The Eagle Reintroduction Wales (ERW) project:

An assessment to restore our native-lost eagles.

Sophie-lee Williams

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“Breuddwydiwch yn fawr, dechreuwch yn fach, actiwch nawr, ond yn anad dim, dechreuwch!”

“Dream big, start small, act now, but most of all, start!”

Roy Dennis, MBE, Pers. Comms (2016).

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Thesis Summary

The Golden Eagle (*Aquila chrysaetos*) and White-tailed Eagle (*Haliaeetus albicilla*) were once widespread across historic Britain, before declining at the hands of human persecution during the 18th and 19th Centuries. With both eagle species now breeding in limited parts of Northern Britain, both eagles are currently extinct from many parts of their historic range, including England and Wales. This thesis examines the feasibility of restoring either/or both native species of eagles to Wales, by addressing the standard reintroduction criteria set out by the International Union for Conservation of Nature (IUCN; ***Chapter One***). Little scientific research has previously been conducted on this notion, however, this thesis provides evidence that both species were historically widespread across Wales prior to the 18th Century, and the extinctions of both species were attributed solely to persecution by humans (***Chapter Two***). With knowledge that the Welsh landscape has been devoid of eagles for over 150 years, breeding ranges of ecologically similar birds of prey were mapped to examine their habitat assocations and avoidance of modern-day anthropogenic factos, providing proxy environmental indicators of how reintroduced eagles would potentially use the Welsh landscape (***Chapter Three***). Species Distribution Models (SDMs) were then created to examine the distribution of suitable habitats that meet the breeding requirements of both species across Britian, including Welsh local maps(***Chapter Four***). By understanding the distribution of breeding eagle habitats in Wales, spatial analysis and mapping of anthropogenic land uses was overlaid with breeding habitats, to reveal Wales' modern-day availability to sustain populations of both the Golden and White-tailed Eagle (***Chapter Five***). This thesis provides the most in-depth assessments to date, of the feasibility of restoring either/or both eagle species to Wales. The biological, ecological and environmental evidence gathered in this thesis, provides the fundamental information needed to initiate restoration programmes (***Chapter Six***), and further discuss the additional regional assessments that need to be carried out to complete the license application to reintroduce eagles to Wales.

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List of Publications and News Items Covering the PhD Thesis Work

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Abbreviations

IPBES - Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services

IUCN - International Union for Conservation of Nature

UK – United Kingdom

EU – European Union

BAP – Biodiversity Action Plan

SPAs - Special Protected Areas

SSSIs –Sites of Special Scientific Interest

SAP – Species Action Plan

SNH – Scottish Natural Heritage

NRW – Natural Resources Wales

ERW – Eagle Reintroduction Wales

AONB – Area of Natural Beauty

JNCC – Joint Nature Conservation Committee

BUA – Built up Area

CPAT – Clwyd – Powys Archaeological Trust

DAT – Dyfed Archaeological Trust

DEFRA – Department for Environmental, Food and Rural Affairs

GAT – Gwynedd Archaeological Trust

GGAT – Glamorgan – Gwent Archaeological Trust

GWCT – Game and Wildlife Conservation Trust

LERC – Local Environmental Records Centre

NIWT – National Inventory of Woodland and Trees

NNR – National Nature Reserves

OS – Ordinance Survey

OSOR – Ordinance Survey Open Roads

RSPB – Royal Society for the Protection of Birds

UKWED – UK Wind Energy Developments

WTW – Wildlife Trust Wales

Chapter One

General Introduction

"Mae eryrod yn rhan goll o fioamrywiaeth frodorol Cymru 'ac fe'u collwyd yn llwyr trwy weithgareddau dynol. O ganlyniad, mae llawer o bobl yn credu bod gennym ddyletswydd foesol i'w hadfer."

"Eagles are a missing part of Wales' native biodiversity and were lost entirely through human activities. As a result, many people believe we have a moral duty to restore them."

Roy Dennis, MBE, Pers. Comms (2017).

The Eagle Reintroduction Wales (ERW) Project: General Introduction.

1.1. The Importance of Reintroduction Biology

Our natural environment is continuously changing, and this transformation has resulted in a high rate of biodiversity loss across the globe. The rate at which we are losing our biodiversity has been reported to be more rapid in the past 50 years than ever recorded at any time in human history (Watson *et al.,* 2015). The Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES) announced that species extinction rates are between 1,000 and 10,000 times more rapid than recorded natural rates (IPBES, 2019). These elevated rates are largely attributed to modern land use change, anthropogenic activities (Reidsma *et al.*, 2006) and expanding human habituation (Concepción *et al.*, 2015), in turn, resulting in habitat loss (Pardini, Nichols and Püttker, 2017), fragmentation (Haddad *et al.*, 2015) or destruction (Storch, Jetz and Keil, 2015), which has direct negative impacts on native biodiversity. In the face of unprecedented biodiversity losses, effective strategies for the conservation of ecologically important species are urgently required (Lauber *et al.*, 2011; Bainbridge, 2014).

Virtually every country across the globe suffers with biodiversity loss, which has motivated both national and international responses to attempt to reverse these trends (Dirzo and Mendoza, 2008). Many governments realise the need to establish better spaces for nature for the benefit of wildlife and people (IPBES, 2018). The Convention on Biological Diversity (Convention on Biological Diversity, 2018), an international response to biodiversity loss in 1992 (Convention on Biological Diversity, 2006), led many countries to derive '*National Biodiversity Strategies'*, with standardised aims to: i) conserve and enhance biodiversity; ii) support healthy well-functioning ecosystems, and iii) where practical to restore species populations to their natural historic ranges (Secretariat Convention on Biological Diversity, 2010).

The rate of biodiversity loss is not consistent for all species and spaces. Species which require larger territories, have low population numbers and low reproduction rates are more vulnerable to population declines and regional extinctions (Collen *et al.*, 2011). The rate of biodiversity loss across the globe also varies, with some countries suffering higher declines than others. According to the UK's State of Nature Report (2019), biodiversity loss has been significantly higher than global averages (Hayhow *et al.,* 2019); with 56% of recorded species declining between 1970 and

2019, ranking Britain one of the 29th worst countries analysed (Hayhow *et al.,* 2016). Extinction rates in Britain rose from the 19th to the 20th Century, with habitat loss reported to be the principle driver (Hambler, Henderson and Speight, 2011). Britain has lost many ecologically important species such as; the wolf (*Lupus*), eagle (*Aquila*), and beaver (*Castorea;* Carroll *et al.,* 2003*;* Evans, O'toole and Whitfield, 2012*;* Stringer and Gaywood, 2016).

The health of our natural environments is maintained by their native plants and animals. When native species fall regionally extinct, the loss of one species often triggers the loss of others (Kaneryd *et al.*, 2012), often leaving our natural environments less ecologically resilient and less able to support human basic life necessities (e.g., food, clean air and water; Mace *et al.,* 2020). In light of this knowledge, species recovery programmes are increasingly seen as a valuable tool for conservation (Corlett *et al.*, 2016). As part of the international and national responsibility to conserve our natural habitats and their respected biodiversity, there is an increasing pressure to restore native biodiversity and habitats (Santamaría and Méndez, 2012). This moral duty to restore extinct species is further supported by; Article 22 of the Habitats and Species Directive and Article 11 of the Bern Convention of European Wildlife and Natural Habitats:

i) **Habitats and Species Directive** - '*members should explore the possibility of reintroducing species on Annex IV listings, that are native to natural geographic ranges, where this may benefit their global conservation status'* (Council Directive 92/43 EEC, 1992).

ii) **Bern Convention of European Wildlife and Natural Habitats** - *'encourage the reintroduction of native species of wild flora and fauna' to contribute to the international and national conservation status of endangered and conservation concern species'* (Council Directive 82/72/EEC, 1979).

1.2. Conservation Translocations, UK

Species translocations are defined as the '*intentional movement'* of a living organism into a wild space, from other wild or captive populations (Armstrong and Seddon, 2008; Carter *et al.,* 2008). Across Britain, there are species translocations registered for two primary objectives: i) the intentional movement of exotic species (i.e. non-native) for recreational (e.g. fish, game birds), nutritional (e.g. cultivation, livestock) or ornamental objectives (e.g. plants, alpacas; Griffith *et al.,* 1989; Seddon., 2010); or ii) the intentional movement of native species for conservation purposes

(IUCN/SSC, 2013). Reintroduction biologists commonly use the term '*species reintroduction'*, such terminology allows conservationists to catalogue this management strategy for conservation purposes only (Manchester and Bullock, 2000).

British species translocation projects, relate almost exclusively to globally rare, endangered, regionally extinct or species of conservation concern (Tarszisz *et al.,* 2014). Translocation programmes are formerly conducted on an *ad-hoc* basis, often as the last resort to avert a population decline or extinction or to restore lost ecological functions (Corlett, 2016). Species translocations have matured into its own discipline in Britain (IUCN/SSC, 1998, 2013; National Species Reintroduction Forum, 2014), with many archives of successful species translocation programmes, including; the Beaver,*Castor fiber (*Harrington *et al.,* 2015); Red Kite, *Milvus milvus (*Evans *et al.,* 1999); Pine Marten, *Martes martes (*Macpherson *et al.*, 2014); and White-tailed Eagles,*Haliaeetus albicilla (*Mee, 2016*;* Dennis *et al.,* 2019).

Species translocation programmes are now accepted as an important component of British nature conservation and has developed in response to two separate conservation management interventions: Species '*restoration*' or 'i*ntroduction*' programmes (Griffiths et al., 1989; IUCN/SSC, 2013). Species restoration programmes comprehend the population restoration, reinforcement or reintroduction of native species, within the species historic range (Seddon and Armstrong, 2019). While conservation introduction programmes involve the introduction of non-native species, outside the species historic range (Seddon, 2010). It is common knowledge that conservation introduction programmes are the least preferred option in Britain (IUCN/SSC, 2013), as species outside their historic ranges can frequently cause negative ecological, social and economic impacts (Ewel *et al.*, 1999, Nel *et al.,* 2014; McGinley *et al.,* 2017).

Restoration programmes, which translocate native species within their historic ranges, meaning reintroducing native species into known ranges they once historically occupied, are reported to offer a range of potential benefits. Such programmes enable great contributions to ecosystems, habitats and other species by restoring lost ecological functions (Byrne and Pitchford, 2016); to culture and hertiage by restoring parts of heritage (Laurila-pant *et al.*, 2015); to further promote the long-term survival of species at a global scale (Tarszisz et al., 2014); and by providing additional economic benefits to wild release sites across Britain (Weeks *et al.*, 2011).

Species translocations, thus far, have proved to be an effective conservation tool in the UK, but its application on its own or in conjunction with other conservation or mitigation strategies needs rigorous assessment, evidence and justification (Griffith *et al.*, 1989; IUCN/SCC, 1998, 2013). Species translocations can be viewed as a response to the 'clear obligation' under international law and present era of increasing biodiversity loss and accelerating ecological change (Armstrong and Seddon, 2008).

1.3. Species Translocation Policy, UK

The release of native species into an empty landscape is not straightforward. Species translocations are often a strict, highly regulated licensed process and in the case of the UK, with standard translocation criteria set out by the International Union for Conservation of Nature (IUCN/SSC, 1998, 2013). There is also guidance from the National Species Reintroduction Forum (2014).

The assessment, proposal and licence application of a species translocation in the UK are usually in the form of multiple inter-linked reports hitting upon a number of '*Feasibility Phases'* surrounding the restoration of focal species (Jones *et al*. 2012; Macpherson *et al*., 2014). These reports include the assessment and identification of the following phases:

i) Biological and Ecological Feasibility
ii) Environmental Feasibility
iii) Genetic Feasiblity
iv) Social and Socio-economic Feasibility
v) Risk Assessments

Species licence reports are usually different for each species, as every species has different critical dependencies on other species, landscape features and within their ecosystems (Dennis, 2003; Guisan *et al.*, 2013; Tarszisz, Dickman and Munn, 2014). So, how do we know what questions to address for certain species translocations? Any well-planned species recovery programme starts by addressing: *whether a species translocation is the most acceptable option?*. The criteria to answer this question is the premise of a '*Species Feasibility Study'*, criteria questions are as follows:

i) The international and national conservation status of the species.
ii) If the release environment is within the historic range of the species (Pérez *et al.*, 2012).
iii) If the cause of extinction has reduced, eliminated or been rectified (Batson, Abbott and Richardson, 2015).

iv) If there is a possibility for the species to naturally colonise without human intervention (Clark and Westrum, 1989).

If these initial criterion point to a species reintroduction (***Figure 1***), then a series of inter-linked '*Feasibility Phases'* sub-titled below, are initiated and evidence gathered to establish project logistics, in the form of a licence application, to restore focal species to their once historic ranges.

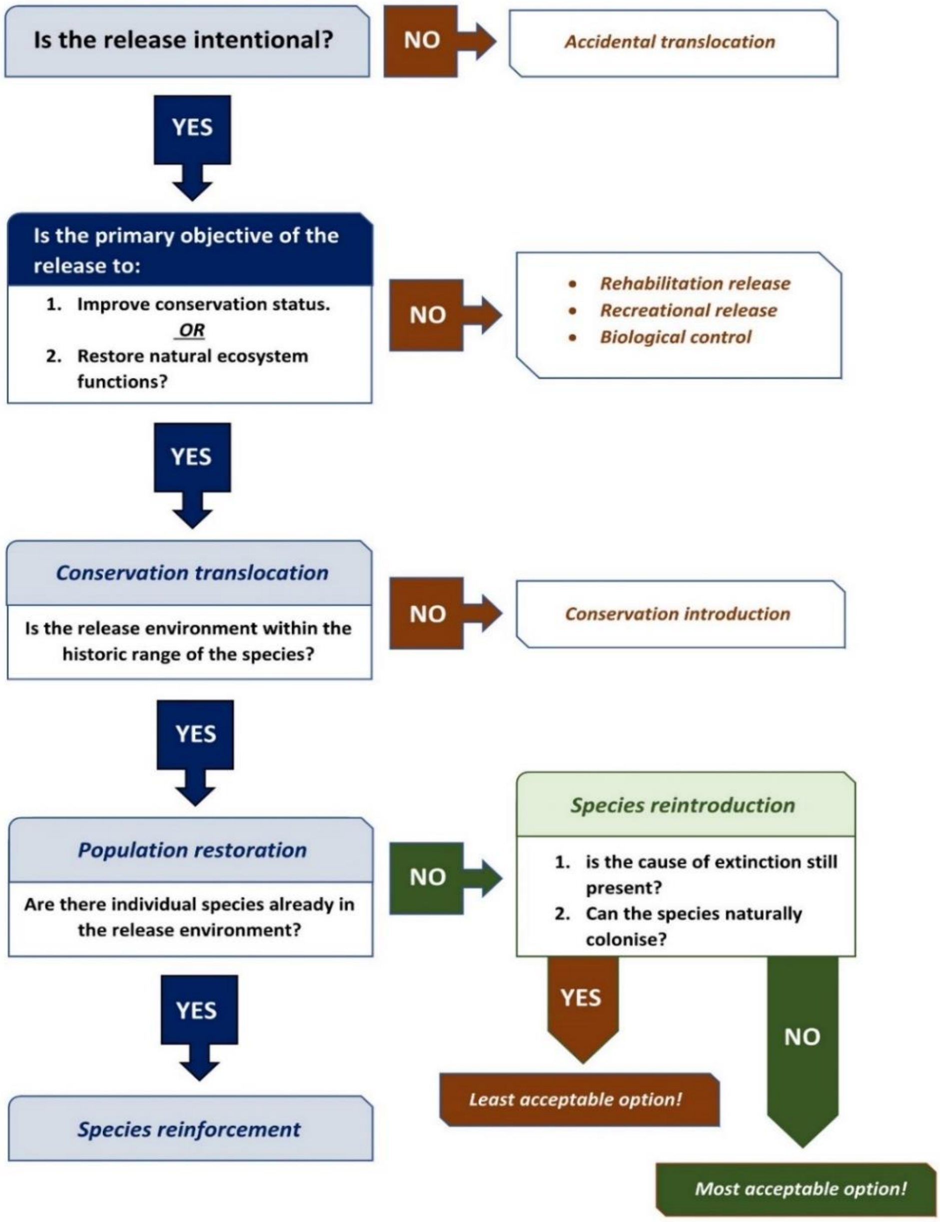


Figure 1. *The initial translocation spectrum to initiate whether a species translocation is the most acceptable option for the release species (IUCN/SSC, 2013)*

1.3.1. Biological and Ecological Feasibility

This phase compliments initial assessments by gathering information on the focal species biology and ecology, to evaluate *'if a translocation is the most acceptable option* ***for the species****?'*. Information can be collated from available publications, reports, action plans and consultations with professional naturalists (Sarrazin and Barbault, 1996). Understanding the basic biological knowledge of release species (e.g. reproduction, social structures, population growth, population dynamics, etc.), enables a comprehensive picture of the biological needs and requirements of the species for the release environment (Sutherland, 1998). Understanding the species ecological abiotic and biotic requirements, such as: habitat use, regional adaptations, dispersal and dietary requirements, are also an important component of this phase (Hirzel *et al.*, 2004; Cheyne, 2006; Ewen and Armstrong, 2007). It is common practice, where knowledge on focal species is limited, to retrieve the best available information from closely-related species to be used as evidence (Tegan *et al.* 2016).

1.3.2. Environmental Feasibility

In conjunction with complied information on the biology and ecology of the species, this phase takes into consideration the modern-day land use of the release environment, to evaluate *'if a translocation is the most acceptable option* ***for the release area****?'*. It is often the case that environmental conditions have been modified, altered or transformed post species extinction (Mouri, Shinoda and Oki, 2013; Schmid, Dallo and Guillaume, 2018). Thus, It is extremely important for translocation proposals to include information on modern-day land uses and if they are compatible for species release (Donaldson, Wilson and Maclean, 2017). Landscapes vary over space and time, and it is often recorded as good practice to illustrate a hierarchy of habitat suitability within the release environment, highlighting areas of low, medium and high land use risks (Guisan and Thuiller, 2005). By assessing suitable and available habitats within the release environment, the practical steps of how many species and source population can then be further derived.

1.3.3. Genetic Feasibility

The genetic feasibility is a phase that considers the donor/source population selection. This phase aims to provide evidence and select the most appropriate donor stock for the reintroduction process. Following IUCN guidelines, source population selection should aim to provide adequate genetic diversity (IUCN/SSC, 2013). Therefore, source populations physically closer to, or from habitats that are similar to, may be more genetically suited to release areas. Genetic considerations for source population selection is case-specific. In general, if the source population has a wide genetic base to start with, then it is unlikely to limit the feasibility of a reintroduction programme. However, if the source population has low genetic variability and are widely separate populations there may be genetic incompatibilities (i.e. inbreeding, genetic deterioration, outbreeding depression & genetic drift; Leberg, 1993; Negro and Torre, 1999).

There are examples of conservation introductions that may justify more radical sourcing strategies. For example, the re-establishment of the Noth American Peregrine Falcon *(Falco peregrinus*) deliberately mixed multiple donor populations aimed to maximise natural selection and diversity among individuals (Tordof and Redig, 2001; Johnson et al. 2010). Hence increasing the likelihood of some translocated individuals and their offspring thriving under novel conditions.

Thus, it is important to consider the genetic difference between the original population and the translocated population for any reintroduction programme. For eagles it is good practice, to avoid generic deterioration, unrelated individuals need to be reintroduced at regular intervals (Vali et al. 2019). Also to avoid outbreeding depression translocated individuals need to be from the same species and evolutionary significance (Hailer et al. 2006). The genetic feasibility for eagles to be translocated to Wales is discussed in detail in **Chapter 6**.

1.3.4. Social and Socio-economic Feasibility

This phase combines the knowledge of modern-day land uses with human interests and social attitudes, to evaluate *'if a translocation is the most acceptable option* ***for the release area's social infrastructure****?*'. Social interests towards species translocation are usually varied, and social attitudes, beliefs and values can be extreme and internally conflicting (Byrne and Pitchford, 2016). This was particularly true in British translocations for Beavers (Auster, Puttock and Brazier, 2019), eagles (Fielding and Haworth, 2014; Mayhew *et al.*, 2016) and Pine Martens (Ambrose-Oji, Dunn and Atkinson, 2018). An understanding of the local attitudes, beliefs and values allows for cost-effective ways to identify and address points of conflict between humans and wildlife (Coz and Young, 2017). In light of this, species translocations should be developed within the regional conservation, human and social infrastructures (Hayward and Somers, 2009; Consorte-McCrea and Thompson, 2014); in recognition with key conservation enterprises, stakeholders and local communities (Sharma, 2005); Seddon *et al.* 2007),

1.3.5. Risk Assessments

By gathering information on the previous phases, specific risk factors at a species and landscape level can be addressed. Risk assessments, however, should also include information on risks to source populations and translocation methods (Weeks *et al.,* 2011), the ecological consequences of translocated species on other species or ecological processes (Furlan *et al.*, 2020), disease risks (Hartley and Sainsbury, 2017), and socio-economic risks (Seddon and Armstrong, 2019). Conservation through human intervention, like species reintroductions are now common, but with increasing evidence and appreciation of the risks (Fernandez, Kramer-Schadi and Thulke, 2006). There are many reasons that are reported (Cox and Gaston, 2018), why a translocation may be of high risk:

i) Species with lengthy extinction durations.
ii) Landscape with large-scale environmental changes
iii) Species that have high dependencies on other species.
iv) Species with extreme genetic differences from original population.
v) Disproportionately high numbers of released animals
vi) Extreme negative impacts on human interests.

When all IUCN feasibility phases are complete, translocation methods are planned and all evidence gathered, all reports are submitted to statutory conservation agencies for approval. Dependent on the location of the release environment, British translocation licences are commissioned by either: Natural England, Scottish Natural Heritage (SNH), Natural Resources Wales (NRW) or Norther Ireland Environmental Agency.

1.4. Eagle Reintroduction Wales (ERW) Project

In 2016, the Eagle Reintroduction Wales (ERW) was developed as a PhD funded project at Cardiff University, to assess the potential of restoring two native eagle species back to soaring the skies of modern Wales (https://www.Eaglereintroductionwales.com/). The concept of translocating eagles to Wales is not a novel concept and has been suggested for many years (Dennis and Ellis, 1984; Yalden, 2007; Evans, O'Toole and Whitfield, 2012), but little research has yet been conducted and no formal proposal developed. The ERW project has become the leading project guiding scientific research in Wales for both the Golden Eagle (*Aquila chrysaetos*), known in the Welsh language as Eryr Euraid, and the White-tailed Eagle (*Haliaeetus albicilla*), known in Welsh as Eryr y môr. Initiating species feasibility studies to provide sufficient information to Welsh Government and Natural Resources Wales (NRW) on '*if the translocation of Golden and/or White-tailed Eagles is the most acceptable option* ***for the species*** ***<u>AND for</u>*** ***Wales***?'.

1.4.1. ERW Project Aims

The information and research in this thesis aims to provide information for the biological, ecological and environmental feasibility of restoring either/or both the Golden Eagle and White-tailed Eagles to Wales, by drawing information from national and international literature. The primary objective of this thesis is to draw a conclusion on whether a conservation translocation is the most acceptable option for both eagle species and the welsh landscape, with the short-term objective to initiate a conservation translocation programme and in the long-term restore both/either species to Wales. The information in this thesis, ranges from literature reviews to novel analysis of the species and welsh landscape.

Through the next section of this chapter, we explore the biological and ecological literature for both eagle species, why we believe both eagles' conservation and ecological status fits species translocation criteria, why Wales is considered to hold sufficient eagle habitat, and the main justifications for our research.

1.4.2. Candidate Release Species'

1.4.2.1. <u>The Golden Eagle (Eryr Euraid)</u>

Among all eagles worldwide Golden Eagles are, on average, the seventh heaviest and have the fifth longest wingspan. In the UK, the average male weighs 3.7 kg (8 lb), with an average wingspan of 2.0 m (6½ ft.) and the average female weighs 5.2 kg (11½ lb), with an average wingspan of 2.2 m (7 ft.; Watson, 2010). British Golden Eagles are considered a 'medium sized' race, as there is up to six races of this species across the globe (Doyle *et al.*, 2016). Adult Golden Eagles are essentially dark brown with an auburn nape that flashes gold in the sunlight and areas of paler grey on the wings and tail (Forsman, 2016). The young are uniformly brown, with prominent white underwings and tail and by annual moults they slowly attain their adult plumage over four to five years (***Figure 2***), by which time they are sexually mature (Cieslak and Dul, 2006).

Figure 2. *The dark brown and pale grey plumage of an adult Golden Eagle (left; Bleam, 2019), compared to the uniformly brown plumage with prominent white underwings and tails of a young Golden Eagle (right; Waschekies, 2019).*

Historically, the Golden Eagle nested throughout much of the northern hemisphere. Although many of these areas are still used for nesting today, the species has been locally extirpated from several areas, including; eastern Nebraska, southeastern South Dakota, Wisconsin, the Central Valley of California (Harlow et al. 1989), Iowa, Minnesota, Indiana (Wingfield. 1991). North America now has the largest population, it occurs from Mexico up through the western United States and across Canada (Kochert et al., 2002). Historical changes have also occurred across Eurasia and Africa, however, publicised information of these changes are limited. Although the species is still extinct as a breeding species in Southern Britain (i.e. Wales & England; Evans, O'toole and Whitfield, 2012). Golden Eagles now inhabit mountainous regions of continental Europe from the Iberian Peninsula through the Pyrenees and Alps to eastern Europe and Scandinavia, with the biggest populations in Spain and Norway (Birdlife International, 2015). In Asia, they occur across Russia and China, east to Japan and South to Turkey, the Caucasus, the Himalayas and the central steppes (Unwin, 2016). In the Middle East and North Africa, they breed in the mountains of Israel, Oman, Morocco and Tunisia (Brown, 1996).

The species is associated with open and semi-open habitats with mosaic short to medium length vegetation. The largest number of Golden Eagles are found in mountainous regions across the globe, with many eagles hunting and nesting in upland rock formations (Collopy, Woodbridge and Brown, 2017). The species largely avoids areas with human habituation and land used for intensive agriculture, as well as heavily forested regions (Ruddock and Whitfield, 2007). The species can be fairly adaptable to habitats, they are not solely tied to high elevated upland habitats and have been recorded to utilize trees in lowland areas (Moss, 2015) if regional habitats are suitable.

Golden Eagles are opportunistic raptors and are recorded to catch and eat a range of prey items (Simmons, 1980), from insects, reptiles, mammals and birds and small ungulates to scavenging carcasses. Despite a wide array of prey items, the average breeding pair subsists on just 3.57 prey species, with the average weight of prey being 1.6 kg (3 ½ lb) – typically consisting of small to medium-sized, ground-dwelling birds (e.g. game birds) and mammals (e.g. *leporids;* Whitfield *et al.*, 2009). They are often observed flying close to the ground in search of ground-dwelling species in short vegetation. They build large stick nests, which are usually constructed on inaccessible cliffs (Taylor, 2010), or in some parts of the world in large mature trees (Newton, 1979). A pair normally produces one to two eggs and the eggs hatch around 41 – 45 days of incubation (Hardey et al. 2009). The chicks, one or both, fledge after roughly 75 days, but are recorded to stay with their parents for another three to six months before becoming independent for four to five years before entering the breeding population (Weston, 2014; Murphy, 2017).

1.4.2.2. The White-tailed Eagle (Eryr y môr)

White-tailed Eagles are on average the fourth largest eagle in the world. In Europe and Britain, the average male weighs 4.5 kg (10 lb), with an average wingspan of 2.2 m (7 ft.) and the average female weighs 6.9 kg (15 lb), with the maximum recorded wingspan of 2.5 m (8 ¼ ft.; Unwin, 2016). Originally considered to have two races or sub-species across the globe, only one is recognised, as the population in Greenland is no longer considered a distinct sub-species (Del Hoyer and Colar, 2014; Hailer *et al.*, 2007). Adult White-tailed Eagles have an unmistakable plumage, a brown body contrasting with a pure white-tailed, a pale head with a bright yellow bill (Forsman, 2016). The young are a mixture of yellow and browns all over, including the tail and head and by annual moults, they slowly attain the adult plumage over a four to five-year period (***Figure 3***), before reaching sexual maturity (Cieslak and Dul, 2006).

***Figure 3**. The dark brown body with contrasting pure white tail, pale head and vibrant yellow beak of an adult White-tailed Eagle (left; Davies, 2019), compared to the brown and yellow full-body plumage of a young White-tailed Eagle (right; Daly, 2019).*

Historically, the White-tailed Eagle was once distributed as a breeding bird across the northern Palaearctic. With drastic population reductions and extinctions, during the 19th century, from extensive areas of their historic range, including; Britain, Faeroes, Western Europe and most of the Mediterranean (Dementavicus et al. 2016) The population has now recovered in many regions and now occurs from Japan, Kamchatka and the Bering Strait in the east, to Germany, Scotland, Ireland and Iceland in the west, extending to Greenland in the Nearctic (BirdLife International, 2020). Total population numbers are not known, however, they are a rarer bird than the Golden Eagle, with the largest breeding population recorded to be in Norway (i.e. >2000 pairs), followed by Russia (i.e. >1500 pairs; Hailer *et al.*, 2006). Across their global range, the majority of populations are associated with coastlines (Evans *et al.*, 2010), estuaries and lowland wetlands (Radovic and Mikuska, 2009), where they often nest in mature trees and coastal cliffs (Taylor, 2010). The species is also capable of inhabiting inland ranges where there are plentiful large mature trees to build their nests near rivers and large freshwater lakes, with sufficient food (Krone, Nadjafzadeh and Berger, 2013).

White-tailed Eagles are generalist raptors, often eating carrion such as dead mammals, birds and often dead fish washed up in coastal and freshwater shorelines (Whitfield *et al.*, 2013). They are extreme food pirates (i.e. kleptoparasites), often stealing food from Otters (*Lutra lutra*), Gulls (*Larus*), and Cormorants (*Phalacrocoracidae;* Nadjafzadeh, Hofer and Krone, 2015). They are seasonal hunters mostly feeding off live prey such as; water birds and fish near the water's surface in the spring and summer seasons (Sulkava, Tornberg and Koivusaari, 1997), and switching to carrion, waterfowl and small to medium mammals in the winter (Wille and Kampp, 1983).

They build large stick nests, which may be constructed in large mature trees, on rocky cliffs and even on the ground on small Islands (Love, 2013). A pair normally produces one to three eggs and the eggs hatch after 38 days (Hardey et al. 2009). The chicks, on average usually one or two, will fledge the nest at eleven or twelve weeks (Whitfield *et al.*, 2009). Young eagles stay with their parents for another three to six months before moving away from their familiar natal territories. Young eagles wander widely before becoming sexually mature at the age of four or five (Balotari-Chiebao *et al.*, 2016).

1.4.3. Conservation Status

The Golden Eagle is a species of European Conservation Concern, category 3 species (BirdLife International, 2018a), mainly attributed to the total European population still being relatively small and declining in many countries, associated with human persecution and land use change (Madders and Walker, 2002). The species is on Annex 1 of the EU Wild Birds Directive (Directive 2009/147/EC) and as such within the UK, has 'Special Protected Areas' (SPAs) in Scotland for its protection and conservation. Many countries, including Britain, contain regionally small populations of breeding Golden Eagles, so it is important to enhance the species' conservation across the wider countryside with measures to protect and enhance both foraging and nesting habitats (Whitfield *et al.*, 2006). There is no UK Biodiversity Action Plan (BAP) for Golden Eagles, and no overall plan in the public domain for the species recovery. Nevertheless, a species translocation and the restoration of Golden Eagles to suitable habitats in parts of their British historic geographical range would represent a significant further conservation measure of national (UK) and European importance (Whitfield *et al.*, 2008).

