the number of GDD relates to the 2001-2020 baseline except for the 2001-2020 baseline.**

	Baselines			1.5° rise		2.0° rise		3.0° rise	
	81-00	01-20	% rise	GDD	% rise	GDD	rise %	GDD	% rise
<b>UK</b>	1543	1741	12.8	1831	18.7	1979	28.3	2207	43.0
<b>PRZ A</b>									
Cheviots	1160	1326	14.3	1418	22.3	1547	33.4	1756	51.4
North Pennines	1097	1274	16.2	1355	23.6	1482	35.1	1699	55.0
Lakes	1286	1476	14.8	1563	21.6	1694	31.7	1921	49.4
York Dales	1205	1394	15.7	1479	22.7	1612	33.8	1838	52.5
North York Moors	1452	1645	13.3	1732	19.3	1889	30.1	2115	45.7
Bowland	1383	1577	14.1	1668	20.6	1803	30.4	2035	47.1
South Pennines	1389	1597	14.9	1685	21.3	1829	31.7	2065	48.7
Borders	1692	1918	13.3	2004	18.4	2159	27.6	2414	42.7
South West	1798	2021	12.4	2107	17.2	2273	26.4	2546	41.6
<b>PRZ B</b>									
Cheviots	1174	1342	14.3	1434	22.2	1562	33.1	1773	51.1
North Pennines	1085	1262	16.3	1343	23.8	1470	35.5	1687	55.5
Lakes	1372	1564	14.0	1655	20.6	1789	30.4	2017	47.0
York Dales	1243	1434	15.4	1520	22.3	1656	33.2	1883	51.5
North York Moors	1487	1683	13.2	1771	19.1	1929	29.7	2157	45.0
Bowland	1443	1642	13.7	1734	20.2	1872	29.7	2107	46.0
South Pennines	1367	1576	15.2	1662	21.5	1807	32.2	2043	49.4
Borders	1704	1930	13.3	2018	18.4	2174	27.6	2428	42.5

	Baselines			1.5° rise		2.0° rise		3.0° rise	
	81-00	01-20	% rise	GDD	% rise	GDD	rise %	GDD	% rise
South West	1834	2056	12.1	2144	16.9	2313	26.1	2584	40.9
NE Coast	1458	1638	12.3	1736	19.1	1894	29.9	2102	44.2
Solway	1615	1810	12.1	1906	18.0	2049	26.9	2281	41.3
Lincolnshire	1705	1924	12.8	2015	18.2	2177	27.7	2414	41.5
East Anglia	1907	2139	12.2	2235	17.2	2410	26.4	2651	39.0
Cotswolds	1801	2038	13.1	2127	18.1	2291	27.2	2553	41.7
Wessex-									
Chilterns	1832	2076	13.4	2166	18.3	2333	27.4	2602	42.0
Mendips	1926	2162	12.3	2250	16.9	2414	25.3	2690	39.7
South Downs	1960	2207	12.6	2301	17.4	2480	26.6	2750	40.3
Dorset -									
Wiltshire	1916	2156	12.5	2243	17.1	2415	26.0	2693	40.5
Isle of Wight	2074	2313	11.5	2408	16.1	2596	25.2	2874	38.6
<b>Home ranges</b>									
Scotland	1110	1265	14.0	1349	21.5	1469	32.3	1655	49.1
Outer Hebrides	1206	1357	12.5	1440	19.4	1561	29.5	1750	45.2
South of Scotland	1132	1301	14.9	1384	22.2	1510	33.4	1711	51.2

**Table 8. Mean spring rainfall 1997 - 2006 plus the standard deviation (sd) in the spring rainfall and coefficient of variation (CV).**

<b>Region</b>	<b>Mean (mm)</b>	<b>sd</b>	<b>CV</b>
<b>PRZ A</b>			
Cheviots	244.8	41.8	0.17
North Pennines	253.1	28.6	0.11
Lakes	332.3	55.2	0.17
York Dales	278.1	19.4	0.07
North York Moors	228.4	36.6	0.16
Bowland	340.2	31.9	0.09
South Pennines	286.8	19.3	0.07
Borders	205.1	18.7	0.09
South West	260.0	15.0	0.06
<b>PRZ B</b>			
Cheviots	243.7	39.1	0.16
North Pennines	248.8	26.2	0.11
Lakes	337.3	45.7	0.14
York Dales	271.3	15.7	0.06
North York Moors	216.0	32.3	0.15
Bowland	281.1	24.1	0.09
South Pennines	264.2	17.8	0.07
Borders	203.8	17.5	0.09
South West	270.2	21.8	0.08
NE Coast	178.3	64.6	0.36
Solway	223.3	21.1	0.09
Lincolnshire	182.3	25.1	0.14
East Anglia	153.3	10.6	0.07
Cotswolds	192.5	13.0	0.07
Wessex-Chilterns	183.3	9.9	0.05
Mendips	231.8	42.5	0.18
South Downs	173.4	8.3	0.05
Dorset - Wiltshire	200.8	10.8	0.05
Isle of Wight	151.9	39.9	0.26
<b>Home ranges</b>			
Scotland	339.6	86.7	0.26
Outer Hebrides	272.2	70.4	0.26
South of Scotland	317.3	69.5	0.22

**Table 9. Median distance (m) to Urban Areas (OS Built Up Areas data of areas  $\geq$  20 ha).**

<b>Name</b>	<b>Median</b>
<b>PRZ A</b>	
Cheviots	9,500
North Pennines	6,500
Lakes	5,000
York Dales	6,500
North York Moors	4,500
Bowland	6,500
South Pennines	2,500
Borders	2,500
South West	2,500
<b>PRZ B</b>	
Cheviots	8,500
North Pennines	5,000
Lakes	4,500
York Dales	5,500
North York Moors	4,000
Bowland	4,000
South Pennines	2,500
Borders	2,500
South West	2,500
NE Coast	1,500
Solway	2,000
Lincolnshire	3,000
East Anglia	1,000
Cotswolds	1,500
Wessex-Chilterns	1,500
Mendips	1,500
South Downs	1,000
Dorset - Wiltshire	2,000
Isle of Wight	1,000
<b>Home ranges</b>	
Scotland	11,500
Outer Hebrides	9,000
South of Scotland	8,500

**Table 10. Length of road (km) per km<sup>2</sup> of PRZ or Golden Eagle home range area. LDP - Long Distance Path, MW - Motorway.**

Name	LDP	Minor	B Road	A Road	Primary	MW	All
<b>PRZ A</b>							
Cheviots	0.03	0.27	0.05	0.00	0.03	0.00	0.34
North Pennines	0.05	0.26	0.08	0.05	0.01	0.00	0.40
Lakes	0.00	0.43	0.05	0.06	0.06	0.00	0.60
York Dales	0.03	0.34	0.08	0.03	0.02	0.00	0.47
North York Moors	0.06	0.59	0.04	0.03	0.00	0.00	0.66
Bowland	0.00	0.24	0.01	0.00	0.22	0.00	0.47
South Pennines	0.12	0.56	0.09	0.11	0.09	0.00	0.85
Borders	0.03	1.00	0.18	0.07	0.06	0.00	1.31
South West	0.01	1.22	0.11	0.08	0.07	0.00	1.49
<b>PRZ B</b>							
Cheviots	0.07	0.25	0.05	0.09	0.03	0.00	0.42
North Pennines	0.05	0.32	0.10	0.00	0.02	0.00	0.44
Lakes	0.00	0.53	0.05	0.00	0.08	0.01	0.68
York Dales	0.03	0.46	0.09	0.08	0.04	0.00	0.67
North York Moors	0.07	0.64	0.05	0.19	0.07	0.00	0.95
Bowland	0.00	0.70	0.05	0.00	0.04	0.01	0.80
South Pennines	0.11	0.67	0.09	0.40	0.09	0.00	1.25
Borders	0.03	1.01	0.17	0.13	0.08	0.01	1.39
South West	0.13	1.07	0.13	0.02	0.05	0.00	1.27
NE Coast	0.00	0.77	0.24	1.16	0.11	0.00	2.28
Solway	0.13	0.70	0.21	0.32	0.03	0.01	1.28
Lincolnshire	0.00	0.75	0.10	0.07	0.14	0.00	1.06
East Anglia	0.04	0.90	0.16	0.06	0.08	0.00	1.19
Cotswolds	0.07	1.02	0.15	0.02	0.10	0.01	1.30
Wessex- Chilterns	0.05	0.85	0.11	0.00	0.05	0.02	1.04
Mendips	0.00	1.01	0.21	1.25	0.07	0.02	2.56
South Downs	0.07	0.98	0.14	0.04	0.10	0.03	1.29
Dorset - Wiltshire	0.03	0.94	0.13	0.11	0.09	0.00	1.27
Isle of Wight	0.00	0.83	0.22	0.41	0.00	0.00	1.46
<b>Home ranges</b>							
Scotland	0.01	0.11	0.03	0.04	0.03	0.00	0.21
Outer Hebrides	0.00	0.12	0.05	0.05	0.00	0.00	0.21
South of Scotland	0.02	0.10	0.01	0.03	0.01	0.00	0.16

**Table 11. Renewable Energy, wind and solar farms (solar farms in England only) Key to solar farms: AS - Application Submitted, O - Operational, UC - under construction, WC - waiting for construction.**

<b>Region</b>	<b>Wind farms (Turbines)</b>	<b>Solar Farm</b>
<b>PRZ A</b>		
Cheviots	0	1 (UC)
North Pennines	0	0
Lakes	3 (23)	0
York Dales	0	3 (WC)
North York Moors	0	2 (WC)
Bowland	0	0
South Pennines	10 (81)	2 (AS)
Borders	0	12 (AS 3, O 5, WC 2, UC 2)
South West	6 (50)	116 (AS 18, O 87, WC 12, UC 1)
<b>PRZ B</b>		
Cheviots	0	0
North Pennines	2 (4)	0
Lakes	2 (4)	0
York Dales	2 (12)	2 (WC 2)
North York Moors	0	2 (WC 2)
Bowland	1 (8)	0
South Pennines	2 (17)	1 (AS 1)
Borders	0	11 (AS 2, WC 2, O 6, UC 1)
South West	3 (15)	33 (AS 2, WC 7, O 24)
NE Coast	0	0
Solway	0	0
Lincolnshire	0	0
East Anglia	2 (4)	17 (AS 4, WC 7, O 5, UC 1)
Cotswolds	0	21 (AS 5, O 14, WC 2)
Wessex-Chilterns	0	22 (AS 8, WC 4, O 9, UC 1)
Mendips	0	4 (AS 1, WC 1, O 2)
South Downs	0	36 (AS 14, WC 9, O 13)
Dorset - Wiltshire	0	74 (AS 11, UC 2, WC 12, O 49)
Isle of Wight	0	7 (AC 2, O 5)
<b>Home ranges</b>		
Scotland	85 (1,444)	
Outer Hebrides	1 (1)	
South of Scotland	6 (65)	

## 2. Work Package 2: Population Viability Analysis

### 2.1 Background and Introduction

In this section we use population modelling techniques to investigate how a recovering Golden Eagle population in England may expand, if at all. Two scenarios are modelled.

1. Natural, unassisted, spread of Golden Eagles from the South of Scotland into England.
2. Targeted movement of young nestling Golden Eagles translocated from Scotland, after subsequent release into England.

### 2.2 Population modelling approaches

Robust population modelling of Golden Eagles requires estimates of four key population parameters:

1. number of occupied home ranges;
2. average number of young fledged per occupied home range;
3. proportion of young birds surviving each year; and
4. proportion of range holding birds dying each year.

In addition, it is useful to know the between-year variability of the above and if there is evidence of trends in their values.

Items 1 and 2 are usually known with a reasonable degree of confidence, at least in some years. Previously, items 3 and 4 could only be inferred from other studies and the evidence for, or absence of, trends in factors such as the number of occupied ranges.

Models were constructed using the R statistical programming language (v 3.6.1) and the Popbio library (v. 2.6, Stubben & Milligan 2007 [updated 2018]). The main approach is an adapted Population Projection Matrix (PPM), or Leslie matrix, augmented with year specific (cohort) calculations and adjustments. This approach is used because it is simpler to incorporate stochastic noise and additional mortality. Some of the novel aspects of the R code are described in the text.

Models are built with two age classes: juvenile/sub-adult and one adult class. Sub-adults are defined, in these models, as individuals less than the usual first age of breeding (although there may be a small number who breed earlier). Only the adult age class is assumed to fledge young. Although a model with more age classes might be considered 'more realistic' the reality is that such a model has a large number of parameters, possibly >20, all of which have uncertain values which permeate more uncertainty throughout the model and its results.

A model's predictions will only be accurate if the parameter values are correct and there is no systematic change over time.

### 2.3 Investigating the parameter landscape

Given that there is uncertainty about parameter values a useful starting point explores 'parameter landscapes' and identifies combinations of values which affect the value of lambda ( $\lambda$ ). Lambda is the population growth rate and if  $\lambda = 1$  a population is stable,

whereas  $\lambda < 1$  indicates a population in decline. A population will grow when  $\lambda > 1$  and the rate at which a population increases or declines depends how far  $\lambda$  is from 1.

Initially, a simple PPM investigates how  $\lambda$  changes as the fledging rate ( $f$ , females fledged per pair), sub-adult survival rate ( $s$ ) and the adult survival rate ( $v$ ) change within ecologically realistic ranges (Table 2.1). Note that this approach provides no information about a future population size as that depends on how many individuals were present in the starting population.

**Table 2.1.** Exploring PPMs with a range of values for  $f$  (female fledging rate 0.15 - 0.25),  $s$  (sub-adult survival rate 0.40 - 0.70) and  $v$  (adult survival rate 0.86 - 0.94). Rows and columns highlighted in yellow approximate to those used in later population models. Cells in italic, red bold have a growth rate  $< 1$ , i.e. the population will decline. Cells with a pink fill have a growth rate less than 1%, essentially the population would be stable. Rapid population expansion,  $>5\%$  per year, is highlighted in bold black. Note that rows have been removed if all values were significantly below or above  $\lambda = 1$ .

f	v	Sub-adult survival rate s																	
		0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70		
0.150	0.90	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.00	
	0.91	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	1.01	
		<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	
	0.92	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	
	0.93	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	
	0.94	1.00	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	
0.175	0.88	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.00	
	0.89	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	
		<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	1.02	1.02	
	0.91	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	
	0.92	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.04	
	0.93	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.04	1.04	1.04	1.04	
0.94	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05		
0.200	0.86	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	
	0.87	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.01	1.01
		<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	1.01	
	0.88	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.02	
	0.89	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.03	
	0.90	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.04	
0.91	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	
0.92	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.05	1.05	1.05	1.05	
0.93	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.05	1.05	1.06	1.06	1.06	1.06	
0.94	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.07	1.07	
0.225	0.86	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.01	1.01	1.01	1.02	
	0.87	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.02	
		<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.03	1.03	
	0.88	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	1.00	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.03	1.03	1.03	
	0.89	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.01	1.01	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	
	0.90	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	1.00	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.05	1.05	
0.91	1.00	1.00	1.01	1.01	1.02	1.02	1.02	1.03	1.03	1.04	1.04	1.04	1.04	1.05	1.05	1.06	1.06	1.06	

0.92	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.04	1.0	1.0	1.0	1.0	1.0	1.0
0.93	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.250	0.86	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.00	1.00	1.01	1.01	1.02	1.02	1.03
	0.87	0.9	0.9	0.9	0.9	0.9	1.0	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.04
	0.88	0.9	0.9	0.9	1.0	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.04	1.04
	0.89	0.9	1.0	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.03	1.04	1.04	1.0	1.0
	0.90	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.04	1.04	1.04	1.0	1.0	1.0	1.0
	0.91	1.01	1.01	1.02	1.02	1.03	1.03	1.04	1.04	1.04	1.0	1.0	1.0	1.0	1.0	1.0
	0.92	1.02	1.02	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.0	1.0	1.0	1.0	1.0	1.0

If the fledging rate is less than 0.175 (0.35 for both sexes), population growth is only possible if both survival rates are large. Conversely, once the fledging rate is 0.25 or larger (0.5 for both sexes), population growth is possible even with relatively low annual survival rates.

The above models are deterministic as the value of  $\lambda$  is fixed by the rules of matrix algebra for any combination of  $f$ ,  $s$  and  $v$ . In reality,  $f$ ,  $s$  and  $v$  will vary over time, for example more young will be fledged in some years than others. This type of between-year stochastic variability is not the same as a trend over time in which, for example, survival rates gradually increase or decline. Stochastic variability (chance) may result in a population becoming extinct because of a series of chance events, such a sequence of years with poor May weather, and this needs to be incorporated into models to provide estimates of the probabilities of observed population trajectories. For example, in the annually censused Scottish NHZ 10 population the fledging rates were: 2020 - 0.75; 2021 - 0.96; 2022 - 0.46; 2023 - 1.12; and 2024 - 0.74 (Benn and Whitfield, 2024).

Stochastic variability is included in the next two models.

## 2.4 Scenario 1. Natural, unassisted, spread of Golden Eagles from the South of Scotland southwards into England

The aim is to model the recovery of an English population. There are no historic data which can be used to provide informed estimates of the correct values of  $f$ ,  $s$  and  $v$  so assumptions have been made.

### 2.4.1 Number of ranges

It is assumed that the bulk of a future English population is geographically linked to the South of Scotland and this combined population is effectively isolated from the majority of the Scottish population (Fielding *et al.* 2024). The combined South of Scotland - Northern England population is therefore a closed population. As such, a starting population of 15 pairs in the South of Scotland is assumed.

### 2.4.2 Average number of young fledged per pair

Most pairs in the South of Scotland are made of translocated young birds who, in 2024, have not yet fledged young. The three long-established pairs have been productive in recent years. As productivity for the whole population is uncertain a range of values is tested: 0.3 - 0.5 young of both sexes fledged per pair (not per successful pair). The models

described below are female-based and assume a 50% sex ratio at fledging and the observed fledging rates are therefore halved in the models (0.15 - 0.25).

### 2.4.3 Proportion of young birds surviving each year

The models are female-based, and it is assumed that survival rates are the same for each sex.

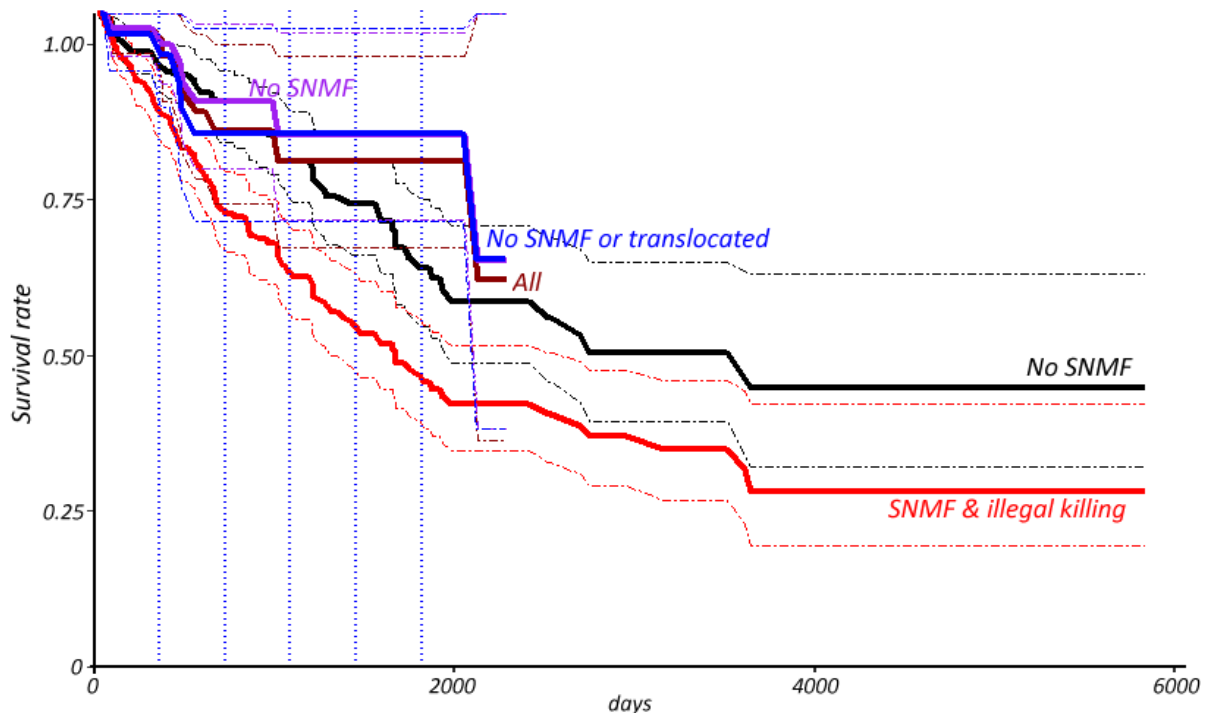
Survivorship values for Golden Eagles in Scotland were unknown but Whitfield *et al.* (2006) identified minimum values consistent with favourable conservation status: 40% survival from fledging to adulthood (equivalent to an annual survival rate of ~75%); and 95.12% annual survival of adults (derived from an expected average of 20 years of home range occupation by an adult).

More recently, using satellite tracking information, Whitfield & Fielding (2017) found that survivorship to breeding age was much higher than previously expected once the effects of illegal persecution were discounted but adult survival is probably less than 95.12%.

Since 2018 there has been good data on the survival of dispersing young Golden Eagles in the South of Scotland as almost all young birds in the South of Scotland have been fitted with satellite tags. Similarly, there is now much more extensive data from the rest of Scotland compared to what was available to Whitfield & Fielding (2017).

The R survival package (Therneau 2024) was used to estimate survival rates. Cases were censored if they were still tracking or there was a fault with the satellite tag which stopped further transmissions. The data set of 232 tags contained data from tags known to have stopped transmitting because a bird was killed illegally, or an illegal act was suspected causing the tag to stop transmitting suddenly without any prior tag data of imminent malfunction. These events were labelled as Stop No MalFunction (SNMF) by Whitfield & Fielding (2017). Consequently, bird survival was also estimated when all tags suspected of being subject to illegal acts were removed. This left a data set of 173 cases. Unsurprisingly, estimated survival rates were much higher when SNMF tags were removed (Figure 2.1).

If analyses are restricted to the South of Scotland there is an extra complication given there have been two types of release: birds fledged in the South of Scotland; and birds translocated there as dispersing young birds. Consequently, three survival analyses were undertaken for the South of Scotland (Figure 2.1). Irrespective of the South of Scotland tag group, survival rates were higher in the South of Scotland than in Scotland generally.



**Figure 2.1.** Survival curves with all tag data (SNMF & illegal killing) and with SNMF tags removed plus three data sets from the South of Scotland (terminate at ~2,000 days): all South of Scotland tags; (all tags - SNMFs and illegally killed birds); and (all - SNMF and illegally killed - birds translocated) from the Outer Hebrides.

In the full data set ( $n = 232$ ), survival to the start of year 5 (1,460 days) was estimated at 0.504 with 95% confidence limits of 0.432 - 0.586. If SNMF tags are removed the estimated survival rate to the same age was 0.694 with 95% confidence limits of 0.613 - 0.786. Both of these are considerably larger than the 40% used as minimum for favourable conservation status by Whitfield *et al.* (2006).

In the analyses restricted to the South of Scotland, the three survival estimates to the start of year 5 are quite similar but with wide confidence limits: all tags 0.762 (0.623 - 0.931); all tags - SNMF tags 0.805 (0.670 - 0.969); and all tags - SNMF tags - translocated tags 0.807 (0.667 - 0.977).

If it is assumed there will be no illegal killing of Golden Eagles in England (although the model described below incorporates additional mortality, which could include intentional illegal killing), the mean estimated survival to the end of year 4 for all tags in Scotland is 0.504 which is much lower than the 0.807 estimated for the South of Scotland. The fates of recent releases into the South of Scotland are likely to be a better guide to survival rates than the national data set. However, to be conservative, we use the lower confidence limit (0.667) of the South of Scotland mean survival rate.

#### 2.4.4 Proportion of range holding birds dying each year

Satellite tracking data cannot provide robust information about adult survival as tags do not operate over the necessary timescale. There have been estimates, mainly in the US, which are in the range 0.90 to 0.93. In Scotland, a crude annual survival rate can be inferred from those birds tagged as range holding birds. The estimate is inevitably crude as there is no information on the ages of these individuals when tagged, presumably older individuals are more likely to die.

We use an annual survival for adults of 0.9 which approximates to a life expectancy of 9.5 years for adult, range holding birds. Note that this is considerably lower than the 0.9512 annual survival rate which Whitfield *et al.* (2006) assumed was necessary to achieve favourable conservation status, albeit with a much smaller survival rate for young birds.

So far, the oldest tagged birds were ringed and subsequently caught and tagged as a range holding bird on Lewis. The oldest is 7,796 days (21 years) and she was still alive on 20/10/24. A second bird reached at least 6,919 days (19 years); she removed the tag after ~18 months and may still be alive (an example of a censored tag). In the South of Scotland, Roxy was tagged in a Galloway nest and she subsequently settled while very young in December 2011, having fledged in August 2010. Her tag is still working 14.2 years later and it is believed she killed an intruding bird in late June 2024 (Cat Barlow *pers comm*). She and her very old partner fledged twins in 2024. It is known from camera trapping and a leg ring that Roxy's mate is more than 30 years old.

#### 2.4.5 Initial number of sub-adults

The number of sub-adults in year 0 is derived from the number of satellite tracked dispersing birds in the South of Scotland. In October 2024 there were eight young female birds in the South of Scotland.

#### 2.4.6 Density dependence

Some models incorporate density dependence which begins to operate at higher densities of home ranges. If a population approaches its carrying capacity there are biological consequences which are usually a combination of reduced productivity and/or reduced survival, resulting from direct intra-specific effects, such as the killing of one bird by another, insufficient prey resources or enhanced disease/parasite transmission. These are density dependent processes because the intensity of the effect is determined by the number of individuals in the modelled area.

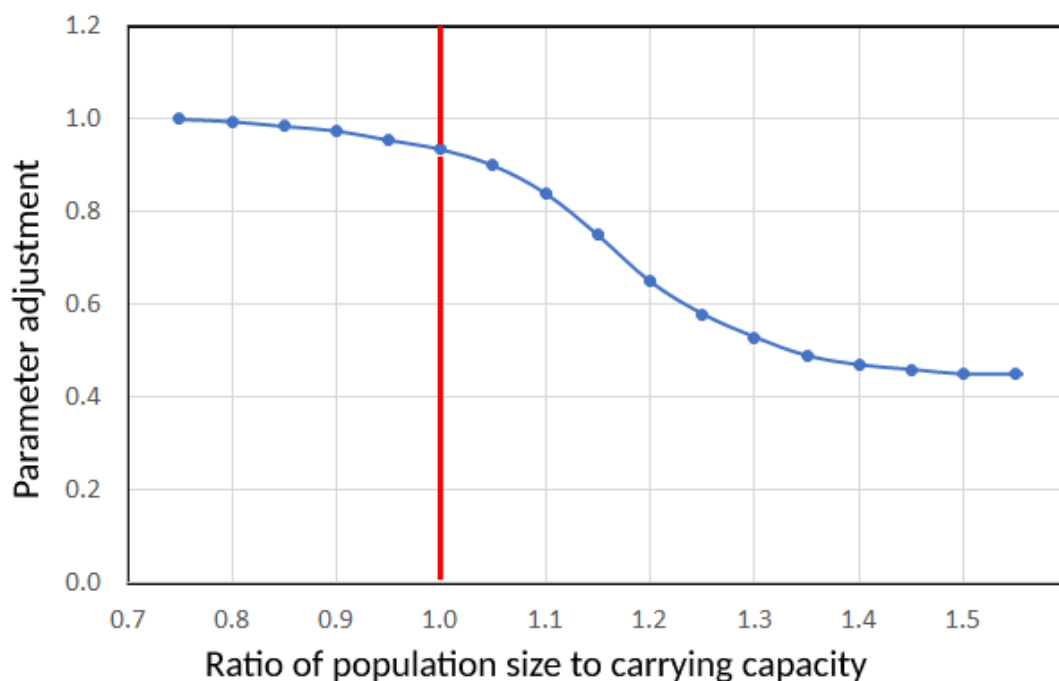
For example, Zimmerman *et al.* (2022) assumed that density dependence influenced recruitment into a bald eagle population by affecting the probability of breeding, which was thought to have declined from approximately 0.988 to 0.66 (95% CI = 0.34-0.99) over a 22-year period. Chambert *et al.* (2020) used 35 years of monitoring data from a population recolonizing a French National Park during which time the Golden Eagle population increased from ~11 to 41 territorial pairs. Their results suggest that habitat heterogeneity and interference mechanisms might actually play an important role in density dependence. Fasce *et al.* (2011) studied a population in the Italian Alps and found evidence of density dependence regulating their population via the percentage of pairs that bred and a breeding success which declined significantly with increasing density.

Density dependence was also shown in the Lake District peregrine population as it recovered from the effects of pesticides and the theft of young birds (Horne & Fielding, 2002).

The main problems with incorporating density dependence into a population model is identifying a realistic carrying capacity and the nature of the effect. Using a carrying capacity that is too low would underestimate of the magnitude of the impact of additional deaths.

In these analyses it is assumed that the combined carrying capacity for England and the South of Scotland is 80 pairs. This is likely to be an overestimate.

Millsap *et al.* (2022) demonstrated that the effect of density dependence on Golden Eagles is nonlinear and greatest as populations approach carrying capacity. We model this using a generic sigmoidal curve (Figure 2.2) to simulate the effect of density dependence on productivity and survival. The same curve is used for the fledging rate and all survival rates. As the population approaches the carrying capacity parameter values are slowly reduced. Once past the carrying capacity the rate of decrease increases to minimum of 45% of the original value. For example, assume a carrying capacity of 100 and a current population of 120 (20 above the carrying capacity), a ratio of 1.2 on the x-axis. From Figure 2.2 the growth rate and survival rates would be reduced to 65% of their default values. A fledging rate of 0.22 would become 0.143 and an 80% survival rate would become 52.0%. Density dependence is applied as an R function (Box 1.1).



**Figure 2.2.** Effect of density-dependence on growth rate and survival. The red line shows a point at which the population is at its carrying capacity. The blue line shows the amount of adjustment to the parameter's value.

**BOX 1.1.** R Density dependence function (dd.adj).

Four values are passed to the function: 1 param (current fledging rate or survival rate); 2 pop (current population size), 3 pop.max (carrying capacity) and 4 DD (True or False, no changes are made to the parameters if DD is false)

```
dd.ratio<-c(0.995,0.985,0.975,0.955,0.935,0.900,0.840,0.750,0.650,0.580,0.530,0.490,0.470,0.460)
# for ratios between 0.8 and 1.45
dd.adj<-function(param,pop,pop.max,DD){
# If DD is false x = 0 and param remains unchanged otherwise round ratio to 0.05
ifelse(DD,x<-round((pop/pop.max)/0.05)*0.05,x<-0)
```

```

if(x<0.8) y<-1 #if the popn is <80% of carrying capacity leave it unchanged
if(x>1.45) y<-0.55 #if the popn is >145% of carrying capacity reduce to 45%
# between 80% and 145% of the carrying capacity reduce the parameter by a value
# extracted from dd.ratio
if(x>0.75 && x<1.5){
  indx<-(x-0.75)/0.05
  y<-dd.ratio[indx]}
return(param*y)
}}

```

## 2.4.7 The model

The default Population Projection Matrix (PPM) is shown below. In this example productivity is 0.50 fledged per occupied range (0.25 females fledged). The two columns are the sub-adult and adult age classes. The first row is the productivity (fledging rate) per age class. Only adults are assumed to fledge young at the rate of 0.25 females per pair per year. The figures in the second row are the annual survival rates for the age classes (s - sub-adult, v - adult).

	Sub-adult	Adult
0.000	0.000	0.25 x 0.90
0.667	0.667	0.90

Example calculation: assume a starting population of 30 pairs, 10% of adults do not survive the winter so in the next year there are  $(30 \times 0.90) \times 0.25$  young females fledged = 6.7 and 66.7% (4.5) of these survive to become adults. Assuming a 90% adult survival there would be 3 adult female deaths so there is potentially an excess of recruits into the adult population ( $4.5 > 3$ ) allowing population growth.

In the model 1,000 simulations are run in which random values of the growth and survival rates are generated (within defined limits) rather than using fixed values of  $f$ ,  $s$  and  $v$

The most important piece of information from a basic PPM analysis is the expected rate of increase, lambda ( $\lambda$ ), which is 0.0577 or ~6.0% per year for the above model. The number of pairs is expected to increase by ~6% each year or one to two more pairs in the second year ( $30 \times 0.0577 = 1.7$ ). Density dependence mechanisms would influence survival or productivity values as the population expanded and prevent unfettered growth. For example, without density dependence the above population is predicted to expand from 30 to 94 pairs over 30 years.

The above model is dominated by its sensitivity to the adult survival rate (0.7405 elasticity) compared with 0.1300 for the other values, including the fledging rate. This means that changes to adult survival have the largest effects on the population growth rate.

## 2.4.8 Incorporating additional mortality

A PPM is normally projected over a number of years, typically 20 - 30, but it can be projected forward just 1 year which provides a mechanism by which:

- different random (stochastic) noise can be added to each parameter each year; and
- birds can be removed (for additional mortality events) at a known rate for each age class.

Random sampling is used to add stochastic noise to simulate the effects of between-year variability in survival and reproductive rates (Box 2.2).

Uniform distributions ranging between 95% and 105% of the default value are created and a single random value is sampled from this distribution. For example, the default adult survival rate ( $v$ ) is 0.9; a random value is sampled from a uniform distribution between 0.855 and 0.945. Note that noise is not added just once to a simulation; random noise is applied to every year within a simulation.

**BOX 2.2.** R function to add noise to parameters.  
 $p.list$  is a list of 3 parameters (sub-adult survival rate, adult survival rate and the fledging rate). Noise is added by sampling from uniform distributions with a lower limit of default value  $*0.95$  and an upper limit of default value  $*1.05$ .

```
params.r<-function(p.list,std){
  p.list[1]<-runif(1, min=s1*0.95, max=s1*1.05)
  p.list[2]<-runif(1, min=v*0.95, max=v*1.05)
  p.list[3]<-runif(1, min=f*0.95, max=f*1.05)
  return(p.list)
}
```

Additional mortality was added in each year of the simulation according to a pre-set age class specific rate, expressed as a percentage of the number of pairs (0, 0.5, 1.0, 1.5, 2.0 and 2.5%). Therefore, as the population increases so do the number of possible additional deaths. This is intended to model a situation in which additional mortality increases as the population increases.

Each mortality scenario was simulated 1,000 times over the 40-year projection. Because stochastic noise is added to the population parameters the actual additional mortality figure varies between years within a simulation but, over all of the simulations, the average number of additional deaths is close to the defined level. Additional mortality can be split between the age classes on the basis of the proportions of sub-adults and adults but in these models, it was assumed that all additional mortality would be to dispersing (immature) individuals rather than adult range holding birds.

Box 2.3 shows the code for one year of a 40-year simulation (there were 1,000 40-year simulations).

**BOX 2.3.** Applying additional mortality  
 $\#p.imm$  and  $p.Ad$  are the proportions of collisions in the sub-adult (immature) and adult age classes. mortality is the current % level of additional mortality, e.g. 2%

```
p.Imm<-0.1
p.Ad <-1 - p.Imm

#obtain some random values for the parameters for this year, std is 0.05
s.params<-params.r(params,std)
#the next three lines apply density dependent reductions if required.
#the order is sub-adult survival (s1.ran), adult survival (v.ran) and
#the fledging rate (f.ran). Note these are applied to the random values in s.params and not the default
values in params
s1.ran<-dd.adj(s.params[1],pop.proj[i,3],car.cap,Dens.Dep)
v.ran <-dd.adj(s.params[2],pop.proj[i,3],car.cap,Dens.Dep)
f.ran <-dd.adj(s.params[3],pop.proj[i,3],car.cap,Dens.Dep)
#create the PPM matrix (ge) with the new values
ge<-matrix(c(0,f.ran, s1.ran,v.ran), nrow=2, byrow=TRUE)
#project population forward to next year (2) using the current age structure (n)
p<-pop.projection(ge,n,2)
```

```

#find the numbers of sub-adults (n[1]) and adults (n[2])
n<-p$stage.vectors[,2]
# remove the appropriate number of individuals from each class based on the level of mortality and the
proportion of individuals in that age class.
n[2]<-n[2]-(n[2]*(p.Ad*mortality))      #Adult mortality
n[1]<-n[1]-(n[1]*(p.Imm*mortality))     #SubAdult mortality
#the adjusted values of n[1] and n[2] are the age structure for the projection to the following year

```

Each model (combination of fledging rate, additional mortality and presence or absence of density dependence) is simulated 1,000 times over a 40-year period.

Results are presented in tabular form with the minimum, maximum and median values for the number of pairs and population growth rates ( $\lambda$ ) after 40 years. The first and third quartiles are also shown. These results are summarised graphically as boxplots.

In addition, 40-year population trajectories are shown for 250 simulations. The number of simulations is reduced to 250 from 1,000 to help with the interpretation of the graph.

### 2.4.9 Results

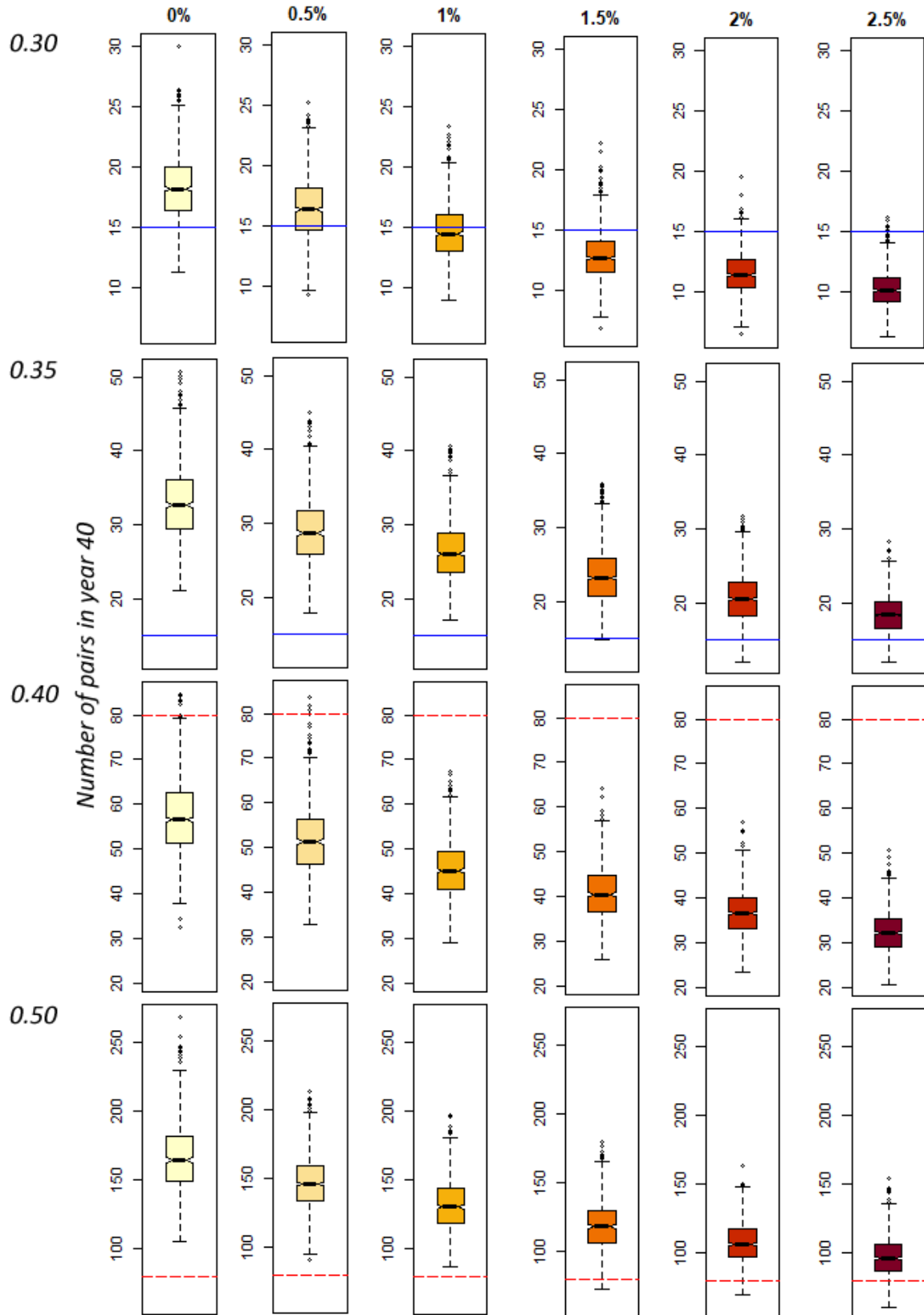
The results are summarised in Figures 2.3 and 2.4a & 2.4b. Appendix A has the numerical summaries.