The White-tailed Eagle, albeit a rarer eagle than the Golden Eagle, enjoys high ranking protection status in most international conventions. White-tailed Eagles are a species of global conservation concern and a SPEC 1, rare species (BirdLife International, 2018b). The global population is still very small with almost 66% of the world's breeding population in Norway and Russia (BirdLife International, 2015). The species is considered vulnerable across most of its range due to its low production, slow adult maturity and illegal persecution (Sansom, Evans, and Roos, 2016). It is extinct as a breeding species in many parts of its historic range, including habitats along Southern Europe – Italy, France, Iberia, England and Wales (Evans, O'toole and Whitfield, 2012). The species is on Annex 1 of the EU Wild Birds Directive (Directive 2009/147/EC) and a Red-listed Species in Britain, as such within the UK, has 'Special Sites of Scientific Interest' (SSSIs) and SPAs in Scotland and Ireland for its protection and conservation. There is no recognised BAP for White-tailed Eagles, but there is a UK Species Action Plan (SAP; Scottish Natural Heritage, 2017). There are two main long-term objectives of the SAP, these are:

i) "to seek a recovery of White-tailed Eagles to as much of their former UK range as is suitable"

ii) To seek the removal of factors limiting further natural expansion into all suitable habitat throughout the UK, in particular estuaries, coasts and inland wetlands"

These long-term objectives are advised to be best achieved in the short term by a rolling scheme of reintroduction programmes for the species in Britain. This confirms that any plan to restore the White-tailed Eagle to Wales would substantially aid, National, European and International efforts to restore the species to its historic ranges and contribute to the global species recovery programme.

1.4.4. Ecosystem Functions of Eagles

The Golden and White-tailed Eagle occupy the role of apex predators across their respective habitats. That is, they are situated at the top of the food chain and play a crucial role in the way an ecosystem functions (Sergio *et al.*, 2007), rendering them keystone species. Both eagles main ecological role is to directly serve their ecosystems, responding to seasonal fluctuations, preying upon the most abundant prey source to keep populations in balance (Donázar *et al.*, 2016). Without the top-down influence of apex predators, like eagles, trophic levels of the food chain can quickly get out of balance (Morris and Letnic, 2017). This is known as a trophic cascade and can lead to an ecosystem being completely transformed (Leo *et al.*, 2019). Both eagle species catch a broad array of prey items, and provide this balancing service across many levels of the food chain, in multiple habitats. This top-down force influences a wide range of ecosystem processes that often enhance biodiversity.

An eagle can provide this service much faster than a terrestrial predator, by seeking out an aerial view and weeding out slow, weak, injured, diseased and dying prey, strengthening the general health and gene pools of prey populations in multiple habitats (Hedenström and Rosén, 2001).

When apex predators are no longer present, lower orders of the food chain increase in abundance and generally occupy larger foraging grounds, these trends put a great deal of pressure on ecosystem functions and native biodiversity (Rodriguez-Lozano *et al.,* 2015). For example, in North America, the absence of apex predators such as wolves and cougars had significant impacts on the numbers of both native (deer) and non-native (wild horses, Equus ferus; donkeys, Equus africanus) ungulates. High-density populations of middle-trophic ungulates led to over-grazing leading to biodiversity loss through the food chain and desertification (Vevra et al. 2007; Beschta et al. 2013)

Lennox *et al.* (2018) revealed many negative connections to the removal of apex predators, including; increased inter and intra-specific competition over food and resources, increase in smaller predators (i.e. mesopredator release; (Prugh *et al.*, 2009), increased spread of disease, less biodiversity and lower quality habitats. Thus, a reintroduction of eagles to Wales would support and regulate resource availability, habitat complexity and healthier biodiversity, generally creating more resilient ecosystems. A prime example of this is when White-tailed Eagles recolonized the Finnish archipelago they were found to significantly suppress the introduced American mink (*Neovison vison*), in turn, leading to cascading benefits to native birds, amphibians, small mammals, and plants (Roberge et al. 2004).

Apart from their main ecological roles, eagles also provide other regulatory and supporting services to their habitats. The Golden and White-tailed Eagle are both facultative scavengers and provide critical ecosystem services by removing decaying animal matter and maintaining clean habitats (Peisley *et al.*, 2017). DeVault *et al.* (2016) suggest this service helps break down organic matter, in turn accelerating nutrient cycling, limits the spread of disease (e.g. leptospirosis), provide natural pest control (e.g. Red fox (*Vulpes vulpes*), Ravens (*Corvus corax*), Jackdaws(*Corvus monedula)*) and transfers a significant amount of energy between trophic levels, for a more balanced food web. Both eagles are known to use multiple habitats across their life cycles and transport organic material and nutrients between many ecosystems (Sekercioglu, 2006). By transporting minerals and nutrients eagles can be vital resource linkers, particularly between lowland and upland and aquatic and terrestrial habitats. Both eagles are also sentinel species to track trends in environmental toxicants. For example, the systematic collection of blood and feather samples from Canadian BaldEagles are used to measure/track concentrations of bioaccumulative compounds in aquatic systems (Bowerman et al. 2002)

Thus, the restoration of either/both species to Wales enhances the conservation status of the species, but will ultimately contribute to restoring ecosystem functions to priority habitats and improving ecosystem resilience across Wales.

1.4.5. Why Restore Eagles to Wales and Known Limitations?

We believe that by gathering the appropriate evidence, the information in this thesis presents an opportunity to initiate the restoration of either/both the Golden and White-tailed Eagle to parts of their historic ranges in Wales. Both species of eagles were once widespread and abundant throughout much of Britain, from which it is believed both species were eradicated due to persecution by humans during the 19th century (Yalden, 2007; Evans, O'toole and Whitfield, 2012). Evans, O'Toole and Whitfield (2012), estimated the population size of each species to be 800 – 1,400 and 1,000 – 1,500 pairs in 500 CE for Golden and White-tailed Eagles, respectively, with breeding pairs located in Wales. Across Wales, however, there is a lack of historic information about eagles, which has presented questions around their indigenous breeding status in Wales (Marquiss, 2005). The knowledge gap orientated around the indigenous state of eagles in Wales is deliberated in ***Chapter Two***.

The restoration and translocation of young eagles is not a novel concept to Britain and are thoroughly understood, following the successful reintroduction projects that have been undertaken for both species in Scotland and Ireland (Scottish Natural Hertigate, 2009; Mee, 2016), with the most recent being White-tailed Eagles translocated to the Isle of Wight, Southern England, in 2019 (***Figure 4;*** Dennis *et al.,* 2019).

Figure 4. *The first White-tailed Eagle arrives at Fair Isle, Scotland in 1968, with Roy Dennis, George Willgohs and George Waterston (left; Love, 20 13) and the first White-tailed Eagle at Isle of Wight, England in 2019, with Steve Egerton-Read, Tim Mackrill, Ian Perks and Roy Dennis (right; Roy Dennis Wildlife Foundation, 2019).*

The managers of these projects have offered the opportunity to share experience and best practice, as they believe that a reintroduction project would be the most efficient way to re-establish both eagle species, in Wales. The project would also complement wider European and Global efforts to restore both species to their historic ranges.

Although the general population trends, at present, are said to be increasing for both species in Europe, the current European range remains restricted compared to historic times (BirdLife International 2015, 2018; Sato et al. 2020). This can be attributed to the life history traits of eagles, which are monogamous and have long-life spans, low reproductive rates, delayed sexual maturity, strong competitive ability, and slow dispersal (Webb, Brook and Shine, 2002). Whitfield et al (2009), found that the White-tailed Eagle display strong natal philopatry, parallel to Ewan *et al's.* (2016) findings for Golden Eagles; meaning that when they reach sexual maturity and enter the breeding population at the age of four or five, they breed close to their natal sites. This is particularly true for reintroduced birds, with Scottish birds staying loyal to release sites, which can be suggested to create '*artificial natal areas'*, with the breeding eagles breeding on average 11 km away from release sites (Whitfield *et al.*, 2009).

Given the constraining nature of strong natal philopatry and its significance in terms of where new territories are established. It has been mentioned by eagle experts that there is little chance that either species can naturally colonise Wales, or southern England for the foreseeable future (Marquiss, 2005; Dennis, 2019), despite suggesting there are great expanses of suitable breeding habitat in Wales for them (Dunan Halley and Roy Dennis, pers. comm). In recent years, Wales has experienced scarce and sporadic visits from young wandering European and British eagles (Dennis, 2020). Wandering sub-adult eagles would likely join a breeding population once established (Roy Dennis, Duncan Halley pers. comm). The lack of any breeding eagles in Wales, however, means there is no clear incentive to settle. Nevertheless, a reintroduction of Golden and White-tailed Eagles would act as an important link and facilitate gene flow between newly established and expanding populations in Europe with those in Scotland and Ireland (Kelly and Phillips, 2016). Due to the lack of eagle sightings in Wales (Aderyn, 2018a, 2018b), there is an increasing effort to understand how eagles would use the modern welsh landscape. One common reintroduction method is to assess how ecologically similar species are using the landscape (IUCN/SSC, 2013), thus, to fill in this knowledge gap we discuss the environmental features associated with breeding distribution and features that were correlated to areas not occupied by breeding Welsh mesopredators in ***Chapter Three.***

Both species are also regarded as important '*flagship'* species for upland, coastal and wetland conservation across Europe (Smith and Sutton, 2008); thereby corroborating the notion that the conservation of iconic and charismatic species would bring wider biodiversity conservation. The restoration of either/both species would help raise the profile of the conservation and protection of associated habitats in Wales, in turn leading to knock-on benefits for a much broader array of threatened or declining species that share the same habitats (Entwistle and Bowen-Jones, 2002). In this regard, eagles could also be considered as '*umbrella*' species; meaning the conservation protection of the species' habitat requirements will aid a range of other species at the same time (Roberge and Angelstam, 2004). While there have been many studies looking into the expansion of British eagles (Fielding and Haworth, 2014; Sansom, Evans and Roos, 2016), there has been no focus on Britain's full ability to support breeding eagles, which we explore in ***Chapter Four.***

In addition to the conservation and ecological case for the reintroduction of Golden and White-tailed Eagles to Wales, evidence suggests that it will also have economic benefits. In Scotland eagle tourism is popular and recent RSPB commissions reports have shown that the presence of White-tailed Eagle generates up to £5 million to the economy of the Isle of Mull each year, and £2.4 million to the Isle of Skye through visitor spend in local areas (Molloy, 2011). To complete our assessments of '*whether a reintroduction is the most acceptable option for both species*?', there needs to be a thorough understanding of what areas of Wales can support breeding birds, main areas of risks and best areas for release. Information on the best available breeding areas in Wales for both the Golden and White-tailed Eagle are discussed in ***Chapter Five*.**

1.4.6. Why the Welsh Landscape?

The Welsh landscape is characterised by a rich mosaic of habitats; from coastal sand-dunes, rocky shorelines and several offshore Islands, through to ancient oak woodland and pastures, up to moorlands and high mountains (Blackstock, Howe, and Stevens, 2010). The terrestrial habitats of Wales are mostly mountainous and surrounded by stretches of mainland coastline ~ 2,205 km (1,370 mi) in length. The stretches of the Welsh coastline are embedded with seagrass beds and several specialised reefs, which support high levels of biodiversity (Hayhow *et al.* 2016, 2018). The Welsh coast encompasses an array of protected heritage coasts, with a number of internationally important seabird colonies and have been recommended to be highly suitable foraging sites for the White-tailed Eagle that will feed on the adults and young and scavenge dead birds (Duncan Halley and Roy Dennis pers. comms).

Wales encloses more than twenty-two mountain ranges, many of which have been advocated to be suitable for Golden Eagles. North Wales has the highest mountains including; the Snowdonia hills, Arenig hills, Cadair Idris and the Berwyn mountains in the north-west and the Clwydian range in the north-east (Styles, 1973). The Cambrian mountains run from north-east to south-west and cover most of mid-Wales. There are the Brecon Beacons, the Black Mountains and south Wales and Gwent Valleys (Pennigton, 2017). Wales has a relatively small human population of 3,187,203 individuals (Office for National Statistics 2019), 64.9% of the population is and around the industrial areas of South Wales, specifically, Cardiff, Swansea and Newport and the adjoining South Wales Valleys. A large proportion of the population in Wales live in small settlements, of less than 1,500 individuals (Gartner *et al*. 2007).

Wales has large protected areas, with 30% of its land and 36% of its oceans protected (***Figure 5***), due to their international or national natural and cultural importance (Natural Resources Wales, 2017). There are 123 sites in Wales recognised and protected by European and international law (Marsden et al. 2015). The European Union identified 112 Natura 2000 sites, 92 Special Protected Areas (SPAs), and 20 Special Areas of Conservation (SACs), across Wales. There are also 10 Ramsar sites of international wetland importance and a single UNSECO Biosphere reserve. Wales also recognises 142 protected areas of national importance (Wales Association of National Parks, 2019), including three National Parks, five Areas of Outstanding Natural Beauty (AONBs) and 134 Nature reserves.

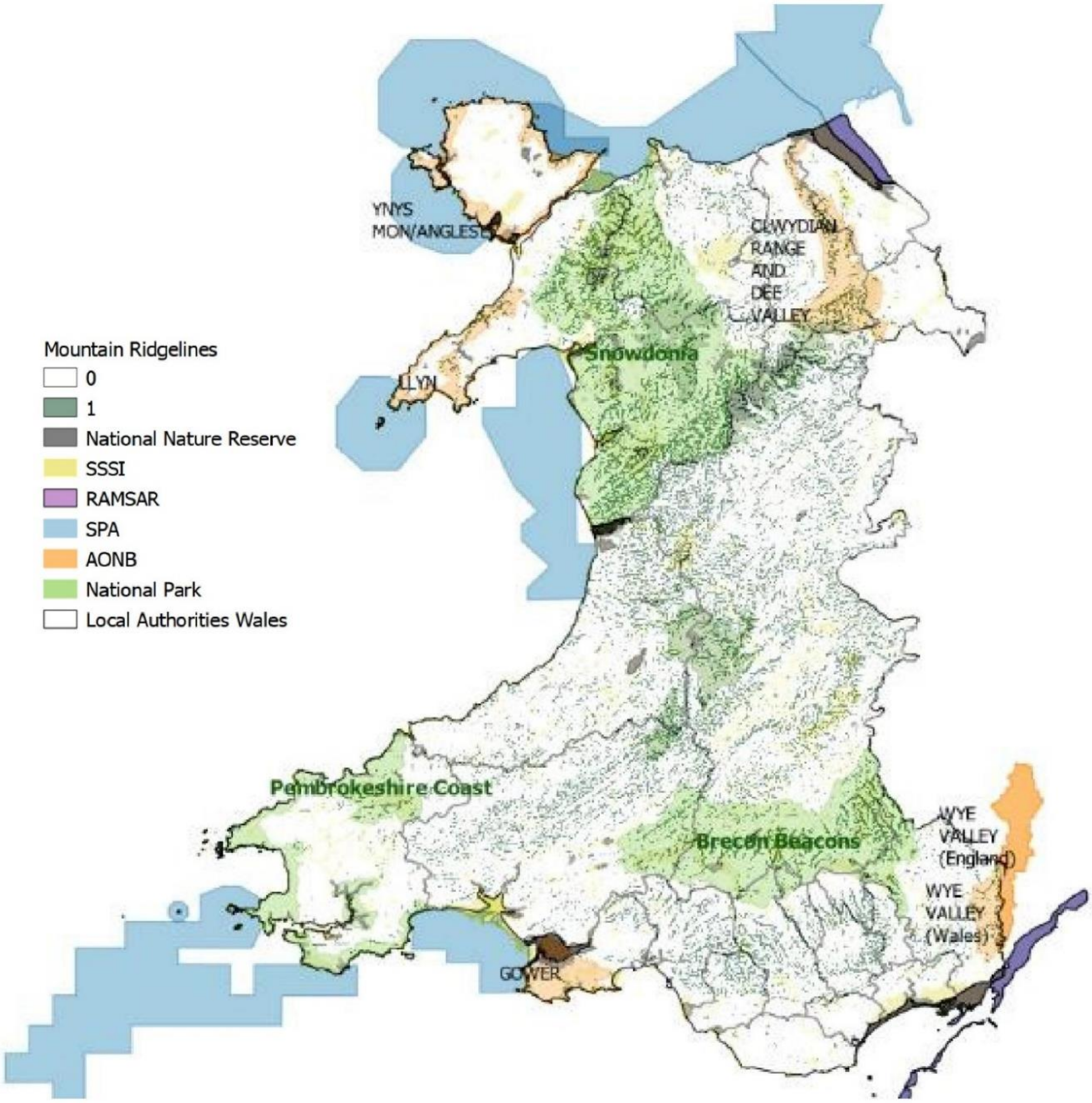


Figure 5*. The national and international terrestrial and marine statutory designated landscapes of Wales, including ridgeline mountain contours.*

Chapter Two

History of Eagles in Wales

"Nid oes amheuaeth bod yr Eryr Cynffon Aur a Chynffon Gwyn yn gyffredin ledled Cymru, yn union fel de Lloegr."

"There is no doubt that both the Golden and White-tailed Eagle were formerly widespread across Wales, just like southern England."

Roy Dennis, MBE, Pers. Comms (2018).

An evidence-based assessment of the past distribution of Golden and White-tailed Eagles across Wales.

2. *Chapter Summary*

Two species of eagles (Golden and White-tailed) bred in Wales during prehistoric and historic times and became regionally extinct as breeding species in the mid-1800s. They are iconic and charismatic, and discussions about reintroducing them back into the Welsh landscape have been ongoing for years. Reintroductions, however, can be risky, costly and/or contentious. To address these concerns, and to judge whether it is appropriate to reintroduce a regionally extinct species; the 'International Union for Conservation of Nature (IUCN) have produced criteria by which a proposed reintroduction can be assessed. A key criterion is that the potential reintroduction location lies within the former range of the species. In this study, we addressed this criterion by assessing the past distributions of Golden and White-tailed Eagles within Wales. Using historic observational data, fossil/archaeological records and evidence from place-names in the Welsh language, we demonstrated strong evidence for the presence of both of these eagle species in Wales in pre-historic and historic times. We used kernel density functions to model the likely core distributions of each species within Wales. The resulting core distributions encompassed much of central and west-north Wales for both species, with the White-tailed Eagle exhibiting a wider core distribution extending into south Wales. Our results fill knowledge gaps regarding the historic ranges of both species in Britain, and support the future restoration of either or both species to Wales.

2.1. Rationale

Knowledge of a species' current and past distribution is fundamental to many aspects of biodiversity conservation. Historic occurrence data are often used to infer former distributions and changes in these distributions over time, as well as the current vulnerability and future conservation of a species (Elith *et al.,* 2006*;* Kuemmerle *et al.,* 2012; Guisan *et al.,* 2013; Yang *et al.,* 2016). Historic data and distribution modelling are vital tools to guide the restoration of species to areas from which they have become extirpated (IUCN/SSC, 1998, 2013). The combination of environmental history, which is principally the interpretation of the past, and conservation biology, which predominantly aims to shape the future, provides a framework for understanding the conservation of species that are represented on the International Union for

Conservation of Nature (IUCN) Red List. This understanding enables the development of conservation strategies appropriate to the species (e.g. reintroduction programmes; Syfert *et al.*, 2014), and the implementation of new policies, legislation and regulations appropriate to the management of such populations *(*Sinclair, White and Newell, 2010; Guisan *et al., 2013;* Syfert *et al.,* 2014).

2.1.1. The History of Eagles across Britain and Wales

There are two eagles native to Britain, the Golden Eagle (*Aquila chrysaetos*) and White-tailed Eagle (*Haliaeetus albicillia*). Both eagles belong to the family *Accipitridae* (Mindell, Fuchs and Johnson, 2018), however, the two species are not closely related and belong to different Genera; *Aquila* (booted eagles) and *Haliaeetus* (sea eagles) and differ substantially in their behaviour and ecology (Evans *et a*l., 2010; Whitfield *et a*l., 2013). In Wales, both the Golden Eagle (known in the Welsh language as Eryr Euraid), and the White-tailed Eagle (known in Welsh as Eryr y Môr) are currently regionally extinct. They are iconic and charismatic species of ecological, cultural and conservation importance across the British Isles. A restoration project for either/or both species would contribute to the Welsh, National and International aims of Article 22 of the Habitats and Species Directive (Council Directive 92/43/EEC, 1992); to restore native species to their former ranges.

Golden Eagles were extirpated from England and Wales by the late 19th Century, and from Ireland by 1912 (Eaton *et al*., 2007; Hayhow *et al*., 2017). A pair returned to breed in England from 1969 until 2004 (Dennis and Ellis, 1984; Evans, O'toole and Whitfield, 2012). Golden Eagles remained extant in parts of Scotland, where the population today stands at more than 500 breeding pairs (Whitfield and Fielding, 2017). White-tailed Eagles became extinct in England and Wales by 1860, and in Scotland and Ireland by 1918 (Yalden, 2007; Evans, O'toole and Whitfield, 2012). The subsequent recoveries of both species elsewhere in the British Isles have been attributed both to legal protection from 1880 (Dennis, 2003; Taylor, 2011), and a rolling scheme of successful reintroduction programmes, including in areas of western and eastern Scotland (Love, 1988; Bainbridge *et a*l. 2003), in Ireland (Nygard, Halley and Mee, 2009), most recently in southern Scotland (Fielding and Haworth, 2014) and southern England, specifically the Isle of Wight (Dennis *et al*., 2019).

2.1.2. Welsh Obligations to Restore Extinct Eagles

Both species display strong natal philopatry, meaning; when they reach sexual maturity and enter the breeding population at the age of four to five, they are attracted to areas with other breeding eagles and generally breed close to their natal sites (Whitfield *et al.* 2009; Millsap *et al*., 2014; Whitfield and Fielding, 2017). Given the constraining nature of natal philopatry on where new territories are established, it has been suggested that other breeding populations within the British Isles are too distant for natural dispersal to lead to the re-establishment of Golden or White-tailed Eagles in Wales (Marquiss, 2005; Dennis *et al.* 2019). Populations of both eagle species are subject to increasing environmental pressures in the UK (Sansom, Evans and Roos, 2016; Whitfield and Fielding, 2017), and a species restoration project to Wales would be an effective long-term conservation programme to conserve both eagle populations, both nationally and internationally, by expanding their current range into an area where they are regionally extinct. The first step in any well-planned reintroduction feasibility study, following IUCN guidelines (IUCN/SSC 1998, 2013), is to assess the historic distribution of both species within the proposed region for the reintroduction, and program approval is subject to release sites being located within the former distribution of a species.

2.1.3. Knowledge Gaps in British Eagle History

Robust information on the historic distribution of both eagle species in Wales is, therefore, an essential requirement of a properly planned species recovery programme. Yalden (2007) and Evans, O'Toole and Whitfield (2012) published assessments of the former distribution of eagles in the British Isles. The latter study estimated the population size of each species to be 800 – 1,400 and 1,000 – 1,500 pairs in 500 CE for Golden and White-tailed Eagles, respectively, with historic records located in Wales. However, while this research referenced detailed historic evidence for the distribution of eagles in England, Ireland and Scotland, they did not have the same level of information for Wales. Therefore, there is a need to fill in this knowledge gap. This requires a comprehensive review of historic data for eagles in Wales, in order to address the IUCN criteria for the validity of any proposed species restoration project.

2.1.4. Chapter Two Research Objectives

This study addresses the historic evidence for both Golden and White-tailed Eagles as breeding species in Wales and estimates the core regions where historic records are distributed for each species, collated from both English and Welsh-language sources. Throughout this paper, these historic resources are categorised into three record types: i) historic observational records – including ornithological literature, persecution records and museum specimens; ii) archaeological or palaeontological records; and iii) place-name records. We utilise the increasing understanding of the habitat preferences of both species within the UK (Evans *et al*., 2010; Whitfield *et al.,* 2013; Sansom, Evans and Roos, 2016) to maximise the utility of the available data. We first identify the environmental features associated with Golden and White-tailed Eagle records in Wales. We then use these environmental predictors of species identity and apply Discriminant Function Analysis (DFA) to assign likely species identities to historic records of unknown eagle species. This enables us to map and model the historic distribution of both species across Wales, utilizing both known species identities, and species identities predicted by the Discriminant Function Analysis.

2.2. Methods

2.2.1. Collection of Historical Data

The historic distribution of both the Golden Eagle and White-tailed Eagle were investigated by collating information from three types of records: historic observational, archaeological and place-name records, ranging from pre-historic times to 1920 CE. Date and location information were also collected for all record types, where available. Historic records without sufficient locality information (i.e., coordinates or specific place-names) were excluded from the main analysis.

We extracted information by searching (manually or electronically) for the keywords set out in ***Table 1***, comprising common, regional and international terminology for eagles in general (i.e. non-species-specific records) and Golden and White-tailed Eagles in particular (i.e., species-specific records).

2.2.2. Historic Observational Records

2.2.2.1. Ornithological Literature

Primary sources were natural history accounts and historic regional bird reports. From such documents, 46 sources were found to document eagle sightings in Wales, with 23 sources providing sufficient locational information to be included in the analysis.

***Table 1.** Search terms used in the study to collate non-species and species-specific historic eagle records for Wales.*

Species	Search term	Language and context
Non species-specific records		
Unspecified eagle species	*Eagle* *Erne* *Eryr (heryr)* *Eryrod (heryrod)* *Aquila*	English English (historic) Welsh (+ mutated form) Welsh plural (+ mutated form) Latin
Species-specific records		
Golden Eagle	*Golden Eagle* *Eryr Euraid* *Aquila chrysaetos*	English Welsh Latin
White-tailed Eagle	*White-tailed Eagle* *Sea Eagle* *Great Erne* *Eryr y Môr* *Haliaeetus albicilla*	English English English (historic) Welsh Latin

2.2.2.2. Persecution Records

Persecution records for both eagle species were collated primarily from The National Online Library of Wales (Welsh Online Newspaper Library, 2019). The search returned a total 1,551 articles reporting a persecution incident of an eagle species, representing over 84 individual incidents between 1804 and 1920.

2.2.2.3. Museum Specimens

In search of historic eagle records, 52 museums around Wales and neighbouring parts of Britain were contacted regarding taxidermy mounts or skeletal parts of Golden and White-tailed Eagles. Specimens were only used if they had accompanying documentation stating the geographical origin of the material.

2.2.3. Place-name Records

Place-names in Wales referring to eagles were collated from the Royal Commission on the Ancient and Historical Monuments of Wales (2019); the "*Archwilio*" Historic Environment Records (Archwilio, 2019), the Melville Richards Archive Place-name Database (2019); and Ordnance Survey Six Inch Maps of England and Wales, 1842-1952, supplemented by the National Library of

Scotland (2019). These sources were searched for place-names with components ostensibly representing variations of the Welsh terminology for '*Eagle'* such as '*Eryr'*, '*Eryrod'*, '*Heryr'* and '*Heryrod'*, as well as the English terms '*Eagle'* and '*Erne'*. Out of a total of 82 place-names incorporating an eagle-related component, only 64 were considered valid to be included in the analysis (***see Results 2.3.1.2***).

2.2.4. Archaeological and Paleontological Records

Archaeological (i.e. human-associated) recoveries of bones, as well as paleontological (non-human-associated) sub-fossil and fossil records were collated from previously published work from Yalden (2006), Harrison (1987), Bramwell (1980), and Bell (1915). Additional archaeological and paleontological eagle records were collated from open sourced documents produced by four Welsh Archaeological Trusts; Clwyd - Powys Archaeological Trust (CPAT, 2017), Dyfed Archaeological Trust (DAT, 2017), Glamorgan – Gwent Archaeological Trust (GGAT, 2017), and Gwynedd Archaeological Trust (GAT, 2017). There were 12 archaeological records found for Wales, only 8 provided enough information to use in the study.

2.2.5. Data Preparation, Modelling and Mapping

All records were assigned as either 'Known ID' – records referring to a named eagle species; or 2) 'Unknown ID' – records denoting an 'eagle' of unknown species. Records in the 'Unknown ID' category mainly consisted of place-name records. Date, latitude, longitude and county were compiled for both record types. All eagle records were assigned to the thirteen old counties (i.e. Anglesey, Brecknockshire, Caernarfonshire, Carmarthenshire, Ceredigion, Denbighshire, Glamorganshire, Flintshire, Gower, Gwent, Meirionnydd, Pembrokeshire & Radnorshire), as well as to the modern "preserved" counties of Wales today (i.e. Gwynedd, Clwyd, Powys, Dyfed, West Glamorgan, East Glamorgan, Mid Glamorgan & Gwent).

In order to identify the habitat features associated with the past distribution of both eagle species, historical environmental variables were compiled for each record, using current sources and historic data sources from the 19th and early 20th Century. From these, the habitat associations of White-tailed and Golden Eagles were modelled. For example, as White-tailed Eagles are more closely associated with lowland areas in close proximity to marine and freshwater sources than the Golden Eagle, distance to the coast and altitude (OS Terrain 50, 2019) were included (Evans *et al*., 2010; Moss, 2015; Sansom, Evans and Roos, 2016; Hayhow *et al*., 2017). The Ancient Woodland

Inventory (2011) and Historic LandMap Wales (2017) were chosen to reflect historic land use data for Wales between 1805 and 1920 CE. From the Historic LandMap of Wales (2017), we extracted data on historic standing waterbodies and urban settlement areas for further analysis.

QGIS spatial software (v 2.18; QGIS Development Team, 2019) was used to overlay landscape and eagle-location data onto a Welsh Country Boundary-line shape file. This was done to assess the distribution of such spatial attributes across Wales in relation to historic eagle records. To assess the association between the species-identity of species-specific historic records and selected habitat variables, the distance to the nearest habitat feature (m) and the area of that habitat feature (m^2) were calculated in QGIS for each eagle record.

Quantitative data analysis was carried out using R (R Core Team, 2019), implemented in R-Studio (v 3.4.2, RStudio Team, 2019). A Generalised Linear Model (GLM) with a binomial error distribution and a 'logit' link function was initially used to determine which historic habitat features were most strongly associated with species identity of eagle records, using the subset of records with a known, species-specific identification. Habitat variables were retained in the final model based on stepwise deletions (following the rationale set out in Thomas *et al*., 2017)

The environmental variables retained in the final GLM explaining species identity were subsequently used in a Discrimination Function Analysis (DFA), using the 'MASS' package in R (v 7.3 – 47; Venables and Ripley, 2002). The prediction accuracy of the Discriminant Function was tested by comparing the species identities predicted by the DFA, with the actual species identities of the 'known ID' data records. Having assessed the validity of the DFA in this way, this function was then used to predict the likely species identity of the records with an 'Unknown ID'. Both predicted species records and known species records were then combined, and species distribution plots for each eagle species were overlaid with computed utilisation distribution "kernels" to represent the core areas where historic records were prevalent for each species in Wales. These core areas were assessed by plotting 50% kernels (i.e. the area enclosing the central 50% of the total distribution of historic records) using the 'KernelUD' function of the 'adehabitatHR' package (v0.4.14; Calenge, 2006).

2.3. Results

2.3.1. A Review of Eagle Records for Wales

2.3.1.1. Historic Observational Records

A total of 55 historic observational records were collated from the ornithological literature, 24 from written persecution records and 15 from museum specimens. All but one of the 15 museum specimens were excluded from the main analysis due to the lack of locality data provided with each specimen. Of the remaining 80 historic observational records included in the analysis, 73 records (91%) were described to species level and included 37 White-tailed Eagle and 36 Golden Eagle records, the remaining 7 records being assigned to unknown 'eagle' species. The historic observational records were distributed across all of the modern preserved counties of Wales, apart from Mid Glamorgan (***Figure 6, a***).

2.3.1.2. Place-name Records

Eighty-two records were collated, of place-names ostensibly incorporating an eagle component. All of these records represented an unknown 'eagle' identity. Of these, 18 records were not included in the analysis as they were considered either to have a 'human' or 'modern' component (e.g., including 'settlement, 'enclosure' or 'house'), or 'hybridised' Welsh and English components (e.g., Eryrys Mine and Cymery-Mawr Well), considered unlikely to indicate the past occurrence of eagles. Of the remaining 64 place-names, all were Welsh-language names; 57 records (89%) incorporated the word 'eryr', and 7 (11%) incorporated 'eryrod'. There were no acceptable place-name records including the Welsh forms 'heryrod' or heryr', or the English forms 'eagle' or 'erne'. Place-name records were distributed widely across Wales, clustering more abundantly in the north and north-west of the country, mostly in Gwynedd and Clwyd (***Figure 6, b***). Place-names included and not included in this analysis are shown in ***Appendix 1.***

2.3.1.3. Archaeological and Paleontological Records

Of the 8 such records, 4 were identified as Golden Eagle, and 4 as White-tailed Eagle. These records were mainly distributed near coastal areas across Wales (***Figure 6, c***).

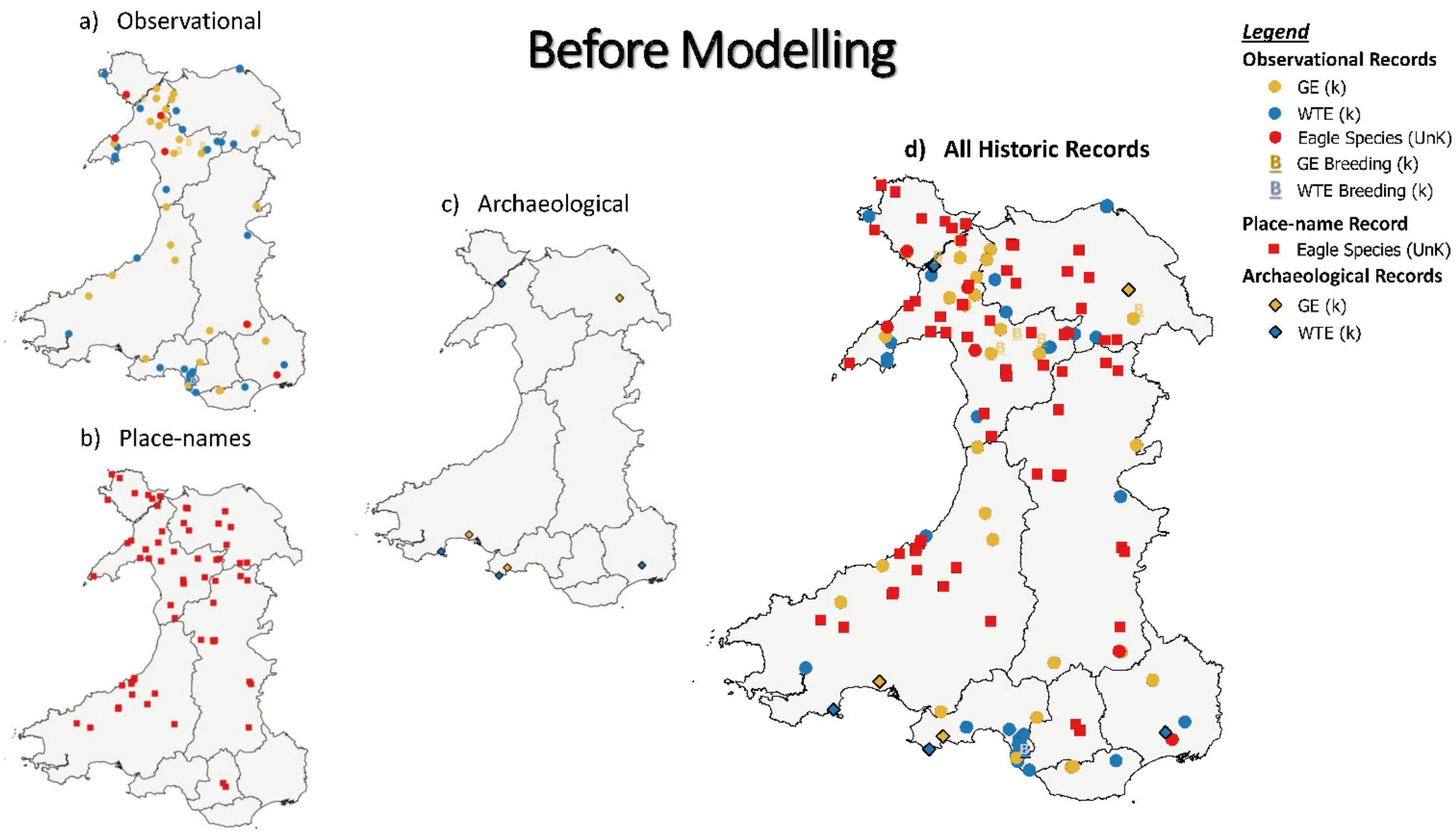


Figure 6. *The historic distribution of known (k) and unknown (Unk) eagle records in Wales before modelling –* ***a)*** *observational records;* ***b)*** *place-name records;* ***c)*** *Archaeological records and* ***d)*** *all historic records together.*

2.3.2. Known and Unknown Species Eagle Records

Including all acceptable record types, the dataset consisted of 151 separate records representing the past occurrence of eagles across Wales, with earliest records dating back more than 5,000 years, *see* ***Appendix 1***. The dataset comprised 80 'known ID' records, 40 representing Golden Eagles and 40 representing White-tailed Eagles. The dataset also included 71 'Unknown ID' records which could indicate the historic occurrence of either species (***Figure 6, d***). The geographical distribution of these 151 records provides compelling evidence that eagles were widespread across Wales, with records obtained from every modern preserved county in Wales.

2.3.3. Habitat Features Associated with Species-Specific Eagle Records

The binomial GLM model to explain species identity of Known-ID eagle records, identified altitude (m asl; LRT = 8.9, d.f. = 1, p = 0.01) and distance to the nearest coast (m; LRT = 6.4, d.f. = 1, p = 0.003) as being significantly associated with species identity. As expected, White-tailed Eagle records were associated with lower elevations (mean elevation: 104.2 +/- 19.4 m), located closer to the coastline of Wales (mean coastline distance: 9039.4 +/- 1935.4 m), whereas Golden Eagle records were associated with higher elevations (mean elevation: 244.9 + 39 m asl), further from the coast (mean distance to coast: 17,383.6 + 2127.8 m). Altitude and distance to nearest coast were themselves positively correlated (Pearson's correlation coefficient: r = 4.3, d.f. = 80, p = <0.001).

Species identity was also significantly associated with distance to nearest waterbodies (m; LRT = 8.6, d.f. = 1, p = 0.003) and the area of such water bodies (m^2; LRT = 7.1, d.f. = 1, p = 0.007). As expected, White-tailed Eagle records were associated with closer proximity to waterbodies (average distance to waterbody: 2120.5 +/- 259.4 m) than Golden Eagles (average distance to waterbody: 2254.9 +/- 308.7 m). White-tailed Eagles were also associated with smaller waterbodies (average waterbody area: 131,080.3 +/- 58,604.5 m^2), whereas Golden Eagles were associated with larger waterbodies (average waterbody area: 202,758.9 +/- 71,597.6 m^2). Distance to the nearest historic settlement was the least significant influential habitat variable. There was little difference between the mean distance of Golden Eagle records to historic settlements (average settlement distance: 4372.5 + 3701.3 m) and White-tailed Eagle records (average settlement distance: 4198.8 + 3610.6. m). Initially, this variable was sequentially eliminated from the model as the variable was marginally non-significant. However, due to inclusion of this variable presenting a much more efficient model (i.e., lower AIC, higher pseudo R^2, and later providing higher DFA prediction values) and the biological relevance of this habitat variable for both eagle species, distance to settlement areas was retained in the final model

Other environmental variables: distance to nearest woodland cover (m), area of the nearest woodland cover (m^2), woodland type (coniferous/broadleaved/mixed), historic environment type (rural/built) and the area of the nearest historic settlement (m^2) were not significantly associated with species identity and were not retained in the final averaged model. The six habitat features retained in the final averaged GLM model were incorporated into the Discriminant Function Analysis used to assign likely species identities to the ‘Unknown’ species records.

2.3.4. Predicting Species Identity of “Unknown ID” Eagle Records

The Discriminant Function correctly classified 86.3% of the known-ID eagle records; specifically, correctly classifying 34 of the 40 known White-tailed Eagle records (85%), and correctly classifying 35 of the 40 known Golden Eagle records (87.5%). Classifications of unknown-ID eagle records had a mean likelihood of 84.4% for records classified as White-tailed Eagles and 72.6% for records classified as Golden Eagles. Combining both ‘known-ID’ and DFA-assigned species identities, gave 51 species-specific eagle records for Wales – 81 Golden Eagle and 70 White-tailed Eagle records (***Figure 7***).

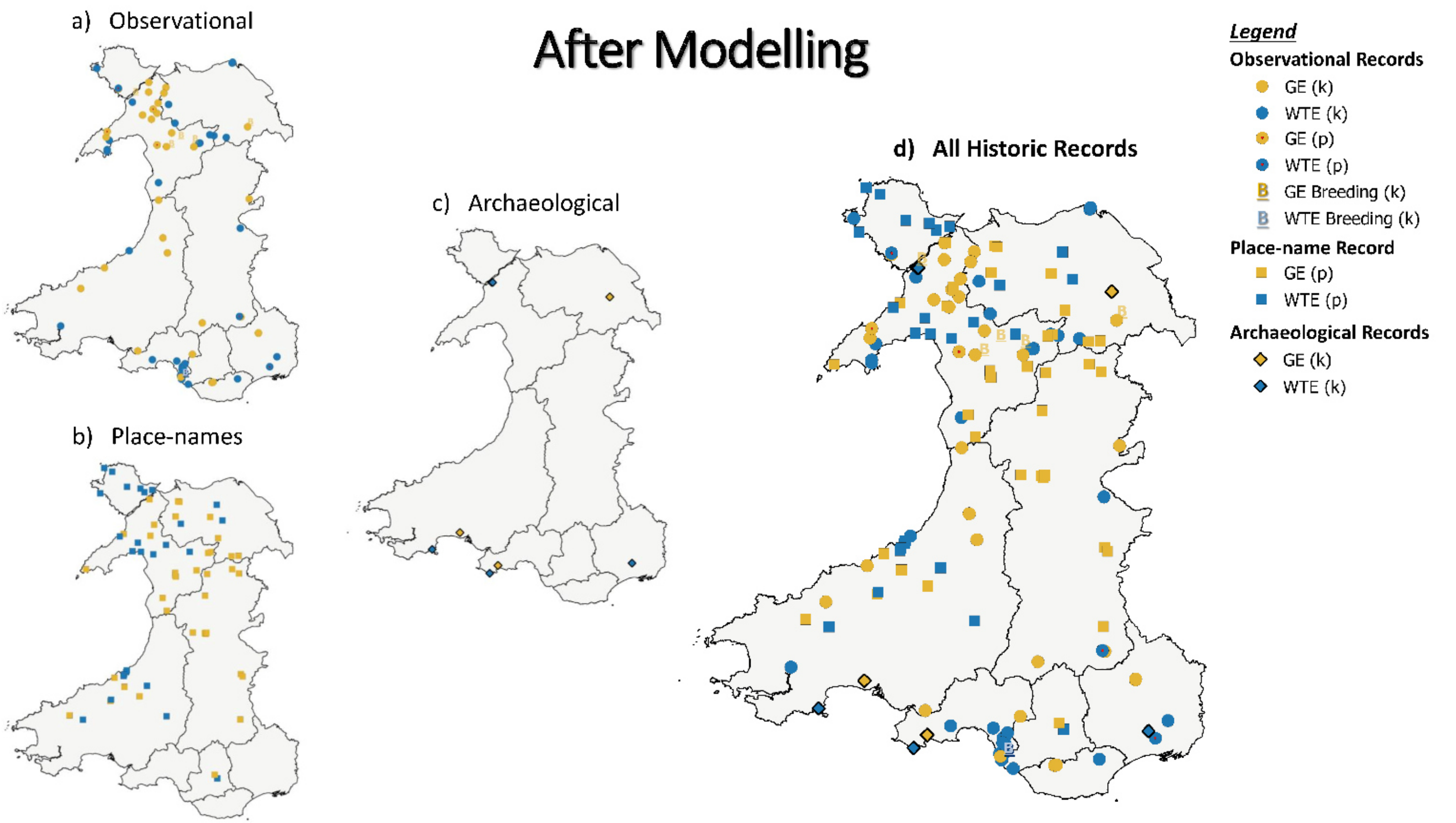


Figure 7. *The historic distribution of known (k) and predicted (p) eagle records in Wales after modelling –* ***a)*** *observational records;* ***b)*** *place-name records;* ***c)*** *Archaeological records and* ***d)*** *all historic records.*

2.3.5. Where were Eagles Formerly Distributed in Wales?

All eight modern counties in Wales hold historic records of either or both eagle species, with the north western parts of Wales holding over half of the records (***Figure 8***). White-tailed Eagle records are distributed across all modern counties. Similarly, the Golden Eagle records are distributed across all modern counties of Wales, apart from Mid Glamorgan. The Golden Eagle's core range in Wales encompassed areas of Gwynedd, including the Snowdonia Mountain range, parts of Clwyd and north-west Powys; 74.2% of Golden Eagle records were distributed within this core historic range (***Figure 8, a***).

The White-tailed Eagle's core historic range encompassed a much larger area of Wales than the Golden Eagle's core range, including areas of Gwynedd (including parts of the Isle of Anglesey); parts of Dyfed (mainly the Ceredigion Coast), West Glamorgan (predominantly the Kenfig and Gower coast); and fragmentary areas of Mid Glamorgan (***Figure 8, b***). The north-western core range held 36.4% of records and the south-eastern core range held 42.9% of records.

a) Golden Eagle, Eryr Euriad (*Aquila chrysaetos*)

b) White-tailed Eagle, Eryr y Môr *(Haliaeetus albicillia)*

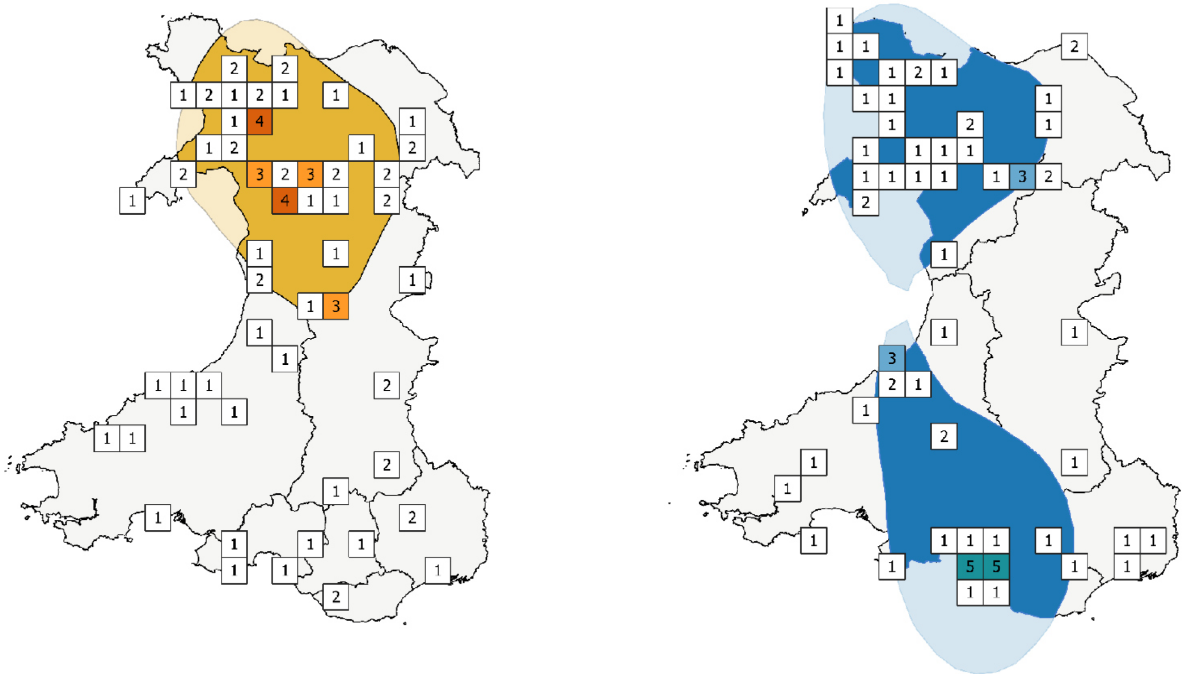


Figure 8. *10 x 10 km distribution of eagle records in Wales: Historic record abundance and core historic distribution for the;* ***a)*** *Golden Eagle and* ***b)*** *White-tailed Eagle.*

2.4. Discussion

The historic and pre-historic presence of Golden and White-tailed Eagles across England, Scotland and Ireland is well understood (Yalden, 2007; Evans, O'toole and Whitfield, 2012), but the historic evidence for these two species in Wales has, until now, been sparse (Lovegrove *et al.* 2010). Our collation, modelling and mapping of 151 separate eagle records from Wales makes a significant contribution to the history of eagles in Britain and provides compelling evidence for both Golden and White-tailed Eagles being historically widespread in Wales, identifying partially overlapping core ranges for the two species. These core ranges include locations where historic records are now well evidenced.

2.4.1. Temporal Distribution of Historic Records

Evidence for the presence of eagles in Wales extends back into pre-history; paleontological and archaeological records date back to the Neolithic period (Harrison, 1980; Harrison 1987). Written records of eagles date back to the 9th Century, in early Welsh-language "englyn" -poems such as 'Canu Heledd' (the Song of Heledd), 'Eryr Eli' (Eli's Eagle) and 'Eryr Pengwern' (the Eagle of Pengwern; Rowland, 1990). Many of these earlier literary references lacked sufficient information to be included in this analysis, yet they still contribute to the overall picture by highlighting the importance of eagles in the heritage and culture of historic Wales.

There is historic evidence for breeding Golden Eagles in Wales, with nests being recorded in Castell Dinas Brân in Denbighshire (Forest, 1907), Carnedd Llewelyn in Gwynedd, and on the high crags of Eryri (Snowdonia; Johnson, 1644). The temporal distribution of historic records that we collated suggests that Golden Eagles became extinct as a Welsh breeding species in the 1850's, with the latest breeding records coming from Snowdonia (Evans, 1974).

Our evidence reveals that White-tailed Eagles were eliminated as a breeding species in Wales in the early 1800's. During the 18th Century, White-tailed Eagles were frequently observed in Gwynedd, including the Llyn Peninsula, the Carmarthenshire and Ceredigion Coasts, and the area surrounding Kenfig, Bridgend and Margam in South Wales (Heathcroft, Griffin and Salmon, 1967; Hurford and Lansdwon, 1995). The Kenfig area yielded over 50 years of regular White-tailed Eagle records between 1810 and 1860, with one record reported in 1906. The last nesting pair of White-tailed Eagles at Kenfig appears to have been eliminated by persecution; the female was shot in 1816, and the male in 1828 (Welsh Online Newspaper Library, 2019b).

The extinction of both species in Wales was driven by persecution. Persecution records collated here often detailed shootings of adult and juvenile eagles while scavenging on sheep carcasses (Welsh Online Newspaper Library 2019d). The elimination of raptors was an accepted rural practice to protect domestic livestock; not only in Wales, but across Britain and Europe (Newton, 1979). Persecution was encouraged and subsidized by bounty payments, recorded in Britain as early as the 16th Century (Newton and Rothery, 2001). While we have no evidence of bounty payments in Wales, there is evidence for ongoing persecution of eagles within Wales, even after eagles become only sporadic visitors (Lovegrove *et al.*, 2010).

Persecution and observational records continued into the early 20th Century; these patchy and sporadic observations presumably relate to non-breeding eagles dispersing into Wales from other parts of Britain. The spatial and temporal distribution of records after the extinction of eagles as breeding birds in Wales, suggests that these sporadic records were widely distributed across their former range.

2.4.2. Classification of Unknown Species Records

Several habitat variables provided significant explanatory value in separating species records. These variables correspond well with the observed habitat preferences of the two species across their historic and current North-Western European range, as described in the recent literature (Radović and Mikuska, 2009; Evans *et al.*, 2010; Evans, O'toole and Whitfield, 2012; Sansom, Evans and Roos, 2016; Whitfield and Fielding, 2017). Golden Eagles are largely associated with high elevations and inland mountainous habitats (Watson, 2010). By contrast, White-tailed Eagles are associated with low-elevation, coastal habitats such as estuaries, wetlands, and with inland waterbodies (Radović and Mikuska, 2009; Evans *et al.*, 2010; Krone, Nadjafzadeh and Berger, 2013).

The Discriminant Function Analysis was able to classify correctly 85% of known White-tailed Eagle records correctly, and 87.5% of known Golden Eagle records, with an 86.3% prediction accuracy on average across the two species. This prediction accuracy compares favourably with that reported in a previous study of Booted Eagles (*Hieraaetus pennatus)* and Lesser-spotted Eagles (*Clanga pomarina)*, where DFA yielded on average a 60-82% prediction accuracy (Galanaki, 2004; Poirazidis et al., 2007).

A *post-hoc* assessment of the species identities assigned to place-name records by the DFA showed an interesting congruence between the species identity and elements of the place-name relating to geographical features known to be associated with that species. For example, place-names in upland Wales incorporated components such as; 'cefn' (Welsh for ridge), 'crug' (hill-rock), 'bryn' (hill) and 'gwaun' (moorland); all elements that can be associated with Golden Eagles (Fielding et al., 2019). Place-names in lowland areas included 'allt' (Welsh for a wooded hillside), 'coed' (forest or wood), 'nant' (stream) and 'llyn' (lake); habitat features associated with White-tailed Eagles (Sansom, Evans and Roo, 2016).

While it is not possible to insist that any individual place-name is related to the past presence of a particular eagle species, the distribution of these geographical elements in eagle-related place-names across upland and lowland Wales, supports the DFA-predicted species-identities of Golden and White-tailed Eagle historic records, which ultimately reflects the distribution of the two eagle species across the Welsh landscape.

2.4.3. Core Historic Distributions in Wales

Mapping of both the species-specific and the predicted-species eagle records revealed clear distinctions between the core historic ranges of Golden and White-tailed Eagles. The core historic range of Golden Eagles is weighted towards North Wales, centred on the upland areas of Snowdonia, whereas the core historic range of White-tailed Eagles encompasses much more of southern, lowland Wales, including the coastal areas and estuaries of the Isle of Anglesey, Ceredigion and parts of the south Wales coastline.

Core ranges mapped highlight areas of Wales where historic records, breeding and non-breeding are now well referenced. Due to the sedentary behaviour of UK eagles, the spatial dynamics of populations are shaped by the territorial behaviour of occupied breeding territories (Chambert et al. 2020). The home range of non-breeders and breeders are different, however, significantly overlap due to shared habitat preferences of immature and mature birds, including; sufficient prey availability and an abundance of nest, roost and perching sites (Mcloed *et al.* 2002; Sansom, Evans and Roos, 2016; Feilding *et al.* 2020). Most of the records within these core ranges are dated within the 16^{th}, 17^{th} and 18^{th} Centuries. providing an insight into the core distribution before the extinction of both species as breeding birds in Wales. Most records within the 19^{th} century in Wales refer to young visiting eagles. Thus, the use of both non-breeding and breeding records provided a much comprehensive picture of the fine-scale historical presence of both species and were used as a proxy measure of historic habitat suitability.

2.5. Conclusion

IUCN guidelines (IUCN/SSC, 1998, 2013) state that the reintroduction of a species should be carried out within its historic indigenous or native range. Assessing the historic distribution of species has proven to be a valuable part of the toolkit of methods for validating and planning reintroduction programmes in Britain (Hendricks *et al.*, 2016). The reconstruction of species historical ranges for regionally extinct species has aided the successful regional restoration of species such as the White-tailed Eagle (Bainbridge *et al.*, 2003; Nygard, Halley, & Mee, 2009; Dennis *et al.,* 2019), European Beaver, *Castor fiber* (Kithchener and Conroy, 1997; Gaywood, Batty & Galbraith, 2008) and Pine Marten, *Martes martes* (Macpherson *et al.*, 2014).

It has previously been suggested the restoration of either or both eagle species to Wales is not feasible due to the lack of historic evidence suggesting their widespread occurrence in Wales (Marquiss, 2005). Our collation of records and reconstruction of the historic distributions of Golden and White-tailed Eagles has revealed both species to be widely distributed in Wales until the early-mid 19th Century and identifies the core areas within which we are most confident of the historic presence of each species.

Our analysis confirms that both species were once widespread across Wales, and both fell victim to persecution by humans. The Welsh landscape has changed significantly since both eagles last bred in Wales over 150-years ago. Additional analysis is now needed to assess whether the modern Welsh landscape can still support both the Golden and White-tailed Eagle and to assess whether reintroduction of either or both eagle species to Wales is a realistic possibility.

Chapter Three

Ecologically Similar Species in Wales

"Yn ystod y blynyddoedd diwethaf, mae effaith ecolegol gadarnhaol y ddau eryr brodorol wedi dod yn fwyfwy amlwg trwy'r egwyddor rhaeadrau troffig."

"In recent years, the positive ecological impact of both native eagles has become increasingly apparent through the principle of trophic cascades"

Roy Dennis, MBE, Pers. Comms (2018).

Breeding distribution and habitat associations of five avian mesopredators in Wales: proxy indicators of habitat suitability for the restoration of native eagles.

3. *Chapter Summary*

The Golden and White-tailed Eagle are regionally extinct as a breeding species in Wales. In the absence of these two avian apex predators, middle-trophic avian mesopredators can be released from competition and predation, leading to rapid growth in population numbers and distributions. With mesopredators now substituting new roles and ecosystem functions, their current distribution and habitat associations are crucial 'proxy indicators of habitat quality and anthropogenic threats. As part of ongoing studies to restore either/both eagle species to Wales, the International Union for Conservation of Nature (IUCN) suggest gathering information on ecologically similar species. With no systematic monitoring of birds of prey in Wales, we address this IUCN criterion by estimating the core breeding ranges and habitat associations of five avian mesopredators that share behavioural, ecological, dietary or nesting requirements with eagles. Using observational data in the breeding season, we use kernel density functions to model likely core breeding ranges and generalised linear models to assess the habitat associations within these ranges. We demonstrate the spatial differences between specialist and generalist mesopredators, resulting in four main landscape references to consider for eagle restorations in Wales. Our results contribute to knowledge gaps in Wales for birds of prey and provide an optimistic outlook for eagle reintroductions that may contribute towards an ecologically resilient Wales.

3.1. Rationale

There are fifteen species of diurnal birds of prey native to Britain, with eleven of these species confirmed to be currently breeding in Wales (Dobson *et al.* 2012). These fifteen species are highly diverse; physically ranging in size from the White-tailed Eagle (*Haliaeetus albicilla*), known in the Welsh language as Eryr y môr, with a maximum wingspan of 2.5 m; to the Merlin (*Falco columbarius*), known in Welsh as Myrddin, with a wingspan measuring around 0.69 m. Ecologically, they encompass both habitat generalists and specialists; and in terms of their diet, range from scavengers and terrestrial insectivores to aerial hunters of other vertebrates (Donázar *et al.* 2016).

Birds of prey play crucial roles in their relevant ecosystems due to their behaviour, ecology and position in the food chain. Depending on their hunting strategy, they can be either apex predators, being the most dominant predator in a given area, or mesopredators, being middle trophic level predators, which prey on smaller species but can potentially be preyed upon themselves (Prugh *et al.* 2009; Richie & Johnson, 2009). There are two apex predatory birds of prey native to Britain, the Golden Eagle (*Aquila chrysaetos*), known in Welsh as Eryr Euraid, and the White-tailed Eagle. Both eagle species are currently geographically restricted to breeding in Scotland and Ireland, with recent translocations of young Golden Eagles to South Scotland (Fielding and Haworth, 2014) and White-tailed Eagles to the Isle of Wight (Dennis *et al.* 2019); aiming to establish long-term breeding populations across North and South England, respectively.

The other thirteen bird of prey species are more widely distributed across Britain and are considered mesopredators. Both apex and mesopredators exert top-down control over trophic levels; apex predators positioned at the top of the food chain have stronger behavioural and population-level control over their prey and other predators (Hayward & Somers 2009; Leo *et al.* 2019), mesopredators generally exert middle-down control, as they are adapted to hunt smaller prey items in smaller territories (Feit *et al.* 2019).

3.1.1. The Mesopredator Release Effect

The removal of apex predators, such as the Golden and White-tailed Eagle, can alter the behaviour, habitat selection and abundance of other species, including herbivores and mesopredators, which can lead to substantial ecosystem changes (Morris & Letnic 2017). For example, mesopredators previously kept in balance by apex predators can be 'released' from competition and predation when apex predators are removed, leading to rapid growth in mesopredator numbers, substituting new roles and ecosystem functions (Newsome *et al.,* 2017). For example, in the absence of eagles, medium-sized birds of prey may claim the hunting grounds, nest sites and food resources once controlled by native eagle species.

Rising populations of mesopredators place substantial pressure on their prey, such as songbirds, small mammals and insects, causing many species to suffer dramatic declines (Richie and Johnson, 2009). As stated by Nishijima *et al.* (2014), ecosystems experiencing mesopredator release have lower levels of biodiversity than ecosystems intact with their native apex predators. This is because medium-sized birds of prey are typically outcompeted by eagles for food and other resources. Eagles are also capable of predating on other birds of prey, resulting in mesopredators often avoiding areas claimed by eagles or altering their hunting and foraging strategies to reduce the chances of an encounter (Jimenez *et al.* 2019).

The 'meso*predator release effect'* may be found in areas of Britain where Golden and White-tailed Eagles are absent, particularly in England and Wales (Roo *et al.* 2018). There has, for example, been a significant increase over the last decade in some adaptable and versatile mesopredators such as the Red Kite, Barcud Coch (*Milvus milvus*) and Common Buzzard, Bwncath Gyffredin (*Buteo buteo*). Although both mesopredators are abundant and widespread across most of Britain, they are less abundant in the mountainous areas of Scotland where Golden Eagles are present (Austin & Houstin 1997; Murn and Hunt 2011). This could be related to the unnatural balance between avian apex and mesopredators across England and Wales.

3.1.2. Birds of prey as indicator species

Despite mesopredators playing an important ecological role by exerting middle-down control to the food web (i.e. small birds, mammals & rodents); the mere presence of these birds in a given landscape serves as a barometer of ecological health. Mesopredators and apex predators, due to their position in the food chain, are considered globally as biological indicator species (Rodriquez-Estrella et al. 1998). Attributed to the lack of apex predators in Wales, mesopredators are powerful indicators for several reasons.