As in the ‘parameter landscape’ investigation (Table 2.1), once the fledging rate is 0.4 or above the population is almost certain to expand, even in the face of 2.5% additional mortality.

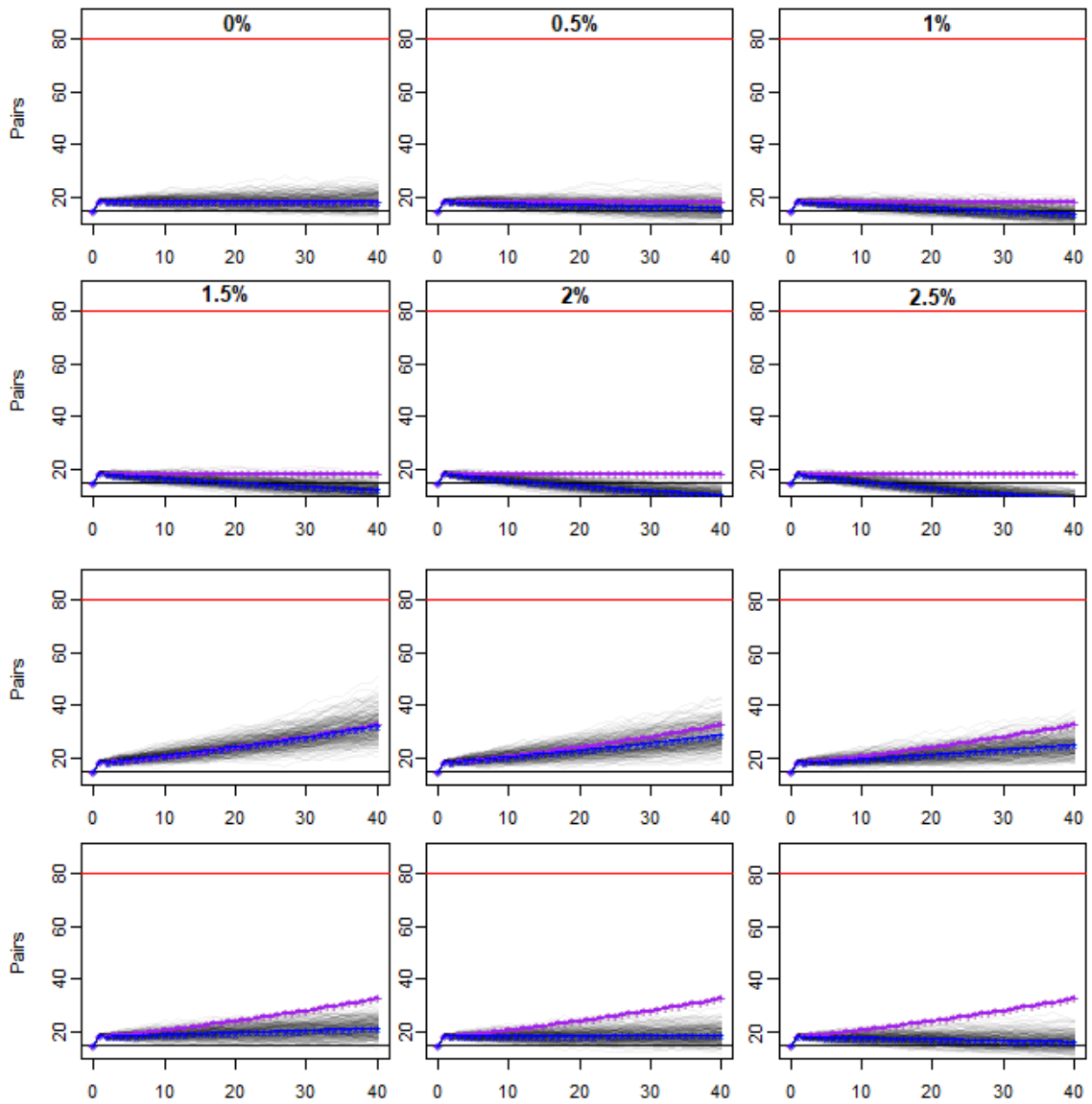
The population was very unlikely to expand and could become extinct if the productivity was 0.3 or less, particularly if there is even a small amount of additional mortality. Whitfield *et al* (2006) also found, using extensive population modelling but different survival rates, that a fledging rate >0.3 was needed to allow Golden Eagle populations to expand.

Once the fledging rate is 0.5 or larger the population is expected to pass its notional carrying capacity even in the face of significant additional mortality (Figure 2.3, 2.4b).

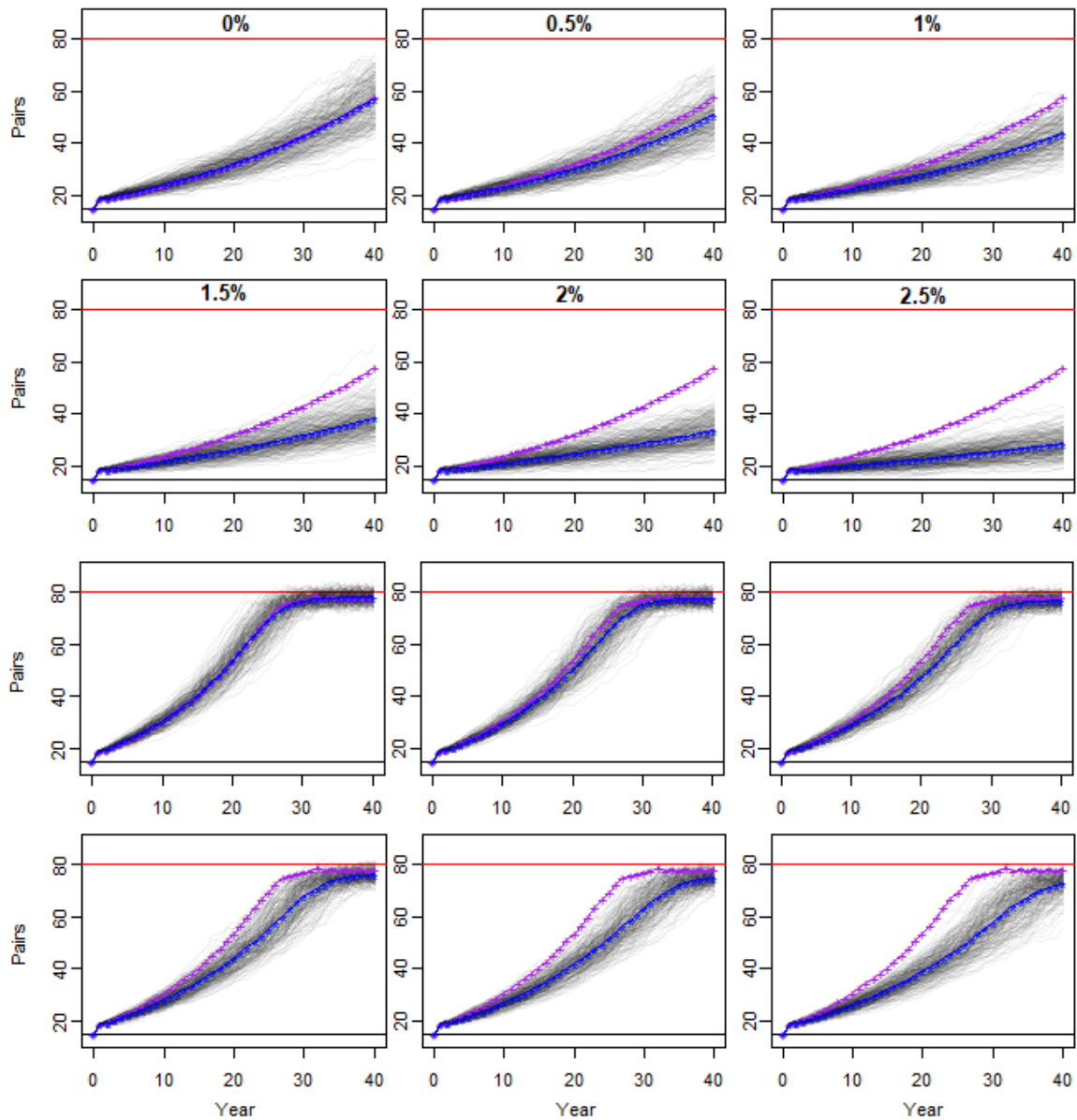
Figures 2.4a & 2.4b show example simulated population trajectories. The first two rows in Figure 2.4a show that there is high probability of no population expansion and possible extinction if the fledging rate is 0.30. Rows three and four in Figure 2.4a show that, if the fledging rate increases to 0.35, there is a good chance of population growth as long as additional mortality is 1% or less.



**Figure 2.3.** Box plots of the number of pairs in year 40 from 1,000 simulations at four levels of productivity: 0.30, 0.35, 0.40 & 0.50 (male and female fledged). The blue line is the starting population and the dashed red line is the assumed carrying capacity. There is no density dependence.



**Figure 2.4a.** 250 simulated population trajectories for two levels of productivity and five levels of additional mortality (0, 0.5, 1.0, 1.5, 2.0 & 2.5%) with no density dependence. The first two rows are a fledging rate of 0.30 (both sexes), Rows three and four are with a productivity of 0.35 (both sexes). The red line is the notional carrying capacity. The blue trajectory is the mean trajectory across the 250 simulations. The purple line is the null trajectory with no noise and no additional mortality.



**Figure 2.4b.** 250 simulated population trajectories for two levels of productivity and five levels of additional mortality with density dependence. The first two rows are a fledging rate of 0.40 (both sexes). Rows three and four are with a productivity of 0.50 (both sexes). The red line is the notional carrying capacity. The blue trajectory is the mean trajectory across the 250 simulations. The purple line is the null trajectory with no noise and no additional mortality.

It is not until the fledging rate is close to 0.5 (both sexes) that the population reaches its notional carrying capacity of 80 pairs within the 40-year simulation (Figure 2.4b). The effects of density dependence are apparent with the population levelling off at ~80 pairs. Additional mortality has the effect of delaying the time taken to reach 80 pairs.

## 2.4.10 How will movement barriers, and Golden Eagle behaviour, affect the rate of population expansion into England?

If England is colonised by a natural expansion southward from the South of Scotland it is important to understand how Golden Eagle behaviour, in particular natal dispersion distances (NDD), and the landscape might benefit or hinder such progress. The above model assumed that northern England and the South of Scotland represent a single, isolated population and there were no natural factors that would slow the expansion rate.

Fielding *et al.* (2024 and See Appendix A in Fielding *et al.*, 2023a) showed, using extensive satellite tracking data, that the GET model was a good surrogate for Golden Eagle movements and that large expanses of water or unsuitable terrain were barriers to movements (see Figure 3 in Fielding *et al.*, 2024). The barriers are not absolute but the probability of birds crossing either was very low. The maximum limit for a water crossing was ~20 km, with less than one in a thousand tag tracks being greater than 16 km across water. The distance between the good Golden Eagle habitat and the northern Lake District is ~30 km including a significant distance across the Solway Firth. Meanwhile, the distance between good habitat in South Wales and good habitat in North Devon is at least 30 km including at least 19 km across the Severn estuary.

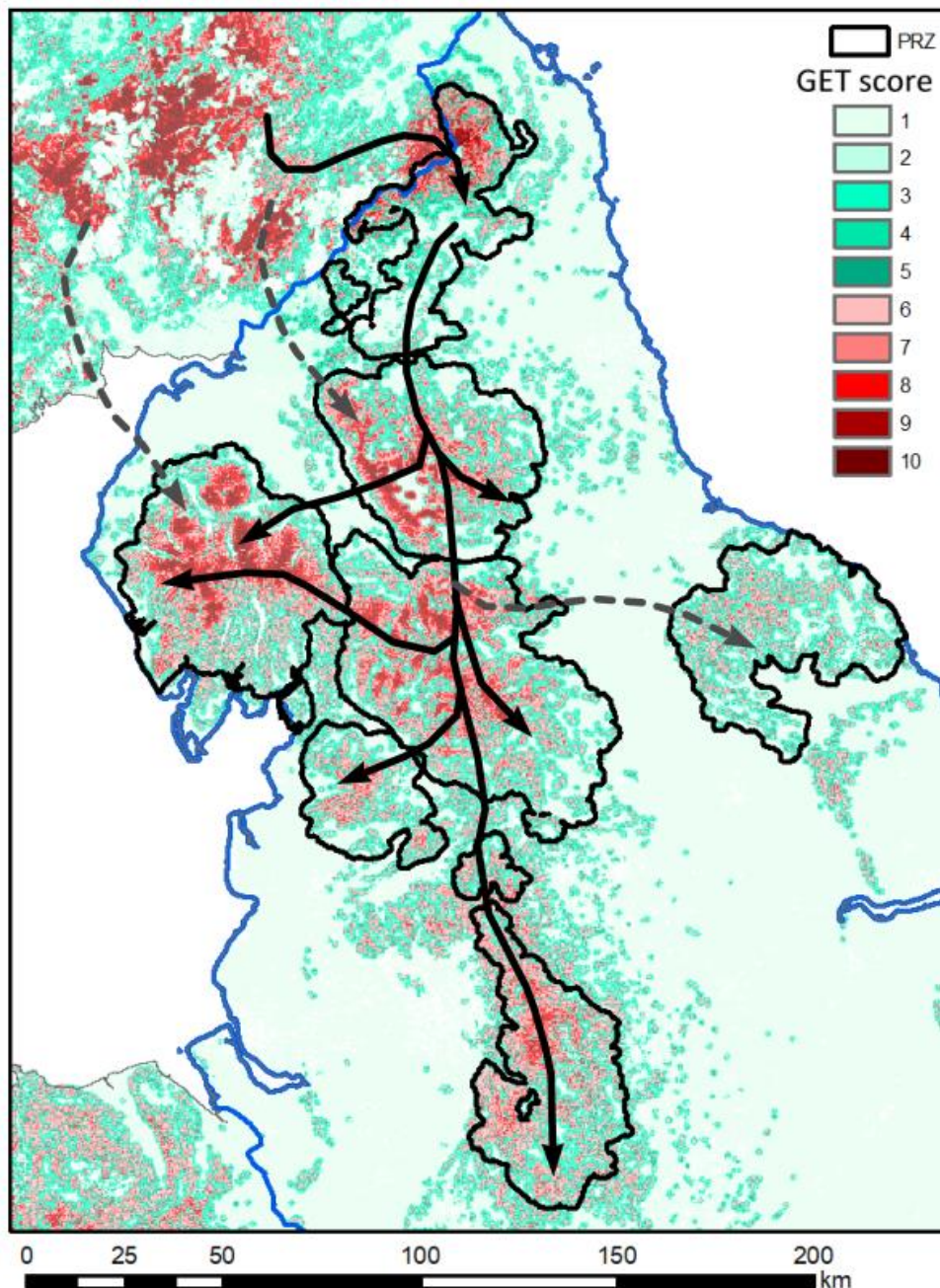
Whitfield *et al.* (2024) found median estimates of the NDD were 30 km for males and 59 km for females (38 km averaged across the sexes, with a significant difference between sexes). The maximum estimates were 82 km for males and 87 km for females. Although records of the juvenile dispersal distance (JDD) were typically much higher than the NDD (Whitfield & Fielding. 2017) the JDD and NDD probably operate in conjunction with physical barriers to restrict population or sub-population expansion (Fielding *et al.* 2023b). The JDD affects how much of England and beyond is explored by dispersing young eagles. If it is small, this must reduce the rate and potential for range expansion across England. However, even if the JDD is large, geographical range expansion will be slowed if the NDD is smaller and there are landscape restrictions. For example, observing dispersing birds from southern Scotland venturing into northern England does not necessarily mean they may settle there to breed, particularly if the NDD is less than the distance between the two areas.

As such, if there were Golden Eagles breeding in the South West of England, they would be part of a closed population as there are no easy movement corridors to or from there (see the GET model in the Data Dictionary), Golden Eagles will only colonise the South West of England if there is a release programme there. But this should only be considered after extensive research of both the ecological and sociological constraints.

Although the North York Moors are less isolated than the South West of England a Golden Eagle would have to fly >20 km across unsuitable terrain to get there (and stay there, with another bird to breed once reached). Breeding in the North York Moors could be unlikely until density dependence processes in the rest of England result in greater NDDs. Unlike the South West there is insufficient Golden Eagle habitat in the North York Moors to consider a release programme there.

Figure 2.5 shows the probable direction of expansion from the South of Scotland. Given the relatively short male NDD it is likely to be a gradual progression to the south which could become multi-directional if pairs become established in the Yorkshire Dales. It should be possible for Golden Eagles to move between the Northern PRZ and, given the large JDDs, it is possible that Golden Eagles would be seen across the region, even as far

south as the South Pennines, within 10 years. It will take much longer for breeding pairs to become established over a wider area. Based on the NDD and the time needed to disperse and breed it could be 12 - 20 years before pairs are breeding in the Yorkshire Dales. If pairs are successful in the Yorkshire Dales there could be a subsequent more rapid expansion. As shown in Figure 2.5, it is possible that the North Pennines and North Lakes would be directly colonised from the South of Scotland and this is more likely for the North Pennines, based on distance alone.



**Figure 2.5.** Probable expansion routes for breeding Golden Eagles into England. The least probable routes are dashed and gray. Contains Ordnance Survey data © Crown copyright and database right 2020.

## 2.5 Scenario 2. A reinforcement model

### 2.5.1 Background

If a natural expansion of the Golden Eagle population from the South of Scotland is too slow or is unlikely to reach potentially suitable parts of England, it will be necessary to consider releasing young birds at a suitable site(s) in England, similar to what was carried out in the South of Scotland.

Before undertaking such a programme, it is wise to consider if it is likely to be successful and the number of released birds is critical in this assessment (Green, 1997). In an ideal world a large number of birds would be released. In reality, there will be a compromise between how many young can be sourced each year (this depends on NatureScot rules, land owner agreement, local SRG cooperation and the number of twins fledged that year) and the number of years which releases and subsequent monitoring can be funded.

It was recommended that 15 birds should be released per year for 5 years for the Irish Golden Eagle reintroduction (O'Toole *et al.* 2002). The SNH licence allowed for up to 12 chicks per year with a maximum of 75 chicks in total. It proved difficult to source this many birds and Foot and Mouth disease disrupted one year and some chicks were not considered suitable for release (congenital disease). Fifty-three Golden Eagles were released into Ireland between 2001-2008 (~7 per year). A SNH licence was issued in 2009 but no birds were collected but a subsequent 2010 licence resulted in the release of five more birds (58 over 9 years or ~6 per year). It was believed that at least eight of the original 53 had died, including three as the result of persecution (2 poisoned and 1 shot). By 2010 the Irish Golden Eagle Trust recorded 14 territorial Golden Eagles in Donegal on eight established territories while 7-10 individuals had been identified in different parts of Ireland. As these releases were not satellite tracked (wing tags were fitted) it was impossible to follow their fates but it was known that there were three records of different coloured wing tagged Golden Eagles in Scotland (including Rannoch Moor, Mull and Grampian).

### 2.5.2 The model

Reinforcement of the Golden Eagle into England is modelled in the R programming language. (Appendix D has the source code). This model is based on a number of assumptions:

1. There is a five-release programme with birds of both sexes released each year.
2. The number of females released is drawn at random from a list such as (1,1,2,2,2,3,3,4,4) in which there is a 20% chance of one or four females being released and a 30% chance of two or three females (there will be males as well), in any year. Three release scenarios are tested: low (0,1,1,1,1,2,2,2,2,3), moderate (1,1,2,2,2,3,3,3,4,4), high (2,2,3,3,3,4,4,4,5,5). These three release scenarios approximate to 3, 5 and 7 birds released per year. The last two reflect what was available for the Irish reintroduction.
3. It takes five years for a released female to become a potential breeding bird. It is assumed there are sufficient males and once a female is five years old, she will be a range holding bird.
4. During each of the four dispersal years a female has a 90.5% chance of surviving to the next year (67% to breeding age). Noise is added to the sub-adult survival rate so it is possible to have different numbers of adults with the same release pattern. Not all released birds survive to breeding age. Figure 2.6 is a snapshot of one

simulated release in which three females were released in year 1 (2030) and one died before becoming an adult. In years two and three, one female was released each year and both survived to become an adult. Three females were released in year 4, one died in her second year. Two were released in year 5 and both survived.

5. There is no density dependence. The population is free to expand to any size.

Status	Release Year									
	1	1	1	2	3	4	4	4	5	5
	2	0	2	2	2	0	2	2	2	2
2030	1	1	1							
2031	1	1	1	1						
2032	1	1	1	1	1					
2033	1	1	1	1	1	1	1	1		
2034	1	1	1	1	1	0	1	1	1	1
2035	1	0	1	1	1	0	1	1	1	1
2036	1	0	1	1	1	0	1	1	1	1
2037	1	0	1	1	1	0	1	1	1	1
2038	1	0	1	1	1	0	1	1	1	1

**Figure 2.6.** Example simulation showing the fates of 10 released females. Each column is a separate bird. 1 in the table body indicates she was alive in that year. If she survives the first four years she becomes an adult and her status becomes 2, otherwise it is 0 if she died.

After nine years all released birds are adults or dead (In Figure 2.6 eight adults survived from 10 released birds). The only additions to the population between years 6 and 10 are birds fledged from the previously released birds, who have now become range holding birds.

A single release simulation ends in year 9 when the number of adults is known (all adults are assumed to be in pairs at the age of 5). By year 9 some young may have been fledged and this is more likely for the birds released earlier. An approximate number of young, wild fledged birds in year 10 is assumed to be a half of the number of pairs multiplied by the fledging rate.

In year 10 an initial vector of sub-adults and adult females ( $n_0$ ) starts a 20-year projection of a PPM which has fixed survival rates. Different fledging rates are tested.

Note that lambda, the expected rate of increase from a PPM, is constant for the same values of  $f$ ,  $s$  and  $v$  irrespective of the number of individuals in  $n_0$  but the final number of pairs in year 20 depends on the  $n_0$  values.

For each fledging rate, and release scenario, there are 1,000 release simulations. Each simulation has a potentially unique release and survival scenario because noise is added to the survival rates between release and becoming an adult. Four fledging rates (females fledged per pair) are tested: 0.15, 0.175, 0.20 and 0.25. Results from each set of 1,000

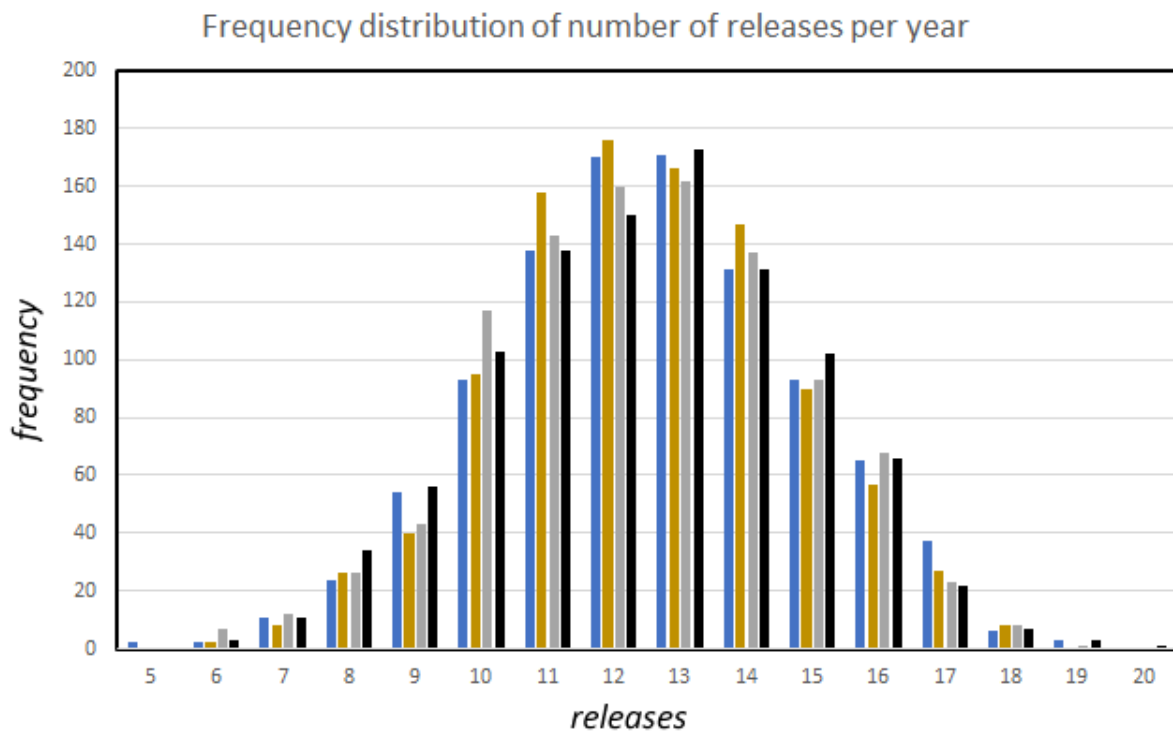
simulations are summarised; showing how many pairs there were in year 20 of the projection for the number of released birds.

### 2.5.3 Model results

As expected, there were no differences in frequency distributions of the numbers of released birds for the four fledging rates (results for the moderate release shown in Figure 2.7, Table 2.2). The median number of released females in the 1,000 simulations were:

- Low 7 (~14 releases or 2.8 per year. Empirical confidence limits 3 - 13 females released over five years).
- Moderate 12 (~ 24 releases or 4.8 per year. Empirical confidence limits 8 - 16 females released over five years).
- High 17 (~34 releases or 6.8 per year. Empirical confidence limits 12 - 23 females released over five years).

Figure 2.7 shows the variability in the simulated number of releases. It should be expected that the number of birds released varies between years depending on what is available for translocation in that year. Also, there is no guarantee of an equal sex ratio of released birds. Generating the variability in the number of females released is the first part of the model.



**Figure 2.7.** Frequency distributions, from 1,000 simulations of the number of released females (moderate release scenario) for four fledging rates: 0.15 (blue); 0.175 (orange); 0.200 (grey); and 0.250 (black).

Even when the same number of females are released there is no reason to suppose that the number of pairs in year 9 will be the same. Adding noise to the annual survival rate models the factors that might affect the annual survival rate and the number surviving to year 9 will vary.

Once the number of pairs, surviving from the released birds, is known the subsequent population trajectory is modelled with a deterministic PPM. In reality, fluctuations in the fledging and survival rates would continue throughout the next 20 years. It is, therefore, important to also look at the confidence limits for the estimated number of pairs after 20 years. If they are close to 0 there is an increased risk that chance events will result in extinction.

**Table 2.2.** *Frequencies of releases, from 1,000 simulations, for four fledging rates (see Figure 2.7).*

Release d	Female fledging rate											
	Low				Moderate				High			
	0.15 0	0.17 5	0.20 0	0.25 0	0.150 0	0.17 5	0.20 0	0.25 0	0.15 0	0.17 5	0.20 0	0.25 0
1	1	0	0	0								
2	3	2	1	1								
3	9	7	11	7								
4	28	26	35	25								
5	75	80	84	80	2	0	0	0				
6	156	172	156	159	2	2	7	3				
7	219	226	200	226	11	8	12	11				
8	202	223	233	212	24	26	26	34				
9	161	145	159	147	54	40	43	56				
10	98	72	75	101	93	95	117	103	0	0	1	0
11	32	37	35	29	138	158	143	138	5	0	4	3
12	12	9	8	11	170	176	160	150	8	9	10	9
13	4	1	3	2	171	166	162	173	20	20	30	33
14					131	147	137	131	66	47	63	46
15					93	90	93	102	98	99	86	109
16					65	57	68	66	159	145	140	129
17					37	27	23	22	166	167	165	163
18					6	8	8	7	160	196	191	177
19					3	0	1	3	123	131	145	128
20					0	0	0	1	88	92	76	103
21									67	60	56	61
22									26	27	27	32
23									12	5	5	7
24									2	1	1	0
25									0	1	0	0

The median number of pairs (with empirical 95% confidence limits) after 20 years are in Table 2.3.

**Table 2.3.** *Median number of pairs after a 20-year projection. Numbers in parentheses are the empirical 95% confidence limits from 1,000 simulations of each female fledging rate scenario.*

Female fledging rate	Release Scenario		
	Low	Moderate	High
0.150	4 (1 - 7)	7 (3 - 11)	9 (5 - 14)
0.175	5 (1 - 8)	8 (3 - 12)	11 (6 - 17)
0.200	6 (3 - 9)	9 (4 - 14)	11 (7 - 18)
0.250	7 (2 - 13)	12 (5 - 18)	17 (10 - 23)

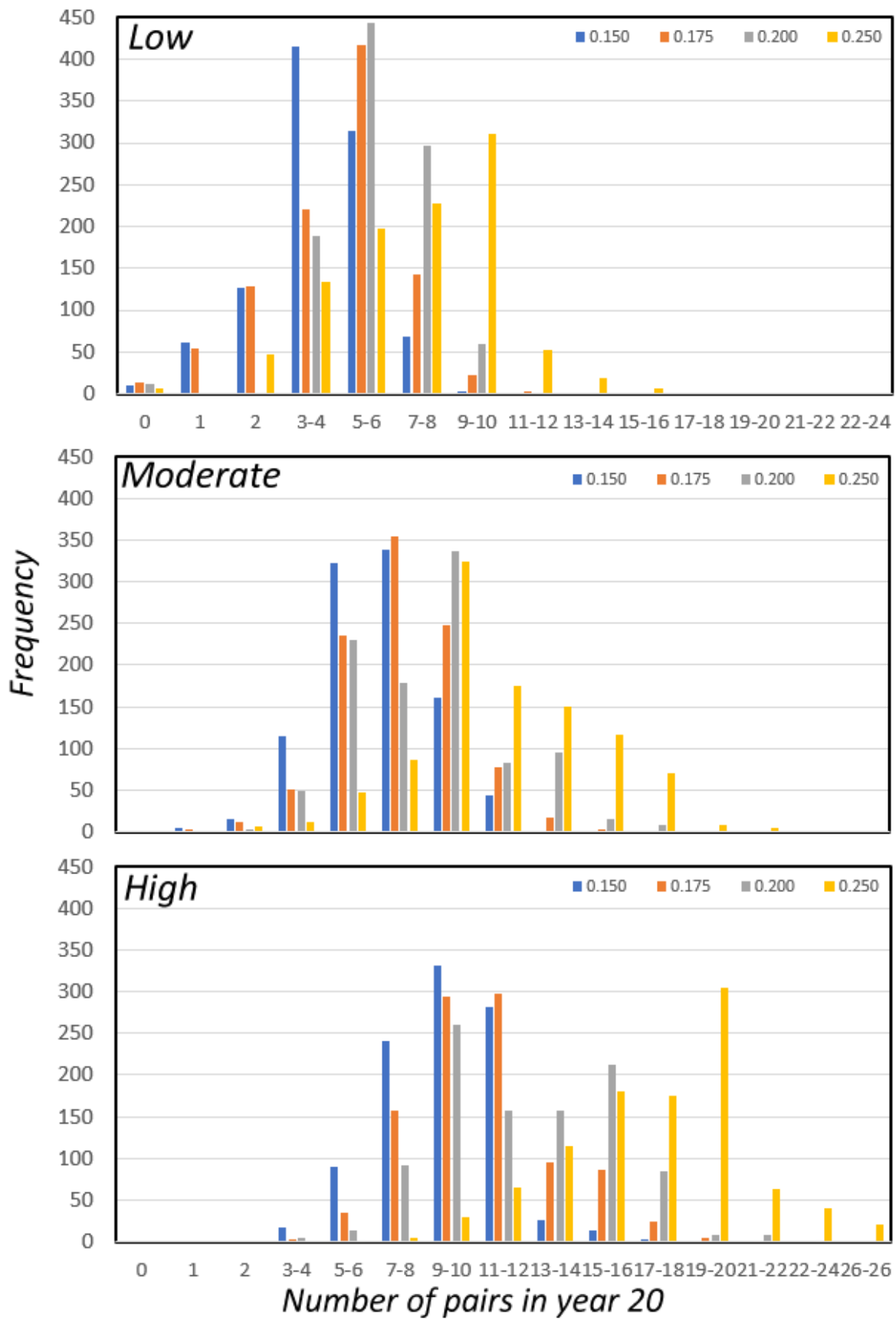
Table 2.4 and Figure 2.8 show the variability in the number of pairs in year 20. Detailed results are in Appendix A. There is a clear effect of the fledging rate on the year 20 population size with anything above 0.175 indicating a reasonable chance that there will be a sufficient population expansion (Table 2.4, Figure 2.8). However, the number of birds released also has a role to play. When only ~3 birds are released each year (low release scenario) the lower confidence limits range from 1 to 3 pairs after 30 years, even at the largest fledging rate tested. The highest probability of a successful reinforcement programme is achieved if productivity is large and enough birds are released.

The median number of pairs nine years after the first release is approximately half the number of females released (see Appendix C for detailed results). This means that when the female fledging rate drops below 0.25 there is > 50% chance that there will be fewer pairs in year 20 than there were in year 10.

A reasonable probability of achieving a successful reinforcement requires a moderate to high release strategy combined with good productivity. If there are only 0.15 females fledged per breeding attempt, even with the larger numbers released in the high release scenario, there was a 98.5% chance that the population will decline, compared with the immediate post-release population.

**Table 2.4.** Frequencies of the number of pairs in year 20 from 1,000 simulations with four levels of productivity. The shaded bar shows the approximate expected number of pairs after releases have ended and all released birds are old enough to be adults.

Release Scenario and Female fledging rate												
Pairs	Low				Moderate				High			
	0.15 0	0.17 5	0.20 0	0.25 0	0.15 0	0.17 5	0.20 0	0.25 0	0.15 0	0.17 5	0.20 0	0.25 0
0	10	13	11	7	0	0	1	0	0	0	0	0
1	62	54	0	0	4	3	0	0	0	0	0	0
2	126	129	0	47	15	12	2	6	1	0	0	0
3-4	415	221	189	133	115	50	49	11	17	3	5	0
5-6	315	417	443	197	323	236	231	47	89	35	13	1
7-8	69	142	296	227	338	354	179	86	240	158	91	4
9-10	3	22	59	311	161	248	337	325	331	295	260	30
11-12	0	2	1	52	43	78	82	175	281	297	158	65
13-14	0	0	1	19	1	17	96	151	26	96	157	114
15-16	0	0	0	7	0	2	15	116	13	86	213	180
17-18	0	0	0	0	0	0	8	70	2	25	85	175
19-20	0	0	0	0	0	0	0	8	0	4	9	304
21-22	0	0	0	0	0	0	0	4	0	1	8	64
23-24	0	0	0	0	0	0	0	1	0	0	1	41
25-26	0	0	0	0	0	0	0	0	0	0	0	20



**Figure 2.8.** Frequencies of the numbers of pairs in year 20 from 1,000 simulations at four fledging rates (0.150, 0.175, 0.200 & 0.250) and with three release scenarios (low, moderate & high).

## 2.5.4 Conclusions from the reinforcement simulations

An initial, simple definition of a successful reinforcement could be a population larger than it was post-release (9 years since the start). More robust definitions would take account of current productivity, survival and geographic expansion

**Using this simple definition is clear that the chance that a reinforcement will be successful depends on the number of young fledged and the number of females released.**

Before starting a reinforcement is started it should be a requirement that:

1. There is confidence that enough individuals can be sourced (at least five per year for five years but more and longer is desirable) and there is sufficient funding to cover the initial release years and at least ten years of post-release monitoring, including satellite tracking of all released and wild-fledged birds (subject to a risk assessment when tagging a wild fledged bird).
2. A comprehensive survey of Golden Eagle prey is undertaken prior to the start of the releases. This will be a significant project spatially and temporally and its results should inform the possible success of a release programme.

It is essential that sufficient funds are available to continue the fitting and monitoring of all young birds fledged in the South of Scotland. How these birds behave if and when they enter England to breed will be vital evidence for the documenting of initial re-establishment of English Golden Eagles and any future release programme.

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## Appendix A Population model summary statistics of the number of pairs in year 40 from 1,000 simulations.

Results are shown for models with and without density dependence operating. There are four fledging rates (females fledged per pair): 0.15, 0.175, 0.20 and 0.25. There were five levels of additional mortality: 0.5, 1.0, 1.5, 2.0 and 2.5%. Declines from the starting point of 15 pairs are shown in red. Q1, Q2 and Q3 are the 1<sup>st</sup>, 2<sup>nd</sup> (median) and 3<sup>rd</sup> quartiles.

%Mort	No Density Dependence						Density Dependence (80 pairs)					
	Min	Q1	Q2	Mean	Q3	Max	Min	Q1	Q2	Mean	Q3	Max
<b>0.15</b>												
0.0	11.4	16.3	18.2	18.5	20.3	28.9	11.8	16.5	18.3	18.5	20.4	26.9
0.5	10.3	14.6	16.2	16.4	17.9	26.2	8.9	14.6	16.3	16.4	18.0	26.1
1.0	9.1	13.1	14.4	14.6	16.1	21.7	8.3	13.0	14.4	14.6	16.1	25.1
1.5	8.2	11.6	12.9	13.0	14.3	19.7	7.5	11.5	12.8	12.9	14.2	21.4
2.0	6.5	10.2	11.3	11.5	12.6	17.7	7.1	10.3	11.4	11.5	12.6	19.1
2.5	6.4	9.1	10.2	10.2	11.2	16.2	5.7	9.0	10.1	10.2	11.2	15.7
<b>0.175</b>												
0.0	18.2	29.5	32.6	32.9	35.8	53.4	21.0	29.6	32.6	33.0	35.9	50.0
0.5	17.6	26.6	29.2	29.6	32.3	48.4	18.4	26.0	28.9	29.2	32.0	47.2
1.0	17.3	23.3	25.9	26.1	28.6	41.7	16.0	23.4	25.8	26.1	28.6	44.6
1.5	14.4	20.9	23.2	23.4	25.6	39.8	15.3	20.8	23.1	23.3	25.5	34.0
2.0	12.5	18.6	20.7	20.9	22.9	33.0	13.3	18.5	20.5	20.8	22.6	35.9
2.5	10.2	16.5	18.3	18.5	20.2	29.4	10.9	16.4	18.1	18.4	20.1	29.5
<b>0.20</b>												
0.0	32.3	52.0	57.4	57.9	63.4	86.5	35.1	51.6	56.5	56.8	62.3	75.7
0.5	30.9	45.6	51.1	51.3	55.8	82.3	27.7	46.1	50.7	51.3	56.2	75.6
1.0	26.5	41.1	45.2	45.9	50.2	74.4	30.0	41.3	45.2	45.8	49.7	69.3
1.5	27.1	36.6	40.5	41.0	44.8	65.4	26.0	36.6	40.7	41.0	45.0	63.3
2.0	21.1	32.8	36.1	36.6	40.0	61.2	23.7	33.0	36.6	36.7	40.3	60.5
2.5	20.7	29.0	32.1	32.3	35.2	56.6	19.5	29.2	32.4	32.7	35.5	52.8
<b>0.25</b>												
0.0	110.3	148.4	162.5	164.4	180.2	236.4	72.2	76.0	77.6	77.7	79.5	84.1
0.5	91.4	133.0	146.7	147.5	159.6	236.2	71.4	75.5	77.2	77.2	78.8	83.0
1.0	83.9	119.3	131.4	132.8	144.2	209.9	71.3	75.0	76.9	76.8	78.5	82.7
1.5	72.6	107.2	118.0	119.1	129.6	188.0	69.0	74.2	75.9	76.0	77.8	82.8
2.0	69.4	95.7	105.0	106.5	115.7	177.6	68.3	74.0	75.7	75.6	77.4	81.6
2.5	63.7	85.6	95.0	96.0	104.5	151.9	59.1	72.4	74.2	74.2	76.1	81.2

## Appendix B Frequency of number of pairs in year 20 versus the number of females released.

### Low Release Scenario

		Number of Females Released													
0.150	pairs	1	2	3	4	5	6	7	8	9	10	11	12	13	Freq
	0	1	0	0	4	0	5	0	0	0	0	0	0	0	10
	1	0	2	6	7	12	18	11	5	1	0	0	0	0	62
	2	0	1	2	8	23	32	29	20	7	3	0	1	0	126
	3	0	0	1	9	25	48	60	40	24	5	2	0	0	214
	4	0	0	0	0	12	35	52	50	35	15	1	1	0	201
	5	0	0	0	0	3	16	51	51	48	29	9	5	0	212
	6	0	0	0	0	0	2	12	24	30	26	7	1	1	103
	7	0	0	0	0	0	0	4	10	13	12	9	3	1	52
	8	0	0	0	0	0	0	0	2	2	7	4	1	1	17
	9	0	0	0	0	0	0	0	0	1	1	0	0	1	3
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.175		1	2	3	4	5	6	7	8	9	10	11	12	13	91
	0	0	1	1	5	3	1	0	2	0	0	0	0	0	13
	1	0	1	5	8	9	18	4	7	1	1	0	0	0	54
	2	0	0	1	10	29	33	29	19	7	1	0	0	0	129
	3	0	0	0	3	24	59	62	47	19	5	2	0	0	221
	5	0	0	0	0	12	42	60	62	29	14	6	2	0	227
	6	0	0	0	0	3	15	51	50	43	22	6	0	0	190
	7	0	0	0	0	0	4	17	27	31	14	7	1	0	101
	8	0	0	0	0	0	0	3	7	13	10	6	2	0	41
	9	0	0	0	0	0	0	0	2	2	4	5	2	0	15
	10	0	0	0	0	0	0	0	0	0	1	4	1	1	7
	11	0	0	0	0	0	0	0	0	0	0	1	1	0	2
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.200		1	2	3	4	5	6	7	8	9	10	11	12	13	
	0	0	0	1	3	3	2	0	1	1	0	0	0	0	11
	2	0	1	5	8	10	9	7	7	4	0	0	0	0	51
	3	0	0	5	14	30	39	27	17	2	3	0	1	0	138
	4	0	0	0	6	24	57	40	45	25	8	5	0	0	210
	5	0	0	0	4	13	36	61	64	38	15	2	0	0	233
	6	0	0	0	0	4	13	39	56	41	17	5	1	0	176
	8	0	0	0	0	0	0	24	31	33	22	8	2	0	120
	9	0	0	0	0	0	0	2	11	11	6	10	2	1	43
	10	0	0	0	0	0	0	0	1	4	4	4	2	1	16
	11	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	13	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0.250	1	2	3	4	5	6	7	8	9	10	11	12	13	
0	0	0	0	2	3	1	1	0	0	0	0	0	0	7
2	0	1	3	9	8	11	9	6	0	0	0	0	0	47
4	0	0	3	8	28	35	31	20	6	1	1	0	0	133
5	0	0	1	5	22	47	59	41	15	6	1	0	0	197
7	0	0	0	1	16	45	56	54	30	21	4	0	0	227
9	0	0	0	0	3	18	45	58	39	24	5	1	0	193
10	0	0	0	0	0	2	21	24	36	23	6	5	1	118
12	0	0	0	0	0	0	4	8	16	17	5	2	0	52
13	0	0	0	0	0	0	0	1	3	8	5	1	1	19
15	0	0	0	0	0	0	0	0	2	1	2	2	0	7
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0

### Moderate Release Scenario

		Number of Females Released																
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
<b>0.150 pairs</b>																		
1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	
2	1	1	1	5	2	2	2	1	0	0	0	0	0	0	0	0	0	
3	1	2	3	3	8	8	6	1	1	1	0	0	0	0	0	0	0	
4	1	1	8	15	19	17	9	5	1	4	0	1	0	0	0	0	0	
5	0	0	5	13	19	25	20	19	15	6	5	1	0	0	0	0	0	
6	0	0	2	9	22	36	40	42	18	17	7	2	0	0	0	0	0	
7	0	1	2	6	16	21	45	39	32	14	7	1	1	1	0	0	0	
8	0	0	0	1	4	18	31	43	23	19	11	2	0	0	0	0	0	
9	0	0	0	0	2	4	15	19	26	25	8	3	2	2	0	0	0	
10	0	0	0	0	0	0	4	8	12	12	11	6	2	0	0	0	0	
11	0	0	0	0	0	0	1	3	8	2	6	2	0	1	0	0	0	

12	0	0	0	0	0	0	0	2	1	5	4	5	3	0	0
14	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<b>0.175</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	3	0	2	3	2	0	0	0	0	0	0	0	0
3	1	1	7	7	12	8	8	5	0	1	0	0	0	0	0
5	0	1	7	19	15	14	18	10	6	1	1	0	0	0	0
6	0	1	10	16	22	21	39	16	12	3	2	2	0	0	0
7	0	1	2	11	28	34	34	22	19	15	3	1	0	0	0
8	0	1	3	6	17	26	36	37	34	16	8	0	0	0	0
9	0	0	1	1	6	22	35	22	32	17	14	6	0	0	0
10	0	0	0	0	0	6	11	27	21	9	12	3	2	1	0
11	0	0	0	0	0	0	7	11	13	14	6	4	0	0	0
12	0	0	0	0	0	0	0	1	6	5	5	4	1	1	0
14	0	0	0	0	0	0	0	0	3	2	2	7	3	0	0
15	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
<b>0.200</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
3	1	1	2	2	2	2	0	0	1	0	0	0	0	0	0
4	0	1	7	7	6	8	2	5	1	0	0	1	0	0	0
5	1	6	8	14	13	23	13	6	4	2	0	0	0	0	0
6	0	1	5	22	23	25	28	27	4	5	0	1	0	0	0
8	0	1	6	10	28	26	31	28	28	16	2	3	0	0	0
9	0	1	1	4	16	33	43	31	24	12	12	3	2	0	0
10	0	0	2	2	8	18	25	37	27	22	9	2	2	1	0

11	0	0	0	1	2	6	11	12	20	17	9	3	1	0	0
13	0	0	0	0	0	2	2	11	17	10	10	5	3	1	0
14	0	0	0	0	0	1	2	5	8	9	4	3	2	0	1
15	0	0	0	0	0	0	0	1	2	3	2	5	2	0	0
17	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0
18	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0
<b>0.250</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
2	0	0	2	3	0	0	1	0	0	0	0	0	0	0	0
4	0	2	0	2	5	1	1	0	0	0	0	0	0	0	0
5	0	2	7	7	6	4	11	6	3	1	0	0	0	0	0
7	2	2	12	13	16	9	16	11	2	3	0	0	0	0	0
9	0	1	8	12	24	20	27	24	12	7	3	4	1	0	0
10	0	0	4	5	26	23	52	33	21	13	3	2	0	0	0
12	0	0	1	9	13	27	37	39	22	19	6	2	0	0	0
13	0	0	0	2	5	18	19	36	35	18	12	6	0	0	0
15	0	0	0	1	4	6	12	24	27	24	17	0	1	0	0
17	0	0	0	0	0	2	7	9	8	11	8	3	0	0	0
18	0	0	0	0	0	0	0	2	7	7	4	1	1	0	0
20	0	0	0	0	0	0	0	0	1	2	3	1	1	0	0
22	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0
23	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

### High Release Scenario

0.150	pairs	Number of Females Released																Freq
		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
3	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	
4	0	0	1	1	5	4	2	1	0	1	0	0	0	0	0	0	15	
5	0	2	2	2	2	4	5	5	1	0	0	0	0	0	0	0	23	
6	0	1	3	3	8	15	11	11	7	5	1	1	0	0	0	0	66	
7	0	1	1	3	11	18	20	19	12	5	6	2	0	0	0	0	98	
8	0	0	0	7	14	18	25	29	24	8	11	5	1	0	0	0	142	
9	0	0	0	2	8	17	35	31	21	23	12	10	4	1	0	0	164	
10	0	0	0	1	10	9	25	30	34	26	19	6	5	2	0	0	167	

11	0	0	1	0	3	8	19	24	21	19	11	10	2	3	1	0	122
12	0	0	0	1	4	5	16	16	35	28	19	22	10	2	1	0	159
14	0	0	0	0	0	0	0	0	3	4	7	8	2	2	0	0	26
15	0	0	0	0	0	0	0	0	2	4	1	1	2	1	0	0	11
16	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2
17	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
18	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
0.175	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
4	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	3
5	0	0	1	1	0	3	3	1	1	0	0	0	0	0	0	0	10
6	0	0	0	3	2	6	5	6	2	1	0	0	0	0	0	0	25
7	0	0	3	5	5	10	13	8	13	5	3	0	0	0	0	0	65
8	0	0	2	3	17	20	18	16	10	4	0	2	1	0	0	0	93
9	0	0	1	5	9	15	30	20	19	11	3	5	0	0	0	0	118
10	0	0	1	3	7	18	31	33	41	26	10	5	1	1	0	0	177
11	0	0	1	0	3	18	22	34	32	24	16	8	2	0	0	0	160
12	0	0	0	0	3	5	15	22	41	18	19	9	5	0	0	0	137
14	0	0	0	0	1	1	5	14	17	18	18	13	8	1	0	0	96
15	0	0	0	0	0	2	2	9	15	12	7	6	2	0	0	1	56
16	0	0	0	0	0	0	0	3	3	6	9	4	4	1	0	0	30
17	0	0	0	0	0	0	0	0	1	6	4	5	2	0	0	0	18
18	0	0	0	0	0	0	0	0	1	0	3	0	1	1	1	0	7
19	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	4
21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
0.200	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	0	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	4
6	0	1	1	1	2	2	4	0	2	0	0	0	0	0	0	0	13
7	0	0	1	5	4	2	5	6	5	1	0	1	0	0	0	0	30
8	1	0	1	8	9	6	6	12	13	4	1	0	0	0	0	0	61
9	0	0	3	7	10	19	21	18	22	6	2	4	0	0	0	0	112
10	0	0	0	3	13	23	25	25	31	15	9	2	2	0	0	0	148
11	0	1	1	2	14	16	29	38	26	16	8	5	2	0	0	0	158
13	0	0	1	3	6	12	26	23	30	32	11	11	2	0	0	0	157
15	0	0	0	0	4	3	11	25	25	25	11	11	3	2	0	0	120
16	0	0	0	1	1	2	9	9	20	24	12	11	4	0	0	0	93
17	0	0	0	0	0	0	2	7	13	17	11	6	5	1	0	0	62
18	0	0	0	0	0	1	1	2	4	3	6	1	3	2	0	0	23
19	0	0	0	0	0	0	0	0	0	1	2	3	3	0	0	0	9
21	0	0	0	0	0	0	0	0	0	1	2	1	1	0	1	0	6
22	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2
23	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
0.250	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	0	0	1	2	3	2	1	4	1	0	1	0	0	0	0	0	4
9	0	1	3	4	4	7	5	3	4	1	0	0	1	0	0	0	8
10	0	1	0	10	7	11	6	13	12	5	0	1	0	0	0	0	22
12	0	0	1	5	7	21	22	14	17	6	7	3	1	0	0	0	65
13	0	1	2	4	11	23	32	32	23	9	8	3	1	0	0	0	114
16	0	0	1	3	9	18	22	27	32	26	11	5	4	1	0	0	180
17	0	0	0	5	4	14	25	26	36	29	20	10	3	1	0	0	175
19	0	0	0	0	1	9	10	17	30	17	15	8	5	1	0	0	175
20	0	0	0	0	0	4	5	17	11	14	17	11	4	1	0	0	129
22	0	0	0	0	0	0	1	7	8	11	13	9	6	2	0	0	64
23	0	0	0	0	0	0	0	2	2	6	6	7	3	1	0	0	41

25	0	0	0	0	0	0	0	0	1	1	1	4	3	1	0	0	0	18
26	0	0	0	0	0	0	0	0	0	0	3	1	1	3	0	0	0	2

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**Appendix C Frequency of number of post-release pairs (columns) v number of released females for three release scenarios.**

<b>Low</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	5	0	1	0	0	0	0	0	0	0	0	0	0	0
4	3	5	9	3	0	0	0	0	0	0	0	0	0	0	0
5	6	9	39	22	15	5	0	0	0	0	0	0	0	0	0
6	2	16	40	49	37	18	3	0	0	0	0	0	0	0	0
7	1	7	27	51	58	36	18	2	0	0	0	0	0	0	0
8	0	9	16	35	70	51	28	15	0	0	0	0	0	0	0
9	0	1	7	23	30	49	30	21	4	2	0	0	0	0	0
10	0	0	2	7	11	20	18	11	6	2	0	0	0	0	0
11	0	0	0	2	1	6	8	6	4	1	0	0	0	0	0
12	0	0	0	0	1	1	4	2	3	1	0	0	0	0	0
13	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
14	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<b>Moderate</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>
6	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
7	0	2	0	2	5	2	0	0	0	0	0	0	0	0	0
8	1	0	1	0	9	10	2	0	0	0	0	0	0	0	0
9	0	0	2	7	8	13	10	7	4	0	0	0	0	0	0
10	0	1	4	7	17	25	24	16	6	0	1	0	0	0	0
11	0	0	3	6	21	28	30	31	23	8	2	1	0	0	0
12	0	0	3	5	9	25	27	35	28	11	5	0	1	0	0
13	0	0	0	3	4	13	29	33	26	20	10	4	0	0	0
14	0	0	0	2	9	19	30	32	27	23	13	6	5	0	0
15	0	0	0	0	1	6	15	10	22	16	13	12	3	1	1
16	0	0	0	0	1	0	3	15	9	17	7	7	1	3	1
17	0	0	0	0	1	0	0	3	6	7	3	3	0	1	0
18	0	0	0	0	0	0	2	2	0	1	4	2	0	1	0
19	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<b>High</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>
6	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
7	0	0	1	0	5	2	1	0	0	0	0	0	0	0	0
8	0	2	1	3	10	9	2	0	0	0	0	0	0	0	0
9	0	0	5	7	12	20	10	4	3	3	0	0	0	0	0
10	0	1	2	10	16	29	22	13	8	0	0	0	0	0	0
11	0	0	1	4	13	25	31	20	14	5	1	0	0	0	0
12	0	1	1	7	18	23	29	38	27	13	7	1	0	0	0
13	0	0	0	2	10	26	30	44	28	28	7	2	0	0	0
14	0	0	0	3	6	13	25	28	35	19	11	5	2	0	0
15	0	0	1	0	3	6	16	16	16	16	10	13	3	0	0
16	0	0	0	0	0	2	6	7	6	11	11	5	3	3	0
17	0	0	0	0	0	0	1	6	5	4	2	6	1	0	1
18	0	0	0	0	0	0	0	0	3	0	5	2	0	0	0
19	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

## Appendix D Reinforcement model R code

```
#reinforcement model
library(popbio)

#####INITIALISE MODEL PARAMETERS#####
#s1 is survival to adult;
#sa_surv is year by year probability of sub-adult surviving to 5 - assumes same probability per year
s1<-0.667
sa_surv<-s1^0.25
#rescale survival rate to 0 - 1,000 for use with a later random sampling
sa_surv<-floor(sa_surv*1000)
# v annual adult survival rate,
# f females fledged per pair, f1000 is rescaled f
v <-0.90
f<-0.15
f1000<-f*1000
# create a vector with possible numbers of females released, later sampled
release.vec<-c(1,1,2,2,2,3,3,3,4,4)
std<-0.05 # sd used to generate a random sample from sa_surv distribution
sims<-1000 # 1,000 simulations, each run for 20 years
simyears<-20
# generate a data frame to store the results
mat = matrix(0,ncol = 11, nrow = sims) # initialised to 0
results=data.frame(mat)
names(results)<-
c("sim","lambda","SA","Pairs","Released","Ryr1","Ryr2","Ryr3","Ryr4","Ryr5","PairsYr10")

#####THE SIMULATIONS LOOP#####
for(s in 1:sims){
  #store simulation number in the first column of results
  results[s,1]<-s
  #create a data frame to store a single simulation
  #column 1 -1 = no data, 0 = died, 1 = alive, 2 = alive and adult
  mat = matrix(0,ncol = 12, nrow = 20) # initialises to 0
  df=data.frame(mat)
  df[,1]<- -1 # set bird to no data &
  # initialise number of females released in first 5 years
  released<-c(0,0,0,0,0)
  for(i in 1:5) {released[i]<-sample(release.vec,1)}
  #released is a vector of 5 numbers sampled from release.vec
  #(eg 1,2,4,12)
  #now initialise the release sim matrix
  row.count<-1
  for(i in 1:5) {
    # females is number released in each of the 5 years
    females<-released[i]
    for(j in 1:females){
      df[row.count,1]<-1 #set this bird to alive in this year
      df[row.count,i+1]<-1
      row.count<-row.count+1} # and move on to the next one
    }
  #do released birds survive to be adults?
  #how many adults after nine years - use as input to popbio model
  birds.released<-sum(released) # sum of the released vector
  for(i in 1:birds.released){
```

```

j<-1
# 5 years of release, years start in column 1 of df
# last possible column for a release is year 6
while(j<7){
  j<-j+1
  if (df[i,j] == 1) { break} #first 1 found, release year
}
df[i,12]<-j # record the first column (year of release)
begin<-j
age<-begin+1
while (age < 11) {
  #generate a random survival rate and rescale
  sa_surv_r<-floor(min(998,rnorm(1,m=sa_surv,
    sd=sa_surv*std)))
  # did the individual survive?
  if(sample(1000,1)<sa_surv_r) {
    # Yes
    df[i,age]<-1}
  else {
    #No, so set year value to 0
    df[i,age]<-0}
  if(df[i,age]==0) {
    df[i,1]<-0 #set bird to dead
    break} # bird has died
    age<-age+1
  }
  # if bird has reached adult age set col 1 to 2
  if(df[i,1]==1) {df[i,1]<-2}
}
# Now populate the PPM
# By year 10 all released birds will be dead or adults
pairs<-subset(df,df[,1]==2) # just keep the rows with adults
pairs<-nrow(pairs)
sa<-ceiling(pairs*f/2) # approximate number of young fledged so far
# n0 is the initial population of sub-adults and adults
n0<-c(sa, pairs)
# create the PPM
ge<-matrix(c(
  0, f,
  s1, v), nrow=2, byrow=TRUE)
# deterministic and no mortality
p0<-pop.projection(ge,n0, simyears+1)
#store the results
results[s,2]<-p0$lambda
results[s,3]<-round(p0$stage.vectors[1,21],0) #subadults year 20
results[s,4]<-round(p0$stage.vectors[2,21],0) #adults year 20
results[s,5]<-birds.released #released
results[s,6:10]<-released #released per year
results[s,11]<-pairs # pairs in year 10
} # end of the simulation loop

```

# 3. Work Package 3

## 3.1 Background and Introduction

### *Work Package 3*

*An analysis/review of prey availability*

- *including realistic risk to species of conservation concern and economic interest*

Additional to the initial brief, the prospect of mesopredator suppression by Golden Eagles may affect some prey species and may have a role in a recovery of Golden Eagles in England. This factor is therefore presented as a prelude to evaluations of risk to species of conservation concern and economic interest. The final part of this section considers prey availability.

## 3.2 Potential suppression of mesopredators

A mesopredator can be defined as a mid-ranking predator in a food chain, typically preying on smaller animals. They are differentiated from top predators, such as Golden Eagles, that occupy a higher place in a food chain. The term ‘superpredation’ refers to the depredation of mesopredators by top predators which therefore may also have the moniker of superpredators (Hoy *et al.* 2017). According to Lourenço *et al.* (2011a) superpredation differs from interspecific killing among predators, because it assumes that the prey (mesopredator) is always consumed. The distinction may not always be perfect, however (Fielding *et al.* 2003, Bosch *et al.* 2007). Intraguild predation (IGP) is more restrictive in definition since it refers to raptors<sup>17</sup> killing raptors of other species (Sergio & Hiraldo 2008, Lourenço *et al.* 2011a) and is better studied (Hoy *et al.* 2017).

Top predators may affect the abundance and distribution of mesopredators directly through superpredation (including IGP) by killing them (Petty *et al.* 2003). Indirect effects can include creating a ‘landscape of fear’ (Lyly *et al.* 2015) and spatial refugia (Sergio *et al.* 2003), depressing mesopredator reproductive outputs (Hoy *et al.* 2016, Mueller *et al.* 2016) and/or by taking some prey species or other resources shared with mesopredators (Lourenço *et al.* 2011a). For direct effects, via killing as prey, mesopredators are usually unlikely to represent a major source of food because their densities are often low or risky to capture compared to those of other prey species lower in the food chain (Lourenço *et al.* 2011a). The risk of injury is higher because mesopredators are better equipped both to kill other species and defend their young (Hoy *et al.* 2017).

The occurrence of IGP and superpredation of mesopredators has several hypothetical bases that are not mutually exclusive (Hoy *et al.* 2017). The competitor-removal hypothesis suggests that superpredators kill mesopredators to free up shared resources (Serrano 2000), and so predicts that superpredators will target mesopredators more likely to share resources (including nest sites). The predator-removal hypothesis proposes that superpredation is a preemptive tactic to decrease the chances of the superpredator or its offspring being killed (Lourenço *et al.* 2011b). The expectation is that the mesopredators most frequently killed are those which pose the greatest predatory threat to the superpredator or its young.

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<sup>17</sup> In terminology we have followed McClure *et al.* (2019) on ‘raptors’ as Accipitriformes, Cathartiformes, Falconiformes, and Strigiformes.

A third hypothesis suggests, rather than a response to the presence of other predators closer in the food chain, food-limitation or food-stress increases superpredation to compensate for a dietary shortfall when preferred (and less risky) prey decline or are low in abundance (Polis *et al.* 1989, Lourenço *et al.* 2011a, b, Hoy *et al.* 2017). Increased predation of mesopredators may therefore be associated with reduced breeding success in the superpredator (Hoy *et al.* 2017).

Results and conclusions of research may depend on the community composition of mesopredators (including raptors) in the study system (Natsukawa & Sergio 2022). Nevertheless, most studies, usually involving IGP, support the food-limitation hypothesis (Lourenço *et al.* 2011a, Hoy *et al.* 2017), with some exceptions (Lourenço *et al.* 2011b).

### 3.2.1 The effects of mesopredator suppression

Through a combination of competition and predation, mesopredator suppression including IGP can contribute to high species diversity (Menge & Sutherland 1976), and, via trophic cascades and resource facilitation, top predators can promote biodiversity (Sergio *et al.* 2006, 2008, Natsukawa & Sergio 2022). Reinstatement of a top predator, as a beneficial contribution to biodiversity and ecosystem ‘health’, is a repeated theme of large raptor reintroduction projects (O’Toole *et al.* 2002, Morandini *et al.* 2017, Dennis *et al.* 2019, Wilson-Parr *et al.* 2020, Williams 2021).

However, when the mesopredator (for instance, another raptor) is a threatened species (e.g. Real & Mañosa 1990), superpredation may be problematic (Lourenço *et al.* 2011a). This concern may be more theoretical (and prompted by anecdote) than empirical as we are not aware of the novel presence of or increase in a top predatory raptor causing or be associated with a smaller and threatened raptor’s extirpation, even if it may be possible locally. Nevertheless, when mammals are better studied than birds in this regard (Terraube & Bretagnolle 2018) there are several examples consistently showing that mammalian top predators can suppress sympatric mesopredators to the point of complete exclusion, but only when top predators occur at high densities over large areas (Newsome *et al.* 2017). The results of Newsome *et al.* (2017) further suggested that these conditions are more likely to occur at the core than on the margins of top predator distribution.

There is also ample evidence of top predatory raptors’ increase or novel presence likely causing smaller mesopredator raptors to decline and/or when top avian predators are present, for smaller raptors to be restricted to habitats where they are safer from predation (e.g. Petty *et al.* 2003a, Sergio *et al.* 2003, Mueller *et al.* 2016). When top avian predators increase, such effects may be viewed as consequences of a ‘natural’ restoration and illustrations of a more complete raptor guild by reversing ‘mesopredator release’ generated by top predator absence or lower numbers (Terraube & Bretagnolle 2018).

### 3.2.2 The Golden Eagle as a suppressor of mesopredators

As for other top predators, mesopredators are probably relatively risky prey for Golden Eagles because of the injuries they may inflict during capture or in parental defence of young. Trained falconry eagles used to hunt adult foxes or larger carnivores, notably by Kazakhs in Mongolia (McGough 2019), are not necessarily indicative of what wild eagles are typically prepared to risk, when there are other choices not pre-selected by a falconer. Lyly *et al.* (2015) noted that wild Golden Eagles rarely kill adult Red Foxes *Vulpes vulpes* and found that in Finland there was no evidence that Golden Eagles significantly affected the abundance or distribution of Red Fox and another mammalian mesopredator, the Pine

Marten *Martes martes*. Lyly *et al.* (2016) nevertheless suggested that eagles may create some benefits to shared prey species by fear effects on the two mammals.

Fielding *et al.* (2003) analyzed data on nest sites, habitat use and interspecific interactions from Golden Eagles and five smaller mesopredatory raptors, Peregrine *Falco peregrinus*, Common Kestrel *F. tinnunculus*, Common Buzzard *Buteo buteo*, Hen Harrier *Circus cyaneus*, Short-eared Owl *Asio flammeus* (and Raven *Corvus corax*) on the Isle of Mull in Scotland. Mull hosts a particularly diverse raptor assemblage, also including the White-tailed Eagle and is absent larger carnivorous mammals. All the smaller raptors and Raven were recorded as Golden Eagle prey (see also Whitfield *et al.* 2009). Very occasional fatal interactions between the two eagle species were not apparently through mutual perceptions as prey; rather, unusual consequences of ‘armed neutrality’ (Fielding *et al.* 2003, Whitfield *et al.* 2008) or interspecific killing (Lourenço *et al.* 2011a).

Island-wide results involving Peregrine, Common Buzzard and Raven indicated all three species nested further than expected than expected from Golden Eagle home range centres. In a more intensely studied part of the island, habitat use maps and interspecific interaction frequencies supported the hypothesis that smaller raptors reacted to Golden Eagles consistent with a predation threat. Hence, the results strongly suggested that the distribution of all smaller raptors and Raven was probably affected by the distribution of Golden Eagles.

Fielding *et al.* (2003) pointedly commented that in some other parts of Scotland where Golden Eagles were persecuted then if such activities were stopped, they may ‘naturally’ control the numbers of other smaller species (including Peregrine and Hen Harrier). Albeit that most of these other raptors also suffer from being killed illegally through the same human activities largely associated with Red Grouse moor management (e.g. Gibbons *et al.* 1994, Etheridge *et al.* 1997, Amar *et al.* 2012, North East Scotland Raptor Study Group 2015, Murgatroyd *et al.* 2019). Red Grouse is a favoured prey of Golden Eagles in Scotland, especially (unsurprisingly) where intensive management to enhance grouse numbers is practiced (Watson *et al.* 1989, Watson 2010), hence why some grouse moor managers apparently kill eagles (Whitfield & Fielding 2017).

Fielding *et al.* (2003) nonetheless further speculated that if persecution were to be reduced so that Golden Eagles became more abundant, it could bring about an overall benefit to Red Grouse by lowering predation rates of smaller (medium-sized) raptors. Contrarily, if any persecution on any raptor species persists and if other ‘management’ for driven grouse shoots can consequently persist such human effects can easily overshadow any influence that Golden Eagles may otherwise have (e.g. Kuijper *et al.* 2016).

Related to this speculation of Fielding *et al.* (2003), in a Spanish mammalian community, Palomares *et al.* (1995) concluded that the abundance of a game species (Rabbit *Oryctolagus cuniculus*) was improved by the presence of a top predator (Iberian Lynx *Lynx pardinus*) suppressing mesopredator effects on Rabbits, despite Rabbits being the preferred prey of Lynx. Lyly *et al.* (2016) examined the effects of Golden Eagles, together with Red Fox and Pine Marten, on two forest gamebirds and found support for the hypothesis that Golden Eagles provided protection for juvenile Black Grouse *Lyrurus tetrix* and Hazel Grouse *Tetrastes bonasia* against two mammalian mesopredators (Red Fox and Pine Marten) but were a threat for adult grouse.

Lourenço *et al.* (2011a) reviewed several dietary studies of four large raptors and found that Golden Eagles were more likely to have mesopredators in their diet. This was predominantly through taking more carnivores (Red Fox cubs especially) but on average by

number this was only 5.3 %, with 6.6 % for all mesopredators. In the 23 dietary samples reviewed the maximum contribution of all mesopredators was 20.2 %. This review of diet was understandably unable to reach any conclusions on whether mesopredator abundance or distribution was affected by Golden Eagles. In Scotland, according to Watson (2010) the dietary contribution of mesopredators is below the more widespread average documented by Lourenço *et al.* (2011a) (see also Whitfield *et al.* 2009, and more recently Whitfield *et al.* 2022).

There are observations suggesting Golden Eagles can prevent Peregrines' use of cliff nest sites (Ratcliffe 1993, Gainzarain *et al.* 2000). Other than Fielding *et al.* (2003) and Lyly *et al.* (2015, 2016), however, there are few other detailed studies that specifically address Golden Eagles potentially suppressing mesopredator distribution and/or abundance, with most simply providing dietary data.

More generally, however, Golden Eagles share some features with other large raptors (including IGP) as could be expected. First, while being widespread, predation of mesopredators by Golden Eagles is typically not substantial as a contribution to diet, and in larger carnivores it usually involves younger individuals as prey (Watson 2010, Lourenço *et al.* 2011a). Second, it can vary in time and space. For example, taking mesopredators as prey was uncommon in Estonia (Sein & Väli 2024) but more often recorded in the southern mountains of Poland (Stój *et al.* 2024). In Estonia, three mammalian mesopredators comprised 10 % of the diet by number (Sein & Väli 2024), whereas in Poland fifteen mesopredator species (six raptors, nine mammals) contributed 34 % to the diet by number (especially high: Lourenço *et al.* 2011a) divided equally between raptors and mammals (Stój *et al.* 2024). Stój *et al.* (2024) recorded Northern Goshawk *Accipiter gentilis* as prey, with Common Buzzard (6 % of diet) and Ural Owl *Strix uralensis* (5 % of diet) more frequently taken. Stój *et al.* (2024) remarked that Ural Owl numbers had apparently not been affected by a stable Golden Eagle population in southern Poland.

It is not clear if such differences reflect a greater abundance and diversity of mesopredators or, according to the food-limitation hypothesis (section 3.2) differences in the availability of less-risky and usually more preferred prey occupying a lower trophic level (e.g. largely prey that are mostly or entirely herbivorous). The food-limitation hypothesis would predict that higher dietary contribution of mesopredators should be associated with lower breeding success (Hoy *et al.* 2017). This prediction was not met by the examples of Estonia and southern Poland, with breeding success (fledglings per occupied territory) of 0.41 (Sein & Väli 2024) and 0.55 (Wactawek & Mizera 2002) respectively. Diet breadth was greater in Poland (not just in the diversity of mesopredators as prey) and this may further illustrate that dietary diversity (to which mesopredators as prey may contribute) is not necessarily associated with reduced breeding success in Golden Eagles (Whitfield *et al.* 2009).

As concluded by Lyly *et al.* (2015) more research is needed on the role Golden Eagles may play in mesopredator suppression, as also emphasised for all top avian predators (Terraube & Bretagnolle 2018). Even so, it is important to note that in studies of raptor assemblages (including IGP), suppressive effects of top avian predators are usually found to have wider beneficial consequences on biodiversity and create more 'balanced' ecosystems (not least, of course, as they include the presence of top predatory raptors which globally are disproportionately classed as threatened species: McClure & Rolek 2020). While biodiversity benefits generated by top predators can be expected on average, they are difficult to predict (Natsukawa & Sergio 2022) because interspecific relationships and community dynamics are understandably complex and vary in space and time.

Relationships between a top predator, Northern Goshawk, and a smaller raptor prey species, Tawny Owl *Strix aluco*, in Kielder Forest, Northumberland show such subtle complexities, even when only between two species (Hoy *et al.* 2015). In this study, involving increasing numbers of goshawks, predatory effects on Tawny Owls were mitigated by goshawks' greater selection of individuals with low reproductive value (old females and juveniles), such that owl abundance was unrelated to goshawk abundance. Interacting with owls' food availability, however, goshawk predation appeared to delay owls' recruitment into the Kielder population (Hoy *et al.* 2015).

Illustrative further of the complexities involved, if more subjectively, a return can be made to the example of Golden Eagles and other raptors in the Carpathian Mountains of southern Poland where nationally the Golden Eagle is classed as a threatened species (Stój *et al.* 2024). Ural Owl numbers were apparently unaffected by a stable population of Golden Eagles. But in the absence of eagles, Ural Owls in all likelihood could be more widespread and if, say, the research had involved an increasing population of eagles, then it could well have shown a decline in Ural Owls, as in another study system involving an increasing top predator (Northern Goshawk) and a smaller raptor (Common Kestrel) (Petty *et al.* 2003a). The raptor guild in southern Poland appears to be an assemblage which is diverse and settled, probably in part as a result of the presence of top raptors. Golden Eagles may well have an effect on Ural Owls to limit their distribution, even if this results in stable Ural Owl abundance. However, Golden Eagles also killed other predators of Ural Owls (e.g. Northern Goshawk) and, more often, other raptors that will compete with Ural Owls for resources (notably Common Buzzards and Tawny Owls) and this probably benefitted Ural Owls.

### 3.2.3 Relevance to a recovery of Golden Eagles in England

It is inarguable that the Golden Eagle is a native English species (section 1.2) and seeking its recovery in the country is a justified restorative goal. One might expect, under the food-limitation hypothesis, that Golden Eagle effects on mesopredators (specifically smaller raptors) could be more likely in situations where other 'more typical' prey is less abundant. It is beyond the remit and scope of the present report, however, to consider how possible mesopredator suppression by the novel presence of Golden Eagles may (or may not) be relevant in regional locales and different faunal communities. Hence it is not currently realistic to consider whether it could have widespread benefits for faunal communities, as usually expected (Natsukawa & Sergio 2022) or, in perhaps some few species-specific instances, at least cause re-distributions or create a problematic conservation dilemma (Lourenço *et al.* 2011a). Nonetheless, on the latter prospect, at this stage some insight may be gained by considering species of conservation concern which may (or may not) be adversely affected. This is the subject of the following subsections.

## 3.3 Birds of Conservation Concern

Here we consider potential risk to birds of conservation concern. The fifth iteration of Birds of Conservation Concern (BoCC) was produced in 2021 (Stanbury *et al.* 2021). The Red List involved 70 species.

After excluding Red List UK species that do not occur in England, the next step in evaluating Red List species that may be affected by a recovery of Golden Eagles in England should broadly involve some shared similarity in habitat selection (i.e. the uplands: Data Dictionary, section 1). Red List upland passerines such as Ring Ouzel *Turdus torquatus*, Twite *Linaria flavirostris*, or Whinchat *Saxicola rubetra* are rarely taken as prey by golden

eagles (in part, probably being too small) (e.g. Watson 2010). Similarly, while larger species such as waders (e.g. Northern Lapwing *Vanellus vanellus* or Eurasian Curlew *Numenius arquata*) may be taken occasionally as prey (more often curlew) these tend to occupy altitudes below those used by golden eagles. Golden Eagles are therefore unlikely to have any direct negative effect on these species.

There is a possibility that eagles may suppress the distribution and abundance of mesopredators (section 3.2.2) which can have greater impact on the population dynamics of these species. Hence, the presence of Golden Eagles in the wider English upland landscape may perhaps be beneficial to passerine and wader species. Research on the ecology of these Red Listed species places emphasis on breeding habitat loss/degradation, nest predation by terrestrial mammals, and non-breeding survival, even in areas where Golden Eagles are relatively common (e.g. Sim *et al.* 2010, Franks *et al.* 2017, Wilkinson *et al.* 2018, Stanbury *et al.* 2023). Transferring the results of Lyly *et al.* (2015), depredation of passerine and wader nest contents and young by Red Foxes is unlikely to be reduced by the presence of Golden Eagles by affecting fox abundance. On the other hand, the results of Lyly *et al.* (2016) suggested that Golden Eagles may create a beneficial landscape of fear.

The three BoCC Red Listed upland bird species in England that are arguably more likely to be potentially affected are the Black Grouse, Merlin *Falco columbarius* and Hen Harrier *Circus cyaneus*. Merlin and Hen Harrier are unusual prey but may suffer from a new presence of English Golden Eagles directly through Intraguild Predation (IGP), a specific form of mesopredator suppression, and indirectly affecting their distribution through fear of predation (section 3.2). Black Grouse can be frequent prey of Golden Eagles (more so in places where they are more abundant e.g. Watson 2010, Sein & Väli 2024).

### 3.3.1 Black Grouse

There have been many studies of the causes of the Black Grouse decline in the UK, investigations of the species' status and demography, and reporting on management projects seeking to increase abundance (e.g. Baines *et al.* 2000, 2007, Warren & Baines 2008, Grant *et al.* 2009, Geary *et al.* 2013). The main cause of adult mortality in the UK is predation, and raptors usually figure large in their contribution, as elsewhere (Baines *et al.* 2007, and references therein). In Finland Lyly *et al.* (2016) concluded that Golden Eagles may benefit young grouse by suppressing mammalian mesopredators such as Red Fox but are a threat to adult grouse.

Nevertheless, the co-existence of Golden Eagles and Black Grouse is widespread in Eurasia, including Scotland, and the changing fortunes of a population in Perthshire did not make any note of changing raptor predation (Geary *et al.* 2012), but habitat management initiatives occurred, with consequences noted in later publication (Geary *et al.* 2013, see also Grant *et al.* 2009).

UK restoration initiatives cannot legally control raptors but can legally control Red Fox and some other mammalian mesopredators such as Stoat *Mustela erminea* (a mustelid recorded as the most common predator in northern England: Baines *et al.* 2007). Restoration management (Baines *et al.* 2000, Grant *et al.* 2009) tends to concentrate on recreating or stabilizing the preferred Black Grouse habitat mosaics (Baines 1994, Geary *et al.* 2013), typically at the moorland/woodland edge with the presence of pastures. Over-grazing can be problematic as it reduces cover, food and nest site availability, yet most leks occur on open patches of ground, such as grazed pasture. Maturation of woodland cover, notably fenced (ungulate grazer-proof) commercial conifer plantations, can create

preferred conditions which later disappear (Pearce-Higgins *et al.* 2007)<sup>18</sup>, giving the impression that the species can be an occupant of ‘early-succession’ habitats which may come and go in the wider landscape. In more ‘natural’ situations, however, this woodland edge habitat can be more stable through tree growth being held in check by, for example, water-logged soil (e.g. Estonia and Finland) or by higher altitude at upper tree lines (e.g. Alps) (Watson & Moss 2008).

Globally, despite all grouse species being victims of raptor predation, the main threats to grouse were concluded as loss or degradation of suitable habitat and human impacts on such (Storch 2000a). A worldwide review of Black Grouse status and conservation reported it was not threatened globally but at the species’ southern limits in western Europe, below the boreal forest, it was usually red listed (Storch 2000b). In these threatened populations habitat loss, deterioration and fragmentation were concluded as the main negative impacts, with human pressures and land management practices exacerbating or creating them. Predation was considered as having effects, especially corvids and generalist mesopredator mammals such as Red Fox and mustelids, but these effects were largely further consequential of anthropogenic changes to the landscape, which also adversely affected habitat quality and availability. Storch (2000b) concluded that predation appeared to be proximate but not the ultimate cause of Black Grouse declines where groups of Black Grouse may be small and or/isolated.

Of relevance here, this widespread review (Storch 2000b) did not highlight raptor predation as a major threat (unintentional human disturbance was evaluated as more problematic in some instances). This is probably because raptor predation is a common feature across all Black Grouse populations, regardless of their status, and despite reducing adult survival (Baines *et al.* 2017, Warren & Baines 2008). Amongst other factors, Warren & Baines (2008) noted increasing numbers of Northern Goshawk and Peregrine as being coincident with Black Grouse declines in the UK. This failed to mention, however, that both raptor species were still restricted by persecution (Marquiss *et al.* 2003d, Amar *et al.* 2012, Melling *et al.* 2018) and that raptor persecution is particularly prevalent in the UK, uniquely so in several parts of the uplands managed for driven Red Grouse shoots (Thompson *et al.* 2009, Newton 2021). Otherwise, in sub-boreal western Europe, without any comparable intentional disturbance effects on raptors as in parts of the UK (Rutz *et al.* 2006, Thompson *et al.* 2009, Newton 2021), or any change apparent (or at least recorded/highlighted), Black Grouse were also threatened in several other countries/regions (Storch 2000b). Hence, the conclusion of Storch (2000b) of the common feature essentially being loss of habitat availability and quality, often associated with human activities, without invoking raptor predation.

Golden Eagles would probably have some negative influence on adult grouse survival in England but beneficially may suppress the influence of mammalian mesopredators (Lyly *et al.* 2016), corvids (Storch 2000b), and smaller raptors, notably Peregrine (Fielding *et al.* 2003, section 3.2.2) in places where Peregrines are not already being suppressed by intentional disturbance (persecution) (Amar *et al.* 2012, Melling *et al.* 2018).