The presence, absence and abundance of mesopredators play an important role in ecosystems because they can determine the community structure patterns of their prey (Roth and Weber, 2008; Beuchley et al. 2019) and are considered good indicators of habitat quality because of their sensitivity to human disturbance and environmental contaminations (Helander et al. 2008). The spatial distribution and abundance of such species are often used as conservation management tools to highlight anthropogenic threats like pesticides, habitat loss and climate change (Jose et al. 2016; Vali et al. 2020). For example, the United States, Canada, Mexico and Europe have shown specialist species like the Osprey (*Pandion haliaetus*) to be useful indicators for monitoring environmental contaminants in lakes, reservoirs, rivers and estuaries (Grove et al. 2009) and similarly the use of Hen Harriers for monitoring upland habitats (Madders, 2000).

Generalist birds of prey are also extremely valuable indicator models as they have wider habitat preferences, inhabit wider geographic areas and interact with a greater range of prey items in the food chain (Movalli,Duke and Osborn, 2008). Researching and monitoring the population trends of specialist and generalist meso and apex predators have proven to be a cost-effective and efficient means to detect natural and anthropogenic environmental change (Movalli et al. 2018). Enabling us to take conservation action that is driven by the latest scientific data. Birds of prey are also classed as umbrella species in world conservation. Birds of prey have wide home ranges to cater for nesting, roosting and foraging. Thus, the protection of the large ranges can often facilitate wider conservation benefits to related and unrelated habitats and biodiversity (Regos et al. 2017).

3.1.3. Mesopredators as proxy indicators for Apex Predator Restorations

Inspired by the complexity and dynamic nature of bird of prey distributions and abundance, many studies have monitored mesopredator populations as indicator species to generate important knowledge gaps to understand the ecological requirements or biogeography (Thompson and McGargial, 2002; Poirazidis, 2017) to predict species distributions, identify reintroduction sites, prioritize conservation areas and predict the response of populations to habitat loss and anthropogenic land use (Franklin, 2009; Martin and Ferrer, 2013; Ferrer et al. 2018). ecologically similar mesopredators expanding into the former ranges of past eagles can act as 'proxy indicators' species habitat health, land-use change and anthropogenic threats (Roth & Weber, 2008). Five out of the thirteen British mesopredators occur or co-occur in similar environments to native Golden and White-tailed Eagles, attributed to shared behavioural, ecological, dietary or nesting requirements, represented in ***Table 2***. The five focal mesopredators used in this study include:

i) Hen Harrier, Hen Tinwyn *(Circus cyaneus)*
ii) Common Buzzard, Bwncath Gyffredin *(Buteo buteo)*
iii) Peregrine Falcon, Hebog Tramor *(Falco peregrinus)*
iv) Osprey, Gweilch *(Pandion haliaetus)*
v) Red Kite, Barcud Coch *(Milvus milvus)*

With the absence of breeding eagles and between 1-3 sporadic visits per year from non-breeding eagles across the 20th Century in Wales (Aderyn 2018a, 2018b); information on how suitable the modern-day Welsh landscape is for native-lost eagles is difficult to gather. The IUCN reintroduction guidelines (IUCN/SSC, 2013) suggest gathering literature-based information on closely related or ecologically similar species as indicators of modern-day habitat suitability.

There is, however, no systematic monitoring of birds of prey in Wales, following the closure of the Welsh Raptor Study Group (WRSG) in 2013. Thus, assessing the core breeding distribution and habitat associations of ecologically similar mesopredators, not only fills in crucial species knowledge gaps, but enables a useful management tool to build comprehensive information about land uses in Wales and potential anthropogenic land use risks needed to consider the feasibility of restoring eagles to Wales (Genes *et al.* 2017).

Table 2. *The behavioural, ecological, dietary or nesting characteristics of ecologically similar species that overlap with White-tailed (WTE) and Golden Eagle (GE) traits. Species names are given in English, Welsh and Latin.*

Species	Species Overlap	Habitat Use	Diet	Home Range	Reference
Apex Predators					
Golden Eagle, Eryr Euraid *(Aquila chrysaetos)*	/	Open Habitats Natural Grassland Upland Habitats Moorland Heathland Crags (nests)	Rabbits Hares Upland birds Game birds Waterfowl Carrion	2 to 6 km²	Marquiss *et al.* 1985 Evans *et al.*, 2010 Whitfield *et al.* 2013 Watson, 2010a Unwin, 2016
White-tailed Eagle, Eryr y môr *(Haliaeetus albicilla)*	/	Marine bays & coasts Estuaries Wetlands Rivers Lakes Lowland habitats Mature trees (nest) Coastal crags (nest)	Fish Seabirds Waterfowl Waders Rabbits Hares Carcasses	3 to 8 km²	Evans *et al.*, 2010 Whitfield *et al.* 2013 Sansom *et al.* 2016 Unwin, 2016 Dennis *et al.* 2019
Mesopredators					
Hen Harrier, Hen Tinwyn (*Circus cyaneus*)	GE	Open habitat Natural grassland Forestry plantations Peatbogs (nest) Moorland (nest)	Mammals Rabbits Hares Shorebirds Waterfowl Upland birds	3.6 to 7 km²	Redpath *et al.*, 2001 Watson, 2010b Hardey *et al.* 2013
Common Buzzard, Bwncath Gyffredin (*Buteo buteo*)	GE	Open habitat Upland habitats Moorland Bare rock (nest)	Mammals Upland birds Carrion	2 to 3 km²	Hardey et al. 2013 Walls & Kenward, 2019
Peregrine Falcon, Hebog Tramor ***(inland)*** (*Falco peregrinus*)	GE	Upland habitats Open areas Inland cliffs (nest) crags (nest)	Waterfowl Mammals Waders Corvids Upland birds	2 to 9 km²	Baker et al. 1997 Ratcliff, 2010 Hardey *et al.* 2013
Peregrine Falcon, Hebog Tramor ***(coastal)*** (*Falco peregrinus*)	WTE	Estuaries Natural grassland Rivers Coastal cliffs (nest)	Waterfowl Waders Seabirds Corvids Gulls	2 to 9 km²	Baker et al. 1997 Ratcliff, 2010 Hardey *et al.* 2013
Osprey, Gweilch (*Pandion haliaetus*)	WTE	Marine bays Estuaries Lakes Rivers Lowland agricultural (nest) Forested areas (nest)	Fish	7 to 10 km²	Lohmus, 2001 Marquiss *et al.* 2007 Hardey *et al.* 2013 Mackrill, 2019
Red Kite, Barcud Coch (*Milvus milvus*)	WTE	Open habitat Lowland agricultural Mature woodland (nest)	Carcasses Amphibians Mammals	3 to 6 km²	Davies & Davis, 1973 Davis & Davis, 1891 Hardey *et al.* 2013

3.1.4. Chapter Four Research Objectives

This research chapter uses observational data for five ecologically similar mesopredators to the Golden and White-tailed Eagle. Here we focus on observations during the breeding season to identify core breeding ranges across Wales for the Hen Harrier, Common Buzzard, Peregrine Falcon, Osprey and Red Kite. Throughout this chapter, we assess the avoidance and association with environmental features and habitat types within each species breeding range, as indicators of habitat quality and anthropogenic threats. This study takes a national perspective to derive a present-day understanding of land use and how current mesopredators use the modern-day Welsh landscape, in a trait-based approach to discuss anthropogenic risks and benefits (i.e. landscape references) of potentially restoring the two native eagle species to Wales.

3.2. Methods

3.2.1. Observational Data for Avian Mesopredators

Long-term observational data for the Hen Harrier, Common Buzzard, Peregrine Falcon, Osprey and Red Kite across Wales, dating back to 1920 CE in some cases, were provided by Aderyn: The Local Environmental Records Centre for Wales (LERC Wales, 2019). Aggregated observational datasets, collected by experts and the general public, were processed to reflect the breeding season of each species, using annual observation data between April and August, over 11 years. Breeding season sightings, between 2008 to 2018, were used to assess the core breeding distribution of each mesopredator species in Wales. By processing species data by breeding season, between 2008 and 2018, we utilized 607 data points for Hen Harriers, 5,974 for Common Buzzards, 2,539 for Peregrine Falcons, 593 for Ospreys, and 4,547 for Red Kites.

3.2.2. Mapping Core Breeding Ranges of Avian Mesopredators

Annual breeding season observations throughout 11-years were initially used to create a 10 x 10 km distribution Atlas' for each mesopredator across Wales. Mesopredator distributions were mapped using the 'Biological Records Tool' in QGIS spatial software (v 2.18; QGIS Development Team, 2019). The *'kernelUD'* function of the '*adehabitatHR'* package (v 0.4.15; Calenge 2006) in R statistical software (v 3.4.2, R Core Team, 2019), was further used to define core breeding ranges, by computing the utilisation distribution for each species, and plotting 50% kernel density estimations representing species-specific breeding range kernels. Kernel plots denoting core breeding ranges eliminated any potential sightings in areas only used for migratory routes or stopovers, like the Hen Harrier and Osprey. The 50% kernel plots were used to assess core habitat types and spatial environmental features preferred/selected by each mesopredator across their breeding range in Wales.

3.2.3. Breeding Habitat Associations

CORINE Land Cover (CLC, 2018), was used to derive and map twenty-two land cover types across Wales (***Table 3***). The total proportion of each habitat type (m^2) were calculated for the entire terrestrial surface of Wales and used as a null model to assess the strength between mesopredator breeding observations and their associated habitat preferences. The strength of these interactions were assessed by comparing the frequency of observations in each habitat type within each species breeding range, using the '*generate_null_net*' function of the '*econullnetr*' package (v0.1.0.1; Vaughan *et al.* 2018) in R statistical software (R Core Team, 2019).

Table 3. *The twenty-two CORINE habitat types used to examine the habitat preference and avoidance behaviour of five mesopredator species in Wales.*

Habitat Type	CORINE Class	Land Use Cover (km²)	Lane Use Cover (%)
Arable land	12 - 17	1,830	8.63
Bare rock	31	48	0.23
Beaches, dunes, sands	30	70	0.33
Broad-leaved forest	23	441	2.08
Coastal lagoons	42	12	0.06
Conifer forests	24	1,041	4.91
Estuaries	43	39	0.18
Heterogeneous agricultural areas	19 – 22	1,457	6.87
Inland marshes	35	56	0.26
Intertidal flats	39	187	0.88
Mixed forests	25	589	2.77
Moors and heathland	27	1,456	6.86
Natural Grasslands	26	2,178	10.27
Pastures	18	9,415	44.39
Peat bogs	36	488	2.30
Salt marsh	37 - 38	83	0.39
Scrub and herbaceous vegetation	28 - 29	323	1.52
Sea and ocean	44	83	0.39
Sparsely vegetated areas	32 - 34	194	0.92
Urban	1 – 11	1,155	5.45
Watercourses	40	24	0.11
Waterbodies	41	42	0.20

*Natural grassland includes Nuetral, calcareous and acididic grassland catagories. While pastures include improved grassland.

The frequencies of observations within each habitat type present in core breeding ranges, were then compared to the total proportion of habitat types available across Wales. Each interaction was run for 100 iterations and an average mesopredator-habitat interaction matrix was computed (Null) alongside its Confidence Intervals (CI). If the null value falls outside the CI, the interaction can be significantly greater (e.g. right of the CI – high observed frequencies) or less than expected (left of the CI – low observed frequencies), based on the proportion of habitats available in Wales. For each species, the Standardised Effect Size (SES), a mean value for all interactions were calculated to provide a standardized estimate of the strength between mesopredator-habitat interactions within core breeding ranges.

3.2.4. Environmental Features of Wales

Individual breeding season observations were further used to calculate the distance (km) to a number of selected environmental features, within each species core breeding range; to assess the potential association or avoidance behaviour of each mesopredator species. To test what habitat features are characteristic of each species breeding range, environmental variables used included; distance to nearest; woodland cover (NIWT, 2018), lake (Lakes Inventory, 2018), river (Main rivers, 2018), coast, urban settlement (BUA, 2017), road (OSOR, 2018), windfarm (Onshore Windfarms, 2017) and persecution incident (RSPB Raptor Persecution, 2019). Elevation was also extracted for each observation (OS Terrain 50, 2018).

Additional attributes were also calculated to assess the magnitude (no.) or dimensions (km^2) of environmental features including; area of woodland cover, area of lake, human settlement population number, the number of wind-turbines within windfarms, and the number of persecuted birds for each persecution incident. All datasets were supplied under the Ordnance Survey OpenData Licence or Open Government Licence.

3.2.5. Associative and Avoidance Behaviour

To evaluate the association or avoidance of breeding mesopredator observations with different environmental features in their core breeding ranges, the MASS package (v. 7.3–51.1; Venables & Ripley, 2002) in R was used to fit a Generalised Linear Model (GLM). A negative binomial distribution GLM, with two-way interactions, were fitted for each species (***Table 4***). Environmental features and interactions terms (if any) influencing the occurrence of each mesopredator species in the final model were retained based on multi-model inference (Burnham & Anderson, 2004).

Table 4. *The environmental features were computed to study the associative and avoidance behaviour for five mesopredators in Wales via a negative binomial GLM.*

Dependent Variable	Independent Variables	Interaction Terms
Species Occurrence	Distance to coast Distance to river (km) Distance to road Distance to lake (km) Distance to persecution location Distance to settlement Distance to windfarm Distance to woodland (km) Elevation (m asl)	Distance *to lake x Area of lake* Distance *to persecution x No. of incidents* Distance *to settlement x Population no* Distance *to windfarm x Wind-turbine no.* Distance *to woodland x Area of woodland*

3.3. Results

3.3.1. Avian Mesopredator Atlas' and Core Breeding Ranges

The core breeding ranges within Wales differed for each of the five mesopredator species. The Hen Harrier and Osprey had the smallest breeding ranges covering 10.71% and 11.35% of the Welsh terrestrial landscape, respectively. The Hen Harrier and Osprey encompassed single-core breeding ranges distributed exclusively in North (***Figure 9a***) and North-west Wales (***Figure 9d***). The Common Buzzard had two disjunct core ranges, together covering 29.27% of Wales; one in the south and one in the north, extending into the Isle of Anglesey (***Figure 9b***).

The Peregrine Falcon's core breeding range was very similar, sharing a southerly core breeding range with the Common Buzzard but fragmented into two distinct ranges in the North, altogether covering 27.05% of Wales (***Figure 9c***). The Red Kite was by far the species with the biggest core breeding range, covering 34.14% of Wales. Core ranges for breeding Red Kites comprised of five core breeding areas; two large ranges covering South and Mid-Wales, covering most of the Black and Cambrian Mountains, and three smaller ranges dispersed across North Wales (***Figure 9e***).

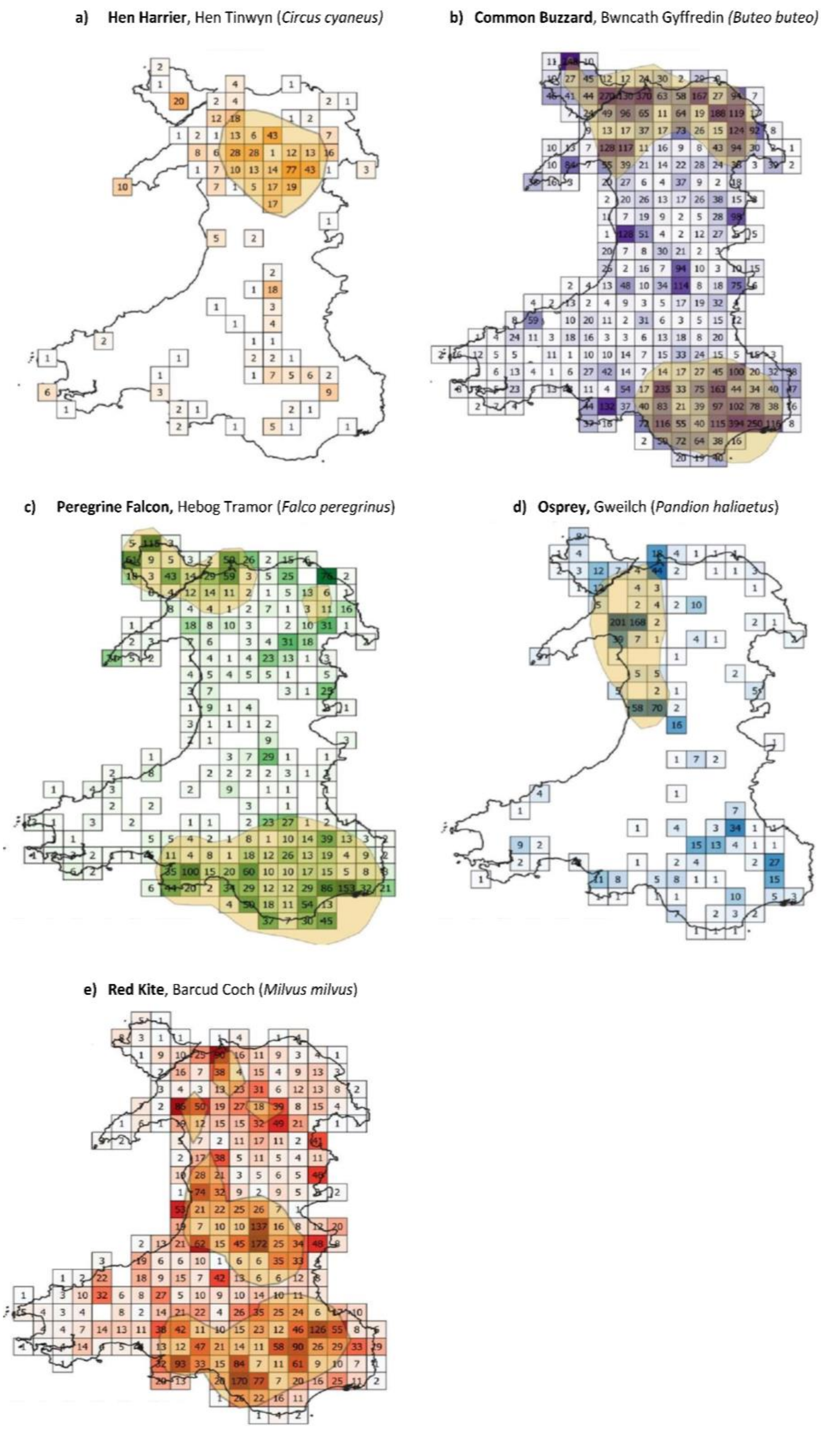


Figure 9. *10 x 10 km atlas maps denoting the core breeding ranges (yellow areas) for the:* ***a)*** *Hen Harrier, Hen Tinwyn (Circus cyaneus);* ***b)*** *Common Buzzard, Bwncath Gyffredin (Buteo buteo);* ***c)*** *Peregrine Falcon, Hebog Tramor (Falco peregrinus);* ***d)*** *Osprey, Gweilch (Pandion haliaetus); and e) Red Kite, Barcud Coch (Milvus milvus) in Wales between 2008 and 2018.*

3.3.2. Habitat Associations of Avian Mesopredators in Wales

3.3.2.1. Hen Harrier, Hen Tinwyn (*Circus cyaneus*)

The largest proportion of habitats within the core breeding range of Welsh Hen Harriers were; pastures (703 km²), moors and heathland (475 km²), natural grasslands (374 km²), conifer forests (220 km²) and peat bogs (201 km²). The greatest number of breeding observations were recorded on peat bogs (n = 139) and moors and heathlands (n = 121). The strongest habitat association for breeding Hen Harriers were demonstrated by a positive association with peat bogs (*null: 9.45, 95% CI: 6.18 – 13.61, SES: 66.15*), followed by moors and heathland (*null: 28.54, 95% CI: 20.96 – 34.86, SES: 24.88*). There were also significant positive breeding associations with scrub and herbaceous vegetation, inland marshes, dunes, and bare rock (***Figure 10a***). There was a significant negative association (i.e. avoidance) of pastures (*null: 184.02, 95% CI: 169.65 – 197.65, SES: -23.45*).

3.3.2.2. Common Buzzard, Bwncath Gyffredin (*Buteo buteo*)

The greatest proportion of land cover within Common Buzzard's breeding ranges were; pastures (2415 km²), arable land (911 km²), urban areas (832 km²), natural grasslands (647 km²), moors and heathland (612 km²), and heterogeneous agricultural areas (470 km²). The greatest number of breeding observations were observed in pastures (n = 1323), urban areas (n = 1192) and arable land (n = 1110). The most positive habitat associations for breeding Buzzards were with urban areas (*null: 312.15, 95% CI: 471.55 – 531.02, SES: 71.02*) and arable land (*null: 495.35, 95% CI: 471.55 – 531.03, SES: 40.06*), followed by sparsely vegetated areas, dunes and sands, coastal lagoons and waterbodies (***Figure 10b***). Despite Buzzards being observed most frequently in pastures, this was shown to be simply due to the abundance of pastures in Wales. Indeed, the distribution of breeding Buzzard observations were significantly negatively associated with both pastures (*null: 2545.16, 95% CI: 2490.13 – 2594.88, SES: -42.69*) and natural grasslands (*null: 590.54, 95% CI: 562.99 – 620.05, SES: -17.86*).

3.3.2.3. Peregrine Falcon, Hebog Tramor (*Falco peregrinus*)

Due to similarities in Peregrine breeding ranges to those of the Buzzard, the highest proportion of land cover across the Peregrines breeding ranges were also pastures (2950 km²), arable land (993 km²), urban areas (924 km²) and natural grasslands (721 km²). The highest number of breeding Peregrine observations were observed in urban areas (n= 368, *null: 87.86,* *95% CI: 74.77 – 99.56, SES: 42.88*) and arable land (n = 268, *null: 139.10, 95% CI: 123.80 – 152.79, SES: 20.18*) and these habitats were also strongly positively associated with breeding Peregrines, along with salt marsh, sea and ocean, intertidal flats, inland marshes, coastal lagoons, beaches and dunes, and waterbodies (***Figure 10c***). The strongest negative habitat association was, as with Buzzards, pastures (*null: 712.53 95% CI: 682.32 – 737.25, SES: -35.57*) and natural grasslands (*null: 165.56, 95% CI: 150.60 – 182.83, SES: -4.20*).

3.3.2.4. Osprey, Gweilch (*Pandion haliaetus*)

The most extensive land cover types in the core breeding range of Welsh Ospreys were; pastures (772 km²), natural grasslands (506 km²), moors and heathland (484 km²), and conifer forests (200 km²). Ospreys were observed more frequently in areas of pastures (n = 214) and heterogeneous agricultural areas (n = 227). There was a weak negative association with pastures (*null: 289.40, 95% CI: 272.76 – 308.38, SES: -8.01*), and a strong positive association with heterogeneous agricultural areas (*null: 44.67, 95% CI: 35.89 – 54.09, SES: 39.13*). There were also positive breeding associations with salt marshes, intertidal flats, sea and ocean, and watercourses (***Figure 10d***).

3.3.2.5. Red Kite, Barcud Coch (*Milvus milvus*)

The highest proportion of habitat cover within core breeding ranges of Red Kites were pastures (3387 km²), natural grasslands (1477 km²) and heterogeneous agricultural areas (1184 km²). The number of breeding observations were also greatest within these habitat types; pastures (n = 928), natural grasslands (n = 348), heterogeneous agricultural areas (n = 315) and urban areas (n = 298). As with Buzzards and Peregrines, pastures were again the habitat with the strongest negative association with Red Kites (*null: 1201.11, 95% CI: 1106.11 – 1174.29, SES: -14.96*). The strongest habitat association for Red Kites was with natural grasslands (*null: 276.84, 95% CI: 253.79 – 297.30, SES: 6.09*), heterogeneous agricultural areas (*null: 186.21, 95% CI: 169.90 –203.81, SES: 14.01*) and urban areas (*null: 145.98, 95% CI: 130.59 –160.63, SES: 19.14*), followed by salt marsh, inland marshes, coastal lagoons and waterbodies (***Figure 10e***). The number of observations and the strength of habitat associations for each mesopredator are tabulated in ***Appendix 2.***

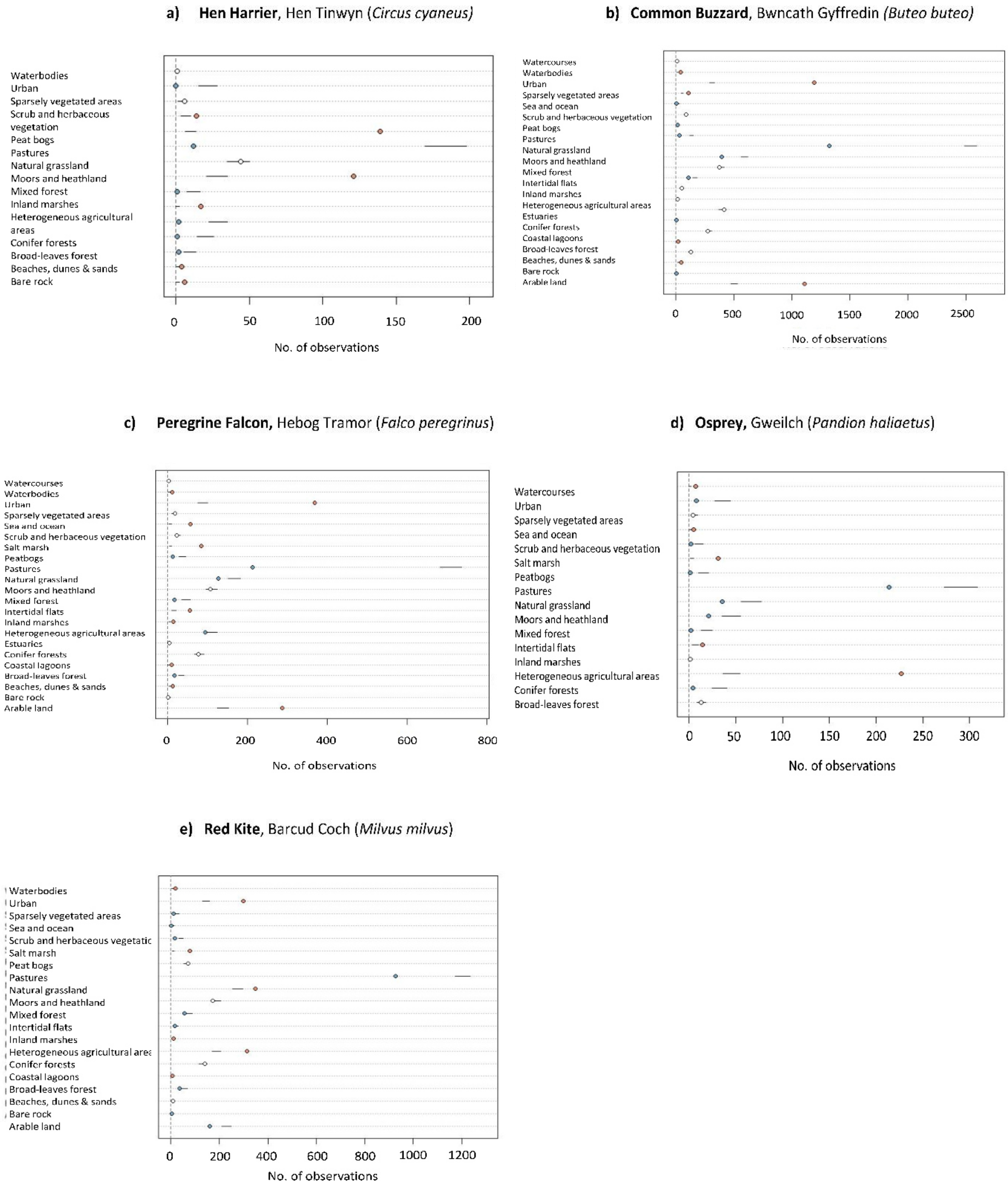


***__Figure 10.__** Habitat association plots comparing the frequency of breeding observations (dots) with available breeding habitats in Wales, of the: **a)** Hen Harrier, Hen Tinwyn (Circus cyaneus); **b)** Common Buzzard, Bwncath Gyffredin (Buteo buteo); **c)** Peregrine Falcon, Hebog Tramor (Falco peregrinus); **d)** Osprey, Gweilch (Pandion haliaetus); and **e)** Red Kite, Barcud Coch (Milvus milvus). Red dots denote a positive habitat association, blue dots denote negative habitat association, and white dots indicate no positive or negative habitat association.*

3.3.3. Environmental Features Selected or Avoided by Avian Mesopredators

3.3.3.1. Hen Harrier, Hen Tinwyn (*Circus cyaneus*)

Five out of nine environmental features assessed provided significant explanatory value in the selection and avoidance of environmental features within the core breeding range for Hen Harriers. There was a positive association between occurrence and distance to; coast (*mean: 73.99 +/- 0.52 km*), lakes (*mean: 2.91 +/- 0.10 km*), and wood cover (*mean: 1.04 +/- 0.04 km*), observations were more abundant in closer proximity to these features. Observations were also more frequent in areas of high elevation (*mean: 460 +/- 4.4 m asl*) and in close proximity to locations of persecution incidents (*mean: 13.79 +/- 0.36 km*). The size of lakes and number of birds persecuted in a given area also affected occurrence, observations were greater in close proximity to larger lakes and decreased in close proximity to smaller lakes (*mean: 0.41 +/- 0.15* km^2). Observations were less likely near areas of high frequency of recorded raptor persecution events (*mean: 2.1 +/- 0.07 birds).* Environmental features and interactions terms significant to Hen Harrier breeding distributions are shown in ***Table 5 – Model 1.***

3.3.3.2. Common Buzzard, Bwncath Gyffredin (*Buteo buteo*)

For this wide ranging species, all nine environmental variables had high explanatory value for the occurrence of observations within the core breeding ranges of Buzzards (***Table 5 – Model 2***). Buzzards were greater at close proximities to; lakes (mean: *1.86 +/- 0.02* km), rivers (mean*: 0.91 +/- 0.01*), woodland (mean: *1.21 +/- 0.03* km), coastlines (mean: *10.05 +/- 0.13* km), the location of persecution incidents (mean: *13.77 +/- 0.11* km), windfarms (mean: *11.24 +/- 0.10* km) and urban settlements (mean: *1.50 +/- 0.02* km). Buzzard observations were also frequent in areas of higher elevations (mean: *126 +/- 1.7 m* asl) and in greater proximity to roads (mean*: 1.75 +/- 0.02* km). Observations were frequent in both low and high populated urban areas (mean: *27,980 +/- 948* people), and in areas with low wind-turbine numbers, however, significantly decreased in areas of high wind-turbines areas (mean: *6 wind-turbines +/- 0.1* wind-turbines).

3.3.3.3. Peregrine Falcon, Hebog Tramor (*Falco peregrinus*)

Within the core breeding range for Peregrines in Wales, seven environmental features provided significant explanatory value (***Table 5 – Model 3***). The occurrence of Peregrines were significantly higher in areas in close proximity to; coasts (*mean: 6.70 +/- 0.24 km*), rivers (*mean: 1.97 +/- 0.04* *km*), lakes (*mean: 2.02 +/- 0.05 km*) and windfarms (*mean: 9.81 +/- 0.26 km*). There was a negative association between occurrence and distance to; urban settlements (*mean: 1.42 +/- 0.04 km*), woodland cover (*mean: 1.00 +/- 0.02 km*), persecution locations (*mean: 16.71 +/- 0.20 km*); observations were more abundant at greater distances from these features. The size and magnitude of lakes, woodland cover and wind-turbines were also associated with Peregrine occurrence, in regards to the proximity to these features. Observations were greater in areas at greater distances from larger woodlands (*mean: 0.63 +/- 0.04 km²*) and in closer proximities to larger lakes (*mean: 0.53 +/- 0.03 km²*) and wind-turbines (*mean: 6 +/- 0.2 wind-turbines*).