A renewed English presence of Golden Eagles would undoubtedly result in them killing older Black Grouse where their distributions overlap. Will this create a conservation dilemma or, more pointedly, should it be seen as an obstacle to any plans encouraging the Golden Eagle’s recovery in England? Probably not.

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<sup>18</sup> Black Grouse also die by colliding with unmarked fences protecting forestry plantations (Baines & Andrew 2003).

### 3.3.2 Merlin

The 2008 Merlin survey in the UK suggested that Merlin numbers were relatively stable from 1993-94 but with local declines, especially in northern England (Ewing *et al.* 2011). It was noted that two regions of England, North Yorks Moors and South Pennine Moors, were Special Protection Areas (SPAs), with Merlin as a qualifying feature. Declines recorded in 2008 resulted in numbers well below those at the time of SPA designation suggesting both were in unfavourable status for Merlin<sup>19</sup>. A 50 % decline between 1996 and 2002 was recorded by Wright (2005) in part of the Yorkshire Dales National Landscape (formerly known as an Area of Outstanding Natural Beauty).

Relayed trends from two intensive study areas in north-east Scotland were interesting (Heavisides *et al.* 2017) since in one Merlin numbers were stable on moorland but had dropped in forestry sites and in the other were probably in decline. In both locations during the reporting period there had been a “massive decrease” in Hen Harrier, Peregrine and Golden Eagle. This does not implicate any effects of Intraguild Predation (IGP) by larger raptors on Merlin population status. Both study areas in north-east Scotland had seen an intensification of practices associated with driven shooting of Red Grouse, including muirburn (see also Thompson *et al.* 2016). Intensification of muirburn (which included Merlin ground nest sites being burnt out) was suggested as a contributor to Merlin decline in the Lammermuirs of south-east Scotland (Barker *et al.* 2017, Heavisides *et al.* 2017). Merlins’ breeding prey abundance was also thought to have been adversely affected by muirburn in this long-term study (see also Pearce-Higgins & Grant 2006).

Reduced breeding prey (mostly small upland passerines) was again noted as a potential driver of more widespread change (Ewing *et al.* 2011). This included several areas managed for Red Grouse in northern England where the intensity and frequency of muirburn had increased (Yallop *et al.* 2006), but also in other areas. The causes of decline in the UK were still uncertain, however, and included possible reduced survival in non-breeding areas through reduced prey availability.

As noted earlier for the two study areas in north-east Scotland, the role of IGP in Merlins’ fortunes appears unlikely, especially involving the Golden Eagle, which is obviously absent from northern England, for example, where Merlins’ fortunes appear especially perilous. A study of IGP in Kielder Forest, Northumberland attributed a marked decrease in Common Kestrels to an increase in Northern Goshawks (Petty *et al.* 2003a). In contrast, even though Merlins mostly nested in old crow nests in conifer trees in Kielder (Little *et al.* 1995) they constituted a much lower proportion of Northern Goshawk diet and IGP was unlikely to be influential on Merlin population decline (Petty *et al.* 2003a). Reduction in Merlin nest sites may have been a factor through age and cropping of conifer plantations (Ewing *et al.* 2011). Conceivably, by killing more crows, increased Northern Goshawk numbers may also have reduced the availability of old crow nests as Merlin nest sites.

A particularly pertinent study of breeding Merlins relevant to IGP involving Golden Eagles was conducted on 450 km<sup>2</sup> of the northern Lewis peatlands in the Outer Hebrides during 2002, 2003 and 2005 (Rae 2010a, b). All Merlins are ground-nesting on Lewis (Rae 2010a) and have a diet typical of the species in the UK, but with a higher proportion of waders which are common on Lewis (Rae 2010b). Merlin density was relatively high on Lewis

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<sup>19</sup> Incidentally, SPA designation and unfavourable status of Merlin would add an extra layer of justification for any translocation of Golden Eagles to these two regions.

(involving c. 27-29 ‘territories’) which has no terrestrial mammalian predators such as Red Fox (Rae 2010a).

Golden Eagles occur at high breeding density on Lewis (Hayhow *et al.* 2017) and while the substantially flat peatlands of northern Lewis offer few Golden Eagle nest sites (as opposed to southern Lewis: Fielding *et al.* 2024a), they support many non-breeding Golden Eagles (Fielding *et al.* 2024b). The main cause of loss of Merlin chicks was predation by Golden Eagles, and a Golden Eagle killed one of the incubating Merlin females being studied. Remains of Merlin were found at two Golden Eagle nests during the study (Rae 2010a). Observations of Merlins mobbing Golden Eagles were also commonly recorded (S. Rae pers. comm.).

While the Lewis study of Merlins did not span many years there was no indication from less-thorough previous surveys to suggest any change and Rae (2010a) considered the population to be stable, in part because the few killed female Merlins were rapidly replaced. Against a recorded backdrop of Golden Eagle predation pressure, likely expected given the high eagle density, the study does not give much or any credence to the notion that the top predator was exerting any substantial influence on an apparently ‘healthy’ and nationally important group of Merlins.

Overall, there is little to suggest that a resurgence of Golden Eagles in England would be problematic for Merlins, despite Merlins being in difficulties in their northern English strongholds for other reasons.

### 3.3.3 Hen Harrier

The reasons for the Red List status of the Hen Harrier in England are better researched. Hen harrier distribution and abundance is affected adversely in England by illegal persecution associated with intensive management for driven shooting of Red Grouse (Etheridge *et al.* 1997, Thompson *et al.* 2009, Murgatroyd *et al.* 2019, Ewing *et al.* 2023). Also, given much higher estimates of Hen Harriers’ potential abundance in England (Potts 1998, Fielding *et al.* 2011), as opposed to its most recent abundance (Natural England 2024<sup>20</sup>), the primary reason for its Red List status in England is well-studied and widely acknowledged (e.g. Natural England 2008).

If this risk factor of intentional disturbance continues in England, it is difficult to ascertain what influence the novel presence of Golden Eagles may have on the threatened Hen Harrier, since it will involve landscapes and faunal communities heavily influenced by humans and this can override any possible natural community relationships (Kuijper *et al.* 2016). Clearly in some English PRZs dominated by management for driven grouse shoots (section 1), if persecution of raptors is not addressed and reduced then as an additional ‘novel’ predator of Red Grouse it is uncertain if Golden Eagles could recover there, never mind what influence they may have on Hen Harriers when harriers are currently persecuted there (e.g. Murgatroyd *et al.* 2019, Ewing *et al.* 2013). If the risk factor of intentional disturbance is alleviated, then more ‘natural’ ecosystem functioning and relationships within raptor assemblages may be freer to operate.

Research on IGP - a specific form of mesopredator suppression - has usually found that top predators (superpredators) resort to taking smaller raptors when lower injury-risk prey is less available (section 3.2). Due to their position in food chains smaller raptors also tend to be less abundant than more frequently taken prey occupying lower levels of food

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<sup>20</sup> With numbers not much increased since 2002-2008 (Natural England 2008).

chains. While IGP (and the wider concept of mesopredator suppression) can lead to higher biodiversity and beneficial cascades of resource availability through communities, for threatened raptors IGP may be problematic (section 3.2).

Through IGP and influences on distribution (Fielding *et al.* 2003) a recovery of Golden Eagles in England may potentially affect the already-threatened distribution and abundance of Hen Harriers. However, as noted above, this could only be envisaged in habitats and PRZs where both species were essentially free of the burgeoning and overriding effects of a persecution risk factor. And in such an environment there would likely be more Hen Harriers anyway. In essence, if both species were 'left alone' by direct human interference then Golden Eagles may well naturally control the distribution and abundance of Hen Harriers (Fielding *et al.* 2003).

Indeed, by their influence on other avian predators of Red Grouse (notably Peregrine) it has been speculated that Golden Eagles may benefit the numbers of Red Grouse by suppressing numbers of other grouse predators (Fielding *et al.* 2003), and despite Red Grouse being a preferred prey of Golden Eagles when sympatric (e.g. Watson *et al.* 1989, Watson 2010, Whitfield *et al.* 2022). This speculation has yet to be tested and at best the possibilities may be especially hopeful, or otherwise redundant, in the context of the minimum (very high) densities of Red Grouse that are deemed necessary for the uniquely British practice of driven shoots to be profitable (Thompson *et al.* 2009).

Despite Golden Eagles' potentially suppressive influence on subordinate raptors, two recent examples from Scotland documenting Hen Harrier recovery in the Cairngorms (Rao & Painting 2022) and the recent expansive colonisation of Lewis, Outer Hebrides (Reid *et al.* in press) suggest that the presence of Golden Eagles has not been an obstacle to Hen Harrier increases. In both examples, persecution of eagles and/or harriers on the breeding grounds was not relevant. On Lewis, Golden Eagle depredation of a harrier brood has been recorded (R. Reid pers. comm.), as elsewhere in the Hebrides, such as Jura and Mull (e.g. Fielding *et al.* 2003).

Both studies of the Cairngorms recovery and colonisation of Lewis emphasise the reduction in grazing pressure (either from Red Deer *Cervus elaphus* or Sheep *Ovis aries*) as a salient contributory factor, echoing research elsewhere in Scotland and Ireland on the association of low grazing pressure with greater Hen Harrier nesting densities (Arroyo *et al.* 2009, Wilson *et al.* 2009, Fielding *et al.* 2011, Geary *et al.* 2018). Hence, in the absence of persecution, the factors affecting the abundance and distribution of Hen Harriers are not solely determined by the presence of larger raptors such as the Golden Eagle.

In summary, of the three BoCC Red Listed species considered to be most possibly affected by Golden Eagle recovery in England, the Hen harrier has the most parlous conservation status, with only tens of breeding attempts recorded recently, despite the hundreds that have been deemed potential. The primary reason for this parlous status is well-known: persecution. In western Scotland, where Golden Eagles and Hen Harriers co-exist in greater numbers, in the absence of persecution of both species, Golden Eagles may nevertheless affect the distribution of Hen Harriers.

As noted earlier, if persecution persists it is difficult to ascertain what influence the novel presence of Golden Eagles may have on the threatened Hen Harrier, not least as persecution would probably be directed towards not just Hen Harriers but Golden Eagles too. In the absence of persecution, or at least its significant reduction, then clearly the two species can co-exist (and thrive) even if the Golden Eagle may well influence harrier abundance through direct predation and indirect fearful effects on its distribution.

### 3.4 Mammals of conservation concern

In this sub-section we examine risk to mammals of conservation concern. A review of the populations and conservation status of British mammals was undertaken by Mathews *et al.* (2018). Golden Eagles prey on several mammals, especially lagomorphs which as prey species in the UK and Ireland are primarily represented by Rabbit and Mountain Hare *Lepus timidus* (Watson 2010). In England the former is deemed a naturalized species and can be killed by humans as a pest species whereas the latter is restricted to the South Pennines (Derbyshire Mammal Group 2022) where its status is 'favourable' (Mathews *et al.* 2018). Hence, Mountain Hares are apparently not of conservation concern in England, even with their restricted distribution. Despite Mountain Hares being frequent and preferred prey of Golden Eagles, we are not aware of any research in the extensive geographical overlap of the prey and predator (with continued co-existence) which suggests that the presence of eagles in England could be deemed as a threat to Mountain Hares. In Scotland, substantial culling by humans in areas with intensive management for shooting Red Grouse appears to be the larger threat to Mountain Hares (Watson & Wilson 2018, Barker *et al.* 2017).

Red Squirrel *Sciurus vulgaris* and Pine Marten are occasionally taken as prey by Golden Eagles and in England are classed as Endangered and Critically Endangered, respectively, under IUCN Red List criteria (Mathews *et al.* 2018). In England Red Squirrels are in decline (mostly through several adverse effects associated with the larger 'invasive' Grey Squirrel *S. carolinensis*) and Pine Marten is classed as increasing in population status and range status.

The Pine Marten is predominantly a species of woodland and the Red Squirrel exclusively so. This may explain why they are usually infrequent Golden Eagle prey and, when they are, it is more often by eagles that nest in trees or close to the upper tree line. In the Carpathian Mountains of southern Poland, with high forest cover and almost all eagle nests in trees, marten species constituted 10 % of Golden Eagle diet by number (Stój *et al.* 2024). By contrast, a dietary study in northern Greece, also having relatively high forest cover found that marten species comprised 3 % by number (Sidiropoulos *et al.* 2022). In Scotland, both species are unusual prey (Watson 2010). Moreover, despite the broad overlap in distribution of these two mammals with a substantial Golden Eagle population, Red Squirrels are stable and Not Threatened, and Pine Martens are of Least Concern and increasing (Mathews *et al.* 2018).

In Finland, where Pine Martens are common and Golden Eagles are much more likely to nest in trees than in Scotland (and prospectively in England), research combined national datasets of eagle nest site locations and wildlife track counts of martens (Lyly *et al.* 2015). This study found little evidence that eagle distribution suppressed marten abundance. While there was a weak trend of lower marten abundance at high eagle densities, marten abundance increased at low to intermediate eagle densities and within close proximity to eagle nests. This research does not provide any concern over what may happen in England with increasing populations of both species.

A study of predation of Red Squirrels by Northern Goshawk in Kielder Forest, Northumberland is revelatory so far as top predator influence (Petty *et al.* 2003b). The research concluded that Northern Goshawks were not limiting Red Squirrel numbers. When the Northern Goshawk is a top predator in woodlands, it follows that the Golden Eagle, as a top predator in predominantly open habitats away from woodlands, will not have any detrimental effect on Red Squirrels.

We conclude that any recovery of the Golden Eagle in England should not adversely affect any mammal species of conservation concern.

## 3.5 Species of Economic Interest

In this sub-section we examine risk to species of economic interest. The Golden Eagle is well-known for its capacity to exploit a wide variety of food sources, whether as live prey (mostly within certain size/weight limits) or as carrion (Watson 2010). Within this wide range of food items, in Great Britain this can include animal species which are cultivated as food for human consumption and use of their by-products, or encouraged by intensive management for, primarily, sport.

Red Deer occur in England but are far more abundant in Scotland and commercialized shooting of adults (“stalking”) is a widespread practice in upland estates of Scotland, with customers usually seeking ‘trophy’ deer. Young deer calves can be taken as prey and dead adults as carrion by Golden Eagles (Watson 2010), but Golden Eagles historically and contemporaneously have not, justifiably, been seen as a threat to the sport provided by deerstalking. Rather, the enclaves where Golden Eagles survived in Scotland during the height of persecution in the late 19<sup>th</sup> and early 20<sup>th</sup> centuries were “deer forests” where deerstalking was a major source of income (Evans *et al.* 2012, 2013). Predation of Red Grouse by Golden Eagles under this land management practice was seen as beneficial because the alarm calls of Red Grouse could alert targeted Red Deer and ruin stalking attempts.

Exotic non-native gamebirds, Common Pheasants *Phasianus colchicus* and Red-legged Partridges *Alectoris rufa*, are raised and released for commercial shoots, and are considered as ‘livestock’ when in raising pens prior to release. Most often they are released for lowland shoots (overall in large numbers, especially Pheasants) but are increasingly released at higher altitudes in the uplands or at the upland edge as ‘traditional’ Red Grouse shoots seek to diversify income and offset the cyclical nature of Red Grouse abundance or poor numbers otherwise. When available, Golden Eagles are not averse to taking these non-native species, after release (or as surviving naturalized individuals) but typically not in high numbers because of the tendency for habitat segregation between eagles and these gamebirds. Occasionally, nonetheless, if Pheasants are released in the uplands/forest edge, Golden Eagle pairs may home in on localized high availability of Pheasants (D. Anderson pers. comm., M. Wilson pers. comm.). Even in these isolated examples, it is unlikely that Golden Eagles will make much inroad into stock available for shooting (not least because of the timing of releases). Overall, therefore, this possibility should not be a widespread issue for Golden Eagles in England.

Only two species are likely to be of concern through the recovery of Golden Eagles in England, with just one considered as domestic livestock: Red Grouse and Sheep (lambs).

### 3.5.1 Red Grouse

The Red Grouse is a preferred prey of the Golden Eagle where it occurs (Watson *et al.* 1989, Watson 2010, Whitfield *et al.* 2009, 2022). The annual food requirements of one pair of Golden Eagles have been estimated to include scores of Red Grouse, where this prey species is available and abundant (Watson 2010).

In Scotland, being a predator of Red Grouse, Golden Eagles are killed by some grouse moor managers, and this can adversely affect their survival, abundance and distribution (Whitfield *et al.* 2004, 2007, 2008, 2017, Whitfield & Fielding 2017, Newton 2021).

Through their predatory activities, Golden Eagles will be seen as a direct threat to grouse stocks by at least some grouse moor managers in England - other raptors already are (section 3.3). Golden Eagles will probably also disrupt some days of shooting because grouse typically go to ground when threatened by Golden Eagle presence overhead (e.g. Whitfield *et al.* 2008). This response, like the response of grouse to Peregrines, acts against the role of human beaters to raise grouse into the air for guns. This will spoil days' shooting bags and, thereby probably, 'customer satisfaction' and economic returns and/or estate shoot status.

If the economic viability of driven grouse shoots apparently depends on very high grouse densities which are considered by moorland managers to be difficult to achieve without (illegal) raptor persecution (e.g. Thompson *et al.* 2009, 2016), this creates a dilemma that has generated considerable discussion and attempted initiatives geared to its resolution. In Scotland, enhanced implementation and policing of existing laws and novel law, the Wildlife Management and Muirburn (Scotland) Act 2024 (<https://www.legislation.gov.uk/asp/2024/4>) (WMM Act), is the latest pathway being attempted.

In the Central Highlands Natural Heritage Zone (NHZ 10) of Scotland, Red Grouse is the predominant prey of breeding Golden Eagles, reflecting more the diet of birds to the east, rather than to the west (Whitfield *et al.* 2022). An ongoing project centred on NHZ 10 (Regional Eagle Conservation Management Plan: RECMP) started in 2015, has seen a marked expansion of range-holding Golden Eagles; a trend probably begun in 2009 (Benn & Whitfield 2023).

*"The past and continuing persecution of raptors on some grouse moors is an extremely sensitive subject and, not surprisingly, one which those that may have been involved in it formerly or know who may still be, are often rather reluctant to talk about. However, through confidential conversations with many people on the ground there is little doubt that much of the recent increase in NHZ 10 has been due to a change of attitude and management over significant areas of grouse moor but that the activities of some others are still affecting Golden Eagle distribution and survival elsewhere within the NHZ (Stuart Benn pers. obs.)"* (Benn & Whitfield 2023). Benn *et al.* (2024) also touch on this issue in the wider Highlands.

If relatively low key, the success associated with the RECMP in most of the Central Highlands shows what can be achieved by project publicity, repeated on-the-ground communication with land managers, changing attitudes of land managers towards Golden Eagles, other land management options (such as 're-wilding' and encouraging 'eco-tourism'), and the increased scrutiny on Golden Eagle fates provided by GPS-tagging (part of the project) and the revelatory level of likely persecution in some parts of Scotland dominated by grouse moor management from analysis of tagging data (Whitfield & Fielding 2017). This latter revelation led, via the "Werritty Review" (Scottish Government 2019, 2020), to the WMM Act.

The Golden Eagle's habitual depredation of Red Grouse will undoubtedly be an issue of potential conflict in any recovery of Golden Eagles in England, especially if recovery involves active measures and in those PRZs dominated by land management for driven grouse shoots. In especial relevance to an English recovery the SSGEP, however, has shown that this issue is not insurmountable, although the extent of driven grouse moors in southern Scotland is more localized and probably less intensive, notably being in the eastern Southern Uplands such as the Lammermuir and Moorfoot Hills.

Prior to SSGEP starting there was evidence of persecution being a prospective problem (Whitfield *et al.* 2003, 2008, Fielding & Haworth 2014) and with Red Grouse liable to be frequent prey in some areas (Haworth & Fielding 2017). SSGEP has deployed a combination of several tools, including community engagement officers, education outreach, liaison with landowners and estate staff, widespread publicity and public events, GPS-tagging of all released eagles and close monitoring of their progress. Likely through this approach, and preparations for the project (such as consultations and background research), there have been very few instances of persecution and eagle survival has been high (C. Barlow, A. Fielding *et al.* unpublished data). Several new breeding home ranges have been established on or near grouse moors.

### 3.5.2 Lambs (and other livestock)

Watson (2010: pp. 100-102) gives a good account summarizing research on Golden Eagles' predation of lambs in Scotland, mostly from older studies in the west where sheep farming was low intensity on husbandry, land productivity relatively low, economic viability was fragile, and Golden Eagle density high. Estimates of lamb mortality attributable to eagle predation were 0.5-8.0 % (Lockie & Stephen 1959, Lockie 1964, Hewson 1984, Leitch 1986). Watson (2010) estimated that in a typical eagle range this would equate to 0.15-2.4 % of the annual lamb crop. In a study on Benbecula, Outer Hebrides predation losses of lambs attributed to Golden Eagles were estimated as 1-3 % of all losses, crudely within the variation reported by earlier studies elsewhere in the west (Campbell & Hartley 2004). Interestingly, from food remains collected at the nest, lamb predation equated to 13-18 % of the estimated eagle diet (Campbell & Hartley 1984). This provides some context as what the dietary percentage involving lambs transfers to actual losses in the lamb crop, also bearing in mind that eagles probably prefer moribund individuals so that predation can be compensatory, not entirely additive i.e. lambs would otherwise have died if not predated.

As noted by Watson (2010), agreeing with Leitch (1986), improved husbandry in western Scotland would lead to much improved ewe condition, and thereby increasing lamb production well in excess of even the highest levels of depredation by Golden Eagles. (Deploying this measure has not been lost when framing the objectives and available funds of the Sea Eagle Management Scheme (SEMS) for sheep farmers and crofters in western Scotland concerned about perceived or actual White-tailed Eagle depredations of lambs: NatureScot 2022.)

Older accounts on Golden Eagles killing lambs in western Scotland may be outdated given advances in husbandry, lower numbers of sheep in modern times (Watson 2010, Reid *et al.* in press: *cf* Fuller & Gough 1999), and post-mortem methods to differentiate active predation from scavenging dead lambs (Marquiss *et al.* 2003a). The most recent dietary studies of Golden Eagles in western Scotland have not focused on lamb predation but provide information on the contribution of Sheep and lambs to the diet, from nest clearances of food remains and analysis of regurgitated pellets (Whitfield *et al.* 2009, 2013).

This research, conducted on the Inner Hebridean islands of Mull and Skye and the Outer Hebrides, did not differentiate between evidence of predation or scavenging; or, in regurgitated pellets, whether the recorded hairs were due to scavenging Sheep carcasses or from lambs, or whether lambs were alive or dead when taken. Hence, they are not directly comparable with aspects of earlier more specific research.

According to food remains collected at nests, the average contribution to the breeding season diet for Sheep was 3.4-12.0 % (Whitfield *et al.* 2009). The lower 3.4 % estimate was recorded on the Outer Hebrides, by contrast with Campbell & Hartley (2004: 13-18 %) for closest geographical context and possible transference to what this could equate to on its contribution to all lamb losses. In a similar dataset from Golden Eagle nest sites, the average dietary contribution of Sheep was 10.7 %, with 19.2 % recorded from nearest-neighbour White-tailed Eagle nests (Whitfield *et al.* 2013)<sup>21</sup>.

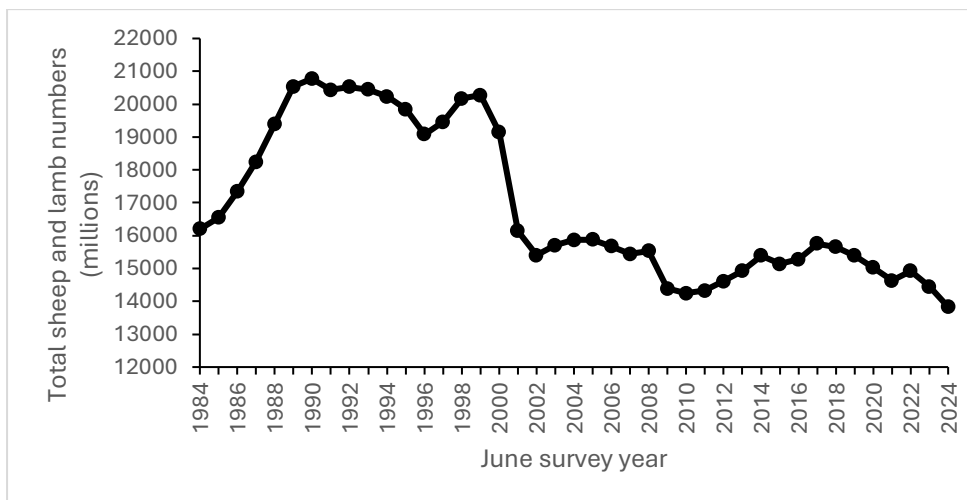
Unlike the White-tailed Eagle (section 3.5.2.2, below) concerns and data on livestock predation have been reported for Golden Eagles internationally (e.g. USA and Scandinavia: Watson 2010). In the USA, attempted solutions of translocating the problematic eagles were unsuccessful but active ‘scaring’ measures were more successful. Longer term measures would conceivably be better through reducing Sheep densities, more intensive husbandry, and coincidentally/consequently increasing the availability of ‘natural’ prey through different land management practices. A restorative theme shared by evaluations for western Scotland (Watson 2010).

### **3.5.2.1 Sheep and lambs in England**

In England, despite relatively high numbers from the late 1980s, the numbers of sheep and lambs have been declining since Fuller & Gough (1999) and the late 1990s (Figure 3.1). This decline is likely greater in hill farms bordering on and in the uplands where economic margins are smaller and more perilous (e.g. Green Alliance Blog 2018). These data could suggest that any concerns over Golden Eagle predation of lambs should be lessened as lambs will be less available and may be afforded greater levels of husbandry. On the other hand, given that each lamb may be valued higher because of slim economic margins, hill farmers and shepherds in and near the uplands may be especially susceptible to worries over the novel presence of a “potential predator”.

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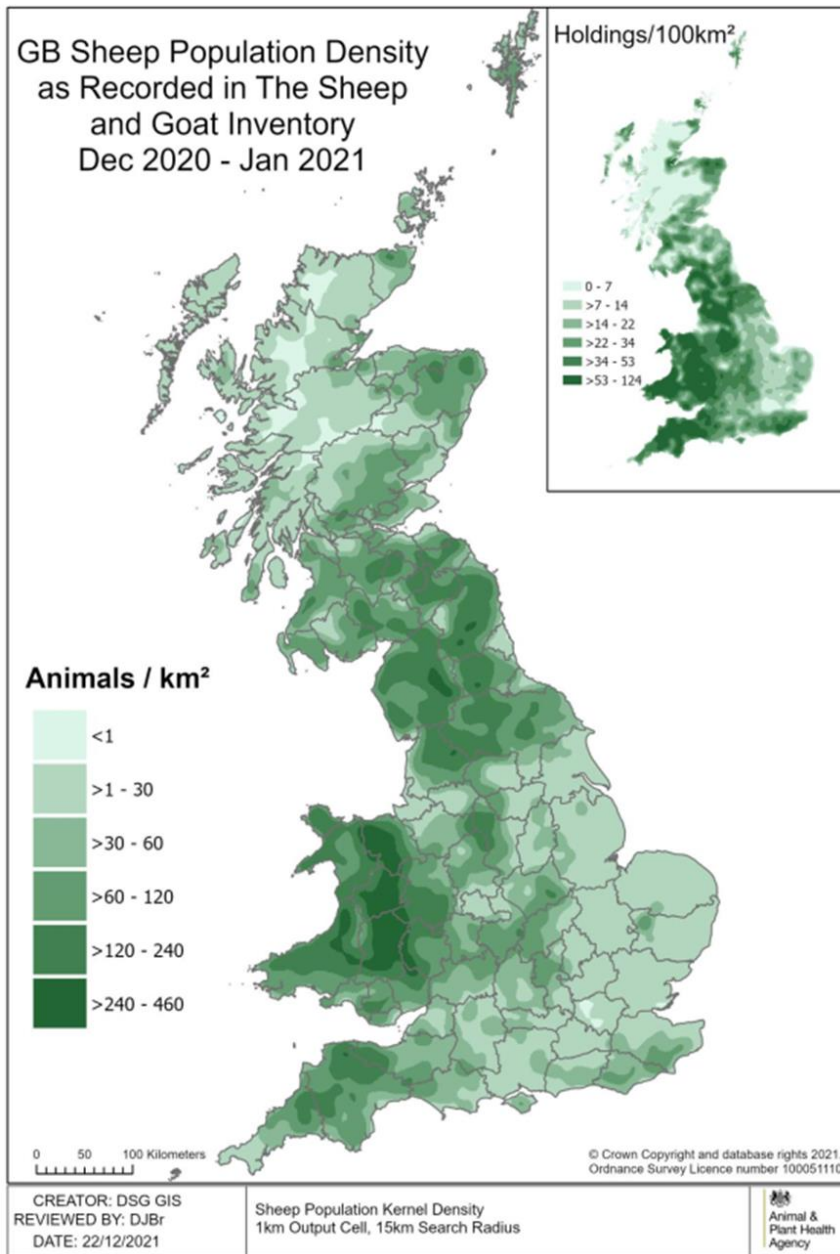
<sup>21</sup> As acknowledged by Whitfield *et al.* (2013) and other studies of White-tailed Eagle diet as adjudged from nest clearances (e.g. Reid *et al.* 2023) the contribution of fish and soft-bodied marine food is underestimated. This will inflate the estimated % contribution of other food types to the diet, including Sheep (lambs).



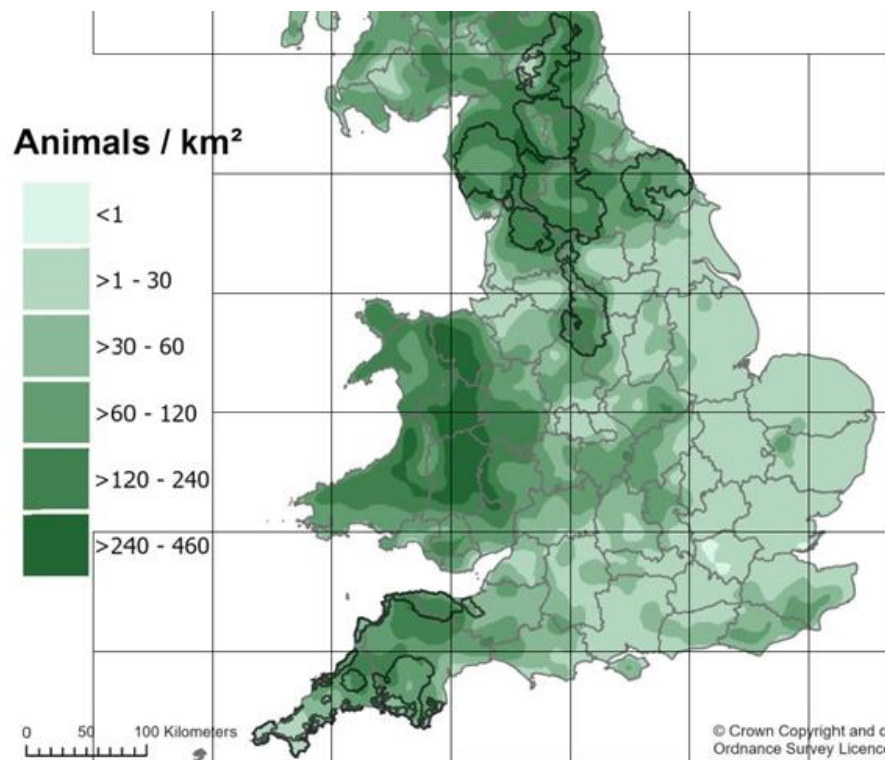
**Figure 3.1.** Annual records of sheep and lamb numbers in England 1984-2024, according to DEFRA statistics <https://www.gov.uk/government/statistics/livestock-populations-in-england/> last updated 29 August 2024.

Sheep densities published by APHA<sup>22</sup> (2021) show higher densities often overlapped with several substantial upland parts of England (Figure 3.2) and, hence, PRZs (Figure 3.3). Of relevance to natural sources of English Golden Eagle recovery, and as to comparability with upland Scotland, the highest sheep densities in several English upland regions were most like those of southern Scotland (re: section 3.5.2.3, below), with those in western Scotland being markedly lower (Figure 3.3). In western Scotland, however, background land productivity (Data Dictionary, Less Favoured Areas) and sheep husbandry levels may typically be lower. This may lead to a higher proportion of weak moribund lambs susceptible to predation and/or dying and being scavenged.

<sup>22</sup> APHA is an Executive Agency of the Department for Environment, Food and Rural Affairs and also works on behalf of the Scottish Government, Welsh Government and Food Standards Agency to safeguard animal and plant health for the benefit of people, the environment and the economy.



**Figure 3.2.** Sheep density in Great Britain, 2020/2021. Taken from APHA (2021: Figure 1).



**Figure 3.3.** Sheep density in England, 2020/2021. Taken from APHA (2021: Figure 1). Black lines show the boundaries of PRZs (section 1).

### 3.5.2.2 White-tailed Eagles and livestock in Great Britain

While not entirely comparable as the two eagle species in the UK have different niches and accordingly several dietary differences (e.g. Whitfield *et al.* 2013), since its reintroduction to Scotland the White-tailed Eagle is reputationally more often described as a “lamb-killer” even if this reputation is substantially undeserved (e.g. Reid *et al.* 2023). It can be instructive, therefore, to consider research on this issue when the White-tailed Eagle’s presence in the UK has been through reintroduction or reinforcement after its historical extinction by 1918, through human activities (Love 2013).

Also, as a species that tends to exploit habitats at lower altitudes than the Golden Eagle (Evans *et al.* 2010, Whitfield *et al.* 2013), the White-tailed Eagle is probably more exposed to young lambs because hill-hefted ewes are often brought down closer to farms and to ‘lambing parks’ to give birth and care for young lambs (and when older lambs released back onto the hills are too large as even potential prey) (Marquiss *et al.* 2003a, b, c, NatureScot 2022). The altitudinal segregation of the two eagle species was speculated on by McAuliffe *et al.* (2024), with the Golden Eagle being more “*out of sight, out of mind*”, as to why sheep farmers and crofters in western Scotland may perceive White-tailed Eagles as the greater threat to lamb stocks.

Early intensive studies (primarily 1998-2002) of White-tailed Eagle “lamb-killing” were conducted at nest sites occupied immediately after the initial re-introduction to western Scotland (Marquiss *et al.* 2003a, b, c). The lambs recorded from these nests were mostly scavenged and of those killed by eagles, more than half could have been particularly vulnerable as they were much smaller for their age than healthy live lambs. The research concluded no economic damage to sheep farming on a broad scale, and little evidence for

economic loss at individual holdings (Marquiss *et al.* 2003a, b, c). *“The claim was that WTEs were causing economic loss to agriculture; the fear was that a pest had been re-introduced. The results of the present work show that this fear is unsubstantiated. Sheep farmers were correct in their claims of lamb killing but the scale of the problem is far less than originally thought”* (Marquiss *et al.* 2003c). More generally, the perception of the frequency of livestock predation by top predators is often not confirmed by scientific studies but the perception can continue (e.g. Ballejo *et al.* 2020, Mathiesen *et al.* 2022).

Subsequently, prompted by claims of frequent lamb predation by White-tailed Eagles in Gairloch, Wester Ross<sup>23</sup>, an intensive 2009 study (including tagging of numerous lambs to document their survival and mortality causes) was undertaken by the Food and Environment Research Agency (Simms *et al.* 2020). This intensive study found little evidence of lamb predation by eagles, despite the more substantive claims prompting its commission. Further commissioned study in this avenue of research has apparently not been forthcoming.

Extensive research has been published recently on the diet of Scotland’s White-tailed Eagles, including the west where the successful reintroduction of the species to the UK was started, and where its reputation as a ‘lamb-killer’ originated (Reid *et al.* 2023). This study re-sampled nest sites where the earlier intensive research had been focused (e.g. Marquiss *et al.* 2003c), but also sampled many more, and it found that *“...foods used were associated with the historical order in which nest territories were settled by eagles. This was particularly clear in the pattern of lamb remains in nests, with most recorded in those territories that were initially settled during recolonization immediately following re-introduction. The earlier intensive study had shown that these territories were centred on areas with Sheep and lamb carrion”*.

The extensive dietary study of Reid *et al.* (2023) showed that the species’ reputation is substantially ill-founded, and increasingly so: *“In retrospect, the previously widespread view that lambs are an important food for White-tailed Eagles has been superseded; the prevailing evidence now is that marine items (seabirds and fishes) are the most important breeding season food in Scotland”*.<sup>24</sup>

The last phase of the White-tailed Eagles’ reintroduction to Scotland, near the east coast, involved the release of 85 birds translocated to Fife from Norway 2007-2012 (e.g. Ferrer *et al.* 2023). With considerable effort devoted to following up any reported claims of livestock predation, there were no substantiated cases of livestock predation consequently (C. Smith & R. Evans pers. comm.).

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<sup>23</sup> *“Whilst previous research on Mull (Marquiss et al. 2001) has shown that some live lambs are taken by white-tailed eagles, the applicability of this finding to other parts of Scotland has been questioned, and some crofters have suggested that levels of predation have increased markedly in recent years.”* (Simms *et al.* 2020). An echo of the finding of Mathiesen *et al.* (2022) on ‘trust’ in livestock-predator research results could easily be surmised.

<sup>24</sup> The Sea Eagle Management Scheme (SEMS) has been run for several years at over £250k per annum by Scottish Natural Heritage and latterly by its rebranded successor NatureScot and includes costs of employing or contracting several fieldworkers knowledgeable in recognising signs of lamb predation/scavenging when called on by reported ‘predation’ incidents. And to conduct observations and interpret trail camera information deployed at potential conflict hotspots. Unfortunately, there is no useful information presented in periodic SEMS reports (e.g. NatureScot 2022) on objective feedback of predation levels from such investigations. These would probably be biased, however, because they would inevitably be focused on potentially ‘problematic’ instances (which could reasonably be a reason for the shortage of presented information) and would be unlike the more extensive work of Reid *et al.* (2023) not exclusively driven by lamb ‘predation’ incidents.

More recently, the reintroduction of White-tailed Eagles to the south coast of England began in 2019, centred on the Isle of Wight, and has so far led to 37 GPS-tagged releases (Roy Dennis Wildlife Foundation 2024). An insightful element of this project has combined observers being directed by GPS-telemetry locations to record the food taken by the translocated birds (Egerton-Read *et al.* 2024). This novel method has confirmed what has been acknowledged by dietary studies based on remains collected at nests (e.g. Reid *et al.* 2023) that fish and other soft-bodied marine food sources can be common and underestimated by nest clearances. It has also been emphasised that “*there have been no cases of livestock predation since the project began*” (Roy Dennis Wildlife Foundation 2024).

It is also worth highlighting that in many other countries this issue of livestock predation by White-tailed Eagles does not occur and is not perceived to occur (e.g. Helander *et al.* 2003, further international references in Dennis *et al.* 2013, Reid *et al.* 2023).

### 3.5.2.3 Golden eagles and livestock: Ireland and SSGEP results from southern Scotland

Perceptions of Scottish sheep farmers and crofters as to the risk to lambs posed by the two eagle species have emphasised White-tailed Eagles as a greater ‘threat’ (McAuliffe *et al.* 2024). However, when the Golden Eagle, as an *Aquila* species, may be a more ‘active’ predator of terrestrial prey sources than the White-tailed Eagle, as a *Haliaeetus* species (e.g. Marquiss *et al.* 2003c), findings from the ongoing reinforcement of Golden Eagles in the south of Scotland, through SSGEP, are arguably more pertinent.

The south of Scotland is also the region that is similar to the most likely English region (Cheviots) where the species may spread naturally to re-occupy England (section 1, see also Figure 3.3). Since SSGEP began practically in 2018 nearly 50 Golden Eagles have been GPS-tagged as translocated or regionally wild nestlings. Several pairs have established new breeding ranges (Fielding *et al.* 2024a) with more continuing to establish (C. Barlow & A. Fielding unpublished data). There have been no substantiated instances of domestic livestock predation during the project (C. Barlow pers. comm.).

On the reintroduction of the Golden Eagle to Ireland (O’Toole *et al.* 2002): “...*a key early priority was to talk to sheep farmers in the area and reassure them about the eagles. When we approached them in 2000 they were quite nervous, but we had good discussions with them and they spoke to the Scottish National Farmers’ Union and were reassured by farmers themselves, their own peers, that golden eagles aren’t an issue in terms of lambing. That made a huge impact. I would liaise with farmers regularly now and there hasn’t been an issue in over 20 years. In fact, I know several farmers who say they actually like to see the golden eagles, because they keep the grey crow numbers down and grey crows can be problematic at lambing time.*” (L. O’Toole, Golden Eagle Trust: BBC News 2022).

These results from eagles’ reintroduction or reinforcement projects in the UK and Ireland are particularly informative because they involve all or almost all birds being tagged, coupled with intensive efforts from the projects’ staff and volunteers to track both the movements of the tagged birds and follow up directly on any reported issues from the public on interactions with livestock.

Hence, a report was received by SSGEP from management of a large free-range chicken enterprise in the Scottish Borders which had presumed some losses could be due to Golden Eagles. From telemetry data it was known that no Golden Eagle had been near the chicken

farm and follow-up contact from SSGEP staff allayed the undeserved concern (C. Barlow pers. comm.). Similarly, in the second of only three received reports of perceived concern over livestock predation received by SSGEP, a concerned farmer had seen a Golden Eagle on a dead lamb but after request from SSGEP the farmer declined the carcass being subject to a detailed post-mortem to determine the cause of death. The farmer in question subsequently provided informal feedback that while he had concerns about possible lamb predation when the project was begun, he had no issues afterwards despite seeing Golden Eagles almost daily. It can be reasonably assumed that the initial report was most likely scavenging of a dead lamb (C. Barlow pers. comm.). The third report, early in the project, of an “eagle with a lamb” also seemed to be a red herring as the reporter was unwilling to provide SSGEP staff with the claimed ‘evidence’ he supposedly had and was unwilling to take the claim further (C. Barlow pers. comm.).

Such examples are illustrative because they were few in practice and were unsubstantiated as predation events under the scrutiny unusually available through the intensity of several validation methods associated with a Golden Eagle reinforcement project and its dedicated staff effort. They are valuable because the available intensity of knowledge and effort is above and beyond what can typically be brought to bear in studying older and larger ‘wild’ populations or subpopulations elsewhere.

They should also be taken as illuminating as to what may transpire in further reintroduction or reinforcement elsewhere as regards the discrepancy between initial concern over livestock predation and subsequent realised case studies in practice.

### 3.6 Prey Availability

It is important to realise that prey availability and prey abundance are different metrics, and it is extremely difficult to document abundance of potential prey (and other sources of food), never mind what may be available to Golden Eagles within any potential food base. In other words, there may be X prey individuals within a given area, but only Y of these will be accessible or ‘available’ to an eagle. When it is extremely difficult to document meaningful differences in prey abundance (X) alone, even between existing individual home ranges, this makes estimating availability (Y) practically impossible.

Early studies in Central Scotland (under the RECOMP: section 3.5.1) to examine differences in prey abundance (and involving only two prey species) between different home ranges were quickly abandoned, given the substantial level of sampling required (even when using easier proxies of faecal surveys) to provide sufficient statistical power to document any differences. Moreover, the Golden Eagle is an adaptable generalist predator (and scavenger) capable of exploiting a wide range of food sources.

If Golden Eagles are to become established as a non-sink population in England they will need, amongst other things, a sufficiently robust and abundant prey base. Both the abundance and identity of food resources influences the density and productivity of Golden Eagles. In several parts of Scotland, e.g. Morven, there is a high density of eagles, but productivity is consistently very low (e.g. routinely only one fledged young from 10 pairs) almost certainly as a consequence of a small prey base (M. Wilson pers. comm.). Although an adequate supply of carrion may be sufficient to enable pairs to survive for long periods without producing any young, a suitable supply of live prey is necessary for successful reproduction (Watson 2010).

Therefore, a more detailed understanding of prey resources is essential to target the best areas from those identified in WP1 (section 1). However, as noted above, it is important to

understand that even if significant resources are targeted at understanding prey the information return is likely to be qualitative and comparative rather than robustly quantitative: see Haworth & Fielding (2017) for southern Scotland.

The relationship between breeding productivity and land management is complex. In general, in Scotland Red Deer are most likely to exert an indirect influence on prey abundance and availability through grazing pressure either on their own or most frequently in combination with Sheep and burning (Whitfield *et al.* 2008). Unfortunately, neither Sheep statistics nor deer counts correspond to Golden Eagle range boundaries (or their current or potential distribution) making it difficult to assess accurately the impacts of varying levels of grazing on breeding productivity (Whitfield *et al.* 2008). Differing levels of grazing intensity are likely to impact differentially on the various key groups of potential prey, particularly Mountain Hares and Rabbits, and this will vary from region to region (notably as Mountain Hare is restricted to one region of England: section 3.4).

In England, Red Deer are far less abundant than in Scotland, if widely distributed in several English PRZs (British Deer Society 2023), and Sheep are the most abundant grazer likely to influence land quality and Golden Eagle breeding productivity. Similarly, while Red Deer calves can be taken as prey by Scottish Golden Eagles, in some pairs by periodic specialisation (Figure 3.4), the species is unlikely to be a focus for considerations in England of either land degradation or as a prospective prey species.



**Figure 3.4.** *Deer calf legs unusually dominate in prey remains at a Golden Eagle nest in the Central Highlands of Scotland in 2024. © Stuart Benn.*

Fielding *et al.* (2009) and Whitfield *et al.* (2009) demonstrated that, contrary to common perceptions, Golden Eagle productivity was not linked to diet specialisation. Instead, it appears that prey abundance is important, and diet specialisation is an inevitable outcome

when a small number of prey items are super-abundant. These two studies concentrated on pairs in the Inner and Outer Hebrides and found that failed breeding attempts occurred most frequently during incubation or with small young but there is relatively little information on the timing of nest failures. However, regional productivity will be a function of the proportion of pairs laying eggs and the proportion of these nests that go on to fledge young. Similar levels of productivity can be seen but with very different underlying mechanisms. For example, productivity will be low if few pairs lay eggs but most of these are successful, and it will also be low if most pairs lay eggs but few of these nests fledge young.

Lockie (1964) wrote that it was clear “*from the writings of sportsmen*” that wildlife, in northwestern Scotland, was much more abundant in the early 19th century. However, Lockie also notes that, despite the decrease in live prey, there were more Red Foxes and Golden Eagles than previously. Lockie quotes Darling to suggest that the reduction in live prey arose because increasing Sheep density combined with excessive burning had destroyed much of the cover needed by many prey species. Watson (2010) suggests that the tendency for Golden Eagles in the United States to lay larger clutches is due to the better food supply and that there is evidence that clutch sizes have declined in Scotland since the middle of the 19th century.

Relevant, but more recently, after translocating 63 Golden Eagles from Scotland over 12 years (2001-2012) the goals of the Irish Golden Eagle reintroduction (O’Toole *et al.* 2002) are not being fully realised even with a stable population (Golden Eagle Trust 2013, Donegallive 2020). With some cases of persecution affecting survival, the stalling of these goals has been ascribed largely to poor breeding productivity. This poor performance has been linked to recent habitat degradation in an ecosystem increasingly in imbalance, despite EU Natura2000 designations, through adverse effects of climate change, overgrazing, burning and a mesopredator (Red Fox)<sup>25</sup> on eagles’ key prey species (Golden Eagle Trust 2020, Birdwatch Meath 2020, BBC News 2022). This has been despite, and not anticipated by, prior evaluations of adequate food abundance to support the reintroduction (Birdwatch Meath 2020, Golden Eagle Trust 2013, 2020).

This may be a cautionary example on predictions of “prey availability”, although as yet it does not seem to be replicated by the results of the SSGEP in southern Scotland, that are more encouraging - not least the rate and timing of new breeding ranges that have been occupied by a lower number of birds (released and wild-bred).

In eastern and central Scotland, the dietary breadth in live prey taken by Golden Eagles may involve only a handful of species, with just two dominating (Red Grouse and Mountain Hare: Watson *et al.* 1989, Watson 2010, Whitfield *et al.* 2022). In the Hebrides of Scotland these two species are also taken locally, but dietary breadth is much wider, although some pairs may specialise in Rabbits (e.g. Uists and Skye) or seabirds (Fielding *et al.* 2009, Whitfield *et al.* 2009). A shortage of key preferred prey species may be linked with poor breeding productivity in some cases (e.g. Golden Eagle Trust 2013) even if often it is not (Fielding *et al.* 2009, Whitfield *et al.* 2009). Elsewhere in mainland Europe, a wide variety of prey is not uncommon in association with high breeding productivity. For example, in southern Poland over 50 species were recorded as food (Stój *et al.* 2024) and breeding

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<sup>25</sup> An interesting suggestion, given the possibility of mesopredator suppression by Golden Eagles, including Red Fox (section 3.2.2). Along with the observation of Lockie (1964) on the rise of both Red Foxes and Golden Eagles, this may indicate, along with some other evidence, that Golden Eagles are limited in their capacity to suppress Red Fox numbers.

productivity was relatively high. As emphasised by Whitfield *et al.* (2009) it is not the number of prey species that is important, it is their abundance. And as noted at the head of this section, prey abundance for large raptors is difficult to quantify and prey availability is usually beyond quantification. One must assume that there is some relationship between the two metrics.

On the domestic front, the Hebridean dietary studies involved tens of food items (Whitfield *et al.* 2009). While several of these were seabirds, it still leaves many prey species whose abundance may be important in an English setting. Some may probably be more important than others (e.g. Rabbits and Red Grouse) but there are still others whose abundance may be influential too, if not individually then cumulatively. Information is available on the diet of the Lakeland birds from the temporary recolonisation in the late 20<sup>th</sup> century (e.g. Walker 1990) but as this event was ill-fated, and in the past, this information may not be the best guide.

Given the number of prey species potentially involved, it would not be usefully informative at this stage of any recovery plan to present, not least try to interpret, information showing the distribution of various and numerous avian or mammalian prey species across England, even though these are available if, in some cases, dated (e.g. Gibbons *et al.* 1993, Crawley *et al.* 2020).

Measures of landscape productivity, or factors associated with it (e.g. Growing Days and Less Favoured Areas: Data Dictionary) may provide an adequate surrogate for the potential abundance of food, both live and carrion (Whitfield *et al.* 2008). NDVI (Normalized Difference Vegetation Index) also provides a measure of vegetation productivity (e.g. Lunetta *et al.* 2006), and this may be an additional surrogate. There could also be quite large differences between some hill groups in NDVI implying that there may be less live prey in some regions (e.g. Lakes). This must be treated with caution because the amount of vegetation biomass available to potential Golden Eagle prey also depends on the 'equity' remaining after accounting for that consumed by domestic livestock such as Sheep (Whitfield *et al.* 2008). Also, whilst it is unlikely that the NDVI can ever provide a precise estimate or a proxy of Golden Eagle prey, if only because it cannot be used to locate Rabbit warrens, it is reasonable to assume that large differences in NDVI can be related to the potential prey in a region. If the vegetation is in poor condition, however, it is unlikely that it will support much eagle prey whilst vegetation in good condition has the potential, which may not be achieved, to support more eagle prey.

Rabbits may be an important potential prey locally in England, as elsewhere. Their colonial/semi-colonial distribution (warrens), often nocturnal habits, changing abundance according to disease outbreaks and any subsequent recovery, and their status as agricultural pests makes them especially challenging to survey and assess their abundance. Large-scale remote simple distribution maps (e.g. Crawley *et al.* 2000) will probably be inadequate, and field effort could well be required in locales where reinforcement of Golden Eagle numbers may be specifically considered.

Regions or areas dominated by management for Red Grouse shooting account for much of several PRZs identified in northern England. Here there is deliberate management to produce high Red Grouse numbers. In such situations Red Grouse is a preferred prey of Golden Eagles. Nevertheless, for example, given that some Red Grouse shooting estates in northeastern Scotland have large quantities of potential Golden Eagle prey but no breeding Golden Eagles, an abundance of prey, by itself, may not be a good indicator of

Golden Eagle distribution if there is an association between Red Grouse shooting estates and a relatively severe risk factor of intentional disturbance otherwise.

A focus on prey abundance and its adequacy to support a Golden Eagle (sub)population in England is most appropriate to any future decision for a reintroduction and/or reinforcement project (e.g. Haworth & Fielding 2017). Golden Eagles disperse well beyond their natal/release site (Fielding *et al.* 2024b) and so that focus should not necessarily be restricted to the site/region of reintroduction/release. But through natal philopatry quantified by Natal Dispersal Distances (Whitfield *et al.* 2024) the release site and its environs will form the locus for where birds later decide to establish a breeding range. Therefore, this is where greatest attention should be paid to evaluating prey abundance.

While the material in this report may help inform whether, and where, such a release site may be needed or decided upon in the future, now it is beyond the scope of the report to be more specific in any regional evaluations on prey abundance. These more specific evaluations should be part of any deliberate plans for a reintroduction/reinforcement, along with other considerations (e.g. Dennis *et al.* 2019). Some generalisations can be made, however.

First, to reiterate, Golden Eagles can take a wide variety of prey (Figure 3.4) and, even when there are few species of sufficient abundance for specialisation and high reproductive output, breeding productivity can still be sufficient to sustain a viable population (although see earlier in this section on the Irish Golden Eagle reintroduction).

Second, also reiterating a common theme of this report, in much of northern England there will obviously be sufficient live prey in Red Grouse, as high numbers are encouraged by driven shoot managers. Those same managers, however, may not see the presence or reintroduction of a novel top predator as welcome, given the reaction of some to other raptorial grouse predators. This dilemma will need to be addressed, as SSGEP appears to have done successfully so far.

Finally, leaving aside the Cheviots, if it is accepted from prior history, proximity to Scotland and SSGEP this region should be where any natural re-colonisation will hopefully occur (section 1). Other risk factors or geographic features may be involved in other PRZs on possible unsuitability (e.g. isolation), but of the other northern PRZs the Lakes are possibly one of the least intrinsically suitable and prey-depauperate because of prolonged heavy Sheep grazing, low upland vegetation diversity and weather, reflected in a low diversity of raptors (e.g. Gibbons *et al.* 1993), even in the absence of substantial persecution.

Nonetheless, to return to the start of this report (section 1.2.2), in a somewhat mysterious event away from the terrestrial border with Scotland, the Lakes were where the Golden Eagle re-colonised England in recent (if short-lived) history.



**Figure 3.4.** *From one extreme to another: prey items at a Golden Eagle nest in Argyll, southwest Scotland, 2024: Short-tailed Vole (top), young Red Grouse (middle) and Red Deer calf (bottom). © Scott Smith.*

### 3.7. Conclusions

The novel presence of Golden Eagles in England may result in them influencing smaller predators (mesopredators), affecting their distribution and abundance through a combination of direct predation and indirect fearful responses. Available evidence suggests that this is less certain for mammalian mesopredators (e.g. Red Fox) which may be because such mammals can escape such possible effects by nocturnal behaviours. For some smaller raptors, there are studies showing that Golden Eagles could affect their distribution and abundance (including through Intraguild Predation). But as faunal communities are complex, so are predicting the consequences of a renewed presence of a top predator. While Golden Eagles may have an adverse effect on some smaller raptors, they may also have a beneficial effect by also suppressing their competitors. Mesopredator suppression effects also pale against effects of persistent and sustained illegal persecution (in the case of smaller raptors).

The presence or restoration of top predators (such as Golden Eagles) has frequently been found to be associated with significantly beneficial knock-on effects on biodiversity. This does not appear to be a 'given' (again through the complexities and other factors affecting any ecosystem/community) but there are few, if any, studies that significantly show the opposite depreciation. It is a reasonable conclusion that the renewed presence of breeding Golden Eagles in England will be at best beneficial for biodiversity and at worst neutral.

For Birds of Conservation Concern, three species were considered as potentially most vulnerable to a renewed English presence of Golden Eagles (Black Grouse, Merlin, Hen Harrier). While all three species would likely be preyed by Golden Eagles (if, or when, sympatric in England: certainly, Black Grouse) our reviews suggest none should be additionally adversely affected by Golden Eagles.

No populations of mammals of Conservation Concern were judged to be vulnerable to a renewed presence of Golden Eagles in England.

Our review of possible effects on (prey) species of economic interest centred on Red Grouse and Sheep (lambs). There are expansive areas, across many English PRZs, where Red Grouse numbers are deliberately elevated by intensive management practices to satisfy an economic model that requires very high densities for profitable driven shoots. Unfortunately, that economic model seems to be associated in several places with the need for raptor 'control' (i.e. illegal killing). Golden Eagles would undoubtedly take many Red Grouse in such areas and if left alone they would thrive. Hoping to be left alone, however, could be optimistic given current attitudes to other smaller raptors on several English driven grouse moors. This dilemma will need to be addressed, as SSGEP appears to have done successfully so far.

There will likely be concerns raised by interested parties on what predatory effect Golden Eagles may have on lambs, especially in any release programme through reintroduction or reinforcement. Our review, covering results from several releases of both Golden Eagles and White-tailed Eagles, illustrates that in practice both species have not been found to have any effect at all or, at worst, have any significant economic effect. There are several examples of this from intensive studies surrounding release projects. The perception of possible adverse effects will remain from some stakeholders, however, so that this will be a concern, and will undoubtedly be an issue that will need to be addressed before any active enhancement efforts are pursued in England through reintroduction/reinforcement.

Within limits, the Golden Eagle can take a broad range of foods, even if there can be preferences (such as grouse and lagomorphs). Prey availability is impossible to quantify even locally, never mind regionally, or nationally. Prey abundance is slightly more tractable to describe comparatively but is still near-impossible practically to quantify for a predatory species which occurs at low density. Specialisation occurs when there are few food sources in high abundance (e.g. Red Grouse and Mountain Hare) and this can be associated with high breeding productivity. Golden Eagle breeding productivity seems to depend not just on the capacity to specialise, however, but on the abundance of all potential prey sources. Some remote measures of 'land productivity' can be useful and, obviously, in the absence of persecution risk there will be more than adequate Red Grouse as food where this gamebird's numbers are actively encouraged.

Nevertheless, evaluating the abundance of numerous potential prey species across England is impossible; or even if assisted via proxies on 'land productivity'. It is also a subject best reserved for more focused spatial evaluations along with other considerations should a reintroduction/reinforcement be deemed necessary and/or possible.

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# Data Dictionary

## Golden Eagle distribution and general biology

### Historic Golden Eagle sites

Evans *et al.* (2012) used place name information to identify Golden Eagle nest locations going back hundreds of years. An Excel spreadsheet of the locations was provided by the authors.

Their data set was used to validate the South of Scotland predictions and new ranges have appeared close to the old place names. These data are used for the same purpose in England.

### Dispersal behaviour

Prior to dispersal, fledged young eagles take exploratory flights but young stay in their natal territory for much more variable time than previously thought. There is a wider range (39-250 days after fledging) for males than females (100-230 days) (Weston *et al.* 2013, 2018). There are other sexual differences as males have bimodal dispersal dates of around modes of 89 and 220 days after fledging while females have unimodal dispersal date of ~168 days post-fledging. Following dispersal (leaving the natal range) birds undertake potentially wide ranging exploratory flights with occasional temporary settlement but there is no consistent behaviour, even amongst siblings.

At the end of the dispersal phase birds need to find a place to settle. First territory settlement is a critical decision which large raptors should theoretically devote considerable effort to acquire accurate information during prospecting that is assumed to be part of the dispersal phase. Fielding *et al.* (2023a) suggested there were two extremes in prospecting behaviours: “Quick, grab it when available with limited reconnaissance”, as opposed to “Slow, waiting game with frequent reconnaissance”. Fielding *et al.* (2023a) analysed pre-settlement data from GPS-tagged nestling Golden Eagles, later recorded as having settled on their first territory. There was substantial variation in prior visits, between less than 10 to several hundred. It was expected that there would be a positive association between number of prospecting visits and natal dispersal duration, giving more time to gather information via more visits. It was also expected there would be fewer prospecting visits in prior vacant territories, which has clear relevance for a recovering English population. However, as neither of these expectations were supported by the data the process by which determine where to settle remain unclear although two reasonable explanations have been ruled out.

### Dispersal distance

Natal dispersal distance (NDD) is the linear distance between the natal location and the first reproductive location after dispersal and is, therefore, very important for understanding how, and at what speed, Golden Eagles could recover in England by natural expansion.

Whitfield *et al.* (2024) analysed natal dispersal data from 39 Golden Eagles GPS-tagged in Scotland to estimate NDD. Raw median estimates were a significantly shorter 29.8 km for males (n = 22) compared with 58.6 km for females (n = 17) (overall average of 38.1 km).

The time needed to prospect a territory opportunity was not associated with the selected territory's distance from the natal site.

## Barriers to movement and Isolation

Significant barriers to Golden Eagle movements could result in demographic and genetic consequences which would be important in a recovering English Golden Eagle population. The Fielding *et al.* (2024a) study used data from more than seven million dispersal records from satellite tags fitted to 152 nestlings to see if there was evidence of barriers to dispersal movements. Movements across a region of largely unsuitable lowland habitat (the Central Belt) between two upland regions were very rare. This was expected from the GET model, and supported the need to translocate eagles from the north into the South Scotland to make this isolated population more robust. This has consequences for isolated PRZs in England.

Second, larger expanses of water are a barrier. There were no movements of tagged Golden Eagles to or from the Outer Hebrides although a sub-adult translocated to the South of Scotland subsequently returned to the Outer Hebrides from the tip of Skye. Open sea or sea lochs crossings elsewhere in Scotland were consistent with an increasing reluctance to cross wider stretches of water.

Based on telemetric results, this study also suggested that natural movements from the South of Scotland into England were most likely via the Cheviots because the distance across the Solway Firth and the surrounding lowlands reduced the probability of direct flights into the Northern Lakes. It should be noted that dispersal distances will be greater than the natal dispersal distances (NDDs) and NDDs are the better arbiter for connectivity between PRZs.

## Home Range Size

Estimating the number of home ranges that could be supported by a PRZ depends on knowing the probable extent of suitable habitat plus the probable home range size. Fielding *et al.* (2024b) estimated golden eagle home range sizes using data from satellite tracked range holding Golden Eagles.

*From Table 4 of Fielding et al. (2024b) - Mean 95% isopleth areas (ha) ± standard deviations by region of the planar area, the area of GET 6+ habitat.*

Region	Planar Area	Area of GET 6+
Argyll	7190 ± (4738)	5141 ± (3315)
NE	8871 ± (6267)	6697 ± (3925)
NW Highlands	6335 ± (3139)	4842 ± (2678)
South of Scotland	10,443 ± (5537)	7636 ± (4423)
Outer Hebrides	2439 ± (940)	862 ± (393)

The South of Scotland home ranges (n = 7 with at least 12 months of data) were the largest by region which may reflect their status as new ranges in an area with few extant home ranges. As such, they are probably the best model for a recovery in England. The mean home range area in the South of Scotland was 10,443 ha, of which 7,636 ha was GET 6+ habitat (~73%).

In England, it is assumed that a new home range will be 10,000 ha with at least 7,000 ha of GET 6+ habitat.

### Satellite tracking data

Satellite tracking data were available for 24 individuals who crossed the border into England. All but one were deployed by the South of Scotland Golden Eagle Project (SSGEP); the other tag was deployed by Ruth Tingay. Tag data up to September 30th 2024 are used, although if subsequent data show a tag with an increased attachment to England this will be included in the discussion.

Tag data are not used to define suitable habitat in England. Instead, these data are used to validate conclusions about English PRZ.

### GET Model

The GET model (Fielding *et al.* 2020) assigns a score between 1 and 10 to 50 m pixels. Land with large contiguous blocks having a GET score of 6+ is a good indicator of potential Golden Eagle activity.

Land with extensive areas, with a score <6, is used infrequently by Golden Eagles in Scotland and in Greece where a related model was developed (Sidiropoulos *et al.*, 2024).

However, Golden Eagles also tend not to use land with a closed canopy forest cover, irrespective of the GET score which is derived from topographic data only.

Since its development the GET model has been tested with a very large amount of new data, including from range holding birds, and the model has performed very well (See Appendix A in Fielding *et al.*, 2023b for details of the tests). We extended the GET model to the remainder of the UK.

Figure 1 shows the GET landscape in England, Wales and the South of Scotland.

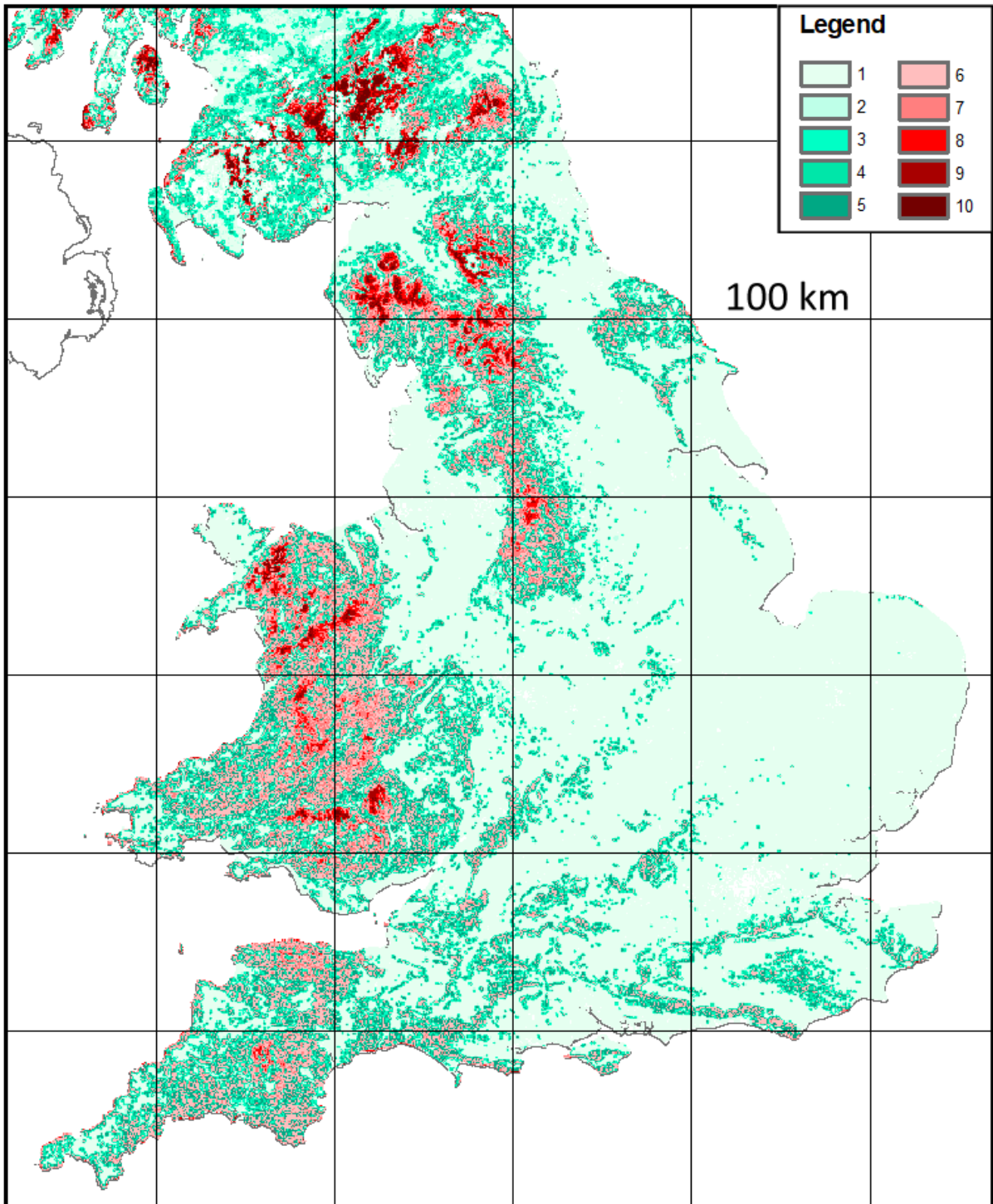


Figure 1. The GET landscape in the South of Scotland, England and Wales. Contains Ordnance Survey data © Crown copyright and database right 2020.

Information of range sizes, including the area of GET 6+ land, is to estimate the number of pairs which could be supported by each PRZ. Fielding *et al.* (2024b) had information from ~70 ranges spread across Scotland.

## Species Distribution Model (SDM)

The random forest species distribution model (SDM) developed by Fielding & Haworth (2014) to make predictions for the South of Scotland to predict *potential nesting areas* south of the Scottish border is used to make similar predictions in England.

### The Fielding & Haworth (2014) model

Active ranges (A) were occupied by a pair of birds during a national survey; vacant ranges (V) had a history of supporting a pair but, at the time of the survey, there was no evidence of resident eagles. A null range centre (N) had no history of occupation by a pair of Golden Eagles and the location was selected as a random point constrained to be outside of a range boundary (vacant and active ranges, derived using the PAT model (McLeod *et al.* 2002)) and a minimum of 1 km from the coast. The separation from the coast prevented locations that were largely sea. Habitat data used in the model were extracted from 1 km radius circles drawn around A, V and N range centres (434 A, 251 V and 701 N). Extant Golden Eagle ranges in the South of Scotland were excluded to provide an independent preliminary test of the model.

Predictor summaries were obtained for 1 km radius circles around the point locations. All topographic data were from a 50 m Ordnance Survey (OS) DTM. The summarised predictors:

- Altitude (minimum, maximum, mean, median and standard deviation);
- Slope (maximum, median and standard deviation) in 5° increments;
- Weighted distance to a ridge (minimum, maximum, mean, median and standard deviation) as described in section 2.3.1 of Fielding and Haworth (2014);
- Area covered by a Corine land cover class (see below).

*Note - these analyses preceded the GET model. However, altitude, slope and distance to a ridge are the three elements in the GET model.*

Although LCS88 habitat data had more attribute classes and a finer spatial resolution than Corine data its age (1988) was considered a problem. Although not a concern at the time, it would have been impossible to extend the model to England had the original model used LCS88 data. Although a new, post-2014 model could be developed using the more detailed Scotland Habitat and Land Cover Map 2020 it would also not be possible to extend the model's predictions beyond Scotland.

Predictors related to prey abundance would be helpful but were unavailable at a national scale. Even data such as national sheep *Ovis aries* statistics were of limited value because publicly available data are summarised at the parish scale and parishes can be very large and there is no reason to suppose sheep are evenly spread throughout a parish.

The class of each point (A, V or N) was predicted using a random forest analysis with 5,000 trees. Each location had a prediction based on the number of votes for each class when it was in the out-of-bag sample (see Box 1), and it was assigned to its majority class.

A more extensive test data set was created for Scotland consisting of a regular grid of data points separated by 500 m, but not within 500 m of the coast. The same predictor values were extracted for 1 km radius circles centred on the test data points. A prediction was made for each point using the trained random forest to produce a national map of predicted Golden Eagle breeding habitat. The map was overlaid with actual range locations, historic Golden Eagle locations from Evans *et al.* (2012) and, where available, locations of young birds obtained from satellite tracking studies. Using this information,

the accuracy of these predictions was tested and also used to identify potential future range locations and exclude predicted locations that are likely to be affected by factors not included in the model's development, such as wind farms. Results from the random forest model from Fielding & Haworth (2014) are described in Box 1. The model's predictions (Figure 7a in Fielding & Haworth, 2014) have subsequently accurately predicted the locations of at least 20 new ranges and re-occupied ranges across Scotland.

**Box 1 The random forest model from Fielding & Haworth (2014)**

- **Areas not used as Golden Eagle breeding habitat tended to be on lower ground with smaller slopes.** Vacant ranges tended to be at slightly higher altitudes than active ones but with slightly reduced slopes.
- Weighted distances-to-ridge values are not Euclidean and, because weights decrease in a non-linear fashion away from ridges, larger values indicate greater proximity to ridges. **Samples from non-breeding locations were further from ridges and there was much less variability in the weighted distances.** Vacant ranges tended to have slightly smaller weighted distances suggesting that there was less ridge habitat in vacant ranges. [Note it is unclear if this is cause and effect or a consequence of such topography being more suitable for commercial forest resulting in a significant loss of open land.]
- All predictor means associated with human activity, including agriculture and pastures, were much greater in the non-breeding habitat samples. There was also more woodland of all types. **Eagle breeding habitat, of both classes, was characterised by more natural grassland, moors and heathland, bare rocks and sparsely vegetated areas.** Vacant ranges had more than double the mean area of pastures and coniferous woodland than the active ranges but slightly less natural grasslands and moors and heathland. Vacant ranges had, on average, about 50% more sparsely vegetated areas.
- It is important not to place too much emphasis on mean differences. Golden Eagle habitat varies considerably across Scotland. For example, many vacant ranges in the east of Scotland are at higher altitudes than active ranges in the west. Vacant ranges in the east are generally not vacant because of large forest plantations while, in the west, there are some vacant ranges at reduced altitude because of afforestation. Random forest analyses are an ideal tool to deal with this type of context dependency because the data are partitioned at nodes and each partition below the noted is subsequently treated separately. This allows for the situation in which, for example, ranges may be vacant for a variety of different and unconnected reasons.

Each tree in the random forest is generated from a random sample. A proportion of cases, the out-of-bag sample, is held back for testing the tree. Each case in the out-of-bag sample is predicted (voted) to be either A, V or N. After 5,000 trees have been generated, each case has a number of votes for each class and the case is assigned to its majority class. Because cases are included in the out-of-bag sample approximately the same number of times (~1,825 times ~36.5% of trees) the votes for each case are normalised to proportions that sum to one.

Table 1 shows how cases were classified by the model. About 20% of active ranges were misclassified but most of these (13.6%) were as vacant ranges, i.e. their characteristics were more similar to vacant ranges than with the other active ranges. The error rate for vacant ranges appears high at almost 75%, however three quarters (140 of 187) were misclassified as active ranges, suggesting that many vacant ranges may be able to support breeding Golden Eagles. Some of those vacant ranges were suitable but remained vacant because there were insufficient recruits or birds were prevented from settling. In recent years many of these vacant ranges have been re-occupied, further

validating the model. Very few of non-breeding sample points (5.8% or 41 of 701) were misclassified as either active or vacant eagle ranges, and mainly as vacant ranges. **Table 1. Training set confusion matrix. Upper table is frequencies, lower table is percentages. For example, 59 (13.6%) of active ranges were predicted to be vacant and 26 (6.0%) were predicted to be non-ranges (N).**

	A	V	N	n
A	349	59	26	434
V	140	64	47	251
N	13	28	660	701
A	80.4	13.6	6.0	
V	55.8	25.5	18.7	
N	1.9	4.0	94.2	

The importance of the predictors to the assignment of breeding class is measured by the mean decrease in the Gini index (Table 2).

A Gini index measures node homogeneity from 0 (homogeneous) to 1 (heterogeneous), i.e. is a node is made up of cases from more than one class and in what ratio? Each time a predictor splits the data at a node, the Gini coefficients for its child nodes are calculated and compared to that of the original node. Gini changes are summed for each predictor and normalized once all trees are constructed. The normalised Gini index scores indicate the relative importance of predictors as those that result in nodes with greater homogeneity (a better separation of the classes) have a higher decrease in Gini coefficient.

Table 2 ranks predictors according to the mean decrease in the Gini index.

- **The most important predictor was the Corine moors and heathland habitat class.** Mean values for the area of this habitat were very similar for the active and vacant eagle ranges (790.0 and 730.1 ha respectively) compared with only 125.3 ha for non-breeding habitat.
- All of the altitude predictors had Gini decrease indices in the top ten. The most important was the altitude standard deviation (means of 101.8, 84.2 and 29.8 m respectively for active, vacant and non-breeding classes).
- Slope variability and the maximum slope were the second and third most important predictors with much larger values for the two range classes.
- **Thus, Golden Eagle ranges were topographically more variable than the non-breeding samples.** They were also, on average, higher but there was evidence for active ranges having a lower mean. The weighted distance-to-ridges, and its variability, were also important predictors.
- The other Corine habitat variables were less important predictors.
- Given the very large differences in the mean area of pastures (9.9, 18.1 and 350.3 ha respectively for active, vacant and non-breeding classes) it is perhaps surprising that this isn't a more important predictor.
- The next two most important Corine habitat predictors both had gradients from active to non-breeding habitat but operating in different directions. Natural grasslands had a larger mean area for active ranges (187.7 ha) than vacant ranges (161.7) and non-breeding habitat (120.0 ha) while coniferous forest was most extensive (150.0 ha) in non-breeding habitat.

- Vacant ranges had more than twice as much conifer forest (71.3 ha) compared with active ranges (31.4 ha).

**Table 2.** *Predictor importance statistics, figures are the mean decrease in the Gini index.*

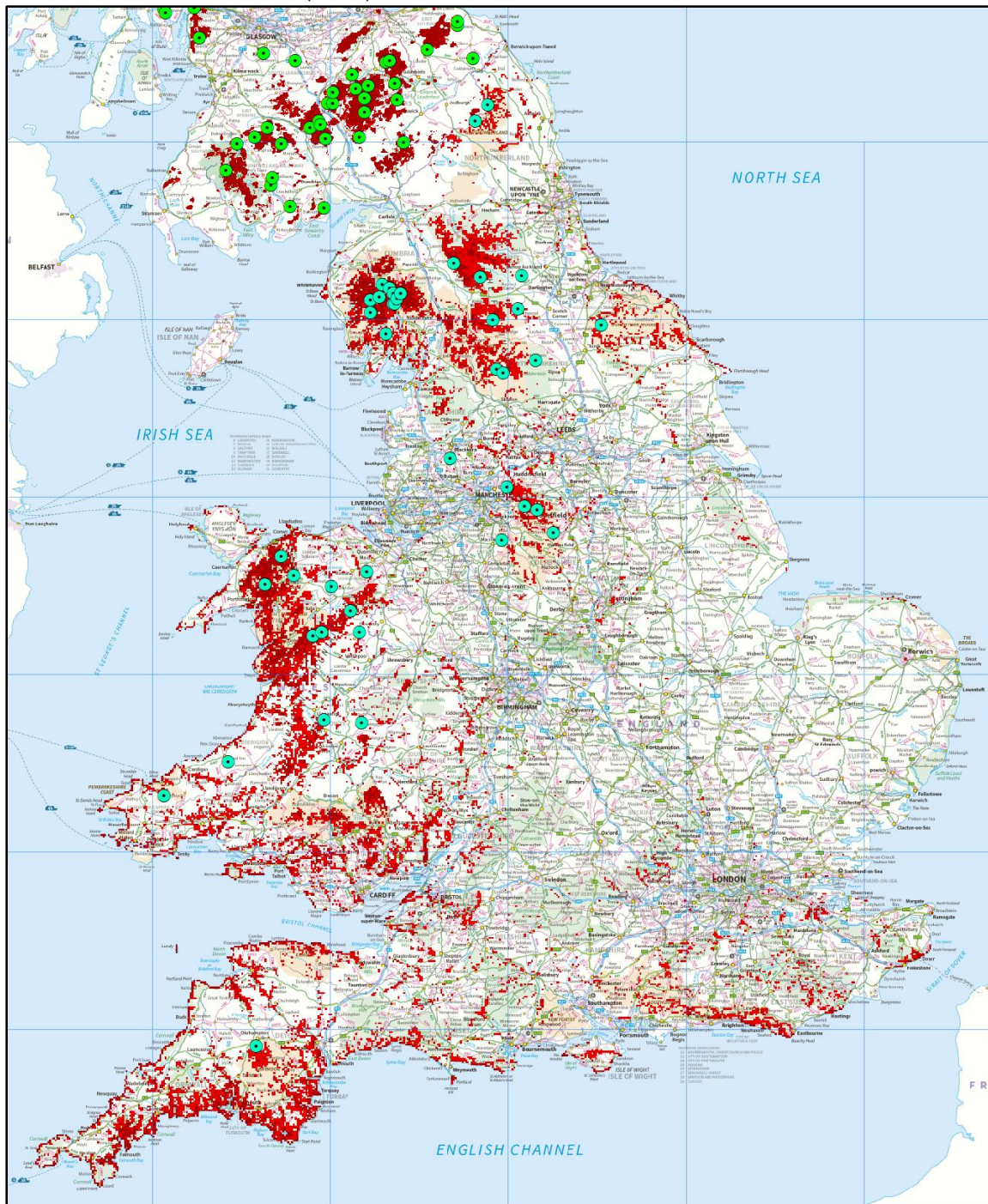
Predictor	Decrease
Moors and heathland	105.4
Slope sd	79.0
Slope maximum	74.0
Weighted distance-to-ridge mean	73.4
Altitude sd	66.8
Weighted distance-to-ridge sd	56.2
Altitude minimum	45.1
Altitude maximum	44.7
Altitude mean	40.4
Altitude median	38.8
Pastures	37.6
Weighted distance-to-ridge median	34.7
Natural grasslands	21.7
Coniferous forest	21.2
Slope median	19.1
Weighted distance-to-ridge minimum	15.0
Sparsely vegetated areas	14.6
Sea and ocean	9.8
Peat bogs	8.6
Water bodies	5.8
Bare rocks	5.5
Transitional woodland-shrub	5.3
Weighted distance-to-ridge maximum	4.6
Agriculture, with significant areas of natural vegetation	3.7
Non-irrigated arable land	3.7
Broad-leaved forest	2.2
Complex cultivation patterns	0.9
Discontinuous urban fabric	1.0
Mixed forest	0.8
Sport and leisure facilities	0.2
Industrial or commercial units	0.0
Mineral extraction sites	0.0

### **Predicting Golden Eagle breeding habitat in England and Wales**

The 2014 SDM was used to make predictions for the whole of England and Wales by creating datasets with the same predictors but, this time, for 1 km square grid cells covering all of England and Wales. Wales was included because it was important to know if potentially suitable Golden Eagle habitat, near to the border, was connected to potentially suitable Golden Eagle habitat in Wales. No further attempt is made to estimate the potential of Wales to support Golden Eagles.