3.3.3.4. Osprey, Gweilch (*Pandion haliaetus*)

Observations of Ospreys within their core breeding range in Wales were associated with only three environmental features (***Table 5 – Model 4***). Osprey occurrence was negatively associated with distance to lakes and with elevation, meaning that observations were greater in areas of lower elevation (*mean: 13.6 +/- 2.1 m asl*) and in closer proximity to lakes (*mean: 1.91 +/- 0.04 m*). Osprey occurrence were higher at greater distances to urban settlements (*mean: 1.38 +/- 0.06 m*), and also higher in areas located away from settlements with high population numbers (*mean: 233 +/- 3 people*).

3.3.3.5. Red Kite, Barcud Coch (Milvus milvus)

All environmental features tested were significantly associated with observations of Red Kites (***Table 5 – Model 5***). There was a positive association between breeding occurrence and elevation (*mean: 190 +/- 2.6 m asl*) and distance to; urban settlements (*mean: 1.51 +/- 0.05 km*), roads (*mean: 1.72 +/- 0.03 km*) and lakes (*mean: 2.21 +/- 0.03 km*); observations were more frequent at greater distances from these features and at higher elevations. There were negative associations between occurrence and distance to; coast (*mean: 21.20 +/- 0.3 km*), persecution incidents (*mean: 8.01 +/- 0.15 m*), windfarms (*mean: 8.33 +/- 0.11 km*), rivers (*mean: 3.10 +/- 0.06 km*) and wood cover (*mean: 0.39 +/- 0.01 m*); observations were greater in close proximity to these features. The relationship between breeding occurrence and distance to windfarms, persecution, lakes and urban settlements were affected by the magnitude or the size of such features. Red Kite observations were greater in closer proximities to areas with a high number of persecuted birds (*mean: 2.8 +/- 0.1 birds*) and urban population sizes (*mean: 777 +/- 25.6 people*), however abundance was lower in areas of high abundance of wind-turbines (*mean: 8.2 +/- 0.2 wind-turbines*) and large lakes (*mean: 0.15 +/- 0.01 km²*).

Table 5. *General Linear Models of environmental spatial features significantly associated with the core breeding range of each indicator species.*

Model	Sig. Variables	Min	Max	Mean	T value	P Value
	Hen Harrier, Hen Tinwyn *(Circus cyaneus)*					
1	*Dis. to coast (km)*	*49.46*	91.76	*73.99*	5.85	*** <0.001
1	*Dis. to lake (km)*	*0*	8.16	*2.91*	2.76	** <0.01
1	*Dis. to lake: Area of lake (m²)*	*0*	4.53	*0.41*	-2.75	** <0.01
1	*Dis. to persecution (m)*	*4.33*	32.38	*13.79*	-3.75	*** <0.001
1	*Dis. to persecution: No. of incidents*	*1*	4	*2.1*	-4.11	*** <0.001
1	*Dis. to wood (m)*	*0*	2.85	*1.04*	1.98	* <0.05
1	*Elevation (m asl)*	*140*	822	*460*	5.75	*** <0.001
	Common Buzzard, Bwncath Gyffredin *(Buteo buteo)*					
2	*Dis. to coast (m)*	0	41.69	10.05	-32.76	*** <0.001
2	*Dis. to lake (m)*	0	8.19	1.86	-15.45	*** <0.001
2	*Dis. to persecution (m)*	0.67	44.92	13.77	-21.21	*** <0.001
2	*Dis. to river (m)*	0	7.08	0.91	-17.86	*** <0.001
2	*Dis. to road (m)*	0	7.99	1.75	26.82	*** <0.001
2	*Dis. to settlement (m)*	0	11.55	1.50	-7.53	*** <0.001
2	*Dis. to settlement: Population no.*	117	345,810	948	-5.54	*** <0.001
2	*Dis. to windfarm (m)*	0.17	32.43	11.24	-11.96	*** <0.001
2	*Dis. to windfarm: Wind-turbine no.*	1	76	6	8.76	*** <0.001
2	*Dis. to wood (m)*	0	3.06	0.48	-10.97	*** <0.001
2	*Elevation (m asl)*	-4	805	126	4.70	*** <0.001
	Peregrine Falcon, Hebog Tramor (Falco peregrinus)					
3	*Dis. to coast (m)*	0	46.27	6.70	-12.42	*** <0.001
3	*Dis. to lake (m)*	0	10.34	2.02	-4.08	*** <0.001
3	*Dis. to lake: Area of lake (m²)*	0	3.08	0.06	-5.39	*** <0.001
3	*Dis. to persecution (m)*	0.60	37.87	16.71	6.42	*** <0.001
3	*Dis. to river (m)*	0.29	8.97	1.97	-11.04	*** <0.001
3	*Dis. to settlement (m)*	0	10.22	1.42	4.80	*** <0.001
3	*Dis. to windfarm (m)*	23	27.86	9.81	1.67	. <0.1
3	*Dis. to wood (m)*	0	5.53	1.00	8.15	*** <0.001
3	*Dis. to wood (m): Area of wood (m²)*	0	270.23	0.06	3.98	*** <0.001
3	*Dis. to windfarm: Wind-turbine no*	1	76	6	-12.33	*** <0.001
	Osprey, Gweilch *(Pandion haliaetus)*					
4	*Dis. to lake (m)*	0	4.58	1.91	-2.66	** <0.01
4	*Dis. to settlement (m)*	0	8.23	1.39	5.61	*** <0.001
4	*Dis. to settlement: Population no.*	32	657	233	-2.74	** <0.01
4	*Elevation (m asl)*	0	664	13.6	-3.60	*** <0.001
	Red Kite, Barcud Coch *(Milvus milvus)*					
5	*Dis. to coast (m)*	0	62.79	21.21	-3.96	*** <0.001
5	*Dis. to lake (m)*	0	8.06	2.21	-2.83	** <0.01
5	*Dis. to lake: Area of lake (m²)*	0	0.27	0.15	6.08	*** <0.001
5	*Dis. to persecution (m)*	0.71	44.57	8.01	4.32	*** <0.001
5	*Dis. to persecution: No. of incidents*	1	22	2.8	-5.34	*** <0.001
5	*Dis. to river (m)*	0.01	14.57	3.10	8.37	*** <0.001
5	*Dis. to road (m)*	0	9.61	1.72	-3.34	*** <0.001
5	*Dis. to settlement (m)*	0	11.78	2.52	-15.80	*** <0.001
5	*Dis. to settlement: Population no.*	1	4,486	777	-7.67	*** <0.001
5	*Dis. to windfarm (m)*	0.29	24.70	8.33	-5.28	*** <0.001
5	*Dis. to windfarm: Wind-turbine no*	1	103	12	3.54	*** <0.001
5	*Dis. to wood (m)*	0	3.49	0.39	-5.29	*** <0.001
5	*Elevation (m asl)*	0	806	190	7.77	*** <0.001

3.4. Discussion

There has been a lack of systematic monitoring for breeding birds of prey (i.e. avian mesopredators) and their associated habitat preferences across Wales, attributed to the closure of the Welsh Raptor Study Group (WRSG) in 2013. Our estimation, modelling and mapping of core breeding distributions, habitat associations and avoidance of five avian mesopredators in Wales make a significant contribution to our understanding of how habitat generalists and specialists use the Welsh landscape. At present, Welsh mesopredators sit at the top of the food chain, attributed to both avian apex predators; the Golden and White-tailed Eagle, being extinct in Wales, and are considered as 'bioindicator species of habitat quality and anthropogenic threats (Roth & Weber, 2008). The information gathered in this chapter provides an interesting frame of landscape references for the consideration of restoring native eagles to Wales, these landscape features include; the proportion of livestock pastures, distance to windfarms, persecution areas and urban settlements.

3.4.1. Breeding Distributions of Avian Mesopredators in Wales

Core breeding ranges were estimated using a Utilisation Distribution (UD) model. The home range can be defined as the minimum area in which a species has some specified probability of being located. While core breeding ranges may be an overestimation of the realised niche used by birds of prey in Wales. The results presented here highlight areas of Wales where the highest likelihood of breeding occurs taking into consideration the density of breeding observations for each species. As a result, revealed clear distinctions between ecological generalist and specialist species across Wales.

The Red Kite and Common Buzzard, are generalists (Carter and Grice, 2000; Swan, 2011), were both the most common and widespread breeders in Wales, followed by the highly adaptable Peregrine Falcon. The Hen Harrier and Osprey, are considered specialists (Bierregaard, Poole and Washburn 2014; Gayward *et al.*, 2016), both had small breeding ranges and were the least common breeders in Wales. Consistent with global trends (Büchi and Vuilleumier 2014; Poisot *et al.*, 2015), the occurrence of specialist species are defined by their affiliation with specific habitats or dependence on specific resources (Colles *et al.* 2009), whereas generalists have wider habitat or resource tolerances (Sillivan *et al.* 2016).

Generalist mesopredators display consistent levels of fitness across a gradient of conditions and stronger dispersal abilities, in comparison to specialists (Julliard *et al*. 2006). Thus, can expand sufficiently into empty patches of suitable habitat (Verberk *et al*. 2010). With two generalist avian apex predators regionally extinct in Wales, generalist mesopredators are reported to be the most common species to fill in former historic ranges of lost apex predators (Jimenez *et al*., 2019; Suraci *et al.,* 2019), commonly referred to as the 'mesopredator release effect' (Prugh *et al.,* 2009). Generalist apex predators are good candidate species for reintroduction programmes (Genes *et al.,* 2017) as they can re-establish more balanced, resilient ecosystems and ecosystem functions across multiple habitats.

There is evidence that restoring either/or both the Golden and White-tailed Eagles Wales would regulate the abundance of generalist mesopredators, not only through competition and nesting displacement but through intraguild predation (Lourenço *et al.,* 2011). Golden Eagles, in particular, are known to predate on other mesopredators across Europe (Lourenço *et al.,* 2011). For example, Roemar et al. (2002) found that the natural colonisation of Golden Eagles to the California Channel Islands had significant impacts on native mesopredators. The top-down effect of Golden Eagles resulted in the decrease of over-abundant populations of Island Fox (*Urocyon littoralis*), which directly increased populations of near-extinct Island Spotted Skunk (*Spilogale gracilis amphialus*)

While this is less common for White-tailed Eagles, there are examples of mesopredator release effects. For example, Kamarauskaite *et al. (*2020) found that White-tailed Eagles occasionally prey upon the nestlings of Buzzards. Across Germany, these apex predators have also been observed to reduce numbers and control the movements of the non-native American Mink (*Neogale vison*) also have been observed (). The mesopredator release effects these apex predators could have on habitats across Wales via the suppression of mesopredators, can promote biodiversity and more ecologically resilient ecosystems (Sergio and Hiraldo, 2008). However, it is worth noting that intraguild predation could include suppression of species that are themselves endangered (e.g. Hen Harrier). Thus, additional assessments will be required to understand the ecological benefits and risks potentially brought to endangered species in Wales.

3.4.2. Prominent Welsh Pastures

Livestock grazing is an important form of land use in Wales, covering 75% of the terrestrial surface (Armstrong, 2016). As a result, pastures, or commonly known as improved grassland, were recorded to be the greatest land cover within the core breeding ranges of all mesopredators in Wales. All avian mesopredators displayed negative associations with this land use; meaning that pastures were actively avoided as a breeding habitat preference for Welsh birds of prey. Livestock pastures do, however, present great opportunities for avian mesopredators, accommodating open expanses of land for hunting and artificial perches (i.e. posts, fences, masts etc.) to aid sit-and-wait hunting (Meunier, Verheyden and Jouventin, 2000; Cardador, Carrete and Mañosa, 2011), explaining why breeding Ospreys, Red Kites, Peregrines and Buzzards were recorded to be frequently observed in pastures (Sim *et al*. 2000; Mackrill, 2019; Hardey, 2013).

Birds of prey desire large territories, which often encompass their hunting grounds. Generalist species that require open space for hunting, may adapt and do well in agricultural landscapes, particularly eagles (Sergio *et al*. 2006b; Sansom *et al.* 2016; Tinajero, Barragán and Chapa-Vargas, 2017). The overlap between apex/mesopredator occurrence in agricultural/farming practices has been correlated to; prey availability, reduced grazing intensity, complex structured habitats, positive socio-economic attitudes and the absence of illegal persecution (Martin and Possingham, 2005; Whitfield *et al.*, 2007; Grande *et al.*, 2018). Intense grazing may benefit some species that prosper from hunting in short or grass-dominated vegetation, like the Common Buzzard (Pearce-Higgins *et al.,* 2009), or carrion feeders which benefit from sheep carcasses year-round, like the Red Kite and White-tailed Eagle (Fuller and Gough, 1999; Evans e*t al.* 2010). By contrast, some species, like the Hen Harrier and Golden Eagle are heavily influenced by the indirect effects of livestock grazing on upland vegetation height, composition and reduced prey availability (Mysterud, 2006; Amar *et al.* 2011; Angerer *et al.* 2016), perhaps throwing light on why ground-breeding Hen Harries avoided Welsh pastures. These results further highlight the importance of considering the habitat quality and prey availability in livestock pastures across Wales; to validate the restoration of Golden Eagles, in particular.

3.4.3. Perils from Persecution

Historic conflicts between avian predators and livestock practices have already caused population declines and extinctions in Wales, being the main cause of extirpation for the Golden and White-tailed Eagle (Evans, O'Toole and Whitfield, 2012). The conflict arises when birds of prey are viewed in a bad light or misconceived for naturally predating on livestock kept for socio-economic benefits (i.e. sheep, lambs and gamebirds: Newton, 2010; Netwon, 1974; Whitfield *et al*., 2003). Persecution rates of birds of prey, now an illegal practice, have materially declined from historic rates across Britain (RSPB, 2018). Illegal persecution does, however, still occur across modern-day rural Britain and is more substantial for certain species with natural habitat and prey requirements that overlap with these conflicting land uses; such as the Golden Eagle and Hen Harrier, that rely on upland birds and mammals (Whitfield & Fielding, 2017; Murgatroyd *et al.* 2019), and scavengers like the White-tailed Eagle and Red Kite, that bank on livestock carcasses (Wiley and Bolen, 1971; Blanco, 2014).

Wales contributes to 6.9% (n=84) of the overall recorded persecution incidents, between 2007 and 2019, across Britain (RSPB RaptorPersecution, 2019). The core breeding ranges of Welsh mesopredators contained at least one recorded illegal killing, apart from the northern lowland breeding ranges of the Osprey. While specialist species, like the Hen Harrier and Peregrine Falcon displayed clear avoidance, the Red Kite and Buzzard overlapped with areas recorded with illegal persecution. The Common buzzard, Red Kite and Peregrine Falcon, mesopredators with the largest distributions in Wales, were the highest victims of illegal persecution, with the use of Beniocarb and Fention poisons the main cause of death for recorded incidents (RSPB Raptor Persecution, 2019). Rural countryside practices are the key to the survival of our birds of prey and their socio-economic attitudes will be the key to the success of a potential restoration of eagles to Wales, in the near future.

3.4.4. Hazardous Obstacles

Windfarms are considered hazardous obstacles for many avian predators (Thaxter et al., 2017). There are 778 onshore and 160 offshore wind-turbines operating in 103 windfarm locations across Wales (UKWED, 2017). The single offshore windfarm (Gwynt y Môr), located off the coast of North Wales does not present a problem to current avian mesopredators but may highlight as a risk for coastal White-tailed Eagles (Heuck *et al*., 2019). The largest onshore windfarm located in South Wales (Pen y Cymoedd), operates 103 wind-turbines and overlaps with the southern breeding ranges of the Common Buzzard, Peregrine Falcon and Red Kite. These species displayed to overlap with small windfarms (under 6 wind-turbines), but clear displacement around large windfarms, apart from the Peregrine Falcon which overlapped with small and large windfarms. Most windfarms in Wales are relatively small; 68% of windfarms hold six or fewer wind-turbines (UKWED, 2017). There were no recorded windfarms in the Welsh breeding ranges of Hen Harriers or Ospreys.

The placement of windfarms can ultimately displace avian predators into less suitable habitat, reducing ability to survive or reproduce (Madders & Whitfield, 2006). Consistent with our results, windfarm displacement and collision rates are recorded to be higher for soaring birds like Red Kites, Buzzards, which can be extended to both the Golden and White-tailed Eagle (Balotari-Chiebao *et al*. 2016; Hötker, Krone & Nehls, 2017; Sur *et al.* 2018); attributed to slow flight manoeuvrability, higher wing loadings and dependencies on thermals or wind for flight (Barrios & Rodriguez, 2004; Péron *et al*. 2017). Mesopredators like the Peregrine Falcon use powered flight to escape the risk of collision (De Lucas *et al*. 2008), explaining the great overlap with wind-turbine distribution in Wales. The placements and size of windfarms in suitable eagle habitat will need to be evaluated as a risk factor in further assessments. There is, however, evidence that high-risk species such as the Red Kite, Golden Eagle and White-tailed Eagle avoid wind-turbines, and do not breed within 3 km of a windfarm (Dahl et al. 2013; Watson *et al.* 2018; Heuck et al. 2019).

3.4.5. Subtle Settlements

The distribution of urban settlements and human disturbance to breeding birds is an additional constraint for many birds of prey (Kettel *et al.,* 2018); some adapt and thrive in urban areas and others avoid them. Mesopredator distribution like the Osprey and Hen Harrier are associated with fewer human settlements (Geary, Haworth and Fielding, 2018; James Reynolds *et al.*, 2019); as our results indicate. Peregrine, Buzzard and Red Kite breeding ranges in Wales all overlapped with urban settlements, with only the Red Kite showing clear avoidance towards large urban areas. All three species were at higher densities in their natural habitats in Wales, but confirm that elements such as; nesting on buildings (Peregrine) and supplementary feeding stations amidst and in close proximity to urban areas (Red Kite and Buzzard) can boost natural population numbers and distributions (Ratcliff, 2010; Orros & Fellowes, 2015). However, as Buzzards, Red kites and Peregrines are common and familiar species in the public eye there may be an observational bias towards breeding habitat selection in/near urban areas. Especially if species observations are more commonly seen in areas with more human activity. However, species like Golden Eagles, Hen Harriers and Ospreys are extremely elusive and avoid urban areas (Ruddock & Whitfield, 2007). By Contrast, White-tailed Eagles are more tolerant and can be associated with areas in closer proximities to urban/industrialised areas (Radović & Mikuska, 2009; Vasile *et al.,* 2019)

Urban settlements in Wales are irregularly distributed across the coast and in rural areas, with only 20% of the Welsh population concentrated in these regions. The majority of the Welsh population (80%) live in urban areas concentrated within lowland zones, including regions close to the English border, with 66% of the entire population centralised within South Wales (Office for National Statistics, 2013). With much of the uplands and coastlines of Wales sparsely populated, estimated to be between zero to one persons per hectare (Office for National Statistics, 2018b); all mesopredators were at higher densities in their natural habitats of Wales. This gives us great optimism for Golden and White-tailed Eagle reintroductions to Wales, as both species required spaces are associated with upland habitats and coastlines (Watson, 2010; Unwin, 2016), signifying the likelihood of great expanses of non-populated areas for them to occupy.

3.5. Conclusion

The information gathered from ecologically similar avain mesopredators, in this chapter, contributes to the understanding of how eagles would use the Welsh landscape, a crucial assessment of the IUCN criteria for UK species reintroductions (IUCN/SCC, 2013). These results provide an informative frame of landscape-scale reference, that will inform future decision making for a potential reintroduction of the Golden and White-tailed Eagle to Wales. The distribution of breeding generalist and specialist mesopredators have indicated certain land uses and anthropogenic threats that currently present opportunities and risks, which are important considerations to assess the environmental compatibility of habitats and land uses for eagles to be returned to Wales. Generalist mesopredators display versatility across a wide distribution, presenting evidence to support mesopredator release effects in Wales. The evidence that generalist mesopredators, like the Common Buzzard, Red Kite and Peregrine Falcon, have a wide breeding range is Wales, and the ongoing population recoveries of breeding specialists, like the Osprey and Hen Harrier, gives us great optimism that both generalist apex predators could also thrive in the Welsh landscape. This suggests that the restoration of either/or both eagle species may contribute to exerting top-down control of generalist mesopredators numbers, and in return natural biodiversity, enabling more ecologically resilient ecosystems across Wales.

Chapter Four

Suitable Eagle Breeding Habitats

"Nid oes amheuaeth bod gan Gymru'r potensial i gynnal poblogaethau bridio o Eryrod Cynffon Aur a Chynffon Gwyn, rwyf wedi bod i lawer o leoliadau fy hun yr wyf yn eu hystyried yn addas"

"There is no doubt that Wales holds the potential to sustain breeding populations of Golden and White-tailed Eagles, I've been to many locations myself which I consider to be suitable."

Roy Dennis, MBE, Pers. Comms (2018).

Suitable Breeding Habitats for the Golden and White-tailed Eagle in Wales and across Britain.

4. Chapter Summary

Species reintroductions are important management techniques to reverse the extinction of many ecologically important species. The Golden Eagle (Aquila chrysaetos) and White-tailed Eagle (Haliaeetus albicilla) were once widespread breeders across Britain. Now rare breeders in the north, we use the ecological traits of these territory-holding birds to develop two Species Distribution Models (SDMs) to define habitat suitability across Britain. We also use SDMs to highlight regional bio-geographic areas in Wales for restoration. Our results show that habitat type and topographical features are two important explanatory variables of the breeding distribution of both species, with distance from mountain ridgeline and distance from coast marking distinct ecological breeding niches. Our research highlights great expanses of new potential breeding areas within the current northern ranges, and empty southern British ranges, with Wales illustrated as the next priority area for the restoration of either or both eagle species. The models presented in this chapter will contribute to directing the conservation for population range expansion, restoration projects and provide confidence for the long-term breeding success for the young eagles reintroduced to South Scotland and Isle of Wight, England. We suggest that these models will aid conservation planning efforts for Golden Eagles and White-tailed Eagles in Britain.

4.1. Rational

The widespread loss of apex predators is a conservation problem in ecosystems across the globe (Palkovacs, Wasserman and Kinnison, 2011; Nyhus, 2016). In Europe apex carnivores such as the Grey wolfs (*Lupus lupus*), Red foxes (*Vulpes vulpes*), Eurasian Otters *(Lutra lutra*), Eagle owls (*Bubo bubo*), White-tailed Eagle (*Haliaeetus abicilla*) and various *Aquila* eagles, exert fundamental roles in ecosystems, and the decline or regional extinction of such species leads to pervasive influences on natural environments (Sergio *et al*., 2014). Although such species are now experiencing population increases, there has been significant range redactions from areas they occupied historically, due to the wide-spread depletion or modification of their regional habitats, and human-wildlife conflicts over land uses, which in turn results in increased mortalities through illegal persecution (Palkovacs, Wasserman & Kinnison, 2011; Worm, 2015;

Nyhus, 2016). In recent years, the negative ecological impacts of losing native predators has become increasingly evident through the proposition of trophic cascades, which often results in dramatic changes in ecosystem structure, quality and functionality (Terborgh & Estes, 2013; Wallach, Ripple & Carroll, 2015). These reasons place apex carnivores near the top of the conservation agenda, and species restoration programmes have emerged as one of the main conservation tools to reverse these trends at a national and international scale (Sergio *et al.*, 2006a; Ordiz, Bischof & Swenson, 2013).

Many apex predators are currently considered '*Species of Conservation Concern'* including both the Golden Eagle (*Aquila chrysaetos*) and the White-tailed Eagle (*Haliaeetus albicilla*; BirdLife International, 2015a; 2015b). Both species have been shown to exert strong behavioural and demographic control within their ecosystems (Taylor, 2011), labelling them as keystone species. A reintroduction of either or both species, into their historic ranges, would help restore biodiversity and key ecosystem functions (Sharma, 2005; Carter *et al.*, 2008; Sergio *et al.*, 2014a; Wolf, Ripple & Wolf, 2018). The small and fragmented global and national populations of both species would considerably benefit from a conservation reintroduction, by increasing the numbers and distribution of the species (Maquis, 2005; Scottish Natural Heritage 2017).

4.1.1. The Native Status of Eagles in Britain

Both species once historically occupied all of Britain, with historic populations estimated to be between 800 -1,400 pairs of Golden Eagles and 1,000 – 1,200 pairs of White-tailed Eagles in 500 AD (Evans, O'toole and Whitfield, 2012) Both species were widespread across Scotland, England and Wales prior the 19th Century, until both eagle populations suffered in the hands of targeted human persecution (Newton, 1979, Yalden, 2007). The Golden and White-tailed Eagle are now limited, as a breeding species, to Scotland and Ireland and are absent from most of their British historic range, including England and Wales. The UK Government is required and encouraged to enhance biodiversity and restore extinct native species, as a signatory of the Convention on Biological Diversity (1992), Habitats and Species Directive (Council Directive 92/43 EEC, 1992), and the Bern Convention (Council Directive 82/72/EEC, 1979). Both species went extinct as a consequence of human activities, as a result, we have a moral duty to restore them. One of the main criteria to restore native species to their historic ranges as set out by the IUCN reintroduction guidelines (IUCN/SSC, 2013); is to understand and assess the proportion of suitable habitat for both species across modern-day Britain.

The international habitat preference of Golden and White-tailed Eagles and the environmental variables that influence their distribution, particularly breeding pairs, are well understood (Radovic and Mikuska, 2009; Evans *et al.*, 2010; Crandall, Bedrosian and Craighead, 2015). Much of lowland and upland Britain, particularly in areas where eagles are absent, have changed significantly since eagles occupied the skies, over 150 years ago; Macdonald, 2019). Understanding and learning more about the proportion of Golden and White-tailed Eagle breeding habitat across Britain, is key to provide an insight into the potential modern-day distribution of both species, thereby helping delineate priority areas for reintroduction programmes (Miranda *et al.*, 2019; Tef and Lescu, 2019); a sound conservation strategy for the national and international conservation status of both these apex avian predators (Guisan and Thuiller, 2005).

4.1.2. Mapping Suitable Eagle Habitat

Species Distribution Models (SDMs) are becoming an increasingly valuable tool for reintroduction programmes (Grant *et al.*, 2015; Smeraldo *et al.*, 2017; Parlato and Armstrong, 2018). One of the main advantages of SDMs is to advance the visual scientific evidence and to highlight the capabilities of the proposed release environment to support restored species, that are required by statutory conservation bodies. The premise of SDMs is to attempt to relate the known ecological niche requirements predicted to be correlated with the distribution or abundance of a species (Gomes *et al.*, 2018). In light of this, when species presence is combined with relevant environmental requirements, a value can be produced that denotes a probability of presence. This '*probability of presence'* score assumes the likelihood of a species being present, in a particular area, is some function of the environmental requirements selected (Elith *et al.*, 2006; Ficetola *et al.*, 2014). Thus, by creating SDMs for both Golden and White-tailed Eagles will aid information about the British landscape, which is key to enhancing species conservation management measures (Hengl *et al.*, 2009; Chalghaf *et al.*, 2016).

4.1.3. Chapter Four Research Objectives

In this Chapter, we relate the conservation and ecology of territory-holding Golden and White-tailed Eagles to; 1) develop SDMs for both species to identify regional strongholds and environmentally suitable breeding areas across Britain. We do so by constructing and testing

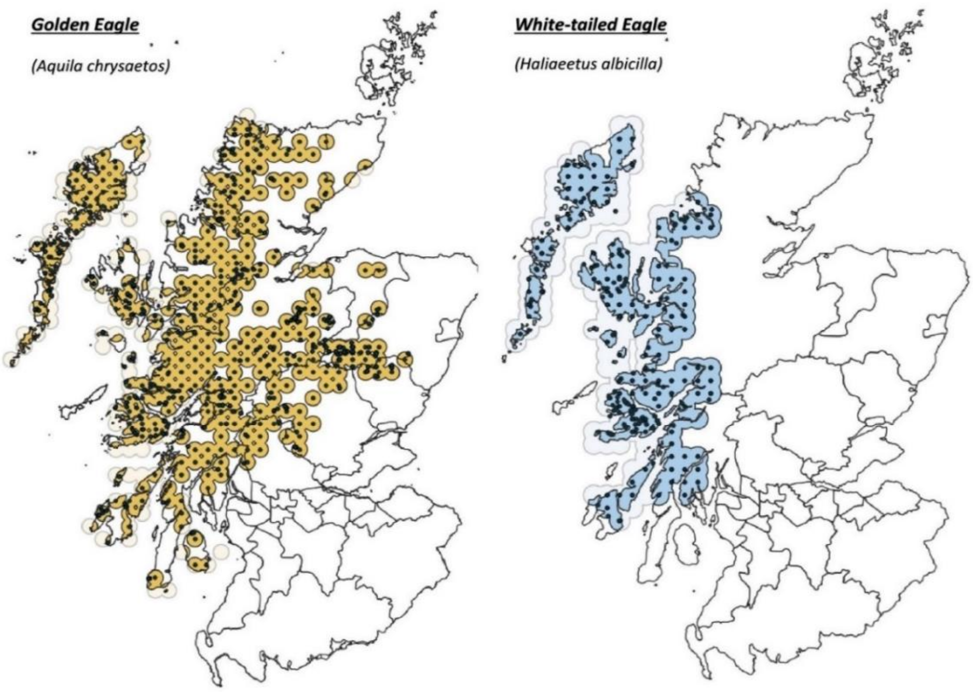
SDMs using spatial maps of environmental requirements that are directly linked to each species breeding ecology, and 2) use these SDMs to highlight biogeographic regions of Wales, and the proportion of suitable habitat that could plausibly hold breeding eagles, as a focus for more targeted work to restore both species to Wales. Only areas that can support breeding eagles were considered, as part of the inter-linked feasibility study to further assess 'whether a reintroduction is the most acceptable option for Wales?'.

4.2. Methods

4.2.1. Eagle Occurrence Data

Breeding locations were obtained for both the Golden and White-tailed Eagle from framework documents (Whitfield *et al.*, 2006; Whitfield *et al.*, 2008; Sansom, Evans and Roos, 2016; Hayhow *et al.*, 2017) and previous datasets collated by local experts (Andrew Stevenson and Cat Barlow pers. comm). Breeding buffers were created to represent the breeding territories of both species, including 6 km buffers for Golden Eagle and 8 km for White-tailed Eagles (**Figure 11**).

As the majority of Britain is void of eagle breeding territories, the size of breeding buffers were selected to represent breeding areas, in Scotland, where the population density is low and still expanding into suitable ranges (McLoed *et al*. 2002; Sansom, Evans and Roos, 2016). Observational records of both species, obtained from the Global Biodiversity Information Facility (GBIF, 2019), were used to enhance breeding occurrence data. Additional occurrence points in each eagle territory maximise the output of the SDM to sufficiently map suitable breeding areas across Britain (Phillips *et al*., 2009). To validate the mapped SDM results for Wales, historic records obtained from ***Chapter Two*** and recent sightings of visiting eagles collected from Aderyn; the Local Environmental Records Centre for Wales (LERC, 2019), were employed. While such data may not reflect breeding habitat preference, the data provides sound means of testing any model predictions for eagle habitat.