Figure 2 maps predicted Golden Eagle breeding suitability for England, Wales and Southern Scotland. No data from these areas was included in the training data.

Generally, there is a good match between areas predicted by the model and the historic sites listed in Evans *et al.* (2012).



**Figure 2.** Predicted Golden Eagle breeding areas using the random forest SDM. Shading is the proportion of votes for the combined active or vacant classes with red being 0.333 to 0.58 and dark red >0.58. The coloured circles are historic Golden Eagle sites from Evans *et al.* (2012) with the green circles being in Scotland. The grid is 100 km. Contains Ordnance Survey data © Crown copyright and database right 2020.

# Land Cover and Land Use

## Forestry (NFI2022)

[https://data-](https://data-forestry.opendata.arcgis.com/datasets/9149ff1ab1a24f87ba1a60837bae872e_0/explore)

[forestry.opendata.arcgis.com/datasets/9149ff1ab1a24f87ba1a60837bae872e\\_0/explore](https://data-forestry.opendata.arcgis.com/datasets/9149ff1ab1a24f87ba1a60837bae872e_0/explore)

Contains, or is based on, information supplied by the Forestry Commission. © Crown copyright and database right 2021 Ordnance Survey [100021242].

*“The National Forest Inventory (NFI) woodland map covers all forest and woodland area over 0.5 hectare with a minimum of 20% canopy cover, or the potential to achieve it, and a minimum width of 20 metres. This includes new planting, clearfell, windblow and restock.”*

Almost 60% of the forest estate in Scotland is Conifer (35.6%) or Felled trees (22.5%). In England almost 60% of the forest estate is Broadleaf (58.7%) with 18.4% Conifer cover.

It is supplied in a vector format with 638,792 polygons (England, Scotland and Wales). Consequently, it was converted to a 50 m raster for analytical purposes.

There are effectively no trees in the Outer Hebridean Golden Eagle home ranges.

Conifer cover is the largest category in the South of Scotland Golden Eagle home ranges (8.3%) and within 5 km of all Scottish ranges (6.4%) but these low figures support the view that densely forested land is land that is unsuitable for Golden Eagles (Whitfield *et al.* 2001).

## Corine land cover

Cole, B.; De la Barreda, B.; Hamer, A.; Codd, T.; Payne, M.; Chan, L.; Smith, G.; Balzter, H. (2021). Corine land cover 2018 for the UK, Isle of Man, Jersey and Guernsey NERC EDS Environmental Information Data Centre. <https://doi.org/10.5285/084e0bc6-e67f-4dad-9de6-0c698f60e34d> Contains data supplied by UK Centre for Ecology & Hydrology.

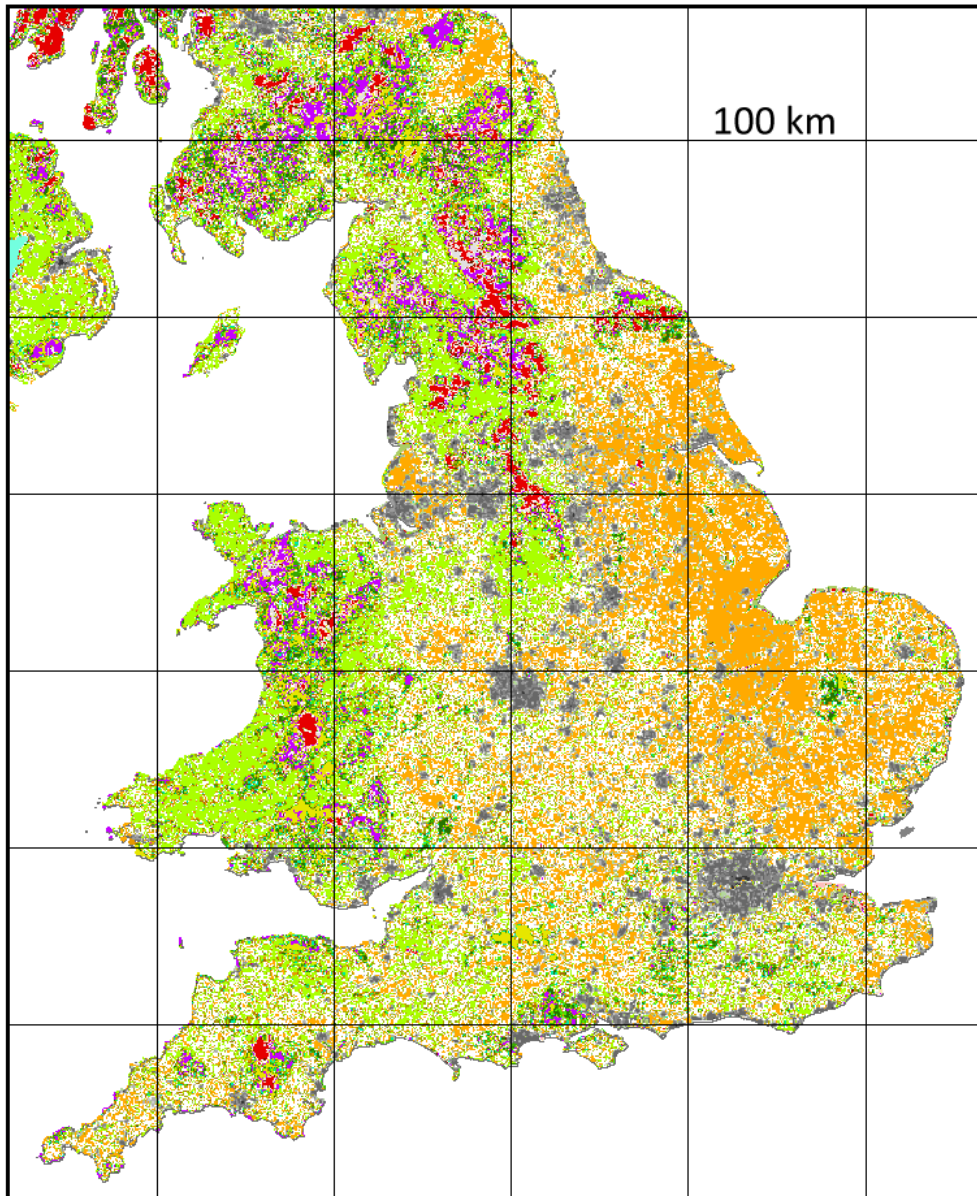
This data set is from the pan-European CORINE Land Cover inventory. There are 44 thematic classes for the 2018 reference year, although not all are present in the UK. The dataset has a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a Minimum Mapping Width (MMW) of 100 m for linear phenomena and is available as vector and as 100 m raster data.

Unlike the recent English and Scottish land cover maps this data set has a national coverage enabling comparisons between land cover in England and Scotland.

Figure 3 is map of the Corine classes in England, Wales and the South of Scotland.

**Legend**

Continuous Urban Fabric	Green urban areas	Coniferous Forest	Inland marshes
Discontinuous Urban Fabric	Sports and Leisure	Mixed Forest	Peat Bogs
Industrial, Commercial Units	Non-irrigated arable land	Natural Grassland	Salt Marshes
Road and Rail Networks	Fruit and Berry Trees	Moors and Heathlands	Water Courses
Port areas	Pastures	Woodland-shrub	Water Bodies
Airports	Complex Cultivation	Beaches, dunes & sand	Coastal Lagoons
Mineral extraction	Agriculture (significant natural vegetation)	Bare rocks	
Dump sites	Agro-forestry	Sparsely vegetated	
Construction sites	Broad-leaved Forest	Burnt areas	



**Figure 3.** A 50 m pixel raster covers the UK. Thirty-two land cover classes are present although we pool the first 11 into one anthropogenic category. Anthropogenic; Broad-leaved forest; Coniferous forest; Mixed forest; Complex cultivation; Fruit trees; Agriculture with some natural vegetation; Non-irrigated arable; Pastures; Natural grasslands; Moors and heathland; Peat Bogs; Transitional woodland-shrub; Beaches, dunes, sands; Bare rocks; Sparsely vegetated areas; Burnt areas; Inland marshes; Salt marshes; Water courses; Water bodies; Coastal lagoons.

## Less Favoured Areas (LFA) and Moorland Lines Layer

ENGLAND <https://environment.data.gov.uk/dataset/8dc2b71d-8cf5-427f-8af9-41a9dbba495a>

SCOTLAND <https://spatialdata.gov.scot/geonetwork/srv/api/records/f4e358c1-df06-4107-bfd2-03f7581ecb07>

Mountains and uplands in the UK are generally found where rocks are resistant to erosion. Over 60% of the British upland and marginal upland landscapes have a predominant rock type of acid igneous or metamorphic. The distribution of rock types in Britain mean that uplands are largely absent from the east and south. Indeed, there are few significant uplands south of a line drawn between Scarborough and Bath.

The type of rock has profound ecological influences on, for example, soil type and topography. The relationship between geology and ecology introduces a complication because northwestern Britain has an almost unrivalled diversity of rock types and differences in upland topography have marked effects on vegetation and the breeding bird fauna. For example, the mountains around Ben Nevis have a much poorer avifauna than the Cairngorms; which is partly explained by differences in landform with Ben Nevis being a much more rugged mountain than the Cairngorm's wide expanse of granite plateau dissected by deep glacial valleys. Many upland boreal birds need slopes of less than 15° for breeding, hence they tend to be absent from the more rugged mountains usually associated with older metamorphic rocks.

Rocks that are resistant to weathering tend to be deficient in calcium. Since many rocks in northern Britain are calcium-deficient, the resulting soils are generally acidic with low productivity. The importance of calcium can be seen in the few upland areas where it is more plentiful, for example Ben Lawers and Y Wyddfa and the flora is richer and more similar to that in European alpine regions. High rainfall in the uplands exacerbates the shortage of calcium, reducing soil pH. The combination of high rainfall and low pH leads to the accumulation of undecomposed organic material in the form of peat and the resultant acidic, nutrient-poor soils cannot support productive vegetation. This in turn affects the land use which is the basis for the government's Less Favoured Areas (LFA) and Moorland Lines datasets which recognise the difficulty of farming in these areas (Figure 4).

The LFA designation is derived from land cover and is defined as predominantly semi-natural upland vegetation, or predominantly of rock outcrops and semi-natural vegetation, used primarily for rough grazing. The Moorland Line is a further land designation within the LFA, and is also used under domestic legislation to target support for the uplands. Land inside the Moorland Line is not just characterised by its vegetation; because it is not economically viable to grow crops but there is also an absence of field boundaries. This open landscape, used largely for grazing, is typical Golden Eagle habitat across Scotland, Ireland and elsewhere in the world. The LFA and Moorland Line datasets may be particularly useful surrogate for Golden Eagle habitat as they integrate many topographic, land cover and weather-related factors.

Most of Scotland, and all of its Golden Eagle areas, are in the severely disadvantaged class or have a forest cover. Scotland's agriculture is limited by its climate, topography, and soils, which means that much of the country's grassland is low quality. The type of farming that takes place in Scotland varies by region: North west: Predominantly sheep farming; East: Larger, productive cereal farms; and South west: Productive beef farming and the majority of the dairy industry.

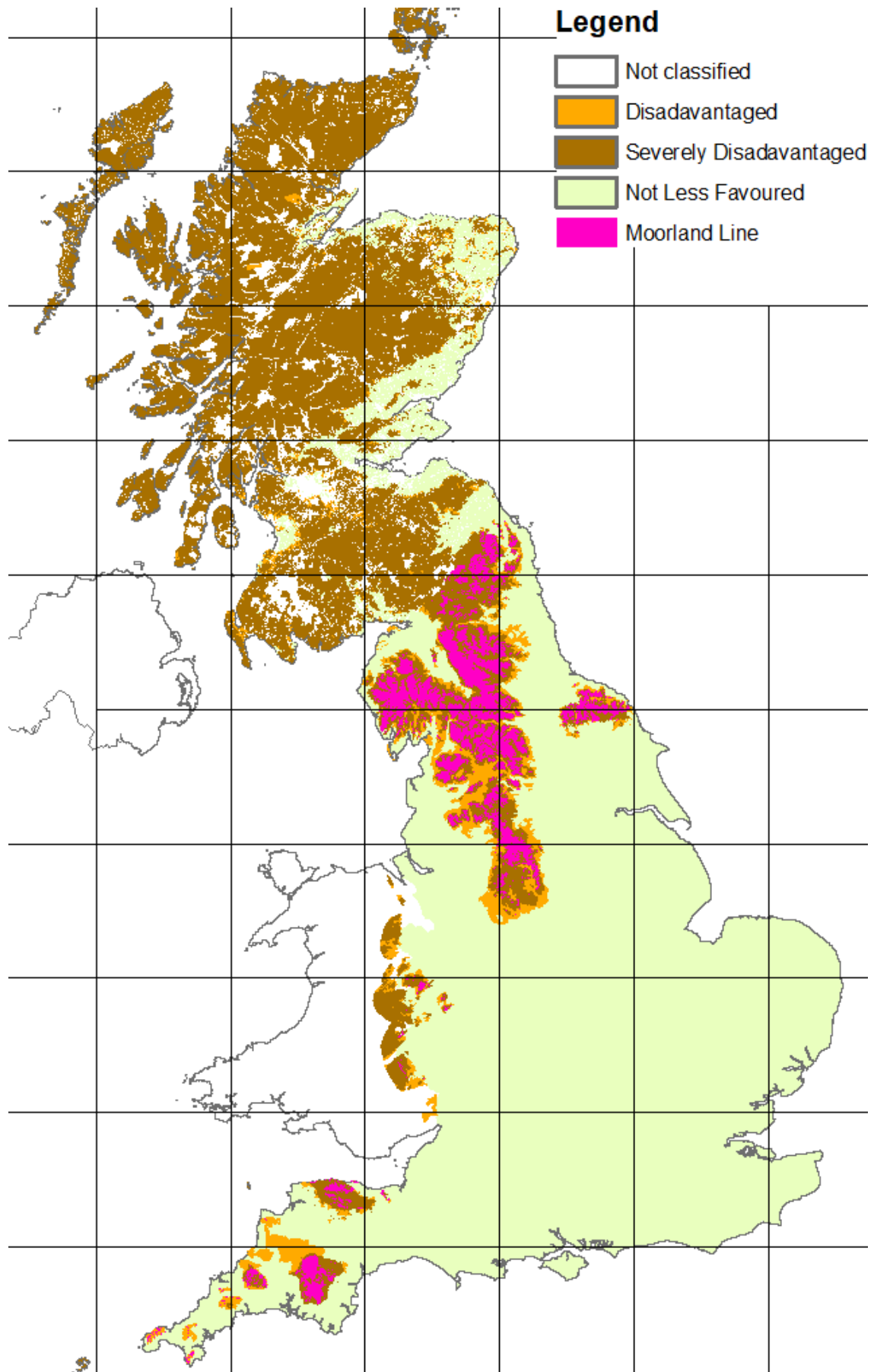


Figure 4. Less Favoured Areas (LFA) and Moorland Lines in England and Scotland.

England and Scotland have very different areas of Less Favoured Areas. There did not appear to be a Scottish Moorland Line dataset.

Over two thirds of Scotland (69%) is classed as severely disadvantaged agricultural land compared with only 13% in England. The disadvantaged Less Favoured class has only a small area in both countries; 1.8% of Scotland and 4.9% of England.

Almost a fifth (18%) of Scotland has no LFA category and 40% of this unclassified land is Anthropogenic ('urban') or Coniferous forest.

Eleven percent of Scotland (881,600 ha) is classed as not being in a Less Favoured Category, i.e. farms do not require additional economic support. This better land has three main Corine land cover classes (93%): non-irrigated arable land (65%); and pastures (21%) and coniferous forest (7%). Most of this better land is in the east which is productive agricultural land. In 2019<sup>26</sup> 347,887 hectares (ha) were classified as areas growing three main type crops. The predominant cereal crop was Spring Barley (134,744 ha or 58% of land used for cereal production). Winter wheat was the second most popular crop production (64,856 ha or 28%). Winter Barley production areas totalled 30,996 ha (13%) while Spring Oats production made up less than one per cent of all area with only 1,054 ha.

None of these cereal growing areas is suitable for Golden Eagles as shown by the composition of the three Golden Eagle range regions. All three (Outer Hebrides, South of Scotland and all Scottish ranges) had more than 99% of their land cover in the severely disadvantaged category. More than 80% of the severely disadvantaged land in Scotland comprised four Corine land cover classes: peat bogs 32%; moors and heathland 22%; pastures 15% and natural grasslands 13%.

The Corine land cover of Less Favoured areas in England has the same four classes forming the majority (84%) of the land cover but the order differs from that in Scotland: a third (33%) is pastures; 18% is moors and heathland; 17% natural grasslands; and 16% peat bogs.

## Living England Map

<https://naturalengland-defra.opendata.arcgis.com/datasets/Defra::living-england-habitat-map-phase-4/explore>

There are no public access constraints to this data. Use of this data is subject to the Open Government Licence - <https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/>

*"The Living England Habitat Probability Map provides an up-to-date prediction of habitat distribution and extent on a national scale for 2021/22."*

The full data set has ~7 million records in a vector format. This creates a difficult data processing problem. Consequently, we converted each layer (A prob field) into a 50 m raster format and merged the 17 raster layers into one raster image of England (Figure 5).

The attribute values of the A prob field were Acid, Calcareous, Neutral Grassland; Arable and Horticultural; Bare ground; Bare Sand; Bog; Bracken; Broadleaved, Mixed and Yew Woodland; Coniferous Woodland; Dwarf Shrub Heath; Fen, Marsh and Swamp; Improved

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<sup>26</sup> <https://www.gov.scot/publications/scottish-crop-map-2019/pages/6/>

Grassland; Coastal Saltmarsh; Coastal Sand Dunes; Scrub; Built-up Areas and Gardens; Water and Unclassified.

Figure 5 shows that there are some clear land cover boundaries across England.

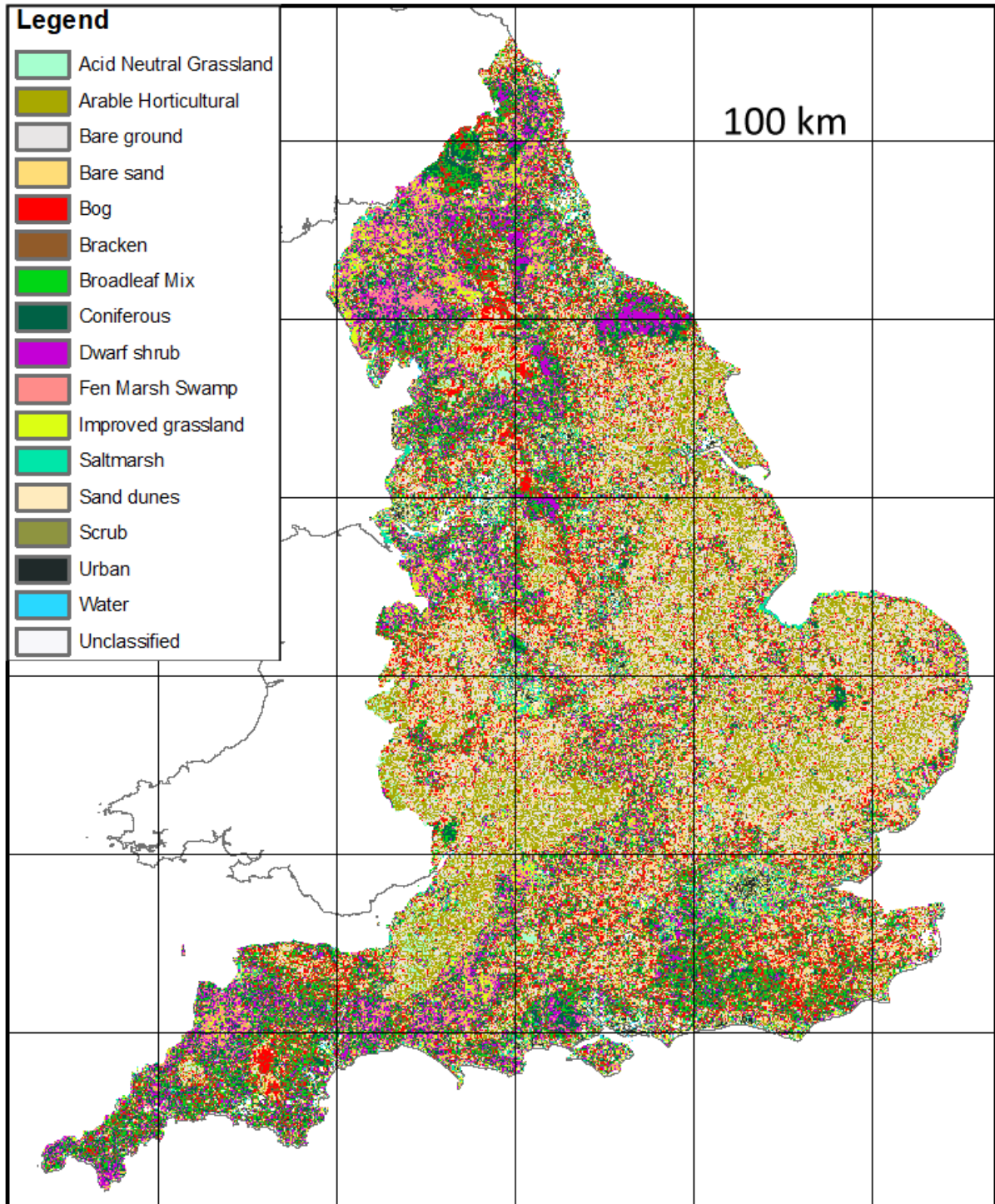


Figure 5. *The Living England Habitat Probability Map*

# Weather Data

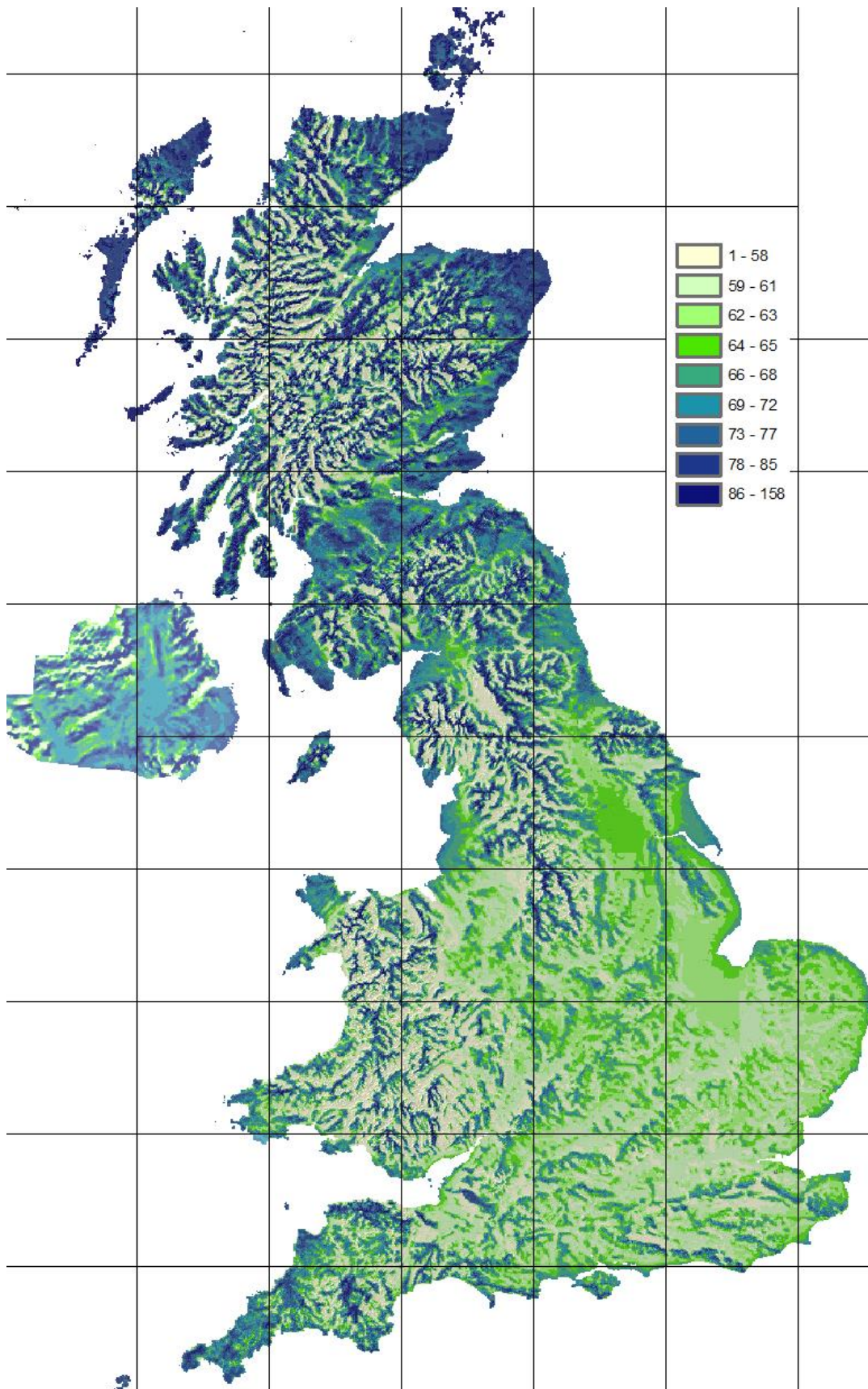
## Wind speed

- <https://webarchive.nationalarchives.gov.uk/ukgwa/20130103011622/>
- [http://www.decc.gov.uk/en/content/cms/meeting\\_energy/wind/onshore/deploy\\_data/windsp\\_databas/windsp\\_databas.aspx](http://www.decc.gov.uk/en/content/cms/meeting_energy/wind/onshore/deploy_data/windsp_databas/windsp_databas.aspx)

This is an archived Department of Trade And Industry Wind Speed Database with estimates of the annual mean wind speed throughout the UK. Data are from an air flow model that estimated the effect of topography on wind speed, but with allowance for the effect of local thermally driven winds such as sea breezes or mountain/valley breezes. The model has a 1 km resolution and makes no allowance for topography on a smaller scale or local surface roughness (tall crops, stone walls, or trees etc), both of which may have a considerable effect on the wind speed.

There is an estimated average for each 1 km square at either 10 m, 25 m or 45 m above ground level (agl). Figure 6 is a map of the wind speed at 45 m agl, illustrating how the mean is generally lower in the south and east of England.

The 45 m agl data were used as a measure of the wind resource available to Golden Eagles (Table 3).



**Figure 6.** Map of annual mean wind speeds (m/ 10s) at 45 m agl. The grid is 100 km. Contains Ordnance Survey data © Crown copyright and database right 2020.

Table 2. Mean annual wind speed (ws, m/s) at 45 m agl in the PRZs and three Golden Eagle home range blocks.

PRZ	ws	PRZ	ws	Home range block	ws
Cheviots A	7.2	NE Coast	7.1	Scotland	6.7
B	7.3	Solway	7.0	Out Hebrides	7.8
North Pennines				South of	
A	7.2	Lincolnshire	6.7	Scotland	7.6
B	7.0	East Anglia	6.4		
Lakes A	6.7	Cotswolds	6.4		
B	6.6	Wessex- Chilterns	6.4		
York Dales A	6.8	Mendips	6.6		
B	6.6	South Downs	6.4		
NY Moors A	7.0	Dorset - Wiltshire	6.6		
B	6.9	Isle of Wight	7.0		
Bowland A	6.9				
B	6.8				
South Pennines					
A	6.2				
B	6.4				
Borders A	6.8				
B	7.1				

## New European Wind Atlas (NWEA)

<https://map.neweuropeanwindatlas.eu/> (licensed under the Creative Commons Attribution 4.0 International license)

The NWEA uses mesoscale simulations for a 30-year period (1989 - 2018) with a horizontal resolution of 3 km to estimate wind speed and wind power. Data are presented at seven vertical levels between 10 and 500 m agl, derived from the mesoscale model simulations. Wind data are provided as Wind Power Density (WPD) (a quantitative measure of wind energy) and Wind Speed (WS).

There are clear patterns in the WPD, which show that the current Golden Eagle distribution is strongly linked to the higher values (Figure 7).

The same patterns are seen using wind speed at different heights above ground level (Figure 8). The mean wind speed shown in the colour scale are for Leeds. This is particularly clear at 10 m agl.

The NWEA webpage interface allows wind profiles to be extracted at point locations or user-defined polygons. Four examples are shown in Figure 9, again highlighting the differences in the wind resource across the UK. The mean wind speed at 100 m, in the two locations with Golden Eagle home ranges, is greater than that at 500 m on the Lincolnshire Wolds or the South Downs, highlighting the restricting nature of the wind resource across parts of the UK.

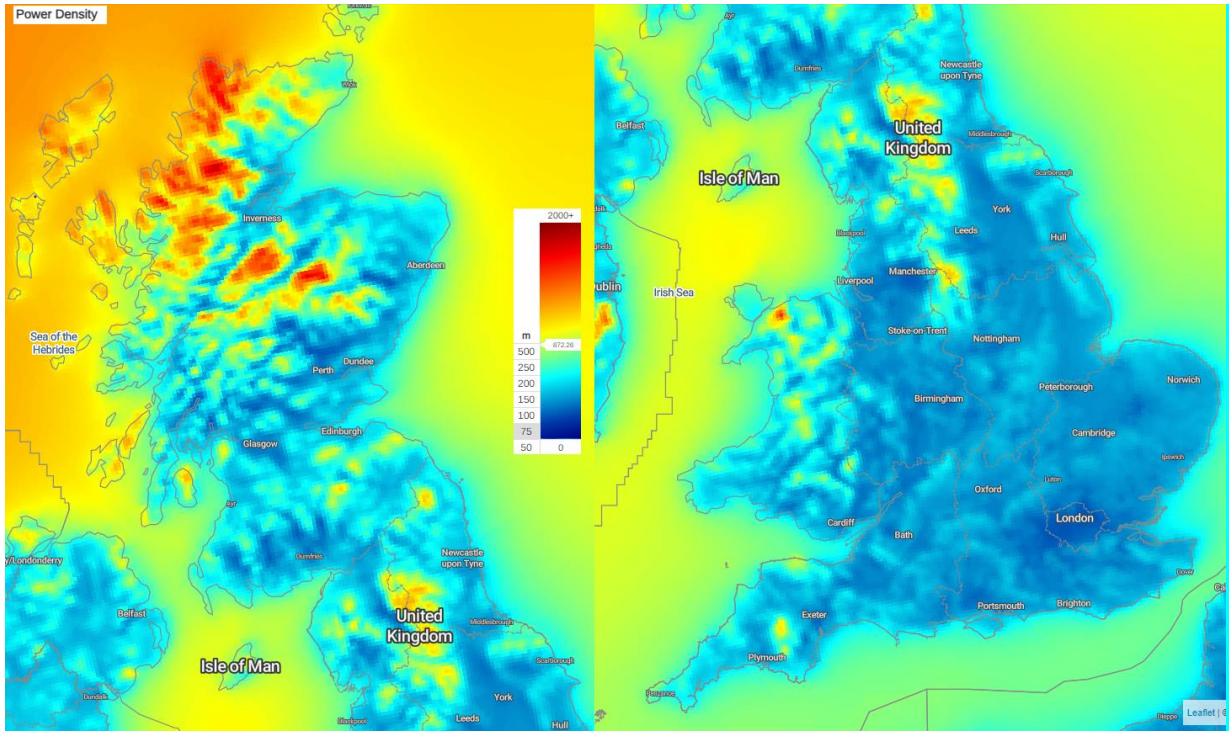


Figure 7. WPD at 75 m agl (European Wind Atlas licensed under the Creative Commons Attribution 4.0 International license)

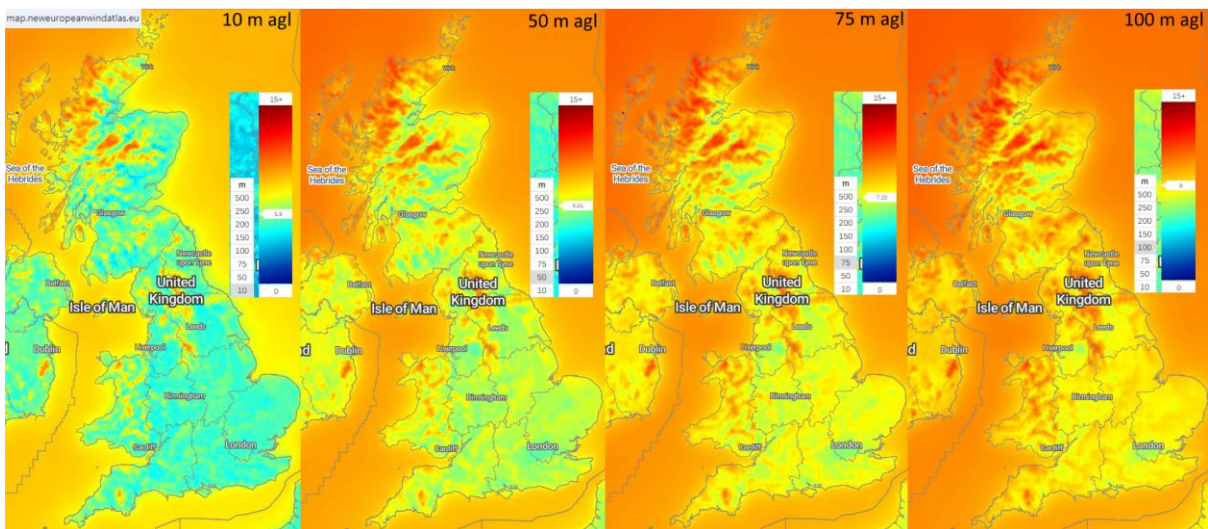


Figure 8. Mean wind speed at four heights above ground level (European Wind Atlas licensed under the Creative Commons Attribution 4.0 International license)

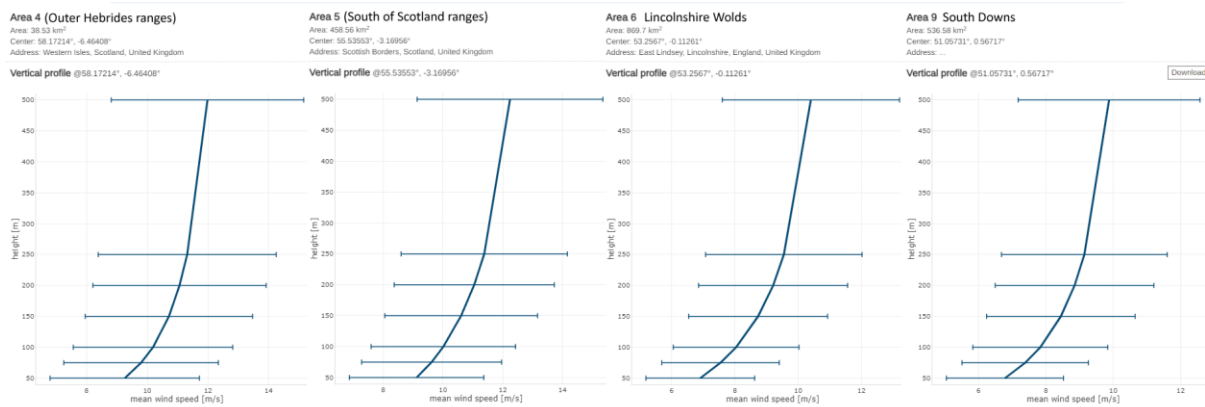


Figure 9. Wind speed profiles at four locations (European Wind Atlas licensed under the Creative Commons Attribution 4.0 International license)

## Growing Degree Days (GDD)

- <https://www.data.gov.uk/dataset/61643ae9-aaca-46b1-b2bd-d564c3438878/ukcp09-gridded-datasets-of-annual-values-of-growing-degree-days>
- <https://climatedataportal.metoffice.gov.uk/datasets/TheMetOffice::annual-growing-degree-days-projections-12km/about>
- <http://ukclimateprojections.defra.gov.uk/content/view/12/689/>.

A GDD is a day in which the average temperature is above 5.5°C and the number of degrees above this threshold counts as a Growing Degree Day. For example, if the average temperature for a day was 6°C, this would contribute 0.5 GDDs to the annual sum, alternatively an average temperature of 10.5°C contributes five GDDs. The annual sum of GDDs can be >365.

Changes to the GDD would affect vegetation growth and possible changes in land use as new agricultural opportunities arise or current agricultural systems become untenable. There is, therefore, potential for changes that would impact a recovering Golden Eagle population.

Annual Growing Degree Days are calculated for two baseline (historical) periods 1981-2000 (corresponding to 0.51°C warming) and 2001-2020 (corresponding to 0.87°C warming) and for possible future global warming levels of 1.5°C, 2.0°C, 2.5°C, 3.0°C, 4.0°C above the pre-industrial (1850-1900) period. The Annual Growing Degree Days show the number of growing degree days that could occur each year, for each given level of warming.

GDD increases indicate potential larger crop yields resulting from warmer temperatures, but crop growth also depends on other factors. For example, GDD do not include any measure of rainfall/drought, sunlight, day length or wind, species vulnerability, or plant dieback in extremely high temperatures. GDD can indicate increased crop growth until temperatures reach a critical level above which there are detrimental impacts on plant physiology. GDD does not estimate the growth of specific species and is not a measure of season length.

Annual Growing Degree Days are calculated from the UKCP18 regional climate projections using the high emissions scenario (RCP 8.5) where greenhouse gas emissions continue to grow. Instead of considering future climate change during specific time periods (e.g. decades) for this scenario, the dataset is calculated at various levels of global warming

relative to the pre-industrial (1850-1900) period. The world has already warmed by around 1.1°C (between 1850-1900 and 2011-2020), whilst this dataset allows for the exploration of greater levels of warming.

Estimates based on the assumption of current international agreements on greenhouse gas emissions suggest a median warming level in the region of 2.4-2.8°C, but it could be higher or lower. Figure 10 has maps of the two historic GDD periods and predictions for the 1.5° and 3.0° rises in temperature.

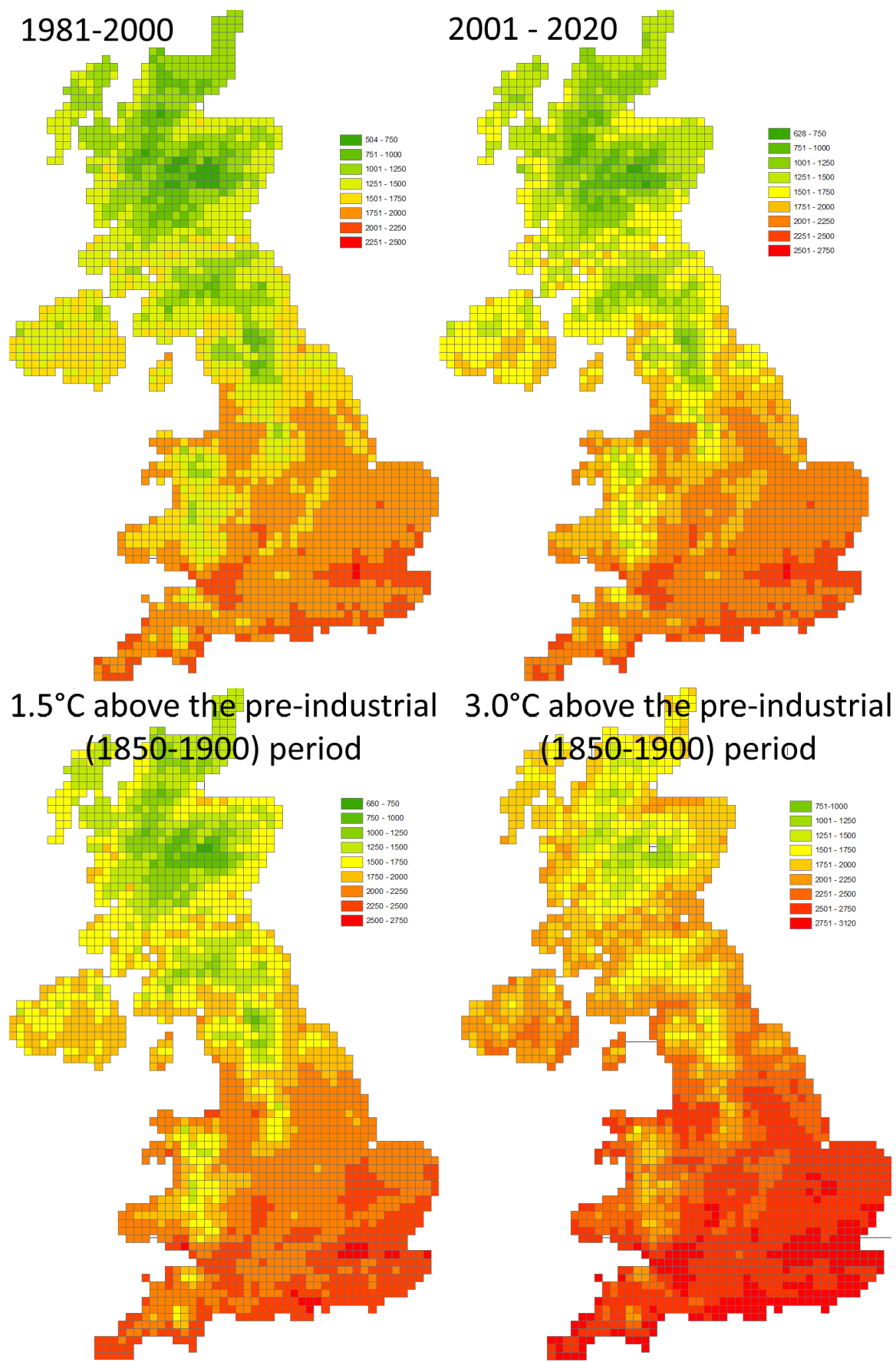
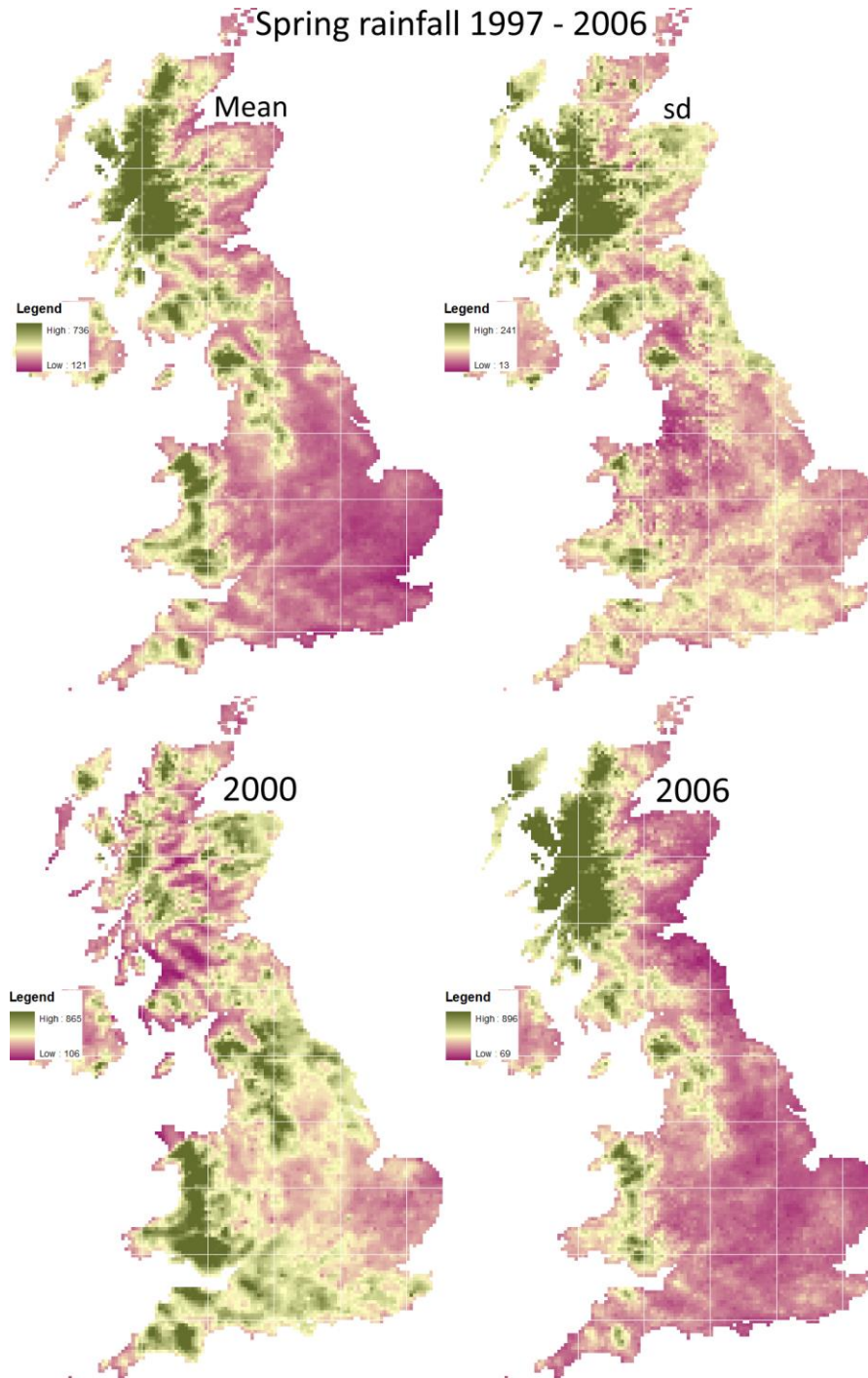


Figure 10. Historic and future GDD maps

## Spring rainfall 1997-2006

<http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/>

Spatial data on rainfall for the period 1981 to 2006 were extracted from Meteorological Office 5 x 5 km gridded data sets. We defined spring as March to May and calculated the mean and standard deviation of spring rainfall between 1997 and 2006. Rainfall maps for 2000 and 2006 illustrate the range of spring rainfall patterns (Figure 11).



**Figure 11.** Upper - mean and standard deviation in spring rainfall between 1997 and 2006. Lower - rainfall maps for 2000 and 2006 to illustrate between-year variability.

# Recreation

## Background

Recreation has the potential to disturb birds but quantifying the significance of disturbance is almost impossible as it depends on the type and timing of the recreational disturbance. Even complex data sets quantifying the number of people using a path cannot predict how birds will be disturbed as it depends on a range of factors such as the group size, time of year and day, presence of dogs, weather conditions, nest proximity and visibility, etc. This is summarised by one of the key findings in a recent review of bird disturbance distances (Goodship & Furness, 2022). “Few species (11 out of 65) were considered to have a low or a low to medium sensitivity to human disturbance. It is important to note that all bird species assessed in this review (including high, medium and low sensitivity species) are likely to vary in their response to human related disturbance in different areas depending on habituation to disturbance and other factors.”

Goodship & Furness (2022) review the evidence for disturbance distances for Golden Eagles but note that there is a lack of disturbance distance studies in the UK. Their summary from global studies is that *“The distance at which Golden Eagles show no reaction to disturbance varies widely depending on the source of disturbance, individual birds, habitats and the time of the year. Caution should be exercised if applying buffer zones to the UK from studies carried out abroad; for example, many of the FID (Flight Initiation Distance) values and buffer zones listed for Golden Eagle in this report are from studies carried out in the USA where habituation to disturbance may be greater than it is for some Golden Eagle individuals present in remote locations in Scotland. Reaction to disturbance can be highly variable between individuals; Spaul & Heath (2017) report that during the breeding season in the USA, some Golden Eagles do not react to people on foot passing by the nest at 200m, whereas other individuals will react at 1300m. When approached by non-motorised vehicles, the lack of reaction between Golden Eagles has been found to vary between 400 and 1100m (Spaul & Heath, 2017). Grubb et al. (2010) found that an Apache helicopter in the USA could pass by a Golden Eagle on a nest at a distance of 400m, whereas other individuals will react to this disturbance at 3000m. Also in the USA, White and Sherrod (1973) found that Golden Eagles did not flush when a helicopter was 18m from the nest and Boeker (1970) report that Golden Eagles did not flush when a fixed-wing aircraft was within 60m of a nest site. 110/274 In the UK, Hardey et al. (2013) state that Golden Eagle nests should not be approached in March and early April as this species is particularly sensitive to human disturbance just before and during egg laying. Disturbance behaviour typically involves both adult birds circling together to a great height and often drifting away from the nest; if this behaviour is seen the observer should move away as quickly as possible (Hardey et al., 2013).”*

*Observer disturbance at nest sites should also be avoided on particularly wet, hot or cold days as the absence of the adults may result in the chilling or overheating of the eggs or young and disturbance may also cause premature fledging (Hardey et al., 2013).”*

We use a variety of indirect indices of potential disturbance based on the assumption that ease of access is likely to increase the potential for recreational disturbance which could be unintentional (people are unaware of the birds or unaware of the consequences of approach) or intentional, which includes people approaching with the aim of getting close to a bird or nest.

## National footpaths

<https://www.ordnancesurvey.co.uk/blog/lake-district-tops-list-of-most-popular-place-in-britain>

The OS blog post analysed data for the last 12 months of routes data captured by users of OS Maps app. Although it has not been possible to access the information (access to the data and permission to use maps was requested but without a response), simple summaries and the maps provided in the post provide some context for the scale of recreation (walking - 2 million routes, running - 256,000, cycling - 156,000 routes and equestrians - 13,000 routes). *“What became clear was how popular National Parks had been, with just under 900,000 routes captured in the 15 British National Parks alone. The Lake District ranks top for popularity with 278,000 routes created, with Peak District second with 144,000, and Yorkshire Dales third with 73,000.”*

## Strava app data

We considered using data from the Strava app but this was heavily biased to urban areas and roads.

## Road Density

Road density provides an indirect indication of ease of access, as road density rises so does potential human access. The data set for these analyses was the OS Open Roads data set. (Contains Ordnance Survey data © Crown copyright and database right 2024.).

We measured the lengths of five road classes within each PRZ (minor roads; B roads, A roads; primary roads; and motorways) and in the three Golden Eagle areas (Table 3). Road lengths were standardised to the length per 1 km<sup>2</sup> to allow a direct comparison between PRZ with different areas. Motorways and primary roads could potentially contribute less opportunity for disturbance and the densities of minor and B roads may be a better indicator of potential disturbance.

Table 3. Lengths of road (km) per square kilometer of the PRZ (A and B refer to the two PRZ sets) and in three blocks of Golden Eagle home ranges.

PRZ	Minor	B Road	A Road	Primary	Motorway	All
Cheviots A	0.27	0.05	0.00	0.03	0.00	0.34
B	0.25	0.05	0.09	0.03	0.00	0.42
North Pennines A	0.26	0.08	0.05	0.01	0.00	0.40
B	0.32	0.10	0.00	0.02	0.00	0.44
Lakes A	0.43	0.05	0.06	0.06	0.00	0.60
B	0.53	0.05	0.00	0.08	0.01	0.68
York Dales A	0.34	0.08	0.03	0.02	0.00	0.47
B	0.46	0.09	0.08	0.04	0.00	0.67
NY Moors A	0.59	0.04	0.03	0.00	0.00	0.66
B	0.64	0.05	0.19	0.07	0.00	0.95
Bowland A	0.24	0.01	0.00	0.22	0.00	0.47
B	0.70	0.05	0.00	0.04	0.01	0.80
South Pennines A	0.56	0.09	0.11	0.09	0.00	0.85
B	0.67	0.09	0.40	0.09	0.00	1.25

PRZ	Minor	B Road	A Road	Primary	Motorway	All
Borders A	1.00	0.18	0.07	0.06	0.00	1.31
B	1.01	0.17	0.13	0.08	0.01	1.39
South West A	1.22	0.11	0.08	0.07	0.00	1.49
B	1.07	0.13	0.02	0.05	0.00	1.27
NE Coast	0.77	0.24	1.16	0.11	0.00	2.28
Solway	0.70	0.21	0.32	0.03	0.01	1.28
Lincolnshire	0.75	0.10	0.07	0.14	0.00	1.06
East Anglia	0.90	0.16	0.06	0.08	0.00	1.19
Cotswolds	1.02	0.15	0.02	0.10	0.01	1.30
Wessex-Chilterns	0.85	0.11	0.00	0.05	0.02	1.04
Mendips	1.01	0.21	1.25	0.07	0.02	2.56
South Downs	0.98	0.14	0.04	0.10	0.03	1.29
Dorset - Wiltshire	0.94	0.13	0.11	0.09	0.00	1.27
Isle of Wight	0.83	0.22	0.41	0.00	0.00	1.46
Scotland	0.11	0.03	0.04	0.03	0.00	0.21
Outer Hebrides	0.12	0.05	0.05	0.00	0.00	0.21
South of Scotland	0.10	0.01	0.03	0.01	0.00	0.16

## Distance to Urban Areas

Distance to urban areas may be considered an indirect measure of the potential level of recreational activity, resulting in intentional or unintentional disturbance of Golden Eagles.

We begin with the OS Built Up Areas data set which represents built-up areas of Great Britain equal to or greater than 20 hectares.

(<https://osdatahub.os.uk/downloads/open/BuiltUpAreas>, Contains Ordnance Survey data © Crown copyright and database right 2024.)

The large vector data set was converted into a 50 m raster and we then calculated the distance from an urban area, rounded to 500 m, for every pixel in a PRZ (Figure 12).

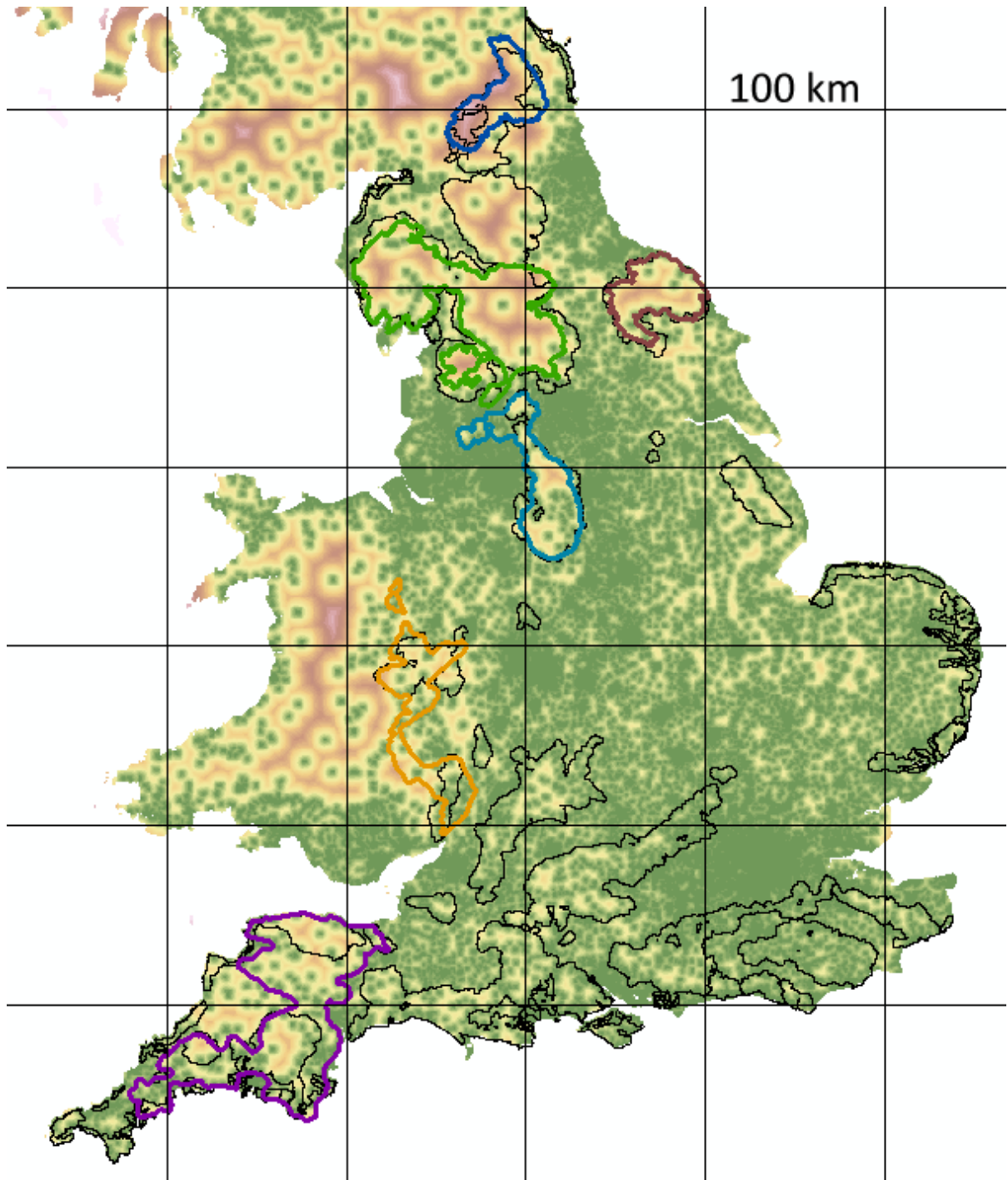


Figure 12. Distance to an urban area in 500 m increments (0 to 40 km, green to brown). Also shown are the PRZs. Contains Ordnance Survey data © Crown copyright and database right 2024.

# Renewable Energy

## Data source

Renewable energy sites (solar and wind farms) were identified using the January 2024 Department of Business, Energy & Industrial Strategy Renewable Energy Database ('REPD').

<https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract>

Using information from the REPD, sites were located on Satellite Images or using Google searches and turbine locations digitised. Wind farm turbine location mapping was restricted to England and, because of the state of the planning laws at the time of this data collection exercise, only operational turbines were mapped. There were only seven small schemes with planning permission awaiting construction. As turbine location data were unavailable they are excluded. Three of these planned schemes were in a PRZ: a four turbine extension at the Hyndburn wind farm in the South Pennines PRZ (planning permission appears to have expired for this extension); a six turbine scheme in the Yorkshire Dales at Aygill Intake (no turbine specifications available); and a four turbine scheme at the proposed Alaska wind farm in the Dorset-Wiltshire PRZ.

## Wind farms

In England there were 1,361 operational turbines in 204 wind farms. More than half of the wind farms (112) have five or fewer turbines, only 37 have 10 or more turbines. The mean number of turbines in a wind farm is 6.7 and the median, reflecting the skewed distribution, is only five turbines. The three largest wind farms are Keadby (34 turbines) on the outskirts on Scunthorpe; Scout Moor (26 turbines) on the South Pennines above Rochdale; and Little Cheyne Court (25 turbines) above Camber in Kent.

There are 224 turbines, in 30 wind farms, within all of the PRZ.

The majority of the 224 (103) are in 11 wind farms in the South Pennines, mainly in the area between the M62 and the M65. Six turbines are on the southern boundary, close to Worksworth.

The Lakes and North Pennines PRZ has 52 turbines in eight wind farms, the majority (35 turbines) in five wind farms between Ulverston and Millom near to the Cumbrian south west coast. The remaining wind farms are all on the PRZ boundary.

The South West has 64 turbines in nine wind farms and East Anglia has four turbines in two wind farms.

AF has maintained a Scottish wind farm database which was last updated in February 2024 when there were 4,734 turbines in 307 wind farms (range 2 - 215, mean 15.4 turbines per wind farm).

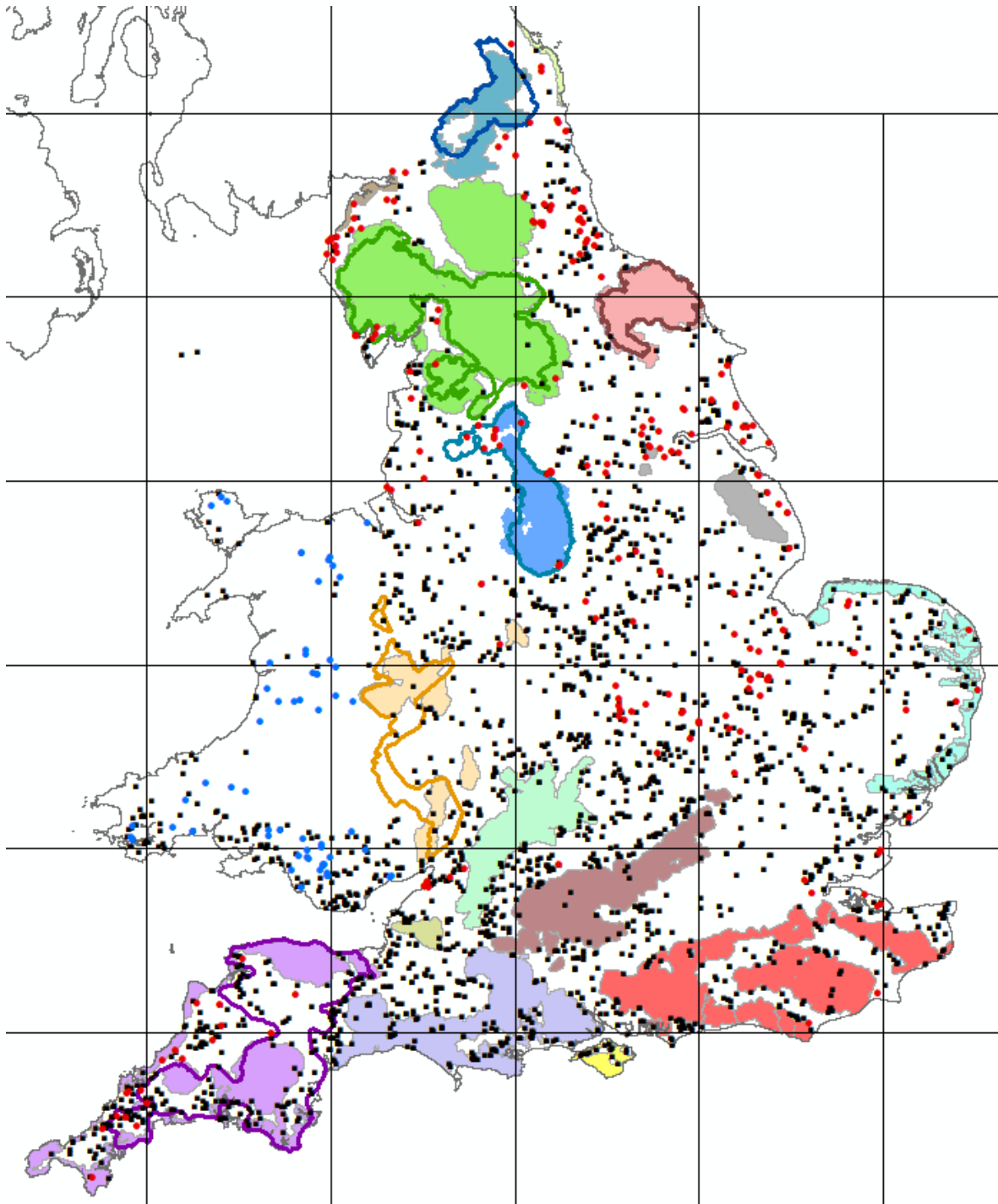
## Solar Farms

In England 1,992 sites were identified: Operational 1,012; Under Construction 72; Application submitted 273; Awaiting Construction 489 and Revised 146.

In Wales 178 sites were identified: Operational 120; Under Construction 2; Application submitted 15; Awaiting Construction 33 and Revised 8.

Very few solar farms are in the northern PRZ and they tend to be on the edge of the more southern PRZ.

Figure 13 shows the renewable energy locations in relation to the PRZs.



**Figure 13.** Renewable energy locations in relation to the PRZs. Black squares are solar farms, red dots are wind farms in England and blue dots are wind farms in Wales. The grid is 100 km. Contains Ordnance Survey data © Crown copyright and database right 2020.

Analyses of satellite tracking records suggest Golden Eagles rarely approach turbines (Whitfield & Fielding 2017; Fielding *et al.* 2021, 2022, 2023b, 2024c). After turbines become operational, Golden Eagles effectively abandon inner turbine locations, and flight

lines close to rotor blades are rare (Fielding *et al.*, 2021, 2024c). Therefore, the main impact of a wind farm in Scotland is habitat loss with a small probability of a collision. Currently, there have been at least seven Golden Eagle collision deaths in Scotland spread over more than 10 years. This rate may increase given recent increases in the numbers of turbines and Golden Eagles, but even if the collision mortality was double that recorded there would not be a significant impact on the Scottish population.

## Designations

National Landscapes, previously Areas of Outstanding Natural Beauty (NL), National Park (NP) and Special Protection Area (SPA) boundaries were downloaded from the [data.gov.uk/dataset/](https://data.gov.uk/dataset/) website.

- NL [8e3ae3b9-a827-47f1-b025-f08527a4e84e/areas-of-outstanding-natural-beauty-england](https://data.gov.uk/dataset/8e3ae3b9-a827-47f1-b025-f08527a4e84e/areas-of-outstanding-natural-beauty-england)
- NP [334e1b27-e193-4ef5-b14e-696b58bb7e95/national-parks-england](https://data.gov.uk/dataset/334e1b27-e193-4ef5-b14e-696b58bb7e95/national-parks-england)
- SPA [a85e64d9-d0f1-4500-9080-b0e29b81fbc8/special-areas-of-conservation-england](https://data.gov.uk/dataset/a85e64d9-d0f1-4500-9080-b0e29b81fbc8/special-areas-of-conservation-england)

## Ministry of Defence land

Large areas of land used by the MoD, such as the Otterburn Ranges, may offer additional security to Golden Eagles if they can tolerate the intermittent military activity. On balance, such land is likely to be beneficial to Golden Eagles.

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# **A review of social approaches to Golden Eagle (*Aquila chrysaetos*) and White-tailed Eagle (*Haliaeetus albicilla*) recovery and population restoration in the UK and Europe**

**A report to Forestry England on Work Package 4**

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**Forest Research**

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## 1. Introduction

The UK's wildlife is continuing to decline, the State of Nature report (Burns et al. 2023) revealed that one in six of the 10,000 species studied could be lost, with 43% of UK bird species at risk of national extinction. Targeted species recovery and population restorations offer an opportunity to reverse declines. Recovery and restoration involve identifying those species which have been lost, or are at high risk, and putting in place management to restore population to sustainable levels. This can involve both habitat improvement and the restoration of species to regions where they have been partially or entirely lost. However, the long-term absence of species from a region, especially apex predators such as the Golden Eagle, can be a major barrier to restoration because over time not only do the ecological conditions change, but also cultural memory of living alongside a particular organism diminishes (Manning et al., 2009). As such, the restoration of species to their former range, where they have been absent for long periods of time, carries cultural, economic, and practical barriers.

Conservation translocation projects have historically been led primarily by natural scientists, with a focus on biological and ecological feasibility, with less focus on socio-cultural and economic aspects, but the publication of the IUCN guidelines (IUCN/SSC, 2013) highlighted the need to engage communities and consider those potentially impacted by such projects. Conservation translocations are complex and expensive interventions, inherently long-term, and so social feasibility research conducted at the start of a proposed project helps to identify the socio-cultural and economic barriers to a success, and identify the key stakeholders likely affected. Such an approach allows for targeted engagement and potentially avoids investment in areas where there are immovable barriers to progress. This research aims to inform social approaches to Golden Eagle restoration in England by reviewing the methods employed by similar projects across the UK and northern Europe.

## 2. Methods

### 2.1 Evidence review

This literature review followed the rapid evidence assessment (REA) method. The literature search was conducted using an online academic database (SCOPUS) and a search engine (Google scholar) with key search terms developed through initial discussion between Forest Research and Forestry England, followed by multiple trials aimed at delivering a reasonable number of articles to review within the time frame of this project.

SCOPUS search terms:

*TITLE-ABS-KEY (eagle OR raptor AND euro\* AND reintroduc\* OR restor\* AND human)*

Google scholar search terms:

*intitle:eagle AND reintroduction AND euro AND consult OR public OR people*

No publication date limit was imposed on the search, and a focus on literature from the UK and northern Europe was specifically sought to provide the most relevant insights for the project. Search results abstracts were screened for relevance, and relevant literature was fully reviewed (Table 1). The grey literature search was conducted through a combined method using a search

engine (Google) and visiting website, blogs and social media channels for known projects and organisations involved with the reintroduction of eagles, or other raptor species, in the UK and northern Europe. Links to additional grey literature were requested during the select interviews. Relevant grey literature was fully reviewed (Table 2).

## 2.2 Select interviews

Through initial discussion between Forest Research and Forestry England, a shortlist of target individuals and projects were compiled to represent White-tailed Eagle (WTE) and Golden Eagle (GE) reintroduction, restoration and conservation projects in the UK and northern Europe. In the first instance, these individuals were contacted by Forestry England and invited to share their relevant experiences and expertise through participation in a semi-structured interview. In all, 8 individuals representing 5 projects participated in an interview, conducted via MS teams between 14<sup>th</sup> October and 7<sup>th</sup> November 2024. Of the projects represented, 5 were in the British Isles/the UK and Republic of Ireland, and one individual was interviewed in a broader capacity for their expertise in Golden Eagle conservation in Norway and mainland Europe. Only one of 5 projects involved Golden Eagle, with the other four projects were relating to White-tailed Eagle.

## 3. Results

### 3.1 Results of summary literature review

#### 3.1.1 Search results

**Table 1.** REA results: peer reviewed publications

Author (date)	Country	Species	Project type
Kovács et al. (2016)	Hungary	Eastern Imperial Eagle	Human-wildlife conflict
Mayhew et al. (2016)	UK	White-tailed Eagle	Reintroduction
O'Rourke (2014)	Republic of Ireland	White-tailed Eagle	Reintroduction
O'Toole (2002)	Republic of Ireland	White-tailed Eagle	Reintroduction
Sutton (2015)	UK	White-tailed Eagle	Reintroduction
Thirgood & Redpath (2008)	UK	Hen harrier	Human-wildlife conflict

**Table 2.** REA results: grey literature

Author (date)	Country	Species	Project type
Barlow (2022)	UK	Golden Eagle	Translocation
Dunn (2022)	UK	White-tailed Eagle	Reintroduction
Lane (2021)	UK	White-tailed Eagle & Golden Eagle	Reintroduction
Mackrill (2021)	UK	White-tailed Eagle	Reintroduction
Mayhew (2013)	UK	White-tailed Eagle	Reintroduction
Mayhew (2013)	UK	White-tailed Eagle	Reintroduction
Mertens et al. (2005)	Romania	Griffon vultures	Reintroduction
Morling (2022)	UK	White-tailed Eagle	Reintroduction
Nygård et al. (2009)	Norway	White-tailed Eagle	Translocation

SSGEP (2023)	UK	Golden Eagle	Translocation
Taylor (2022)	UK	Golden Eagle	Translocation

### 3.1.2 Social perception and feasibility

Mayhew (2013) and Mayhew et. al (2016) describe the findings of a 2012 study that aimed to evaluate public opinion regarding the socioeconomic and environmental impacts of a WTE reintroduction in Cumbria. The research included 300 face-to-face questionnaires, conducted with residents of the area, 41.3% lived in urban areas and 58.3% in rural areas. The results demonstrated robust support for a WTE reintroduction in Cumbria, as 88% of respondents were in favour of the initiative whereas only 2% were opposed. However, 42% of respondents had never heard of WTEs, highlighting the need for an education and awareness campaign. Most respondents (89.3%) were convinced of the benefits to the local tourist industry, but 40.7% of respondents were unsure about detrimental impacts on farming interests, and a substantial proportion of respondents were unsure of the risks to rare species of wildlife in the locality. Mayhew (2013, 2016) found no interaction between respondents' demography (age, gender, occupation) and their views on the proposal.

Dunn (2022) conducted a study to gauge public perceptions of reintroduced WTE on the Isle of Wight (IoW), using an online questionnaire which generated 1,590 responses. The data showed exceptionally high support for the White-tailed Eagle reintroduction on the Isle of Wight, although only 14% of respondents were resident on IoW. Dunn compared results with those from a similar study conducted pre-reintroduction and found that support on the IoW appears to have increased from the “*somewhat polarised state*” observed pre-reintroduction. Support was consistent across a range of stakeholder groups, including shooting and fishing, two groups that had previously been opposed. Survey questions on respondents' reasons for visiting the IoW found WTE ranked highly, suggesting the reintroduction was likely to generate eco-tourism benefits for the local area. Mackrill (2021) conducted a similar study assessing social feasibility of proposed reintroduction of WTE to West Norfolk and eastern England. An online public survey generated 1,839 responses. Public support was overwhelmingly positive, with 83% of respondents “strongly supportive”. Respondents representing key stakeholder groups conservation, birdwatching and tourism showed the highest level of support (86 to 90% respondents were supportive), while those representing farming, shooting and fishing showed lower levels of support (63 to 77% of respondents were supportive). In a public survey of 292 people assessing attitude towards the potential reintroduction of Griffon Vultures in Romania, Mertens (2005) found overwhelming support for the proposal, and a strong public belief that such a reintroduction would be a success.

O'Rourke (2014) conducted a retrospective study to understand the perspectives of key stakeholders in the 2007 reintroduction of the WTE to Ireland. This work involved a series of 30 in-depth interview with the key stakeholder, representing farmers, farming organisations, tourism and recreation interests. They explain that during the project a limited consultation, information dissemination and educational programme commenced only after the introduction of the WTE. The paper highlights that this programme was managed by an experienced ornithologist, but with no training in communications, facilitation or social science. O'Rourke found that farmers and their representative organisation saw themselves as the custodians of the countryside and felt that the project had been imposed on them from the outside, stating “*wildlife restoration was not part of their [farmers] value orientation and was not embedded within the cultural capital of the local farming community*”. They concluded that had there been

meaningful prior consultation, the farming community would probably still have rejected the project: *“Communities need to have an equal stake and ownership in whatever decisions are taken in relation to their landscapes and livelihoods”* and *“Resources are needed to support better facilitation, education, communication and conflict mitigation, especially at the local level.”*

Morling (2022) conducted a study to quantify the economic impact of the reintroduced WTE on the Isle of Mull. A total of 298 face-to-face interviews were conducted with tourists across the island, collecting information on motivations. They report 29% of those interviewed cited WTE as being an important factor in their decision to visit to the island. Morling extrapolated these figures to estimate the economic benefit of the reintroduction, finding that WTE supported a minimum of £4.9m and a maximum of £8m in tourist spend per year on Mull. Concluding: *“White-tailed Eagles continue to deliver large and growing economic benefits to the local community on the Isle of Mull.”*

### **3.1.3 Consultation**

Mackrill (2021) describes an extensive stakeholder consultation on a proposed reintroduction of WTE to west Norfolk and eastern England. They solicited views on the proposal from 36 landowners and land managers and 28 organisations and membership bodies in one-to-one discussions and a series of online webinars. Although these events were planned to take place in person, the Covid-19 pandemic forced the team to conduct these consultations virtually. Overall, the reaction of landowners, land managers, organisations, and conservationist was supportive of the proposals. Some conservationists expressed concern over predation of other species of concern. The tourism sector was found to be strongly supportive, and the major concerns from land managers and landowners were related to the potential impact of bird watchers coming onto private land to view the birds, rather than the birds themselves. They found the NFU to be helpful in distributing information about webinars to its members.

Mayhew (2013) conducted a similar stakeholder consultation to gather views on WTE reintroduction in Cumbria, employing semi-structured interviews with representatives from a range of stakeholder groups. The findings present a complex situation, with each stakeholder type presenting their own concerns. Stakeholders from all sectors conceded that serious obstacles remained and were unanimous that resolving these obstacles would require engagement, collaboration and transparency between the project team and the various stakeholders, interest groups and governance.

When researching the feasibility of reintroducing WTE and GE in Wales, Lane (2021) reported that GE predation losses were equal to less than 3% of lambs produced, while losses to other known cause were between 7 and 23%, and unknown causes were between 5 and 10%. Concluding predation threat to be *“insignificant to the total number of lamb mortalities attributed to other factors”*. Lane consulted NFU Wales and found them to be content with the findings and approved of the project teams’ *“considered approach to assessing feasibility.”* Through consultation with other key stakeholder groups, Lane describes broadly positive engagement, with no clear objections from any single group. However, when discussing consultation with stakeholders in England, Lane notes conflict between GE and private landowners assigning their land to game (particularly red grouse) for recreational shooting.

O’Toole (2002) describes the public consultation that preceded the released of GE in Donegal, Ireland. They conducted a widescale consultation with key stakeholders: farmers; farming association (Irish Farming Association); tourism; the Gaeltacht (Irish speaking) community and the Donegal public.

The consultation process involved testimony from Scottish farmers living with GE, and the IFA accepted that there was a minimal threat to lambs and were happy for the project to proceed. Tourism representatives were highly supportive of the proposal believing GE would become an attraction, especially in the quieter seasons (spring and autumn).

Thirgood and Redpath (2008), while not relating to a reintroduction, discuss the barriers to implementing mitigation measures to reduce red grouse predation by hen harrier, identifying entrenched positions of the major stakeholders as fundamental barriers. They argue that conservationists have refused to contemplate any form of intervention to limit harrier densities, while stating that law enforcement has been ineffective in reducing persecution of harriers. They state, *“stakeholders need to accept that entrenched attitudes will have to change, and compromises be made on both sides.”* They found that differences exist within stakeholder groups at a local level, and in a hierarchical manner, with the views of national organizations not necessarily reflecting the views of individual members.

Kovács et al. (2016) present a consultation method for navigating entrenched attitudes, describing a participatory planning approach for Eastern Imperial Eagle conservation in Hungary, with three stakeholder groups: farmers, game managers and nature conservationists. The project was managed by conservation experts, an independent facilitator and experts experienced in conservation-related participatory processes. A desk-based study highlighted the historical context and the likely conflicts, followed by semi-structured interviews, followed by single-stakeholder consultation forums. They found that this approach proved important for generation new ideas, and mutual learning about the values and interests of stakeholders. They also report that the interdisciplinary composition of the team was a benefit: *“Our study shows that involvement of experts with social science training and experience in participatory methods can be fruitful in conservation related participatory processes, especially in conflict situations.”* However, they note that the lengthy consultation process was a drawback and raised strong concern that some of the issues raised during the participatory planning could not be resolved satisfactorily, as entrenched attitudes and values could not be changed over the project time period.

### **3.1.4 Engagement methodologies throughout project**

Barlow (2022) describes taking a partnership approach to GE translocation in the South of Scotland, including landowners, government organisations, nature conservation organisations and local charities. They argue that this approach has created firm, loyal buy-in from landowners and land managers, which will ultimately improve the long-term prospects of the GE in the region beyond the scope of the current project. The article outlines the project’s ongoing engagement approach, including employing a member of staff to liaise directly with landowners, gamekeepers, and shooting interests to inform, reassure, and advise them. They also highlight the work of two full-time Community Outreach Officers who work with schools, local communities, tourism, and others interested parties, delivering talks, presentations, and raptor identification courses. These outreach events give the team the opportunity to address concerns or difficult questions that may arise from the public. The project supports work aimed at inspiring young people, working with Scouting Scotland to create the ‘Eagle Champions’ badge, and with schools to develop an ‘Eagle Schools’ programme. The project has partnered with a regional town to run an annual 3-day Golden Eagle festival (SSGEP, 2023; Taylor, 2022) that celebrates the GE and other nature in the region. They have also established relationships with local cafes and businesses where information and media about the project can be accessed by visitors.

O'Toole (2002) describes the community engagement component of the reintroduction of GE in Donegal, Ireland. They argue that given the potential home range of the GEs, it was important to promote the project in both English and Gaelic language and engage the public through both radio and print media in English and Irish. They describe a programme of engagement where the project team continued to meet local elected representatives, interest groups, schools and parish councils and development groups throughout the course of the project. They also describe the use of radio-tracking data on released GEs as a tool for liaising and assuring landowners and land managers about the birds' location and diet.

Seeking to understand the leadership and management approaches during the reintroduction of WTE to Scotland between 1975 and 2012, Sutton (2015) conducted a series of face-to-face, in-depth, semi-structured interviews with participants who had been full-time employees of the project. The interviewed highlighted the strength of having a small and consistent team of scientific and political experts who personally released the birds and engaged local and national governance. Interviewees also spoke of the importance of having a clear organisational structure and leadership, but also allowing employees flexibility and autonomy to address issues as they arose. Robust, but infrequent, programme evaluation was also deemed to be a strength. They found that persecution of released WTE in the early stages of the project led to an "*adaptive public approach*", which acknowledged the value of "*cultural sensitivity, inclusivity, transparency, and local "ownership" of conservation initiatives*". They also note that linking the reintroduction to the public's regional identity was likely key to engendering support.