<u>Figure 11.</u> *The breeding distribution is represented by territory buffers for the Golden Eagle(6km) and White-tailed Eagle (8km) in Scotland.*

4.2.2. Important Habitat Variables

At a national level, elevation appears to be a common denominator to determine between the core breeding distribution of Golden and White-tailed Eagles (Evans *et al.*, 2010). Elevation (*elev*) was derived from the Ordnance Survey (OS) 50 m Digital Terrain Model (OS Terrain 50, 2019). The positioning of nests is also an important choice for breeding eagles, while this preference varies internationally, many prefer to position nests facing prevailing winds (Love & Ball, 1979; Watson & Dennis, 1992). Slope (*slop*) and Slope aspect (*aspt*) were generated in QGIS Spatial Software (v 3.6; QGIS Development Team, 2019) using the OS Terrain 50m (2019) raster, to account for nest positioning. To map breeding habitats across Britain, 44 habitat types were obtained from CORINE Land Cover (CLC, 2018) and categorised into 22 common habitat types (*hab1 – hab 22*).

Across their global range, Golden Eagle nests are frequently recorded within 1,200 m from a mountain ridgeline (Mcgrady *et al.*, 2002; Fielding *et al.*, 2019; Tef & Lescu, 2019). By contrast, White-tailed Eagle breeding territories appear to contain a fresh or marine water-source or a mature forested area within their territories (Hengl *et al.*, 2009; Radović & Mikuska, 2009; Sansom, Evans & Roos, 2016). Due to these breeding requirements revealing a non-linear decay in the potential nest use, as distance from the habitat feature increases, additional distance rasters were derived. The OS Terrain 50 m and CORINE land use datasets were further processed to identify mountain ridgelines, lakes and forested areas across Britain. Distance rasters were then derived by generating multi-distance buffers of 200 m increments around habitat features, ranging from 0 to 1,200 m from a ridgeline (*rdge*) for Golden Eagles and 0 to 2,000 m from lakes (*lake*), coasts (*coas*) and forested (*frst*) areas for White-tailed Eagles. Spatial projections, grid cell size, and spatial extent of all variables were processed to ensure consistency across all layers and were projected to the World Geographic System (WGS84) with a grid cell size of 50 m.

4.2.3. Environmental Predictor Variables

A total of seven environmental and twenty-two land type variables, covering aspects of topography and land use, were used to map suitable breeding habitat for both species, all recorded to be important explanatory variables linked to breeding distribution (**Table 6**).

Table 6. *Environmental predictor variables used for the Species Distribution Models (SDM) to map suitable breeding areas for the Golden (GE) and White-tailed Eagle (WTE) across Britain.*

Environmental Variables	Predictor description	Spatial units	Species
elev	Elevation	Metres above sea level	WTE & GE
slop	Slope	Percent	WTE & GE
aspt	Slope aspect	Degrees	WTE & GE
rdge	Distance from ridgeline	Metres	GE
lake	Distance from lake	Metres	WTE
coas	Distance from coast	Metres	WTE
frst	Distance from forest cover	Metres	WTE
hab1	Artificial surfaces (n = 1 - 11)	Polygons/ m^2	WTE & GE
hab2	Arable land (n = 12-17)	Polygons/ m^2	WTE & GE
hab3	Pastures (n = 18)	Polygons/ m^2	WTE & GE
hab4	Heterogeneous agricultural areas (n =19-22)	Polygons/ m^2	WTE & GE
hab5	Broad-leaved woodland (n = 23)	Polygons/ m^2	WTE & GE
hab6	Coniferous forest (n = 24)	Polygons/ m^2	WTE & GE
hab7	Mixed forest (n = 25)	Polygons/ m^2	WTE & GE
hab8	Natural Grassland (n = 26)	Polygons/ m^2	WTE & GE
hab9	Moors and heathland (n = 27)	Polygons/ m^2	WTE & GE
hab10	Scrub and herbaceous areas (n = 28-29)	Polygons/ m^2	WTE & GE
bab11	Beaches, dunes and sands (n = 30)	Polygons/ m^2	WTE & GE
hab12	Bare rock (n = 31)	Polygons/ m^2	WTE & GE
hab13	Open spaces with little vegetation (n = 32-34)	Polygons/ m^2	WTE & GE
hab14	Inland marshes (n = 35)	Polygons/ m^2	WTE & GE
hab15	Peat bogs (n = 36)	Polygons/ m^2	WTE & GE
hab16	Salt marsh (n = 37-38)	Polygons/ m^2	WTE & GE
hab17	Intertidal flats (n = 39)	Polygons/ m^2	WTE & GE
hab18	Water courses (e.g. rivers; n = 40)	Polygons/ m^2	WTE & GE
hab19	Waterbodies (e.g. lakes; n = 41)	Polygons/ m^2	WTE & GE
hab20	Coastal lagoons (n = 42)	Polygons/ m^2	WTE & GE
hab21	Estuaries (n = 43)	Polygons/ m^2	WTE & GE
hab22	Marine waters (e.g. ocean; n = 44)	Polygons/ m^2	WTE & GE

4.2.4. Species Distribution Models (SDMs)

Both eagle species are rare breeders in Britain and attributed to the large extent of the study area, a maximum entropy algorithm was implemented using MAXENT software (version 3.4.1; Phillips *et al.,* 2020). MAXENT models were chosen to account for presence only nest and observational data, for both species, to further project suitable areas across Britain with the habitat requirements to sustain territorial holding pairs. Two separate MAXENT models were produced to gain the most uniform distribution for breeding Golden and White-tailed Eagles, determine the most influential environmental variables correlated to their distribution and estimate parallel areas across Britain with similar characteristics.

4.2.5. Model Validation

To test the predictive performance of the final SDM's produced for both species, occurrence data were randomly partitioned using a jackknife cross-validation procedure (Radosavljevic & Anderson, 2014), resulting in 70% of records assigned as training data and as test data the remaining 30% of records. The relative importance of each environmental variable for each MAXENT model was evaluated by both percent contribution and jack-knife analysis. The contributions of each environmental variable in the models logistic prediction were indicated by response curves. Thus, each models predictive performance was evaluated by calculating the Area Under the Curve (AUC) of Receiver Operating Characteristics (ROC), based on training and test data. The prediction of the model corresponds to a random model If AUC is less than 0.5, while a value above 0.5 indicates a model performs better than chance.

By combining prediction results for both species, a weighted value of breeding suitability was produced for each 50 m cell across Britain. The weighted average, whereby each map was weighted by its AUC value provided a robust method for building a model consensus. An arbitrary threshold of 0.3 was used to illustrate the proportion of suitable and unsuitable breeding habitats for both species in Britain. For Wales, only suitable habitats (i.e. values over 0.3) were used to highlight bio-geographic areas of breeding importance. To represent areas suitable for breeding eagles, polygons were manually plotted to highlight areas of suitability in Wales. Welsh datasets on the historic distribution (pre-1920s) and current eagle visits from Aderyn (1920-2019) were mapped to cross-validate predicted areas with areas of historic and modern use.

4.3. Results

Taking into consideration the number of breeding locations and observations within predicted breeding territories, the two SDMS produced obtained 1021 occurrence records for Golden Eagles (nests = 497; territorial observations = 525) and 362 records for White-tailed Eagles (nests = 119; observations = 243).

4.3.1. Golden Eagle MAXENT Model

Overall, the Golden Eagle SDM displayed a high predictive power, the mean area under the ROC curve (AUC) for the training data was 0.835 and 0.841 for test data. The most important environmental variables influencing the breeding distribution of Golden Eagles were habitat type (57.9%), elevation (*elev*; 28.7%) and distance from mountain ridgeline (*rdge*; 9.1%). We found that these variables also produced high permutation importance; meaning that when used in isolation each variable provided great explanatory value about the distribution of Golden Eagles. Slope (sl*op*) and slope aspect (*aspt*) did not result in high model percent contributions. Despite this, however, *Slope* revealed some permutation importance, while slope aspect did not and was dropped from the model. Percent contributions and response curves for the Golden Eagle MAXENT Model are shown in ***Appendix 3***.

We also found the predicted suitability for Golden Eagle breeding territories increased in areas where elevation was more than 356 m asl, distance to mountain ridgeline was less than 218 m, and slope was more than 10%. The most common habitats used by territory holding Golden Eagles were; peat bogs (*hab15*; 40%), moors and heathland (*hab9*; 13.7%), pastures (*hab3*; 10.8%) and open spaces with little vegetation (*hab13*; 9.2%). Further descriptive statistics on Golden Eagle territories are described in ***Appendix 4***.

4.3.2. White-tailed Eagle MAXENT Model

The mean area under the ROC curve (AUC) for White-tailed Eagle training data was 0.920 and 0.901 for the test data, which indicated a high predictive ability for the MAXENT model. The environmental variables that contributed most to the predictive output of fitting the model were habitat types *(53.7%)*, elevation *(elev; 29.2%) and* distance from *the* coast *(coas; 14.3%).* Using the jack-knife test, all variables with the highest contribution resulted in high permutation importance. Slope (sl*op*) and slope aspect (*aspt*) were the lowest variables with permutation importance and did not reveal sufficient explanatory value when in isolation. *Elevation* was the only variable that decreased the gain when omitted, which indicated that the model depends heavily on this variable. Percent contributions and response curves for the White-tailed Eagle MAXENT Model are shown in ***Appendix 5***.

The models *p*redicted suitability for the White-tailed Eagle increased in areas where the elevation was less than 124 m asl, less than 700 m from the coast or 431 m from an inland lake. The White-tailed Eagle presented a broader preference for habitat types than the Golden Eagle and were more associated to beaches, dunes and sands (*hab11*; 16.5%), bare rock (*hab12*; 12.9%), natural Grassland (*hab8;* 9.9%), peat bogs (*hab15*; 9.6%), watercourses (*hab18*; 9.1%), coniferous forest (*hab6*; 8.8%), estuaries (*hab21;* 8.5%) and marine waters (*hab22*; 8.1%). Further descriptive statistics on White-tailed Eagle territories are described in ***Appendix 6***.

4.3.3. Priority Areas Across Britain

4.3.3.1. Golden Eagle (*Aquila chrysaetos*)

As model parameters were based on Scottish upland habitat features, much of Scotland was highlighted to hold great proportions of suitable habitat for Golden Eagles. The model also highlights new areas in Central, East and South Scotland suitable for breeding birds. Although habitat suitability reduced around the urban areas of Edinburgh and Glasgow and increasing suitability ranging into the uplands of South Scotland (***Figure 12***). Across Southern Britain, Wales provides the second largest proportion of suitable habitat for Golden Eagles, with much of Snowdonia and the Cambrian mountains being suitable. Much of Northern England also highlights priority areas for restoration including; the North Pennines, Lake District and North Yorkshire moors, with Southern England scattered with patchy, fragmented areas.

4.3.3.2. White-tailed Eagle (Haliaeetus albicilla)

Britain's long coastline hosts large expanses of suitable coastal and marine habitats for breeding White-tailed Eagles. Based upon the high habitat suitability of occupied territories across the West and North Coast of Scotland; the model highlighted new breeding ranges extending into eastern and southern ranges, for example, Donorch Firth and Galloway Forests (***Figure 13***). Suitable habitats continue to stretch intermittently into large coastal bays and inlets across much of North and South England, with areas such as; the Humber Estuary, Lincolnshire, Great Ouse Estuary, Norfolk and Pool Harbour and the Solent Estuary, Dorset. Great expanses of Wales also illustrate a stronghold of less fragmentary suitable habitats, including the Isle of Anglesey, Llyn Peninsula and the Pembrokeshire coast.

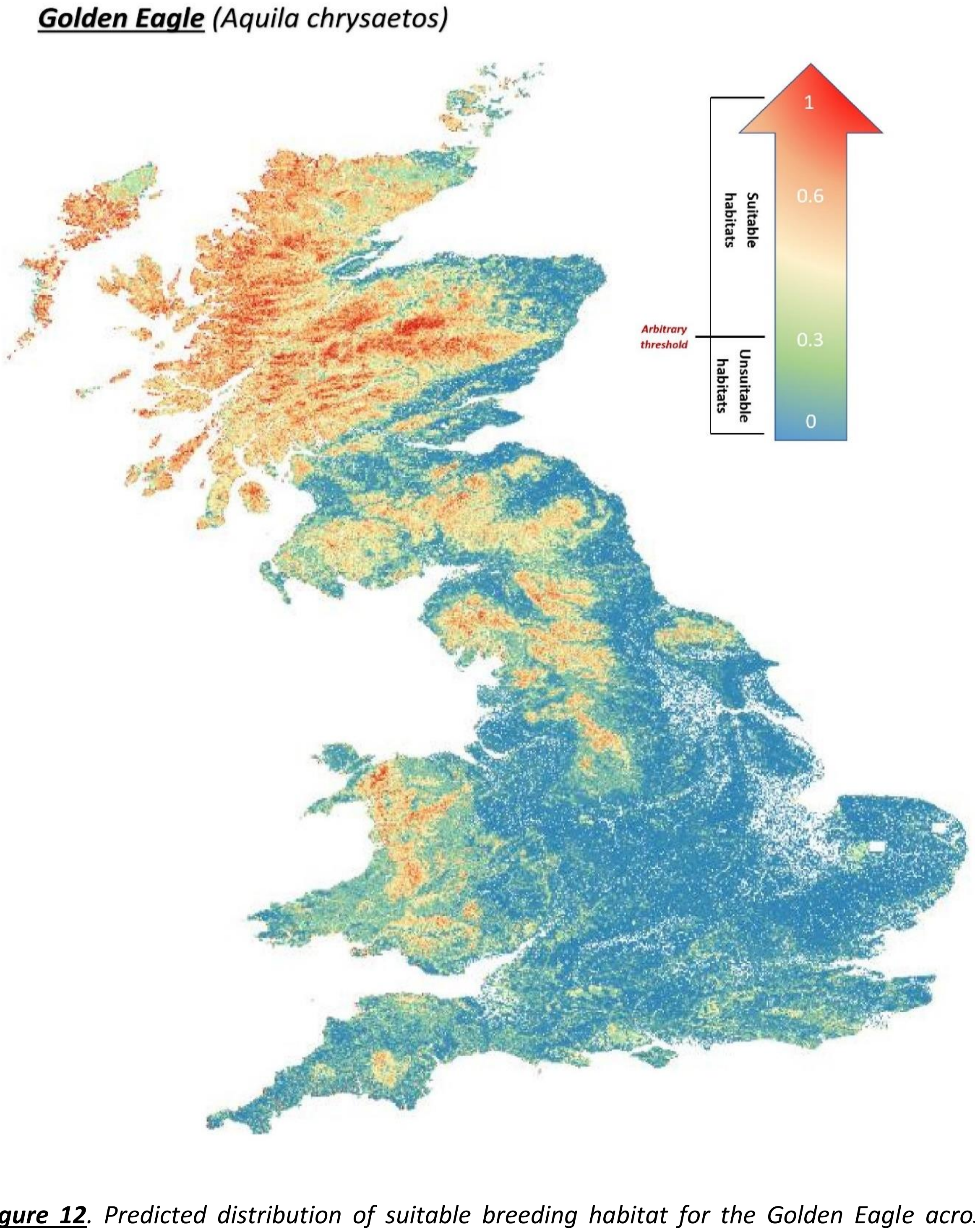
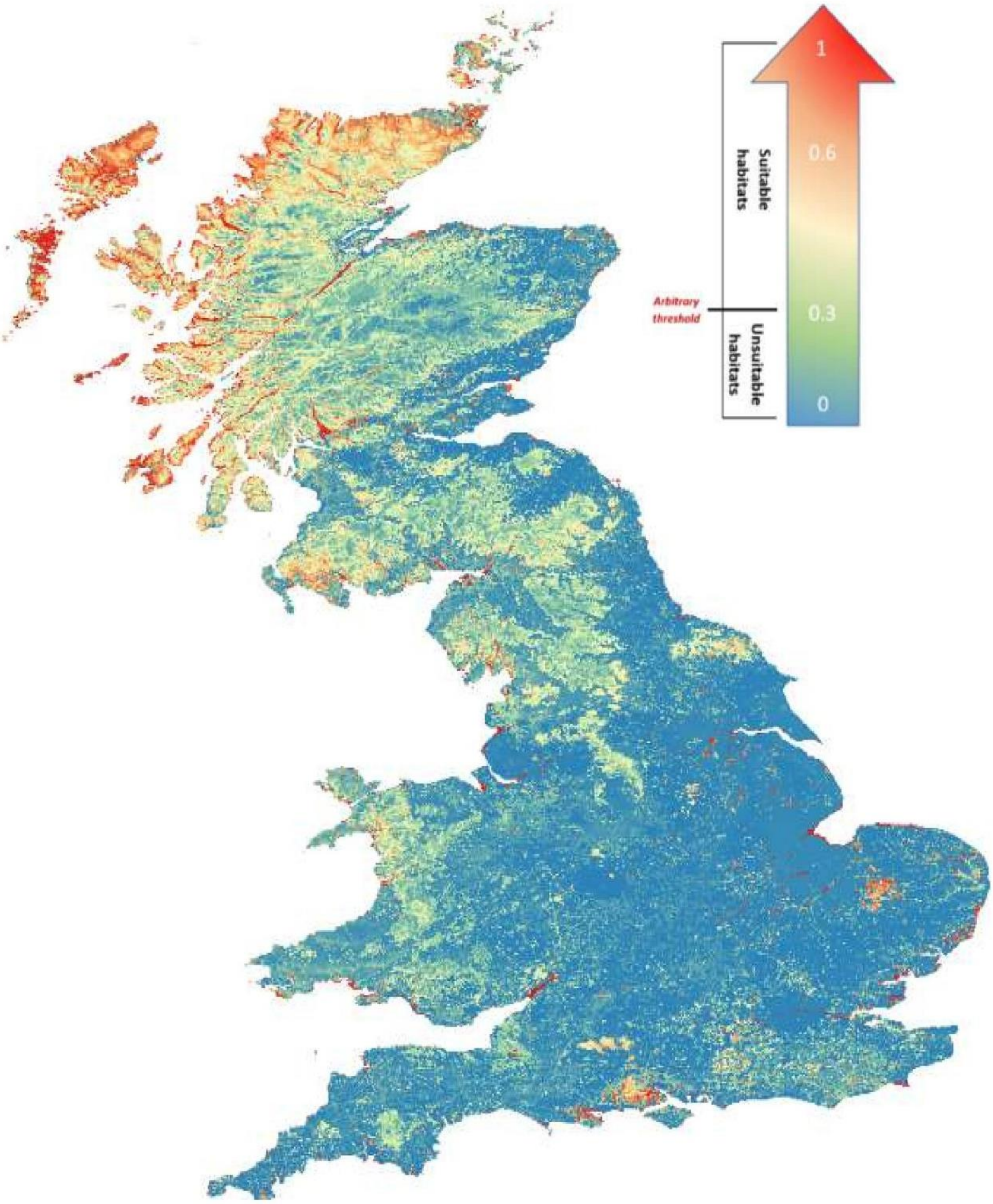


***Figure 12**. Predicted distribution of suitable breeding habitat for the Golden Eagle across Britain. The colour gradient defines the habitat suitability with red and amber indicating high suitability, yellow and green indicating typical conditions and blue for low suitability.*

<u>White-tailed Eagle</u> *(Haliaeetus albicilla)*

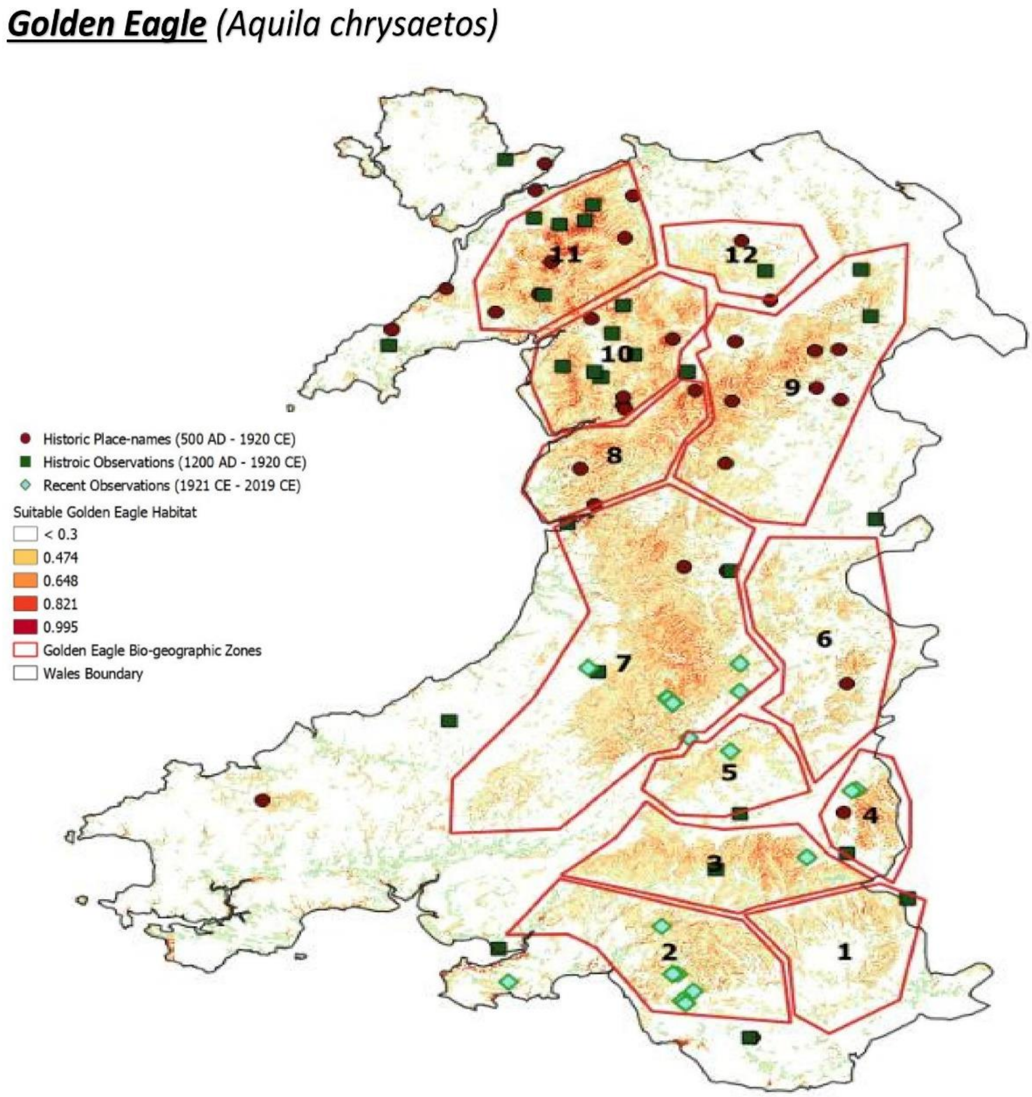


<u>Figure 13.</u> *Predicted distribution of suitable breeding habitat for the White-tailed Eagle across Britain. The colour gradient defines the habitat suitability with red and amber indicating high suitability, yellow and green indicating typical conditions and blue for low suitability.*

4.3.4. Bio-geographic Zones in Wales

On a local scale, Wales offers a high proportion of suitable breeding habitats for both species. For the Golden Eagle, our SDM results highlight 44.1% of Wales encompassing 12 mountainous bio-geographic zones that are environmentally suitable for breeding birds, (***Figure 14***). Including; Snowdonia National Park, Cambrian Mountains and Brecon Beacon National Park.

For the White-tailed Eagle, 38.3% of Wales depicting 14 coastal and 3 inland bio-geographic zones were highlighted as suitable breeding habitats (***Figure 15***). When historic and current records for Wales were overlaid onto suitability maps for both species, 71% of Golden Eagle records (n = 63/88) and 77% of White-tailed Eagle records (n = 52/66) were within predicted bio-geographic zones, validating the past and future ability for the Welsh landscape to sustain both species of eagles.

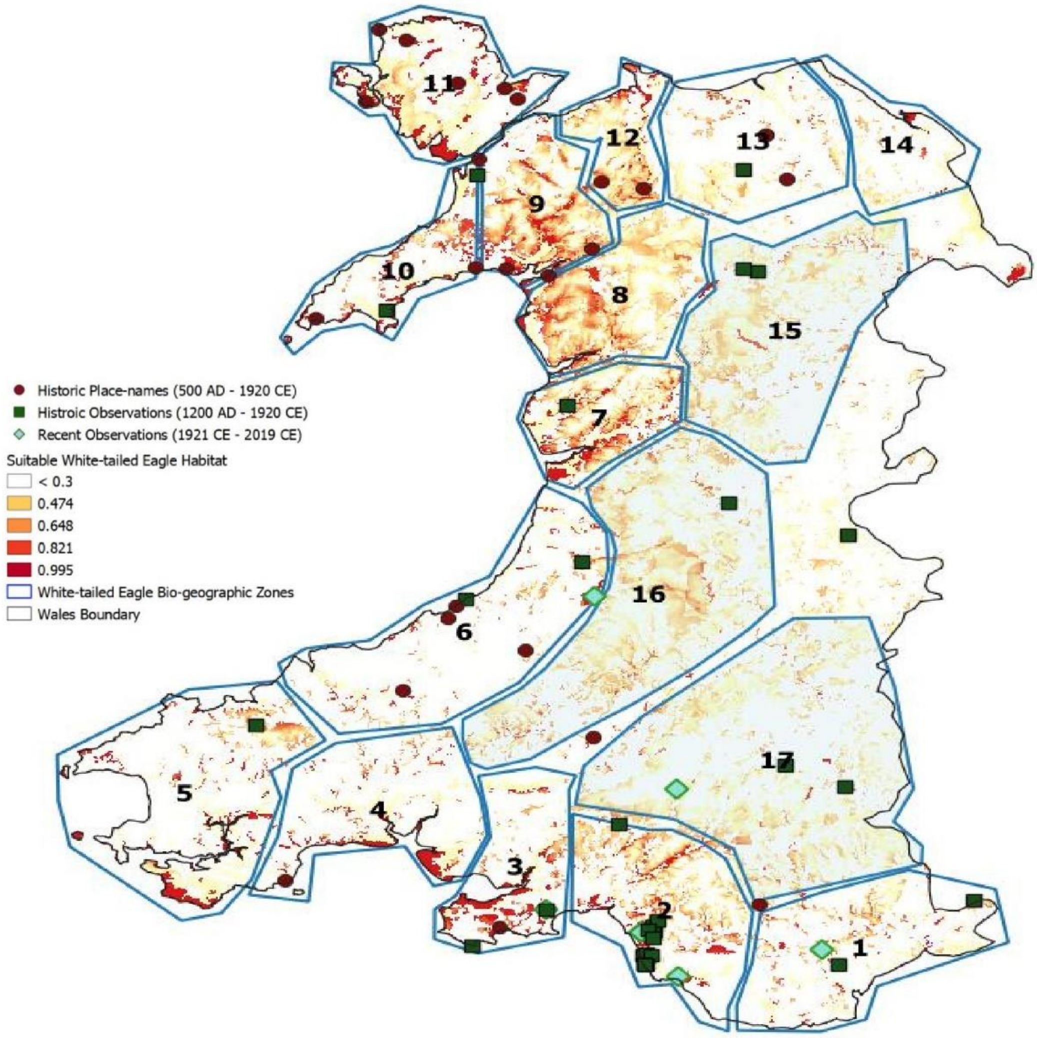


Golden Eagle Bio-geographic Zones of priority for Wales:

1.	*South Wales Valleys (East)*	**7.**	*Cambrian Mountains*
2.	*South Wales Valleys (West)*	**8.**	*Lower Snowdonia National Park*
3.	*Brecon Beacons National Park*	**9.**	*Llangollen & Berwyn Mountains*
4.	*Black Mountains*	**10.**	*Central Snowdonia National Park*
5.	*Hay-on-Wye*	**11.**	*Upper Snowdonia National Park*
6.	*Radnor Forest*	**12.**	Pentre-Llyn-Cymmer

Figure 14. *Prediction of bio-geographic areas highlighted for more focus work for a Golden Eagle reintroduction in Wales, illustrating the historic and current distribution of welsh records across Wales.*

White-tailed Eagle *(Haliaeetus albicilla)*



White-tailed Eagle Bio-geographic Zones of priority for Wales:

1.	*The Severn Estuary*	**10.**	*Llyn Peninsula*
2.	*Swansea Bay & Afon Forests*	**11.**	*Isle of Anglesey*
3.	*The Gower Peninsula*	**12.**	*Conwy Estuary & Gwydir Forests*
4.	*Caerfyrddin Bay*	**13.**	*Clwyd Estuary & Clocaenog Forests*
5.	*Pembrokeshire National Park*	**14.**	*Dee Estuary & Pen y Maes Woods*
6.	*Ceredigion Bay*	**15.**	*Y Berwyn National Reserve*
7.	*Dyfi Estuary & Dyfi Forests*	**16.**	*Cambrian Mountains*
8.	*Mawddach Estuary & Coed y Brenin Forests*	**17.**	*Brecon Beacons National Park*
9.	*Glaslyn Estuary & Snowdonia National Park*		

Figure 15. *Prediction of coast and inland bio-geographic areas highlighted for more focus work for a White-tailed Eagle reintroduction in Wales, illustrating the historic and current distribution of welsh records across Wales.*

4.4. Discussion

In this chapter, we highlight for the first time the plausible, national-scale breeding distribution of the Golden and White-tailed Eagle across Britain; a result that is of prime management and conservation interest to many southern regions (Sharma, 2005), particularly Wales. We find that habitat type and topographical features were the most explanatory variables linked to the breeding distribution of the Golden and White-tailed Eagle in Scotland. Open landscapes, on average, higher than 356 m asl that enclose lowland or upland hills, slopes and mountain ridgelines were important elements characterising and projecting the breeding distribution of Golden Eagles across Britain. By contrast, we found coastal lowlands and inland freshwater sources, on average, less than 124 m asl that enclosed either marine water (e.g. estuaries) or freshwater sources (e.g. an inland lake), to be key elements in mapping the breeding distribution of White-tailed Eagle across Britain.

This chapter highlights great expanses of new potential Golden and White-tailed Eagle breeding areas within the current northern ranges and empty southern ranges in Britain. Our results illustrate lowland and upland bio-geographic areas across southern Britain, particularly Wales, that meet the breeding requirements to potentially sustain populations of both eagle species. Wales is void of eagles, highlighting its landscape potential to hold both breeding eagles and a suitable priority area for an eagle reintroduction.

4.4.1. Golden Eagle Breeding Habitat

The Golden Eagle is a widespread northern hemisphere species, adapted to breed in a broad range of habitats. One shared key element of their global distribution, is the presence of open landscapes (Pedrini & Sergio, 2002; Sergio *et al.*, 2006b; Whitfield *et al.*, 2007; Lado & Tapia, 2012). The preference for open landscapes were reflected in our results, as open habitat types such as; peat bogs, moors and heathland, pastures and open spaces with little vegetation, were correlated to Golden Eagle breeding distribution in Scotland. Breeding territories are known to encompass both nest sites and feeding grounds (Watson, 2010; Millsap *et al.*, 2015). Watson and Dennis (1992), suggest that nest site selection is associated to open habitat with mosaic vegetation, directly linked to favour prey detection and hunting success. Whilst our model does not account for prey availability, it does act as a proxy to map suitable open expanses of habitat, able to support the nesting and foraging requirements of a breeding eagle.