The 2005 WTE reintroductions in Ireland required birds to be imported from existing populations in Norway. The collection of birds for translocation was managed by a partnership between nature conservation NGOs in Ireland and the Directorate for Nature Management, the Norwegian Ornithological Society, and Norwegian Institute for Nature Research in Norway. Nygård et. al (2009) briefly explain the public engagement component of this process. After active WTE nests had been mapped in, local police, government, and landowners were informed that the collection was going to take place. The project was covered in the local and national media. The project garnered considerable media interest both locally and nationally, with articles in Norwegian newspapers and Two filmmakers followed the collection with the aim of making a documentary film on the project.

## **3.2 Results from the select interviews**

### **3.2.1 Social perception and feasibility**

Of the topics discussed during interviews, the greatest difference in opinion surrounded social feasibility research, both in terms of methods employed, and whether it can actually hinder a project. Three out of the five projects conducted no formal social feasibility research before the reintroductions or translocations took place. In one case, this was due to a lack of funding to conduct such work at the beginning of the project, with all resources going instead to ecological and biological feasibility research. Another interviewee stated that their decision not to conduct such research was strategic, believing that public surveys brought unnecessary negative attention to projects that were still in development. They described following an organic, snowball process of initially approaching larger landowners and estates in the proposed region, talking to the land managers and head keepers before asking for introductions to the next estate, avoiding any formal public engagement until relationships had been established:

*“If someone turned up with a clipboard or was asking questions, you know, people would shut down, they'd disappear. Very much close ranks. I think that we've had much better engagement because we didn't do that kind of formal [survey] work at the beginning.”*

One respondent suggested that there is already a lot of research on this topic and that data from previous consultations show that the UK public is generally very positive about eagle reintroductions. Those who did conduct public surveys, found that generally, the public were highly supportive, although one project found that people were less positive about Golden Eagle (GE), versus White Tailed Eagle (WTE), with concerns focussing on perceived prey availability for GEs. One expert stressed the importance of making public surveys available in both digital and paper formats, as many communities in remote, rural areas do not have access to computers and internet. One project used a pre-survey based around *cognitive hierarchy framework* which aimed to understand the public's specific concerns, barriers and opposition to the proposed reintroduction. They went on to explain that data collected during this research directed preparation for subsequent public “drop-in” sessions, as it enabled the team to prepare responses to counter specific concerns.

Two of the respondents who did not conduct social feasibility research at the beginning of their projects expressed regret at not having baseline social survey data, while standing by their decision not to conduct such research:

*“I think it's it would be nice to have some of that baseline data at the beginning. I think to look back on now, not going in that formal way, I think actually benefited us in the end”*

### **3.2.2 Public communications**

Generally, public communications were conducted through social media, project blogs, project websites and local/national media. Some projects described a structured content plan, while others were more reactive, only posting stories or blogs intermittently or when something “newsworthy” arose. Only one project had a dedicated comms officer, with the majority of comms handled by employees of organisations leading or supporting projects.

In the initial stages, all project communications aimed to address widespread misinformation, focussing on the biology, diet and behaviour of the birds:

*“...[over] the last couple of decades has been conflict on the West Coast of Scotland, which is then intensified by clickbait media reporting that sensationalises what may or may not be a problem, depending on who you talk to. So, there's a hell of a lot of preconceptions about the birds and the impact they might have. And at the end of the day...[WTE] is an apex predator, so if you're a sheep farmer and you Google “White-tailed Eagle”, you get a load of scare mongering.”*

The other area of focus for comms was project plans and timelines, and publicising public engagements or consultations to stakeholders who may have been missed via other channels.

Six interviewees described local and national media as strong allies of their projects, but one suggested providing press releases to better “control the narrative”:

*“...we get a lot of requests for interviews, media interviews, newspapers, TV, and we're quite selective in what we do. So that's really good, just keeping the messaging through the community. So, a lot of this engagement is just really positive.”*

*“We look to try and find a high impact comms opportunity once a year, really just to keep the project relevant in the national lens. Sometimes it has the desired impact, sometimes maybe it doesn't. But it's really helpful to of engage all audiences as broadly as you can.”*

One interviewee explained that media coverage of their project had been both a positive and a negative. During the early stages of release, several eagles were killed through poisoning, photos of the dead birds made it into the national media, leading to a strong public backlash against farmers. This in turn created greater animosity between the farmers and the project staff. However, the ongoing practise of poisoning was not previously known to the project team, and the ensuing media storm threatened the integrity of the project:

*“We started recovering dead birds that shone a light on poisoning, and it became big media storm. At that time [redacted] was only one of two countries in the EU that got a derogation for the use of poisons for controlling foxes and crows. So, a large part of WTE were collateral damage. You know, people, farmers weren't waking up saying I have to put a poison to kill eagles, they were doing because they done it for decades, if not centuries.”*

Another interviewee described the importance of timing in communications, after being advised to avoid national media coverage for their project, due to ongoing consultations around farming subsidies potentially pulling eagle reintroduction into a wider political debate.

### **3.2.3 Community engagement**

All interviewees explained that engaging the wider community often helped build relationships with key stakeholders, by demonstrating to those with concerns or opposition that there are positives to having the eagles back in the area:

*“...it is really important to engage [the public] where those birds first start to breed in the wild. I think it is much easier to get people on board because they really see that, you know, the populations are pretty small and you know, they take over ownership of the project.”*

*“I think [public engagement] helped because anyone that does have concerns sees that there is a very positive aspect to having eagles back as well”*

Common methods of engagement described were school visits, with activities and resources (activity books) to help engage children with the project. One interviewee believed that engaging local children in the project was a good way to engage adults in rural communities:

*“...if you're not engaging the public, then they're going to be completely disinterested in what you're doing or unaware of what you're doing. So, you know, even having things like having schoolchildren named Eagles, things like that. It all trickles through.”*

Three interviewees talked about the importance of engaging local community groups, especially local nature or conservation clubs, another project described giving a series of public talks and presentations for “a couple of years” before the project applied for a licence. These talks aimed to increase public knowledge and awareness of the animals’ diet, behaviour and conservation status, counter misinformation and introduce the idea of species reintroductions and how such a project might look. They believed that this groundwork engagement led to strong public support once the project was announced. One project partnered with a birds of prey centre brought a WTE to public events and talks, they found that having the eagle with them was a useful tool in

countering misinformation and helped build excitement for the return of the species to the region. The same project described this engagement as an ongoing commitment:

*“... we get a lot of requests for Community talks, talks to groups. So, we [project team] give a lot of those talks.”*

Two interviewees described having a project stand at agricultural shows during initial stages of engagement and saw these events as an opportunity to collect details from members of the farming community who would then go on to take part in further stakeholder engagement. They were also seen as an opportunity to engage farmers in informal dialogue ahead of any formal stakeholder consultation or engagement.

Two projects stated that the geographic range of their outreach activities were based on where the birds were likely to nest, rather than the full range that the birds were likely to travel.

### **3.2.4 Consultation**

#### **3.2.4.1 Stakeholder mapping**

All experts interviewed carried out stakeholder mapping exercises; there were two main approaches: most projects employed *top-down* approaches where project teams or steering groups developed longlists of likely stakeholder types and populated these lists through their own knowledge and contacts, often incorporating a snowball method once engagement was underway. Two projects employed a *bottom-up* approach, where initial public consultations and events were used to gather details of stakeholders with whom they would later engage one-to-one, or in small focus groups or webinars, a snowball approach was also employed during these follow-up engagements.

One project described emailing 850 stakeholders in one day, to avoid giving the impression that any one group or individual was a higher priority than another. Another project conducted regular stakeholder mapping evaluation, ensuring that stakeholder lists remained up to date and relevant throughout the project, and ensuring that all key stakeholder groups are being engaged equally, shifting focus where necessary.

The main groups identified by all projects: livestock farmers (sheep and poultry); game keepers and estates; wildlife conservationists; land managers; forestry; fishers; schools and community groups; tourism sector; parish councils and local government. The majority of interviewees also spoke of local interests specific to their region, for example, puppy farming and special interest conservation groups in South Wales, highlighting the need to conduct thorough stakeholder mapping at the proposed site. Two projects described using ecological and behavioural data to map the likely movement of reintroduced WTE and using these maps as the geographic basis for their stakeholder mapping exercises. One project described prioritising engagement with stakeholder based on where the birds were most likely to breed.

#### **3.2.4.2 Methods of engagement and consultation structure**

Most projects followed multi-stage approaches to engagement, with some planning this approach many years in advance while others progressed organically, learning from what did and did not work along the way. One project described starting with a series of public talks and attendance at farming shows, these events were an opportunity to counter some of the common misinformation about the animals, and provide the public with details on how a reintroduction might look, but they were also an opportunity to start understanding the major concerns of different stakeholder types, as well as gathering names and details of individuals who would later

be contacted for key stakeholder consultation. This information was used to prepare for a series of interviews, small focus-groups, webinars or meetings, where these invitees could freely discuss their concerns and preferences.

### **3.2.4.3 Initial engagement**

All interviewees agreed that engagement with stakeholders and communities is best done on the smallest possible scale, avoiding “town hall” style meetings which can easily be co-opted by national or regional organisations and vocal individuals. Two projects that did conduct “town hall” meetings found that these events led to strong resistance and anger which set relations back, however, both noted that many of those present later expressed that they did not agree with the content or nature of the arguments:

*“We had public meetings in [redacted], which became very fraught... I had farmers ringing me and come to me and said we didn't agree with what happened there last night. But you know we're not going to stick our head above the parapet...”*

Smaller scale “drop-in sessions”, webinars were identified as more effective ways to engage, as project representatives and concerned stakeholders can talk one-to-one, and discuss the key concerns that they may have. Several experts said they used these opportunities to counter misinformation, which appears to be spread at national and regional levels and on social media:

*“...the key lesson we took was that we should have just had a drop-in session so that people could come and talk to us one-to-one, so that you can give people time, and you can describe the complexities of the project, but you're not doing it to a room full of people who, you know, will be really anti- [reintroduction].”*

*“Some of them you know, particularly with fishermen, just like to go for a pint or something, you know, so most of some of these conversations, you know, with farmer was just one-on-one, you know, just sitting down over a coffee or pint for some.”*

It was suggested that such drop-in sessions and webinars should be publicised through social media and email lists, as well as physical adverts, such as local papers, community notice boards, as not all stakeholders in rural areas are active online:

*“The webinars worked really well, because you'd give a really short presentation, and then you'd open up for question and answers so that webinar structure really helped.”*

All interviewees discussed the vital importance of home visits during the initial stages of engagement. It was suggested that going door-to-door to speak with stakeholders who may have missed the public events and communications was fundamental to building trust between the community and the project, while acknowledging that this is a time and resource heavy approach:

*“If I read one more sentence that says, ‘you just need to build trusting relationships’, I think I might throw my laptop out the window... it's not that easy. It takes a lot of time, but a lot of ecologists and conservationists come to these projects thinking it's all about numbers and forgetting how to be human. I find when working with people that are resistant or concerned, just being human and being there in a farmer's kitchen having cups of tea...overrides all that”*

One interviewee expressed frustration that such practise was not recognised as priority by their project funder:

*“You know, people [funders] still want you to cut corners on things that are really important, like, ‘can't [stakeholders] come and meet you somewhere for an interview?’ And I'm like, no, absolutely not. It has to be somewhere that they feel comfortable at a time that's right for them.”*

#### **3.2.4.4 Focus groups/meetings**

Some projects used single stakeholder focus groups, webinars, and classes i.e. only sheep farmers, game keepers, fishers, to provide an opportunity for individuals to hear and discuss the views and concerns of their peers. Another project successfully ran independently facilitated, mixed-stakeholder workshops, using the information gathered from earlier public engagement to prepare information designed to address major concerns. One project described using webinars as an opportunity to invite co-design of project, presenting stakeholders with pragmatic, tangible options:

*“...what support do you want from the project? If we were to put a licence application in, do you want to make sure that there's a team member that specifically on the end of a hotline? So, if you have any concerns, you can call them? Do you want enhance shepherding? Do we need to set up a volunteer?”*

Another described using scenario-based discussion in co-design workshops:

*“Sometimes their preference isn't realistic. So, I might use a loose choice experiment, [present] the realistic scenarios, [and ask] what would be your preference?”*

One expert believed that their most successful focus groups comprised people who had already engaged with the project at earlier events, alongside those who were engaging for the first time, as this provided an opportunity for assurances and answers to come from informed parties within the group, rather than ‘top down’ information shared by the project team. One expert strongly recommended providing substantial food (i.e. a hot meal), and covering all expenses, as traveling to such an event could take a full day in some rural areas.

One project faced initial backlash for these types of smaller scale engagement, with some members of the community suggesting that the project team were “*avoiding them*” by not hosting “town hall” style public meetings. The same project found that these discontented stakeholders later became strong supporters of the project and acknowledged the benefit of this small-scale approach.

#### **3.2.4.5 Steering groups and partnerships**

A recurring topic throughout the interviews was that rural communities often felt that apex predator reintroductions are being “*done to them*” by conservationists and “*people from outside [the area]*.” All experts highlighted the importance of establishing steering groups or local partnerships from the earliest possible opportunity, bringing together representatives from conservation, statutory bodies, farming, game keeping, estates management, forestry, and other local interest groups. In some cases, relationships were fostered for several years before the formation of steering groups.

One project was developed from the beginning as a partnership between landowners, land managers, and a conservation organisation:

*“Having that kind of equal partnership or having the landowning interests right from the beginning really helped because it meant that they weren't just involved, they were very*

*much fundamental in making it happen ...[this] demonstrate[ed] that whilst there will be some, low level persecution issues, land managers and landowners wanted to see Golden Eagles back [in the landscape].”*

*“You find like one or two people in an area to come on board. They can influence other landowners, whereas me coming in as a conservation person, they would not quite trust us and especially because I'm government. So, having those key people on board [is helpful] just [having] somebody from the area that is interested and can say to the other landowners, ‘Hey, come on, how many lambs were you losing before and really, are you losing more now?’”*

Another project established a charity to manage the project, so the work could proceed without being pigeon-holed as just one of land management, government, or conservation:

*“...being an independent host for the project going forward was really important. We have had feedback from estates, gamekeepers, landowners that have just said, ‘look, if you came with an [conservation organisation] project, we wouldn't let you through the door.’”*

*“...we didn't want it to be government led. It was very much community based but with equal input from all the big partners.”*

Two projects believed that having an independent host organisation, using independent facilitators and meeting at neutral venues was key to fostering an atmosphere of equality in perspectives, and to avoid having any one person or group perceived as *leading* the project.

#### **3.2.4.6 Modelling co-existence**

All of the experts we interviewed insisted that in cases where eagles have been reintroduced, there have been no major issues surrounding predation, and very little conflict of any description. However, misinformation around diet and behaviour of WTE and GE was considered one of the greatest initial challenges when liaising with the farming and gamekeeping community. Several experts talked about the vital role of modelling by farmers and game keepers currently living alongside eagles in other areas:

*“...there were some pairs [of Golden Eagle] in the South of Scotland and the landowners who had those pairs actually came forward and said ‘look, we will stand up and say that we've had eagles for 50 years and we've not had any significant problems’, which was really helpful.”*

*“...we had a meeting with one farmer in particular who was very concerned, and we actually got the concerned farmer and the landowner [living] with eagles. We sat them down at a table and just said, ‘look, I can't promise you anything, but this is a man who's had them for 50 years, you know, he has lambs on the hill and is proud to welcome Golden Eagle.’ So that was really powerful.”*

*“...we've got some contacts across Europe that will log on [to webinars] and the farmers can ask them directly any questions they've got and really, hearing what they've got to say. So, it's not us [the project] telling it them.”*

#### **3.2.4.7 Compensation**

All the interviewees discussed the issue of compensation for lost livestock, and all were strongly opposed to such measures. Ultimately, the projects we spoke to claimed to have had little to no issues regarding predation and so spending time negotiating compensation plans would be

wasted. One respondent spoke of the issues surrounding Golden Eagle predating on lambs and reindeer in Norway, and strongly advised against compensation schemes, which they claim have been abused:

*“...[farmers] will get between 2.5 to 3 times the value of the meat as a compensation when a lamb is killed [by a Golden Eagle] and that doesn't really encourage farmers to herd the lambs, because their compensation is so, so handsome...”*

*“...five or less percent of those [cases of predation] who are compensated are really found and documented.”*

However, most interviewees said that farmers immediately raise the topic during consultation. One interviewee described a co-design workshop which dealt with this topic:

*“One session would be mitigation measures, what we've done is collated all the evidence from Europe and [we] say, ‘this is what happens in Europe’, we give them all the context and ask ‘what would work here. Why? Why not? What would have to be adapted?’”*

While it was generally acknowledged that GE would pose a greater threat than WTE for sheep farmers, three interviewees spoke about this being dependent on the availability of alternate prey, as GE will predate on what is most easily available in the landscape, highlighting the importance of selecting an appropriate site that can comfortably support a population of GE:

*“...if there is enough prey like rabbits, hares, waterfowl, pheasants, they are easier to kill than lambs.”*

One interviewee discussed alternative compensation schemes currently in effect in Finland and Sweden: where reindeer farmers are compensated according to the number of eagle breeding territories on their land, with subsidy payments linked to agreed risk, rather than as payment for damage or loss. They explained that this puts the incentive on the farmers to “*support Golden Eagles on their land*” and “*take better care of their livestock*”.

#### **3.2.4.8 Time frames**

Generally, it was believed that community and stakeholder engagement should start as early as possible, as countering misinformation or deep-seated cultural norms and beliefs can take many years. One project involved landowners from the earliest discussion, 10 years before any eagles were introduced. Another expressed regret at not having started this sooner:

*“...if I was starting a project from scratch now again, the work I was putting in, in the local community should have been done maybe two years in advance [of the licence application].”*

However, there were differences of opinion amongst the interviewees with regards to *when* to consult certain groups. One interviewee suggested that timing needed to be carefully managed, as announcing a project too early will give those opposed time to organise and mobilise opposition, while leaving engagement too late might give the impression that engagement is a “box ticking” exercise.

#### **3.2.5 Key stakeholders**

The following section outlines some considerations and experiences for engaging certain key stakeholder groups, and highlights some of the specific concerns of each group.

### **3.2.5.1 Farming organisations**

The majority of experts highlighted that national farming organisations, local farming associations and individual farmers should be considered separately, as often their interests do not align on issues such as reintroductions:

*“We've done local farm visits, and a lot of local farmers have expressed to us... that [farming organisations] are not really representing [their views] sufficiently, so there's been a lot of farmers that have disconnected.”*

One interviewee said organisations may not always further disseminate information they have provided:

*“We've shared information throughout the course of a project, primarily about [WTE] diet because...we find that information is really useful for reassuring various stakeholders, and you'd think that the bodies represent these farming interests would be keen to share that information, to reassure their members.”*

One highlighted the importance of local engagement in countering organised opposition:

*“...we went to [farming organisation], and we said we want to work with you .... So, we had a meeting for farmers at [redacted]. It was a room full of 70 odd people, they weren't very happy. It was a bit of a baptism of fire, and unfortunately, it was probably the wrong approach... subsequently, [we had] drinks and stuff, refreshments, and then had some really quite sensible conversations with a lot of people...”*

Despite difficult discussions, there was a recognition from all the interviewees that engagement across groups in the farming community is necessary, but that there should be no expectation of support:

*“...as long as they bring in the concerns to the table and you're covering the evidence around those concerns, you know, we can safely say that opposition from [a particular farming organisation] isn't going to influence the acceptance of this program.”*

*“Scotland, Ireland and England have accepted licences to bring these birds back, so there's a reason for that and that's because of the evidence around livestock impacts is very low compared to what appears in the media.”*

Two interviewees discussed the role political climate can have in influencing the position of farming organisations, noting the importance of the timing of consultations:

*“I think the farming organisation felt it could take the [reintroduction] out as a kind of win. You know, they couldn't win on various bigger things like the CAP in EU or whatever... It was difficult [for us], with public meetings where it was quite fraught and votes among farmers to back the project or not, which was, you know, a real straw man kind of thing. A lot of misinformation.”*

One respondent explained that one farming organisation's opposition to WTE reintroduction was primarily focused on concern over expansion of special protected areas, with a fear that larger areas would be designated as protected once eagle populations were established.

### **3.2.5.2 Farmers**

Engagement with farmers is covered in depth in sections **3.2.4.6**, **3.2.6.1** and **3.2.6.2**

### **3.2.5.3 Gamekeeping & shooting**

Most interviewees described their engagement with gamekeepers to be reasonably neutral, one put this down to the idea that gamekeepers are already living with raptors and so are less fearful of the reintroduction of eagles, although several mentioned that Golden Eagle are likely to pose more of a threat than WTE. One interviewee stated that the GWCT take a generally positive position on these types of projects, however, they spoke of a belief within the game keeping community, that the conservation sector is in fact antagonistic towards them, rather than the other way around, and suggested the best way to overcome this assumption was to engage openly and honestly with these communities and show willing to work with them:

*“...the perception from the game community is that the conservation sector is perhaps more antagonistic of game shooting. If that's true or not, isn't necessarily relevant, but certainly some of the keepers we encountered don't feel like we really want to talk to them.”*

One expert recounted a conversation with a gamekeeper, and how this influenced their project communication strategy:

*“...the concerns were gamekeepers getting blamed for any bird that disappears. It doesn't matter whether it was persecuted or whatever. So, we said ‘look if we get a natural death or a turbine collision or run over by train or whatever that we will be completely open about that.’ And we have done that so. Every bird [lost] we put it out as a blog post.”*

One project explained that when consulting gamekeepers ahead of a WTE reintroduction, the major concern raised was relating to behaviour of bird watchers, rather than the birds:

*“...they don't want the birds to then bring in people who are going to be wandering around and trying to see the eagles and then disturbing all their pheasants and partridge and whatever else to be seeing.”*

To address this concern, the project agreed to direct public attention to sites where the birds are nesting in public spaces, away from shooting estates.

### **3.2.5.4 Conservation sector**

Most interviewees discussed difficulties encountered when engaging with the conservation sector, as many specialist interest groups expressed concerns about predation of threatened species, while others were opposed to the idea of species reintroductions in general. One respondent described their attempts to reassure this stakeholder group:

*“[important to] ground what [conservationists] are saying, particularly surrounding issues of predation of [threatened species]. Eagles as we know from our work and from other people's work, eat what is most abundant in the landscape. The fact that [threatened species] are, rare in the landscape should be reassuring to people that are working on them, if they are so rare they're not going to feature in eagle diet.”*

### **3.2.5.5 Forestry sector**

Two interviewees found that the forestry sector was resistant to engagement in the initial consultations, one citing “concerns around exclusion zones interrupting forestry activities”. One described taking a pragmatic approach to engagement with forestry and suggesting that exclusion zones could be “smaller than the guidance suggested”. This approach opened the door to further engagement and the project was able to work with foresters to plan a bespoke solution,

taking into account access and topography at the site, so as to protect the birds while limiting impact on forestry activities.

One interviewee discussed successfully engaging with foresters to encourage them to deliberately leave some areas of plantation to become overmature, as eagles prefer to nest in the tallest tree. This approach was perceived as giving some control back to the foresters, and well received.

### **3.2.5.6 Tourism sector**

All interviewees were consistent in their description of consulting the tourism sector, which they universally considered to be a powerful ally to reintroduction projects. One spoke of the importance of engaging supportive stakeholders, and not just focussing all resources on engaging those with the most concerns:

*“...the tourism sector actually saved the project from being shelved in that first year because, you know, they made it clear to the government that there was more than just a farming sector to consider.”*

### **3.2.5.7 Other stakeholders**

One project described initial resistance from a chihuahua farm and initially struggling to reassure them of the low level of risk posed by the reintroduction.

Another interviewee discussed challenges when engaging parish councils:

*“I think parish councils are interesting. They seem to be quite vocal in getting back, saying they're opposed. But then they don't actually represent the community, so that I feel like is quite an interesting thing that I've come across because, yeah, I've noticed that across projects.”*

## **3.2.6 Engagement methodologies throughout project**

### **3.2.6.1 Project Officer**

The experts interviewed gave similarly strong views on the vital role of the project officer (PO) in engaging and reassuring the community. The project officers were described as vital in ensuring stakeholders could engage the project without seeming to go through any sort of formal procedure. Instead, information, questions or concerns could be fed to the project team, before the PO responded to the stakeholder. All projects spoke of the importance of having a project officer in post from the earliest possible opportunity, to allow for that trust to build before any reintroductions take place. All interviewees also discussed the importance of consistency in this role. Several other factors were consistently highlighted throughout the interviews.

The PO will ideally be from the region or nearby:

*“...there was a perception that a project like that was backed to some extent by tourism, or it could be, you know this is an outside project.”*

*“I remember when we got the licence, I was talking to... farmer and she said, ‘I suppose you're going to fly in a project officer now from some far-flung place’. I said ‘Actually, no. He's from [local area]’ and she just she didn't really know what to say”*

They should have experience working in farming, forestry or gamekeeping. One project described having a member of the Scottish Game Association on the interview panel for the role, helping to identify a candidate who would be “*respected and accepted*” by the farming and game keeping

community. This project eventually hired a former gamekeeper as their stakeholder engagement officer:

*"I think having someone who was a retired game keeper who had worked on shooting estates alongside Golden Eagles, someone that could sit down and say, 'look guys, I understand what your concerns are', [understand] what the issues might be. That was that was really powerful."*

*"... [redacted] always says [the PO] can sit down and talk with anyone about anything. So, it was very much getting someone who was fairly affable."*

The PO will ideally be able to relocate to the reintroduction site, if not already living in the region, to be a visible and known presence in the community:

*"Having someone [project officer] who gets on with people and can see the other view and can be there, like at the drop of a hat, if necessary, is massively important"*

*"...being a face in the community is so important, turning up to the auction market regularly and seeing the farmers. People [funders/project managers] don't realise: it's not what you say, but it's your actions like that [count], [stakeholders/community think] you're here because you care and you do want to understand."*

*"[local community] are the people who pick up the tab. If there's a negative impact, it's on them. I felt it was critical that I would engage the community as much as possible and lived in upland sheep country in the valley. That was critical, because I got to know everybody and if there was an issue, they would ring me straight away and I would go and address it. Probably the most important thing is, regardless of what you think the reality situation might be, is to address it before it grows legs and ends up in the newspapers"*

One interviewee discussed the challenges that come with this role, a PO who lived in the project community, they described themselves as "persona non-grata" during the early years of the project, but over time became a trusted and valued member of the community.

*"...like there's pros and cons of being the face of the project. And now we've got this wider partnership I kind of try to avoid being the face of the project, but I think it helps having somebody that everyone knows: 'Oh well, if I ever have a problem, we can reach out to [redacted] or the project officer'."*

### **3.2.6.2 Tracking birds and sharing data/location**

One recurring topic throughout the interviews was the importance of satellite tracking data in reassuring farmers and game keepers around issues of predation, as satellite tracking enables project provide evidence that eagles are not causing the loss of animals:

*"...because the birds are satellite tagged, we know where they are all the time, in every case we've been able to say, 'well, if you've lost any lamb, it's not due to the eagles because we know where they've been.' So, that's been really valuable."*

One interviewee described sharing the data with game keepers, famers and landowners to help build trust between the project and these stakeholders:

*"I think the farmers knowing that we were satellite tagging the birds was good for them because it showed them that we were going to be able to monitor the birds effectively, which again I think was important."*

*“...having the [tracking] data and the capacity to conduct really thorough monitoring is really important in providing that reassurance [to farmers].”*

*“...someone who is out on the ground will know their land. They'll probably know the eagles are there before anyone [else], so partly [sharing tracking data] was building that trust by saying that we're not trying to hide anything from you.”*

Another described sharing the tracking data as a “soft deterrent” to persecution, as both the project and the landowners were aware where the eagles had been:

*“I suppose, it was a little bit ‘we know that you know where the Eagles are’, but I think keepers had felt from the beginning that they're excluded [from such projects]. So, we said we want to start from a level playing field, put the past behind us.”*

Two projects talked about using tracking data for targeted engagement with stakeholders and the community, as they were able to share the location of nesting and feeding, which built a sense of ownership and buy in from the community.

*“So initially when we would call whichever keeper was in the area and say, look this eagle's here, keep an eye up for it. Now we've got eagles in all of the upland areas, so we don't call every time there's a bird because most of them have them pretty much permanently. But working with them to say right, you know you've got a pair on your patch now. Showing them the maps and working with them when nests were built.”*

### **3.2.6.3 Ongoing engagement with stakeholders**

All interviewees stated that initial dissenting voices dissipated as major concerns, e.g. predation and birdwatchers, never materialised, one noted that misinformation becomes overshadowed by lived reality, as after a time the eagles are:

*“...just another part of the landscape.”*

and that:

*“Many farmers are very thrilled when they have a [white tailed] eagle on their property, there is a lot of tourism sparked off from this and this revenue [is] coming in.”*

When asked about ongoing engagement, two interviewees said that once the project is up and running, it is better not to constantly remind people of it, instead ensure that the community and key stakeholders have an open line of communication to the project officer or project team should any issues arise:

*“We agreed a reporting procedure with [licencing authority], so that if a farmer had an issue, they could see that we were going to go and visit the site and then we were going to report to the steering group what was happening. And then agree, any mitigation that needed to be undertaken. So, there was a clear kind of methodology where if a farmer did have a problem, there was a way for them to contact us and for that problem to be dealt with.”*

One interviewee explained that they initially formed a local group consisting of farmers, local government, national parks, police to plan how to respond to calls relating to predation by eagles:

*“I would generally go out and check, like in Norway when they get potential predation case. They shear the sheep and then they check for the bruising. You know whether it's*

*actually just scavenging. If there's no bruising, then no [predation]. We said we'd play it by ear, if it [predation] became an issue, and it didn't."*

#### **3.2.6.4 Legacy planning**

Every interviewee discussed the issues around legacy planning and ongoing funding, with their main concern being the funding of community-based project officers beyond the scope of the licence. Two experts explained that while POs can answer questions during the initial stages of the projects and reintroductions, the aim of established eagle populations leaves some stakeholders concerned that future issues or conflicts will not be addressed:

*"I've been talking to sheep farmers, they've said they find it kind of unnerving that there's no longevity in projects, so you get somebody in a post three to five years and they disappear, and they never see them again.... It doesn't feel like they have that person [they can rely on]"*

*"...it gets raised at pretty much every steering group meeting we have - what happens when the license is up?"*

One expert described their ongoing struggle to fund the PO role:

*"We had to raise quite a bit privately to keep [the project officer] going. And in the latter years it went from being full time, to being full time self-employed, to being part time self-employed. the national parks and wildlife service themselves have taken on the management of the project."*

They continued that staff unfamiliar with the project and community were ill equipped to deal with issues that arose, and gave an example of the consequences:

*"...sheep had been attacked by something and it all sounded a bit farfetched, and [the farmer] wasn't taken that seriously... the [wildlife service staff] that covered that area never went and visited him, so [the farmer] went to the farming organization, and it ended up in the press. Once the photographs were analysed, it was obviously a stray dog or something, it wasn't an eagle. But the thing is, however wacky or outrageous people's complaints are, you have to take them seriously or it can actually end up [escalated]."*

One interviewee described a situation where a breeding pair of eagles nested by a harbour, while their original plan was to keep breeding sites confidential, the project team decided to go public, and the community were overwhelmingly positive taking ownership of the project. Over 10,000 visitors came to view the birds with no official publicity, it was suggested that this has implications for ongoing governance:

*"...who is going to take the project on, but also what about the birds themselves? I feel like, for the local community take on their pair [is a positive outcome]."*

## **4. Discussion**

This research aimed to inform social approaches to GE reintroduction in England through a review of published evidence and a series of expert interviews with researchers and practitioners involved with the reintroduction of GE or similar species in the UK and Europe.

Findings were organised into *social perception and feasibility*, including public perception and attitudes toward proposed reintroduction; *consultation*, including initial stakeholder engagement; and *engagement methodologies throughout project*, which included ongoing stakeholder engagement and wider community engagement throughout the lifetime of a project and beyond.

Social perception and feasibility was well covered in both strands of the research, and there was general agreement that social surveys were the preferred approach for assessing these factors. Differences existed in methodologies, with some conducting such research online, while others used in-person surveys. The published and grey literature focused primarily on the findings of such research, while the expert interviews gave greater insight into the methodologies. The only area of disagreement emerged during the expert interviews, where some respondents believed that such research could have a negative impact on targeted stakeholder engagements. However, other evidence presented here suggests that such a concern is potentially unfounded, and even those respondents expressing this view commented that they would now prefer to have access to baseline data on public perception. The main take away from the evidence is that the placement of this research within a project timeline is a key consideration.

There was very little detailed discussion of consultation relating to reintroductions within the published literature, most of the major findings presented here are from the grey literature and expert interviews. A range of approaches are described, although one unanimous point throughout the interviews was that small-scale consultations are preferable to larger, public meetings. Another key finding from the interviews is the importance of project partners and steering groups for bringing stakeholders into the project from the earliest opportunity. The scope, depth and outcome of consultations appear mostly to be dependent on lead time and budget, as projects that were established on long term, existing relationships appeared to have the greatest buy-in from stakeholder and communities.

As with consultation, very little of the published or grey literature focussed on engagement methodologies throughout projects, and most of the key findings emerged from the expert interviews. There was little disagreement in how best to approach ongoing engagement, with all projects highlighting the importance of a dedicated and consistent project officer, the usefulness of tracking data in building trust and transparency around a project, and how ongoing community engagement can build a positive narrative around a project.

There were a number of limitations in this study, primarily, the evidence review revealed a limited number of published and grey literature containing any meaningful discussion of the social approaches, or more broadly, the human dimensions of eagle reintroductions in the UK and Europe. Despite the IUCN guidance on human dimensions of such programmes (IUCN/SSC, 2013), the major focus in the published and grey literature was biological and ecological feasibility; most of the initial literature search results contained no exploration of the human dimensions at all. It should also be noted that much of the most relevant literature was relating to reintroduction projects also covered in the expert interviews.

Based on the number of projects alone, the restoration of White-tailed Eagle across the British Isles is more advanced than that of Golden eagle. This was reflected in both evidence review and expert interviews, as most of the projects discussed related to reintroduction of WTE. While GE restoration is likely to require a similar approach for assessing public perceptions, conducting consultation and ongoing engagement, there are obviously limitations to the direct applicability of WTE approaches to GE restoration. A major barrier to direct transfer of WTE approaches to a

GE project is stakeholder type, this is due to the differences between the two species in relation to diet, behaviour and preferred habitat, placing different pressures on interests such as farming and game keeping.

## **5. Recommendations**

This section outlines recommendations based on the combined evidence of the literature review and expert interviews. We consider areas of unanimous agreement and instances of disagreement within the data and present the following recommendations as best practice for social considerations of reintroducing GE in England.

### **5.1 Social perception and feasibility**

We recommend conducting public perception research in the proposed reintroduction area. The geographic scope of this research should be informed by ecological and behavioural data on where the GE are likely to be. This social research should be conducted both online and face-to-face to ensure representation across rural demographics, the sample should cover both rural and local urban areas. We recommend developing a concise social survey to measure:

- Knowledge of GE
- Knowledge of reintroductions
- Attitudes towards GE
- Level of support for proposed GE reintroduction
- Demographic data

On the evidence presented here, public support for reintroduction of GE in England is likely to be high. Evidence of such support in the proposed region will be an asset, if necessary, when countering opposition during stakeholder consultation. The research is also an opportunity to quantify public knowledge on the GE, this data could inform the content and level of outreach programmes or materials, for example, public talks.

We recommend that the timing of the survey be carefully considered, as such research could negatively impact relationships if conducted prior to any initial engagement with key stakeholders.

### **5.2 Consultation**

#### **5.2.1 Stakeholder mapping**

We recommend conducting a stakeholder mapping exercise in the proposed reintroduction region. The geographic scope of this mapping should be informed by ecological and behavioural data on where the GE are likely to be. Mapping should be a hybrid of top down, i.e. project team and steering group develop longlist of known stakeholders, and bottom up, i.e. stakeholder map should be expanded following public engagements, such a drop-in session. We recommend conducting regular evaluation of the stakeholder map to ensure that it is up to date, evaluation should also review ongoing stakeholder engagements, allowing the project team to switch focus should engagement with any group be over or underrepresented. Key stakeholder groups to consider:

- Landowners
- Land managers

- Game keepers
- Farmers (sheep and poultry)
- Local farming groups and associations
- National farming organisations
- Local and regional government
- Tourism
- Wildlife conservation
- Forestry

### **5.2.2 Partnerships and steering groups**

On the evidence reviewed in this report landowners, land managers, gamekeepers, and shooting interests pose the greatest challenges to GE in England. We recommend identifying the major landowners and land managers in the proposed region and engaging them personally as early as possible – before the social feasibility research is conducted. If possible, we recommend entering partnership with representatives from these (and other) key stakeholder groups, to initially increase buy-in from these groups and increase the sense of ownership of the project within the local community. Such groups can ensure the long-term legacy of a project (see **5.3.5**). If such an arrangement is not possible, we recommend developing a project steering group including representatives from the key stakeholder groups. Partnerships and steering group meetings should be held at neutral venues, ideally with an independent facilitator.

We recommend consulting national farming organisations, although they have opposed most eagle reintroduction proposals across the UK and Ireland. The evidence suggests that time is better spent building relationships with individual farmers and local/regional farming associations.

### **5.2.3 Stakeholder and public consultation**

Public and stakeholder consultations should avoid large, “town hall”-style meetings, instead, we recommend running multiple smaller scale consultations that encourage one-to-one discussion. From the evidence reviewed here, we consider the best approach to be a series of open “walk-in” sessions and webinars, where the public can meet the project team, learn about the proposal and raise any major concerns. These sessions should be widely publicised online and offline, through local media, community groups and organisations. Walk-in sessions and webinars should be used to gather information on stakeholders’ major concerns, and to gather names and details of stakeholders for follow-up engagement, while providing the project team the opportunity to offer necessary reassurance.

Alongside these walk-in sessions, we recommend conducting a series of informal semi-structured interviews with representatives of all key stakeholder groups. Interviews should be conducted at a place and time most convenient and comfortable for the interviewee. These interviews should be used to gather information on stakeholders’ major concerns.

Following these initial engagements, we recommend running a series of small, single-stakeholder meetings to discuss major concerns and mitigation measures. We recommend recruiting representatives from current GE regions, their role is to counter misinformation and give their honest view of living and working alongside GEs. In person events should include substantial refreshments, and the project should offer to cover expenses.

On the evidence reviewed here, we recommend avoiding compensation schemes as a potential mitigation measure. Instead, discussion should focus on the lack of evidence of significant predation where GE are currently sharing the landscape with farmers and game keepers, and propose other mitigation measures, such as a dedicated channel for reporting any concerns or incidences of predation.

### **5.3 Engagement methodologies throughout project**

#### **5.3.1 Project officer**

On the evidence reviewed in this report, we consider the role of Project Officer (PO) to be one of the major determinants of successful community and stakeholder engagement. We recommend recruiting a PO as early as possible. Ideally, they will be local to the region and have experience of working in or adjacent to a land-based business, such as game keeping, farming or forestry. This role should be recruited as a long-term position and embedded in the community. The experts interviewed stress the importance of consistency in this role, i.e. ideally, the PO will be the same person throughout the project. The aim of this role is to engage with key stakeholders on a personal level, provide assurance and be an *approachable face* of the project on the ground. In the early stages of the project, the PO should be involved with the consultations, and conduct door-to-door and community visits to introduce themselves and the project. The PO should remain the main point of contact for any member of the community with concerns, issues or questions throughout the project.

#### **5.3.2 Steering group**

For recommendations on steering group membership see **5.2.2**.

#### **5.3.3 Community outreach**

We recommend developing a programme of community outreach, such as public talks and activities, connecting the local communities with the project and developing buy-in from a range of different interest groups. Example organisation:

- Schools
- Youth and sports clubs
- Community organisations
- Local government
- Local businesses
- Conversation and nature organisations
- Eco-tourism businesses

#### **5.3.4 Communications**

On the evidence reviewed here, local and national media are a potentially useful ally for GE reintroduction in England. We recommend providing press releases to ensure accuracy in reporting and engaging local print media to advertise public consultations and other engagements. Social media, project blogs, and websites should be used to update local communities and stakeholders on the project and publicise events or engagements.

#### **5.3.5 Legacy**

While it is difficult to ensure long-term funding for a project, we recommend seeking to reassure stakeholders of the long-term intentions of the project. Steering groups comprising local

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stakeholders, and engaged community groups, can ensure support and buy-in beyond the initial species recovery or restoration project.

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