Topographical features were also important explanatory variables for our MAXENT model. Our results revealed breeding Golden Eagles to position nests at high elevations (>365 m asl), in close proximity to mountain ridgelines (<218 m), two variables in line with the majority of breeding locations across the globe (Mcgrady *et al.*, 2002; Di Vittori & Lopez-Lopez, 2014; Fielding *et al.*, 2019; Tef & Lescu, 2019). According to Evans *et al.* (2010), they position nests at higher elevations to avoid predation risks and illegal persecution, often weighted by extreme weather and difficulties transporting prey uphill If nests are positioned too high (Watson, 2010). Golden Eagles can also be a species of lowland mountains and flat topography, like the Taiga of northeast Europe and North America (Morneau *et al.*, 2015; Clouet *et al.*, 2017), such distributions are heavily correlated with good quality habitat, food availability and regional wildlife and human relationships (Whitfield *et al.*, 2004; Millsap *et al.*, 2015). Our models reveal that across Britain, there are more breeding areas, that meet the requirements of Golden Eagles, in upland habitats.

Airspace can also be tied into our findings as its use has been subjected to the underlying terrestrial topography (Melorose, Perroy & Careas, 2015). The species relationship with mountain ridgelines, in this study, has been correlated with the provision of wind-energetic lift in other studies (Bohrer *et al.*, 2011), a recent finding in low and high mountainous habitats across the globe (Mcgrady *et al.*, 2002; Fielding *et al.*, 2019; Tef & Lescu, 2019). According to Fielding *et al.* (2020), Golden Eagles rely on anabatic and orographic winds to provide vertical lift to supplement their energy fuelling flights. Golden Eagles often position nests sites close to mountain ridgelines, at lower elevations than their surrounding territories to maximise wind sources (Dunk *et al.*, 2019); providing ample conditions for low flight hunting and low energy expenditure, in return maximising hunting and provisioning requirements (Watson *et al.*, 2018). It can assume that these features are expected to be of importance elsewhere in Britain for the Golden Eagle.

4.4.2. White-tailed Eagle Breeding Habitat

White-tailed Eagles are breeding birds of the northern Palearctic associated with lowland habitats. The species has a wide array of selected breeding habitats from the coasts and estuaries of Norway, Ireland, Iceland and Greenland (Radovic and Mikuska, 2009; Santangeli, Hogmander & Laaksonen, 2013), to the alluvial wetlands of Croatia and Romania (Willgohs, 1961), to the shallow, fish-rich rivers and lakes of Germany (Krueger, Gruenkorn & Struwe-Juhl, 2010). Across Scotland, our results indicate that breeding White-tailed Eagles were associated with both lowland coastal (i.e. marine waters and estuaries) and inland areas (i.e. conifer forests and watercourses).

Across the globe, breeding territories share two main ecological characteristics; nest placement is usually close to marine or fresh water and forested areas (Krueger, Gruenkorn and Struwe-Juhl, 2010; Santangeli, Hogmander and Laaksonen, 2013) The species is known to breed in mature trees or coastal cliffs (Hardey *et al.,* 2013). Our results suggested that the breeding selection in Scotland were mostly associated with forested areas close to coastlines (< 700 m), consistent with national and international studies that render them as coastal birds (Mee *et al.*, 2003; Evans, *et al.*, 2010). Global differences between cliff and tree nests have been correlated with the extent of woodland cover and the proximity of forest cover from water sources with sufficient prey availability (Todorov, Daskalova & Shurulinkov, 2015; Sansom, Evans & Roos, 2016; Bekmansurov, 2019). The White-tailed Eagle MAXENT model described in this chapter characterises and predicts coastal and inland areas across Britain suitable to hold breeding pairs.

The species preference to breed in lowland areas, as described in our results, can be mostly explained by their wing morphology. White-tailed Eagle wings are shorter, wider (i.e. lower aspect ratio), and squarer with lower wing loadings, making them better suited to level, active and load-carrying flights than the Golden Eagle (Shatkovska & Ghazali, 2017). The species flight relies on rising currents of air that involve net gain in height, different to the Golden Eagle (Whitfield *et al.*, 2013). According to Evans *et al.* (2010), different ecological niches and the gradual physical adaptations prompted by strong competition in the past has resulted in minimised competition attributed to breeding differences in nesting and foraging habitat. This highlights that the restoration of both species to one area would be feasible in parts of Britain with no eagles if the conditions are right.

4.4.3. Welsh Eagle Restorations

Our MAXENT models illustrate large expanses of new suitable breeding habitat across much of Britain; with Wales highlighted to demonstrate the highest proportion of suitable habitat, for both species. Maquiss (2005) revealed that natural colonisation by eagles to Wales is unlikely for the foreseeable future, attributed to breeding populations being too far north. This statement can be attributed to two main behavioural aspects of the life cycles of both species. Firstly, both eagles are K-selected species that exhibit, low reproductive outputs, slow population growth and limited population dispersal (Byrne and Pitchford, 2016; Morandini and Ferrer, 2017). Secondly, both species display delayed sexual maturity and strong natal philopatry (Whitfield et al 2009; Ewan *et al.* 2016); meaning when the birds reach sexual maturity and enter the breeding population, at the age of four or five, they breed in close proximity (50m) from their natal sites. It has been shown that release sites also act as artificial natal areas (Whitfield *et al*, 2009)

The strong natal philopatry limits the ability of the eagles to naturally establish new territories away from their current ranges. It has been suggested that a rolling scheme of restoration programmes are a sound conservation measure for both species in Britain (Whitfield *et al.*, 2006; Taylor, 2011; Scottish Natural Heritage, 2017). Despite a recent restoration project of young White-tailed Eagles to Isle of Wight, England (Dennis, Mackrill and Sergeant, 2019); natural colonisation to Wales will likely take decades, and presumably even longer for the Golden Eagle. Thus, Wales offers large expanses of suitable breeding habitat for both the Golden and White-tailed Eagle and could serve as the next priority area for restoration in Britain. Our results signpost multiple welsh bio-geographic regions able to host viable breeding populations in the long-term, much like the case for both species restored in Ireland (Mee *et al.*, 2003; Taylor, 2011).

4.4.4. Model Interpretation and Assumptions

Species Distribution Models (SDMs) are based on analysis that relates the occurrence of a species in places to features of those places (Wiens et al. 2009). Both species have global geographic ranges and wide habitat preferences and each species respond independently to the environmental features that determine its niche space (Hirzel and Le Lay, 2008). Presence data for SDMs could have been selected from eagle breeding populations anywhere across the globe. However, Scotland provided the best source of presence data. Both eagles have been widely monitored by the Scottish Raptor Study Group since the early 19th century and both breeding datasets provided a good sample size of accurate and archived data.

Thus, the model presented in this chapter assumes that the variables for each eagle species SDM, do, reflect the niche requirements of both species in Scotland and would be the prefered habitat features selected in Wales. Although there may be data uncertainties with model interpretation, the distribution of breeding eagles in Scotland may be biased towards the North and West coast directly linked to land-use conflicts. Many studies have referenced the spatial avoidance of breeding eagles towards driven grouse moors in Scotland (Whitfield et al, 2004; Thompson, 2008; Sansom et al. 2017; Whitfield & Fielding, 2017). If this is the case and persecution is a serious problem correlated to the spatial distribution of eagles, it does not alter those regions potential as suitable habitat or reduce the potential restoration of an eagle to Southern Britain. If anything, due to this limitation, the SDM's presented in this chapter may be an underestimate of the true potential of habitat suitable for both species of eagles across the UK.

4.5. Conclusion

The models presented in this chapter provide an opportunity to contribute to the conservation status and framework strategies of both the Golden and White-tailed Eagle in Britain. Our results reveal large potential breeding strongholds across most of Britain, particularly Wales. The results from this chapter highlight the potential to restore both species in Wales and England, and provides strong evidence for the potential of population growth and expansion in their current ranges; in line with other predictive modelling studies on the species (Sansom, Evans & Roos, 2016; Whitfield & Fielding, 2017). The results of this chapter also provide great optimism and confidence for the long term-breeding success of two recent conservation eagle translocations in Britain: the young Golden Eagles restored to the upland of South Scotland (Fielding& Haworth, 2014); and the young White-tailed Eagles restored to the Isle of Wight, England (Dennis, Mackrill and Sergeant, 2019).

Chapter Five

Anthropogenic Land Use and Eagle Habitat

"Nid yw defnydd tir yn newid potensial Cymru fel cynefin eryr addas, fodd bynnag, gallai gyfyngu ar feddiant y cynefinoedd addas hyn"

"Land use does not change Wales' potential as suitable eagle habitat, it could, however, limit the occupation of some of these suitable habitats"

Roy Dennis, MBE, Pers. Comms (2019).

Eagle Breeding Habitat and Anthropogenic Land Uses: an assessment of available breeding habitat in Wales.

5. Chapter Summary

Modern-day anthropogenic land uses often limit or reduce a species' distribution, by causing reductions in their survival and/or reproductive success, often due to reductions in food availability. To examine the feasibility of proposals to restore the Golden (Aquila chrysaetos) and White-tailed Eagle (Haliaeetus albicilla) to Wales, we use habitat suitability analysis to identify and map available eagle breeding areas in Wales; to expand our knowledge of whether Golden and White-tailed Eagle breeding habitats are compatible with modern-day anthropogenic land uses. Understanding additionalland use constraints and risks for eagles, and their sensitivity to these land uses within suitable breeding areas, are pivotal assessments to validate an eagle restoration programme in Wales. Spatial analysis and bio-geographic ranking methods are used to illustrate anthropogenic land-use intensity surrounding breeding habitat, the proportion of breeding habitat lost to land uses and the proportion of available nest sites in Wales for the Golden and White-tailed Eagle. The results reveal plentiful nest sites and breeding habitats in Wales for both species and, more importantly, provide strong evidence that Golden and White-tailed Eagle breeding habitats are compatible with modern-day Welsh land uses. The restoration priority areas for the Golden and White-tailed Eagle in Wales are identified. The information represents a significant advance in the evidence required to support the restoration of native eagles back to soaring the skies of Wales.

5.1. Rationale

One of the main factors limiting the distribution of vulnerable species is anthropogenic land use, which often reduces a species' distribution through habitat loss, modification, fragmentation or degradation (McClure *et al.*, 2018). Adverse habitat change causes a reduction in the survival and reproductive success of many bird populations (Wong and Candolin, 2015; Donázar *et al.*, 2016). Gathering information on current and historic anthropogenic threats that limit or constrain a species' population is a well-used tool in conservation management, particularly in regards to restoring native lost species (Foden and Young, 2016). As part of the IUCN reintroduction criteria

(IUCN/SSC, 1998, 2013), it is an essential requirement to recognise and understand environmental constraints that have led or could lead to population declines, extinctions or range contractions.

To restore native species into their former historic range, the species' abiotic and biotic requirements must be compatible with the modern-day land uses found within the release area (IUCN/SSC, 2013). Many modern land uses and landscapes have changed significantly from historic land uses and landscapes. This is certainly true for Wales and some of our lost native species. For example, the Welsh landscape has changed significantly since the extinction of native eagles, over 150 years ago. Recent work has mapped suitable breeding areas across Wales that meet the breeding requirements for both eagle species (***Chapter Four***). Understanding additional anthropogenic land-use constraints and risks for eagles and their sensitivity to these land uses within suitable breeding areas are pivotal assessments to validate an eagle restoration programme in Wales (Corlett, 2016; IUCN/SCC, 2013; National Species Reintroduction Forum, 2014).

5.1.1. Anthropogenic Land Use Threats to Eagles

It is a sad reality that the natural threats that Golden and White-tailed Eagles experience, amount to little compared to anthropogenic threats introduced to their habitats by humans (Urwin, 2016). Almost all current threats to eagles are attributable, directly or indirectly, to anthropogenic land uses and associated human activities (Birdlife International, 2015a, b; Birdlife International, 2020). Anthropogenic land uses can constrain eagle populations by causing direct mortality, or indirectly through negative impacts to habitat, prey and nest site availability (Hunt *et al.*, 2017). Direct land-use threats include shooting, trapping, collisions, nest destruction and poisoning (Sansom, Evans, and Roos, 2016; Whitfield and Fielding, 2017). Indirect land-use threats are largely associated with modifying or losing suitable eagle habitat, in turn reducing the availability of prey, foraging areas and/or nest sites (Whitfield *et al*., 2007; Sansom, Evans, and Roos, 2016).

The quality and security of eagle habitat is an important aspect of global eagle conservation, management and reintroduction (Whitfield *et al.,* 2006; Whitfield *et al.,* 2008; Scottish Natural Heritage, 2017). Historic land-use change has been a critical factor in the range recovery of eagles in Britain, attributed to the loss or modification of suitable habitats (Evans, O'toole and Whitfield, 2012). The expansion and magnitude of livestock grazing and commercial forestry plantations are two modern land uses that have indirect associations in constraining the distribution and abundance of good quality eagle habitat (McGrady, Michael and Petty, 2001; Madders and

Walker, 2002; Van Rijn and Zijlstra, 2011). While the constraining nature of these anthropogenic land uses are dependent on the extent of habitat change, there are land uses, such as urbanisation, which can completely deplete or displace eagles from previously suitable habitats (Leclerc *et al.,* 2015; Collopy, Woodbridge and Brown, 2017; Cosgrove *et al*., 2017).

In addition to transforming the availability of good quality eagle habitat, we have also littered such habitats with hazards and obstacles, from areas prevalent with raptor killings to areas cluttered with wind-turbines (Heuk *et al.,* 2019); Direct persecution and collision risks are influenced by the density of eagle exposure in areas where conflicting issues arise or where wind turbines exist (Whitfield, Fielding, Mcleod, *et al.*, 2004; Percival, 2005). These land uses can also have indirect effects and have been associated with avoidance/barrier effects, disturbance, displacement or complete exclusion of breeding and non-breeding birds from breeding grounds or foraging areas, via learned behaviours (Ruddock and Whitfield, 2007). Thus, it is important, for species reintroduction projects, to understand how empty landscapes void of breeding eagles, like England and Wales, would be influenced by modern-day anthropogenic land uses that either bring a direct threat to survival, or influence species occupancy of otherwise suitable habitats.

5.1.2. Re-evaluating Suitable Breeding Areas to Assesses Availability

In ***Chapter Four***, two Species Distribution Models (SDMs) were derived to display suitable breeding areas for the Golden and White-tailed Eagle in Britain. These models highlight multiple suitable breeding areas across Britain, the chapter also revealed region specific bio-geographic areas across Wales for both breeding species. It is common knowledge, however, that many species can often be absent from suitable habitats (Beyer *et al.*, 2010; Piper *et al.*, 2013), due to anthropogenic land uses that limit their survival or ability to disperse (Pulliam, 2000). Thus, it can be assumed that the proportion of suitable eagle breeding habitat, previously mapped, could be proportionally larger than habitats currently available for eagles to occupy today (Hirzel and Le Lay, 2008). It is essential for any well-planned species recovery programme to re-evaluate areas of suitable habitat, offering reliable information on (i) their overlap with current land uses, (ii) areas lost by certain land uses and or (iii) areas at more or less risk with land uses.

5.1.3. Chapter Five Research Objectives

In this chapter, we relate the bio-geographic zones, that have been highlighted in ***Chapter 4*** as suitable to support breeding eagles, with related anthropogenic land uses, to focus in on the most suitable breeding areas for the Golden and White-tailed Eagle in Wales. We do this by; i) estimating the proportion of suitable breeding habitat lost to certain anthropogenic land uses; ii) rank each bio-geographic zone as a function of the exposure to anthropogenic land use and risk; and iii) illustrate current breeding habitats and nest-sites available for both species across Wales. This study focuses on the modern-day potential of Wales to support breeding Golden and White-tailed Eagles, and the threats to breeding eagle habitat needed to be considered for a reintroduction programme.

5.2. Methods

5.2.1. Suitable Breeding Habitat for Eagles in Wales

Two spatial datasets identifying all suitable breeding areas in Wales, for the Golden and White-tailed Eagle, were obtained from Species Distribution Models (SDMs), created in ***Chapter Four***. For the present chapter, the SDM spatial data for each species were converted into binary data of non-suitable (0) and suitable breeding habitats (1). Spatial SDM data representing suitable habitat were further defined by bio-geographic breeding zones, which were manually created in the previous chapter; to illustrate breeding zones enclosing suitable eagle habitat across Wales. These two spatial datasets, and species-specific bio-geographic zones, were the basis of the research presented in the present Chapter. The spatial SDM data includes 44.1% of Wales' land area being a suitable breeding habitat, across 12 upland bio-geographic breeding zones of focus for the Golden Eagle. For the White-tailed Eagle, 38% of land coverage, across 14 coastal and 3 inland bio-geographic zones were of focus in Wales (***Figure 16***). For a true reflection of the coverage of breeding habitat across Wales, we also assessed suitable habitats that fell in lowland areas of Wales for the Golden Eagle and applied these areas as a single bio-geographic zone (i.e. bio-geographic zone 13).

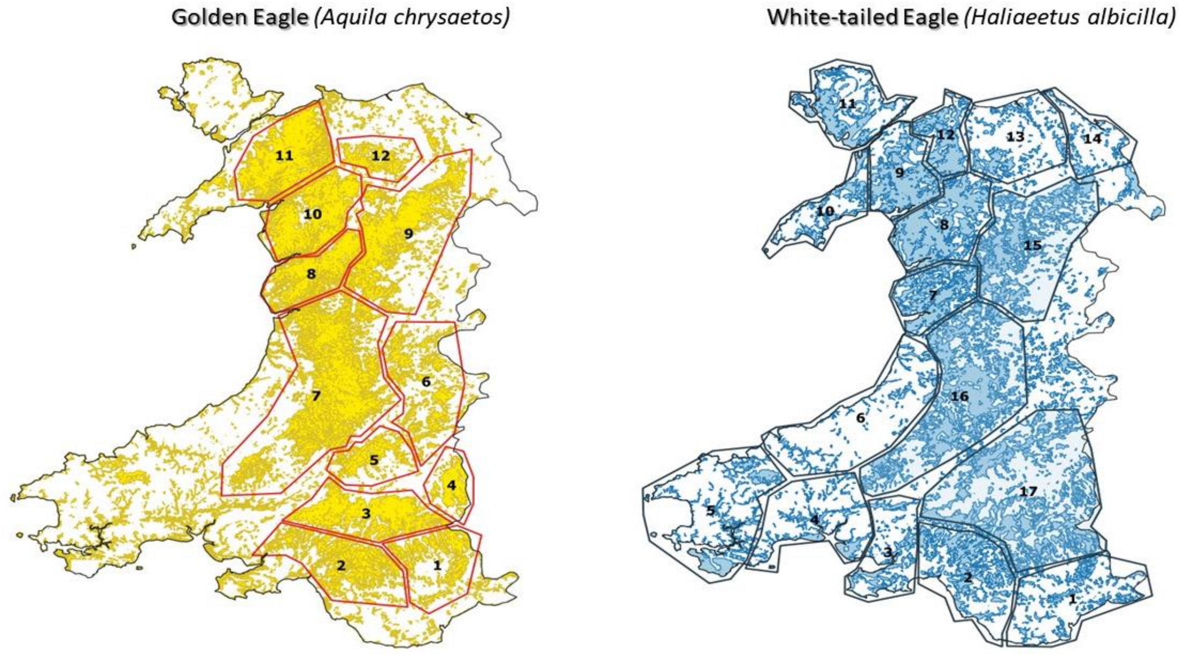


***Figure 16**. Species Distribution Models depicting the plausible distribution of suitable breeding habitats for both the Golden and White-tailed Eagle in Wales; illustrating 44.1% of terrain as suitable for Golden Eagles across 12 upland bio-geographic zones, and 38.3% of terrain as suitable for White-tailed Eagles across 17 bio-geographic zones (14 coastal and 3 upland zones).*

5.2.2. Anthropogenic Land Use Intensity

Anthropogenic land-use features were mapped for Wales using QGIS spatial Software (v 3.6; QGIS Development Team, 2019), and projected using the World Geographic System (WGS 84). Only anthropogenic land uses recorded to directly or indirectly influence breeding eagle distribution were considered. Windfarms (UKWED, 2017), urban areas (BUA, 2017), commercial forestry plantations (NWTI, 2017), livestock pasture (CLC, 2018), and raptor persecution incidents (RSPB Raptor Persecution, 2019) were the additional anthropogenic land-use constraints considered for breeding eagles in Wales. The total proportion of terrestrial cover for each anthropogenic land use were calculated for the whole of Wales and for each bio-geographic breeding zone for the Golden and White-tailed Eagle to derive percentages of land cover that is currently available for eagles.

Anthropogenic land uses were calculated according to either; i) the proportion of terrestrial cover (m^2) allocated to each of the five land uses within species bio-geographic zones, estimated as a percentage (e.g. % livestock pastures); or ii) the magnitude of focal land uses in bio-geographic zones, estimated as a number (e.g. number of wind turbines). The percentage and/or magnitude of these five land uses are used in this study as a measure of anthropogenic land-use intensity within each species bio-geographic zone across Wales; providing proxy measure of habitat quality and/or possible threats to survival or reproductive success. Spatial maps and heat maps were produced to illustrate anthropogenic land-use intensity, with the distribution and regional risks to breeding Golden and White-tailed Eagle habitat in Wales. All spatial maps depicting anthropogenic land uses are provided in ***Appendix 7 to Appendix 26*** for both Golden and White-tailed Eagles.

5.2.3. Eagle Habitat Lost to Anthropogenic Land Uses

In order to assess the proportion of eagle habitat lost to anthropogenic land uses in Wales, we derived the geographic extent for which breeding displacement occurs. The loss of breeding habitat for each eagle species was only considered for wind-turbines and urban areas across Wales, attributed to data availability and the lack of sufficient data at appropriate spatial and temporal scales. Species-specific breeding displacement buffers, obtained from Ruddock and Whitfield (2007), were created to surround windfarms and urban areas; using 4 km and 1 km breeding displacement buffers respectively for Golden Eagles, and using 3 km and 0.5 km buffers respectively for White-tailed Eagles. Relevant land use buffers were combined and overlaid with the suitable breeding habitats for both eagles, to derive the full spatial extent of breeding habitat overlapping with land use buffers that represent areas at high risk of being lost as breeding habitat to eagles. Habitat lost by breeding displacement was quantified by summing the proportion of Golden and White-tailed eagle breeding habitat that fell within breeding displacement buffers across Wales and for each bio-geographic zone. By subtracting the proportion of breeding habitat lost within anthropogenic breeding displacement buffers, from the proportion of suitable habitat across each bio-geographic zone, the proportion of available breeding habitat remaining for the Golden and White-tailed Eagle was revealed.

5.2.4. Available Habitat and Nest Sites

To assess the true availability of breeding eagle habitat across Wales, the proportion of nest sites in Golden and White-tailed Eagle bio-geographic zones were derived. Two spatial datasets, Ordinance Survey crags (OS vector map, 2019) and the National Woodland and Tree Inventory (NWTI, 2017), were utilized to map the extent of available nest sites for both eagle species. For White-tailed Eagles we explored the proportion of crags and tree sites available within 3 km from the Welsh coastline, and tree sites within 3 km from an inland freshwater source. For Golden Eagles, we explored the proportion of inland crag sites available within 1.2 km of a mountain ridgeline. To explore how nest sites and available breeding areas fit into conservation initiatives across Wales, five spatial datasets were combined and mapped to reflect the spatial extent of protected areas in Wales (SPA, 2019; AONB, 2019; RAMSAR Sites, 2019, SSSI, 2019; NNR, 2019). We then estimated the proportion of available breeding habitat that is distributed within protected areas across bio-geographic zones and Wales.

5.2.5. Ranking Bio-geographic Breeding Zones

All empirical anthropogenic measures such as land use intensity (e.g. % livestock pastures and no. of wind-turbines), land use loss (e.g. % loss to urban areas) and the placement of availability breeding areas (e.g. % overlap with protected areas) and nest sites (e.g. % available nest sites) were applied in a bio-geographic zone ranking method. For each species-specific bio-geographic zone, a value was obtained and ranked according to the proportion of anthropogenic land use intensity and suitable habitat loss in a given region. Each anthropogenic land use was given a rank score between '1' and '13' to accommodate for upland and lowland breeding areas for Golden Eagles, and '1' and '17' for coastal and inland breeding habitats for White-tailed Eagles.

For land use intensity and loss rank measures, the lower the rank score the more compatible breeding areas are with anthropogenic land uses in that given area. On the contrary, for the proportion of available breeding habitat and nest sites, ranked scores were similarly obtained, however, in this case the higher the score the more compatible breeding areas are with anthropogenic land uses. The use of this ranking method was to determine the hierarchy of available Golden and White-tailed Eagle breeding areas and their suitability according to anthropogenic land uses across Wales.

5.3. Results

5.3.1. The Proportion of Eagle Habitat Lost in Wales

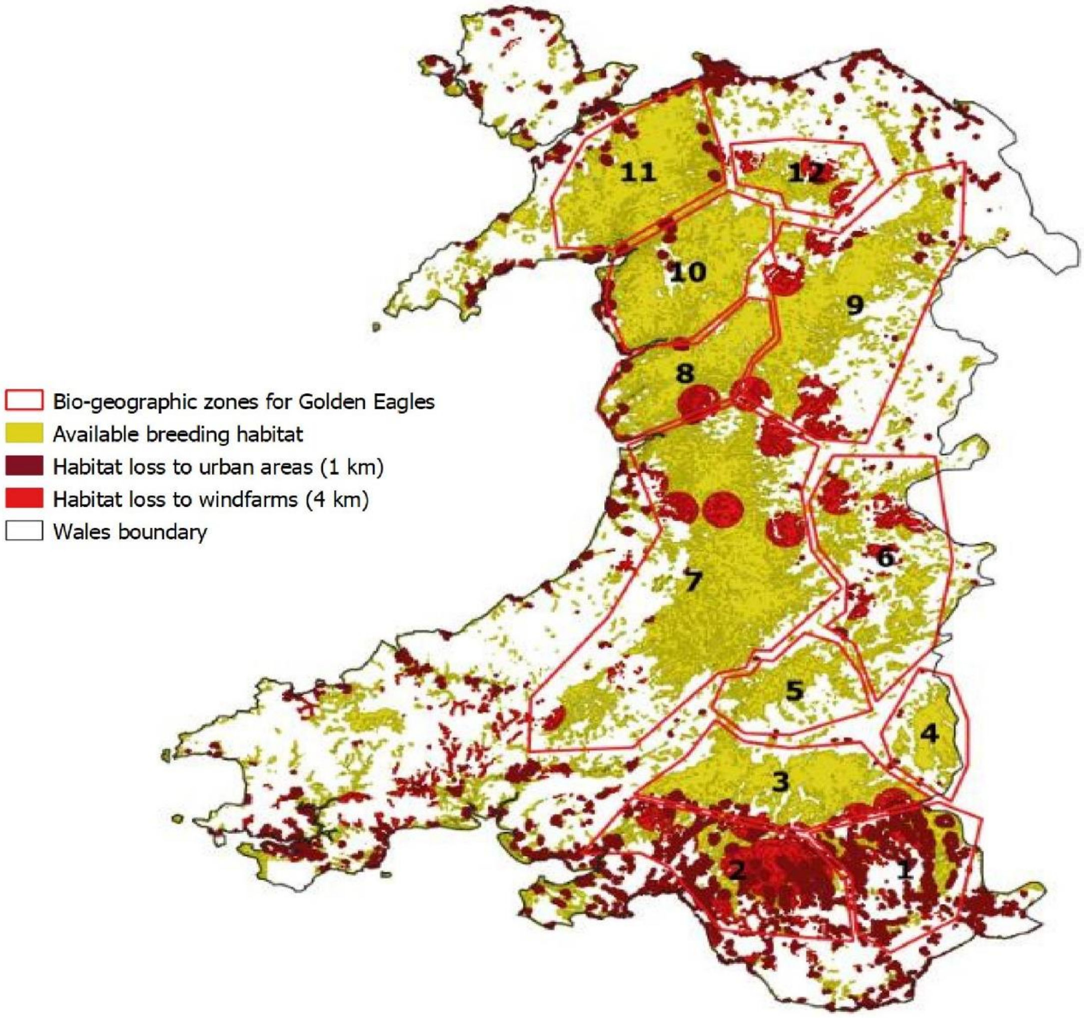
5.3.1.1. Golden Eagle Breeding Habitat Availability

Previous analysis highlighted 44.1 % of land area in Wales being suitable breeding habitat for the Golden Eagle, split across 12 bio-geographic zones. From our analysis, an estimated 8 % of suitable breeding habitat is lost via the placement of windfarms and urban areas (***Figure 17***); 4.9 % lost to windfarms (***Appendix 7***) and a further 3.1 % lost to urban areas (***Appendix 8***). The bio-geographic zones with the highest proportion of Golden Eagle breeding habitat lost, as illustrated in ***Figure 17***, were; South Wales Valleys (West; 32.8 % lost), Pentre-Llyn-Cymmer (31.5 %) and South Wales Valleys (East; 14.8%). The bio-geographic zones with the lowest proportion of habitat lost were; Hay-On-Wye (0 % lost), Black Mountains (0 %) and Central Snowdonia National Park (0 %: ***Figure 17***). Taking into consideration the proportion of breeding habitat lost due to these land uses, leaves 36.1% of total land area remaining available as breeding habitat for Golden Eagle in Wales.

5.3.1.2. White-tailed Eagle Breeding Habitat Availability

Previous estimates quantified 38.3 % of land area in Wales as being a suitable breeding habitat for the White-tailed Eagle, split across 14 coastal and 3 inland bio-geographic zones. Our analysis estimates that 5.3% of suitable breeding habitat is lost via the spatial distribution of urban areas and windfarms (***Figure 18***); 2.5 % lost to windfarms (***Appendix 9***) and 2.8% lost to urban areas (***Appendix 10***). The bio-geographic zones with the highest proportion of habitats lost were: Swansea Bay & Afon Forests (23 % lost), the Severn Estuary (9.7 %) and Dyfi Estuary and Dyfi Forests (9.1 %). The bio-geographic zones with the lowest proportion of habitats lost were; Ceredigion Bay (1.7% lost), Mawddach Estuary and Coed Y Brenin forests (2.2%) and Pembrokeshire National Park (2.5%). Taking into account these losses, 33% of the terrestrial surface of Wales remains available as a breeding habitat for White-tailed Eagles.

Golden Eagle *(Aquila chrysaetos)*

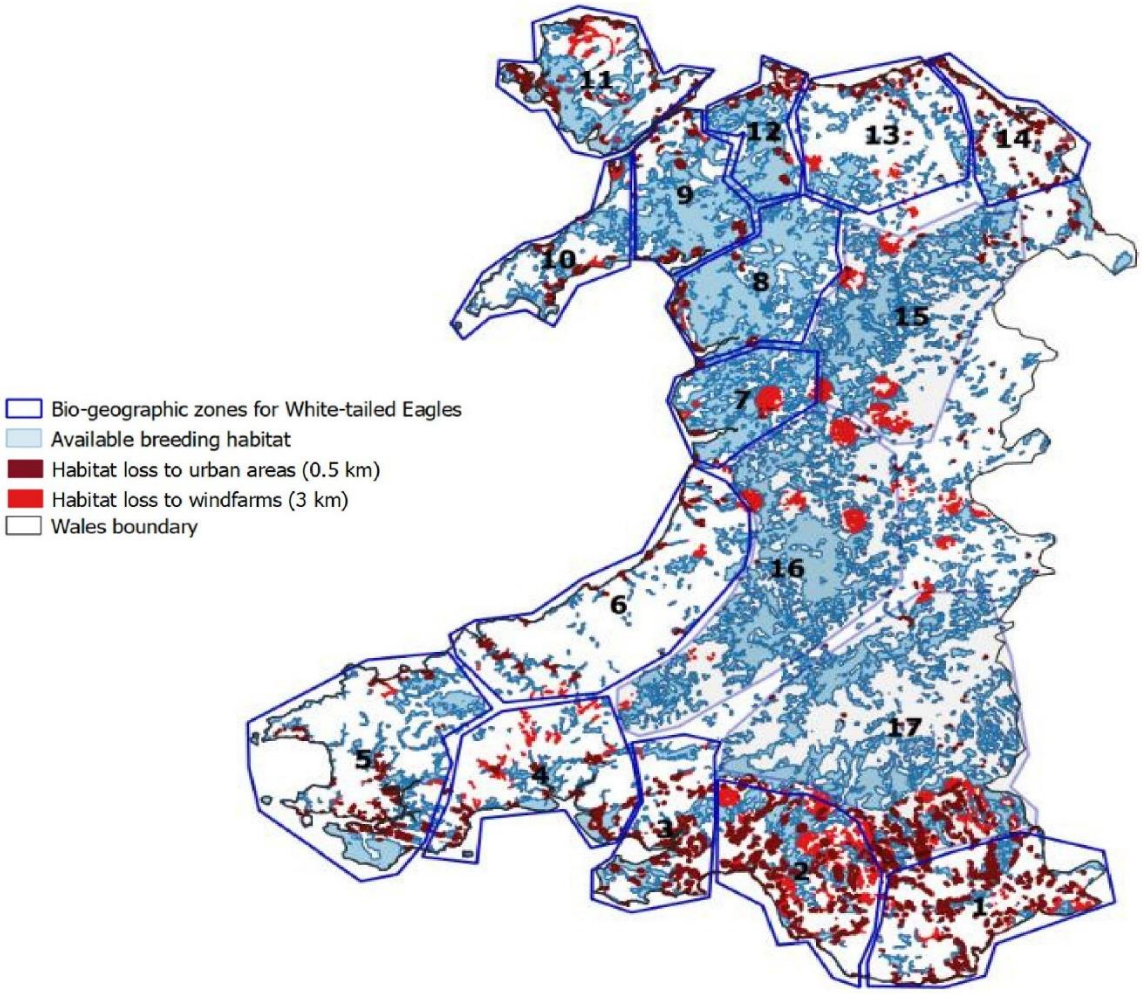


Golden Eagle Bio-geographic Zones and Habitat Loss in Wales:

Zone	% Habitat loss	Habitat loss rank	Zone	% Habitat loss	Habitat loss rank
(1) – South Wales Valleys (East)	14.8	11	**(8)** – Lower Snowdonia National Park	6.0	6
(2) – South Wales Valleys (West)	32.8	13	**(9)** – Llangollen & Berwyn Mountains	9.3	9
(3) – Brecon Beacons National Park	5.4	5	**(10)** – Central Snowdonia National Park	0.0	3
(4) – Black Mountains	0.0	2	**(11)** – Upper Snowdonia National Park	0.1	4
(5) – Hay-on-Wye	0.0	1	**(12)** – Pentre-llyn-Cymmer	31.5	12
(6) – Radnor Forests	10.1	10	***(13)*** *– Other Lowland Areas*	8.3	8
(7) – Cambrian Mountains	6.7	7			

Figure 17. *The estimated loss of Golden Eagle breeding habitat attributed to the plausible displacement by windfarms (4 km displacement buffers) and urban areas (1 km displacement buffer) across Wales. Available breeding habitats are denoted by upland bio-geographic zones (red) and also takes into consideration lowland areas (bio-geographic zone 13).*

White-tailed Eagle *(Haliaeetus albicilla)*



White-tailed Eagle Bio-geographic Zones and Habitat Loss in Wales:

	% Habitat loss	Habitat loss rank		% Habitat loss	Habitat loss rank
(1) - The Severn Estuary	9.7	16	**(10) -** Llyn Peninsula	4.1	8
(2) - Swansea Bay & Afon Forests	23.0	17	**(11) -** Isle of Anglesey	7.4	14
(3) - The Gower Peninsula	6.9	13	**(12) -** Conwy Estuary & Gwydir Forests	2.5	4
(4) - Caerfyrddin Bay	5.2	12	**(13) -** Clwyd Estuary & Clocaenog Forests	2.7	5
(5) - Pembrokeshire National Park	2.5	3	**(14) -** Dee Estuary & Pen y Maes Woods	4.9	10
(6) - Ceredigion Bay	1.7	1	***(15)*** *- Y Berwyn National Reserve*	4.3	9
(7) - Dyfi Estuary & Dyfi Forests	9.1	15	***(16) –*** *Cambrian Mountains*	3.8	7
(8) - Mawddach Estuary & Coed y Brenin Forests	2.2	2	***(17)*** *- Brecon Beacons National Park*	5.2	11
(9) - Glaslyn Estuary & Snowdonia National Park	3.7	6			

Figure 18. *The estimated loss of White-tailed Eagle breeding habitat attributed to the plausible displacement by windfarms (3 km breeding displacement buffer) and urban areas (0.5 km breeding displacement buffer) across Wales. Available breeding habitats are denoted by coastal bio-geographic zones (blue) and zones for inland areas (bio-geographic zones 15 to 17).*

5.3.2. Eagle Breeding Habitat and Land Use Intensity in Wales

5.3.2.1. Golden Eagle Breeding Habitat and Land Use

Livestock pastures currently account for 75 % of the total land use in Wales. Habitats suitable for breeding Golden Eagles encompass 62.2 % of Welsh livestock pastures; 17.9 % in upland pastures within 1.2 km of a mountain ridgeline, and 44.3 % of in lowland pastures (***Appendix 11***). Golden Eagle bio-geographic breeding zones with the highest proportion of pastures were; Other Lowland Areas, South Wales Valleys (West) and Hay-On-Wye (***Table 7***). Commercial forestry plantations constitute 6.7% of land use in Wales, with 5.6% of the total land use overlapping with upland breeding habitats suitable for breeding Golden Eagles, but only 1.1% of lowland breeding habitats (***Appendix 12***). The upland breeding areas with greater overlap with commercial forestry include; South Wales Valleys (West), Cambrian Mountains, and Lower Snowdonia National Park (***Table 7***).

Wales currently accounts for 102 terrestrial windfarms, with 777 operating wind-turbines. Over 69.8 % of windfarms located within habitats suitable for breeding Golden Eagles have 3 or fewer wind-turbines (***Appendix 13***). The breeding zones with the highest number of windfarms were; South Wales Valleys (West); Welsh Lowland Areas and Cambrian Mountains (***Table 7***).

Urban areas make up 4.4 % of the total land area in Wales, with an estimated population of 3.1 million people. Golden Eagle breeding zones with the highest % area of human habitation include; Welsh Lowland Areas, South Wales Valleys (East), and South Wales Valleys (West; ***Table 7***). Welsh urban areas equate to 8.1 % of the land use in upland habitat containing suitable habitat for breeding Golden Eagles (***Appendix 14***).

Eighty-five raptors have been recorded to be illegally persecuted across Wales between 2007 and 2019, of which 63.5 % were recorded within upland habitats suitable for breeding Golden Eagles, and 36.5 % in suitable lowland habitats. Golden Eagle bio-geographic breeding zones with the highest number of persecuted incidents were; all Lowland Breeding Areas, Brecon Beacons National Park, and Llangollen & Berwyn Mountains. Upland zones like Lower, Central and Upper Snowdonia National Park, and Pentre-llyn-Cymmer, recorded no raptor persecution incidents (***Appendix 15***).

5.3.2.2. White-tailed Eagle Breeding Habitat and Land Use

White-tailed Eagle breeding habitat overlaps with 40.5 % of livestock pastures in Wales; 10.6 % of lowland pastures within 3 km from a coastline and 29.9 % within 3 km of an inland freshwater source (***Appendix 16***). Bio-geographic breeding zones with the largest proportion of land use assigned to pastures were; Ceredigion Bay, Caerfyrddin Bay, and Isle of Anglesey (***Table 8***). Commercial forestry plantations constituted 5.8 % of the total land use covering coastal breeding habitat and 45.6 % of inland breeding habitats ***(Appendix 17***). Commercial forestry overlapped greater with inland breeding habitats such as the Cambrian Mountains and Brecon Beacons National Park (***Table 8***).

White-tailed Eagle breeding zones with the highest number of windfarms were; Swansea Bay & Afon Forests, Cambrian Mountains, and Isle of Anglesey (***Table 8***). Only 6.6 % of wind-turbines were positioned near the Welsh coast and 56.8 % across inland breeding habitats (***Appendix 18***). Breeding zones where urban areas prevailed include; The Severn Estuary, Swansea Bay & Afon Forests, and Brecon Beacons National Park (***Table 8***). Urban populations encompass 32.1 % of land cover within 3 km of the Welsh coastline, with 23.5 % of urban areas surrounding inland breeding habitats (***Appendix 19)***. Recorded raptor persecution incidents were recorded to overlap with 6.3 % of coastal breeding habitats and 53.3 % within inland breeding habitats for White-tailed Eagles. Inland breeding zones with the highest number of recorded raptor persecution incidents were; The Brecon Beacons National Park and Y Berwyn National Reserve (***Table 8).*** Coastal zones such as the Mawddach Estuary & Coed y Brenin Forests and Glaslyn Estuary & Snowdonia National Park displayed no recorded raptor persecutions (***Appendix 20)***.

5.3.3. Bio-geographic Breeding Zones of Priority in Wales

5.3.3.1. Golden Eagle Breeding Zones of Priority

The top seven bio-geographic zones with the highest final rank scores in Wales for available breeding Golden Eagle habitat, were: Central Snowdonia National Park, Black Mountains, Upper Snowdonia National Park, Lower Snowdonia National Park, Hay-On-Wye, Brecon Beacons National Park, and the Cambrian Mountains (***Table 9***). Central Snowdonia National Park and Upper Snowdonia National Park gained the highest-ranking score for available upland nest sites (***Appendix 21).*** By contrast, South Wales Valleys (East) and Pentre-llyn-Cymmer revealed the lowest ranks for available nesting crags for Golden Eagles.

***Table 7.** Descriptive statistics of the anthropogenic land-use effects for each upland bio-geographic zone (1-12) and lowland breeding zone (13); suitable to hold breeding Golden Eagles in Wales*

Suitable Habitats		Habitat Loss		Land-use Intensity					Available Habitat and Resources			
Bio-geographic Zones	**% Suitable Habitat**	% Habitat loss to Windfarms	% Habitat lost to Urban areas	% Land covered by Commercial Forestry	% Land covered by Livestock Pasture	No. of Wind-turbines	No. of Persecution Incidents	Population No.	**% Available habitat**	% Available nests (crags)	% overlap with Protected areas	Final Zone Rank Score
1 – South Wales Valleys (East)	**43.1**	14.1	0.7	19.7	53.3	8	7	973,898	**28.3**	0.2	1.1	12
2 – South Wales Valleys (West)	**52.9**	32.3	0.5	36.6	63.0	204	7	689,530	**20.1**	0.9	1.2	13
3 – Brecon Beacons National Park	**67.9**	5.3	0.1	14.4	45.4	1	15	103,493	**62.5**	7.3	8.7	6
4 – Black Mountains	**41.4**	0.0	0.0	11.9	41.6	0	2	11,349	**41.4**	1.0	10.2	2
5 – Hay-on-Wye	**41.7**	0.0	0.0	13.7	57.9	0	1	205	**41.7**	0.2	0.1	5
6 – Radnor Forests	**39.2**	10.1	0.0	10.2	57.6	123	4	22,015	**29.1**	0.6	6.6	10
7 – Cambrian Mountains	**54.0**	6.7	0.0	36.5	43.5	167	7	17,227	**47.3**	10.8	20.2	7
8 – Lower Snowdonia National Park	**75.0**	6.0	0.1	31.8	34.6	2	0	8,274	**69.0**	9.1	3.4	4
9 – Llangollen & Berwyn Mountains	**51.8**	9.3	0.0	17.9	49.7	58	11	107,302	**42.5**	4.3	16.2	11
10 – Central Snowdonia National Park	**78.7**	0.0	0.0	16.1	24.2	0	0	11,600	**78.6**	12.9	13.6	1
11 – Upper Snowdonia National Park	**78.6**	0.0	0.1	12.9	18.3	0	0	28,215	**78.5**	26.9	13.3	3
12 – Pentre-Llyn-Cymmer	**45.9**	31.5	0.0	24.6	55.8	38	0	5,975	**14.3**	0.2	8.4	8
13 – Welsh Lowland Areas	**18.3**	2.5	5.8	2.4	34.5	176	25	1,907,194	**10.1**	3.7	24.0	9

***Table 8**. Descriptive statistics of the anthropogenic land-use effects for each coastal bio-geographic zone (1-14) and inland breeding zones (15-17); suitable to hold breeding White-tailed Eagles in Wales.*

Suitable Habitats		Habitat Loss		Land-use Intensity					Available Habitat and Resources					
Bio-geographic Zones	**% Suitable Habitat**	% Habitat loss to Windfarms	% Habitat lost to Urban areas	% Land covered by Commercial Forestry	% Land covered by Livestock Pasture	No. of Wind-turbines	No. of Persecution Incidents	Population No.	**% Available habitat**	% Available nests (crags)	% Available nests (Coastal trees)	% Available nests (Inland trees)	% overlap with Protected areas	Final Zone Rank Score
1 - The Severn Estuary	**17.5**	3.0	6.7	3.4	59.7	10	0	986,078	**7.8**	1.0	3	3.1	1.9	16
2 - Swansea Bay & Afon Forests	**76.0**	13.0	10.0	9.8	40.5	198	7	524,573	**53.0**	3.3	4	1.8	1.1	17
3- The Gower Peninsula	**27.8**	0.5	6.5	0.3	60.5	1	1	320,677	**20.9**	19.1	9	2.1	3.0	8
4- Caerfyrddin Bay	**21.7**	2.3	2.9	1.9	76.4	33	3	58,853	**16.5**	4.5	13	1.6	2.2	10
5 - Pembrokeshire National Park	**17.5**	0.9	1.6	1.3	48.3	15	2	73,131	**15.0**	19.5	13	5.1	15.7	2
6 - Ceredigion Bay	**8.3**	0.6	1.2	2.4	82.5	15	4	49,988	**6.6**	27.4	9	4.0	5.9	3
7 - Dyfi Estuary & Dyfi Forests	**58.1**	5.1	4.0	6.1	34.3	2	3	8,942	**49.0**	13.9	7	6.5	8.6	4
8 - Mawddach Estuary & Coed y Brenin Forests	**67.9**	0.0	2.2	5.2	32.5	0	0	9,930	**65.7**	12.3	9	9.0	21.9	1
9 - Glaslyn Estuary & Snowdonia National Park	**60.9**	0.0	3.7	1.3	27.5	0	0	63,699	**57.2**	8.8	5	5.1	4.4	6
10 – Lyn Peninsula	**25.5**	2.5	1.7	0.6	56.4	3	1	12,609	**21.3**	32.3	5	1.3	4.7	5
11 - Isle of Anglesey	**35.4**	2.3	5.1	0.5	64.3	74	3	49,678	**28.0**	48.5	10	2.0	9.2	7
12 - Conwy Estuary & Gwydir Forests	**58.4**	0.0	2.5	3.0	25.0	0	4	79,409	**55.9**	3.1	4	4.7	2.5	9
13 - Clwyd Estuary & Clocaenog Forests	**18.3**	1.2	1.5	3.8	60.1	37	2	126,091	**15.7**	0.0	2	5.7	6.2	11
14 - Dee Estuary & Pen y Maes Woods	**22.0**	0.0	4.9	0.6	43.5	0	4	306,571	**17.1**	0.0	3	2.2	0.2	13
15 - Y Berwyn National Reserve	**37.6**	3.9	0.4	9.3	48.3	36	12	38,139	**33.3**	/		6.6	20.6	14
16 - Cambrian Mountains	**44.1**	3.2	0.6	28.8	34.8	126	4	6,657	**40.3**	/		14.2	4.4	15
17 - Brecon Beacons National Park	**41.5**	2.4	2.8	11.7	45.5	8	26	330,634	**36.3**	/		12.2	13.9	12

Lowland breeding zones for Golden Eagles highlighted the highest proportion of breeding habitat in protected areas (***Table 9***). However, upland zones such as the Cambrian Mountains (20.2 % of breeding habitats within protected areas), Llangollen & Berwyn Mountains (16.2 %) and Central Snowdonia National Park (13.6 %) can be strongly suggested to be the best priority breeding areas in Wales for Golden Eagles (***Appendix 22***).

5.3.3.2. White-tailed Eagle Breeding Zones of Priority

The top seven bio-geographic zones with the highest rank scores in Wales for available breeding White-tailed Eagle habitat, include: Mawddach Estuary & Coed y Brenin Forests, Pembrokeshire National Park, Ceredigion Bay, Dyfi Estuary & Dyfi Forests, Llyn Peninsula, Glaslyn Estuary & Snowdonia National Park, and Isle of Anglesey (***Table 10***).

The Isle of Anglesey and the Llyn Peninsula gained the highest ranking score for available coastal nests (***Appendix 23***). By contrast, Clwyd Estuary & Gwydir Forests, and Dee Estuary & Pen Y Maes Woods ranked the lowest for available coastal nest crags, with none present in this region. These regions did, however, illustrate sufficient amount of coastal trees for nesting or foraging (***Appendix 24***). Results indicated sufficient amount of inland breeding habitat for White-tailed Eagles also, across Wales (***Appendix 25***).

The bio-geographic breeding zones with the lowest rank scores include; the Severn Estuary and Swansea Bay and Afon Forests, and Cambrian Mountains (***Table 10***). White-tailed Eagle breeding zones with the most protected breeding habitat and can strongly be suggested to be priority areas in Wales, are; the Mawddach Estuary & Coed y Brenin Forests (21.1% of breeding habitat within protected areas), Pembrokeshire National Park (15.7%), and Isle of Anglesey (5.9%; ***Appendix 26***).

***Table 9**. Bio-geographic zone-specific hierarchies for each bio-geographic zone in Wales; depicting the level of risks and abundance of available resources for Golden Eagles in Wales. High-rank numbers indicate more anthropogenic risks or less resource availability in a given area.*

Suitable Habitats		**Habitat Loss**		**Land-use Intensity**					**Available Habitat and Resources**				
Bio-geographic Zones	**% Suitable Habitat**	% Habitat loss to Windfarms	% Habitat lost to Urban areas	% Land covered by Commercial Forestry	% Land covered by Livestock Pasture	No. of Wind-turbines	No. of Persecution Incidents	Population No.	**% Available habitat**	% Available nests (crags)	% overlap with Protected areas	**Average Zone Rank Score**	**Final Zone Rank Score**
1 – South Wales Valleys (East)	**43.1**	11	12	9	9	7	8	12	**28.3**	13	12	10	12
2 – South Wales Valleys (West)	**52.9**	13	11	13	13	13	8	11	**20.1**	9	11	11	13
3 – Brecon Beacons National Park	**67.9**	6	9	6	7	5	12	9	**62.5**	5	7	7	6
4 – Black Mountains	**41.4**	1	5	3	5	1	6	4	**41.4**	8	6	4	2
5 – Hay-on-Wye	**41.7**	1	1	5	12	1	5	1	**41.7**	11	13	6	5
6 – Radnor Forests	**39.2**	10	4	2	11	10	7	7	**29.1**	10	9	8	10
7 – Cambrian Mountains	**54.0**	8	3	12	6	11	8	6	**47.3**	3	2	7	7
8 – Lower Snowdonia National Park	**75.0**	7	8	11	4	6	1	3	**69.0**	4	10	6	4
9 – Llangollen & Berwyn Mountains	**51.8**	9	7	8	8	9	11	10	**42.5**	6	3	8	11
10 – Central Snowdonia National Park	**78.7**	1	6	7	2	1	1	5	**78.6**	2	4	3	1
11 – Upper Snowdonia National Park	**78.6**	1	10	4	1	1	1	8	**78.5**	1	5	4	3
12 – Pentre-Llyn-Cymmer	**45.9**	12	2	10	10	8	1	2	**14.3**	12	8	7	8
13 – Welsh Lowland Areas	**18.3**	5	13	1	3	12	13	13	**10.1**	7	1	8	9

***Table 10.** Bio-geographic zone-specific hierarchies for each bio-geographic zone in Wales; depicting the level of risks and abundance of available resources for White-tailed Eagles in Wales. High rank numbers indicate more anthropogenic risks or less resource availability in a given area.*

Suitable Habitats		Habitat Loss		Land use Intensity					Available Habitat and Resources						
Bio-geographic Zones	**% Suitable Habitat**	% Habitat loss to Windfarms	% Habitat lost to Urban areas	% Land covered by Commercial Forestry	% Land covered by Livestock Pasture	No. of Wind-turbines	No. of Persecution Incidents	Population No.	**% Available habitat**	% Available nests (crags)	% Available nests (Coastal trees)	% Available nests (Inland trees)	% overlap with Protected areas	**Average Zone Rank Score**	**Final Zone Rank Score**
1 - The Severn Estuary	**17.5**	13	16	10	12	9	1	17	**7.8**	12	12	11	15	12	16
2 - Swansea Bay & Afon Forests	**76.0**	17	17	15	6	17	15	16	**53.0**	10	11	15	16	14	17
3- The Gower Peninsula	**27.8**	5	15	1	14	5	4	14	**20.9**	5	4	13	12	8	8
4- Caerfyrddin Bay	**21.7**	9	10	7	16	12	8	8	**16.5**	9	2	16	14	10	10
5 - Pembrokeshire National Park	**17.5**	7	5	6	9	10	6	10	**15.0**	4	1	8	3	6	2
6 - Ceredigion Bay	**8.3**	6	3	8	17	10	11	7	**6.6**	3	6	10	8	8	3
7 - Dyfi Estuary & Dyfi Forests	**58.1**	16	12	13	4	6	8	2	**49.0**	6	7	5	6	8	4
8 - Mawddach Estuary & Coed y Brenin Forests	**67.9**	1	7	12	3	1	1	3	**65.7**	7	5	3	1	4	1
9 - Glaslyn Estuary & Snowdonia National Park	**60.9**	2	11	5	2	1	1	9	**57.2**	8	9	7	10	6	6
10 – Lyn Peninsula	**25.5**	12	6	3	11	7	4	4	**21.3**	2	8	17	9	8	5
11 - Isle of Anglesey	**35.4**	10	14	2	15	15	8	6	**28.0**	1	3	14	5	8	7
12 - Conwy Estuary & Gwydir Forests	**58.4**	3	8	9	1	1	11	11	**55.9**	11	10	9	13	8	9
13 - Clwyd Estuary & Clocaenog Forests	**18.3**	8	4	11	13	14	6	12	**15.7**	13	14	6	7	10	11
14 - Dee Estuary & Pen y Maes Woods	**22.0**	4	13	4	7	1	11	13	**17.1**	13	13	12	17	10	13
15 - Y Berwyn National Reserve	**37.6**	15	1	14	10	13	16	5	**33.3**	/	/	4	2	9	14
16 - Cambrian Mountains	**44.1**	14	2	17	5	16	11	1	**40.3**	/	/	1	11	9	15
17 - Brecon Beacons National Park	**41.5**	11	9	16	8	8	17	15	**36.3**	/	/	2	4	10	12

5.4. Discussion

Using spatial suitability maps and bio-geographic zones, from Chapter Four, as reference points to validate breeding eagle habitats, we expand our assessments in this chapter, to address additional Welsh land-use constraints. We assess whether Golden and White-tailed Eagle breeding habitats are compatible with modern-day anthropogenic land uses. Our results provide strong evidence that Wales still holds sufficient breeding habitat for the Golden and White-tailed Eagle, and more importantly, breeding populations of both species of eagles in Wales are compatible with existing land uses. This study provides comprehensive information about nest sites available, the proportion of breeding habitat lost, the land use surrounding breeding habitat and the top breeding zones of the priory for the restoration of Golden and White-tailed Eagle across Wales.

5.4.1. Golden Eagle Breeding Habitat in Wales

The results of this chapter illustrate enough upland and lowland breeding habitat to sustain a breeding population of Golden Eagles in Wales; ready for further assessments of how many breeding pairs Wales can sustain. This is not a surprise as much of Wales is characterised by open landscapes, dominated by short vegetation with restricted tree cover, a common habitat preference for Golden Eagles across their global range (Sergio *et al.*, 2006b; Thompson, 2008). With the spatial extent of modern-day anthropogenic land uses taken into consideration, our results revealed compelling evidence that the uplands of Wales are better suited for Golden Eagles than lowland Wales. Most Golden Eagle populations breed in mountainous habitats (Mcgrady *et al.*, 2002; Di Vittori & Lopez-Lopez, 2014; Fielding *et al.*, 2019; Tef & Lescu, 2019), but can also breed in relatively flat, low lying landscapes, where they can nest exclusively in trees. Typical examples are in Siberia, Sweden and parts of the north-western United States (Watson 2010; Moss, 2015; León-Girón, 2016). Breeding pairs of Golden Eagles will avoid lowland areas if the anthropogenic disturbance is high (Whitfield *et al.*, 2004; Millsap *et al.*, 2015). Consistent with such findings, our results for Wales demonstrate that lowland breeding zones hold fewer nest sites and enclose more anthropogenic land uses that may cause additional breeding constraints, compared to upland breeding habitats.

Breeding Golden Eagles are extremely sensitive to human disturbance, avoid areas with high human habituation (Spaul and Heath, 2017), and are often recorded to take sanctuary in less disturbed upland protected areas across their global range (Haworth and Fielding, 2013). Ruddock and Whitfield (2007), revealed the average disturbance distance for Golden Eagles to be disturbed and take flight was between 250 m and 1,500 m. This suggests that the intensity of land-uses in lowland Wales would displace breeding Golden Eagles to inhabit rural Welsh upland habitats, where there are sufficient nest sites and suitable habitats for the birds to avoid human disturbance. The two bio-geographic zones of the South Wales Valleys are a good example from our results of areas with high urban disturbance in Wales for Golden Eagles.

Upland habitats in Wales, however, still present regional challenges for Golden Eagles. Since the 1950s, huge tracts of upland Wales have been converted from sheep walks to commercial forestry plantations (Linnard, 1979). Our spatial analysis shows that the largest proportions of upland afforestation have occurred in the Cambrian Mountains and Lower Snowdonia National Park. Increased afforestation has been associated with loss of carrion and live eagle prey (Whitfield *et al.*, 2001), reduced breeding success of Golden Eagles (Marquiss, Ratcliffe and Roxburgh, 1985), and loss of nesting and foraging habitats (Whitfield *et al.*, 2007). Livestock pastures, according to Collopy, Woodbridge and Brown (2017), also have the same direct and indirect effects as afforestation to the quality of eagle habitat and the availability of prey. Whitfield *et al.* (2007) suggest that upland habitats are experiencing parallel land-use changes; we take optimism from our results and from global evidence that Golden Eagles can thrive in areas where the predominant land uses are low-intensity pastoral agriculture and forestry plantations (Madders and Walker, 2002).

Raptor persecution incidents have significantly reduced across Wales compared to historic times (Newton, 1979; RSPB Raptor Persecution, 2019). Raptor persecution is more abundant in upland Wales than lowland Wales and has been recorded in eight out of the 12 bio-geographic regions for Golden Eagles. Raptor persecution in upland Britain has been correlated with land use allocated to recreational shooting estates (Whitfield *et al.*, 2004). Wales has proportionately fewer game shoots in upland areas compared to England and Scotland (GWCT, 2017), perhaps explaining why there are fewer raptor kills reported in Welsh uplands, compared to English and Scottish uplands. Regional persecution does not alter upland Wales' potential to support breeding habitat or reduce the potential population in Wales. It could, however, act as an additional anthropogenic constraint to the selection of breeding habitat near recorded incidents (Whitfield *et al.*, 2004). Our results suggested the Cambrian Mountains, Llangollen & Berwyn Mountains and Central Snowdonia National Park be the best breeding habitat for Golden Eagles in Wales and should be the focus of further work for the planning of a licensed reintroduction scheme.

5.4.2. White-tailed Eagle Breeding Habitat in Wales

Throughout most of its global range the White-tailed Eagle tends to be associated with coastal habitats, especially in Norway, Iceland and Greenland (Willgohs, 1961; van Rijn and Zijlstra, 2011; Zeiler, 2019), where 80% often nest on cliffs or low rock faces (Love, 1983). In Central Europe, for example; Germany, they also inhabit inland areas invariably within 3km of lakes, rivers, wetlands and marshes, where 75% of breeding pairs nest in trees (Krueger, Gruenkorn and Struwe-Juhl, 2010). The results of this chapter highlighted great expanses of coastal and inland areas of Wales able to support breeding White-tailed Eagles. For Wales, translocated birds would likely be sourced from Norway, part of the Atlantic coast phylogenetic clade (Hailer *et al.*, 2007), rendering coastal Wales as priority areas to release this species, with the hope that this generalist bird disperses inland to breed in due course. The Welsh coast, characterized by fewer wind turbines, commercial forestry plantations, sporadically distributed urban areas and fewer raptor persecution incidents, illustrate just how suitable coastlines may be for White-tailed Eagles in Wales.

White-tailed Eagles are not as wary of humans as Golden Eagles are, and can breed in closer proximities to urban areas (Korsman *et al.*, 2012). Ruddock and Whitfield (2007), revealed the average flight distance for White-tailed Eagles in response to an approaching human to be between 50 m and 500 m. Wales has large stretches of coastline (2,704 km), where the majority of coastal populations are estimated to hold between 0 to 1 person per hectare (Office for National Statistics, 2018a), perhaps explaining why there is still an abundance of available breeding habitat for White-tailed Eagles situated around the coast of Wales. Coastal Wales also encompasses a higher proportion of breeding habitat within already protected areas than inland breeding zones; Including 14 heritage coasts that are stretches of outstanding, undeveloped habitats, that could provide sanctuary for White-tailed Eagles. Mawddach Estuary, Pembrokeshire National Park and the Isle of Anglesey are three examples of already protected habitat that encompasses sufficient coastal breeding areas for White-tailed Eagles.

White-tailed Eagles are known to be vulnerable to collisions by wind-turbines, and they have not been recorded to show any clear avoidance flight responses shown by other species including Golden Eagles (Mcleod *et al.*, 2002; Balotari-Chiebao *et al.*, 2016). Heuck *et al.* (2019), revealed that wind-turbine density was a strong predictor of collision mortality for White-tailed Eagles. As the majority of on-shore windfarms in Wales are positioned in upland habitats and much of coastal

Wales is devoid of large windfarms, in a similar distribution to wind farms in Scotland and Norway (Dahl *et al.*, 2013). This evidence indicates that collisions with lowland wind-turbines should be of little concern, especially as 70% of lowland windfarms in Wales comprise 3 or fewer individual wind-turbines. Once the species ranges inland, however, wind-turbines could be a much larger risk, as is the case in central Europe (Thaxter *et al.*, 2017). Swansea Bay and the Cambrian Mountains are examples of areas of high wind turbine density of high risk to birds of prey in Wales. Wales also has one operational off-shore windfarm; Gwynt y Môr, which is positioned 14 km off the coast of North Wales, the positioning of this windfarm is too far offshore to be of risk to coastal White-tailed Eagles if they inhabited the Clwyd Estuary.

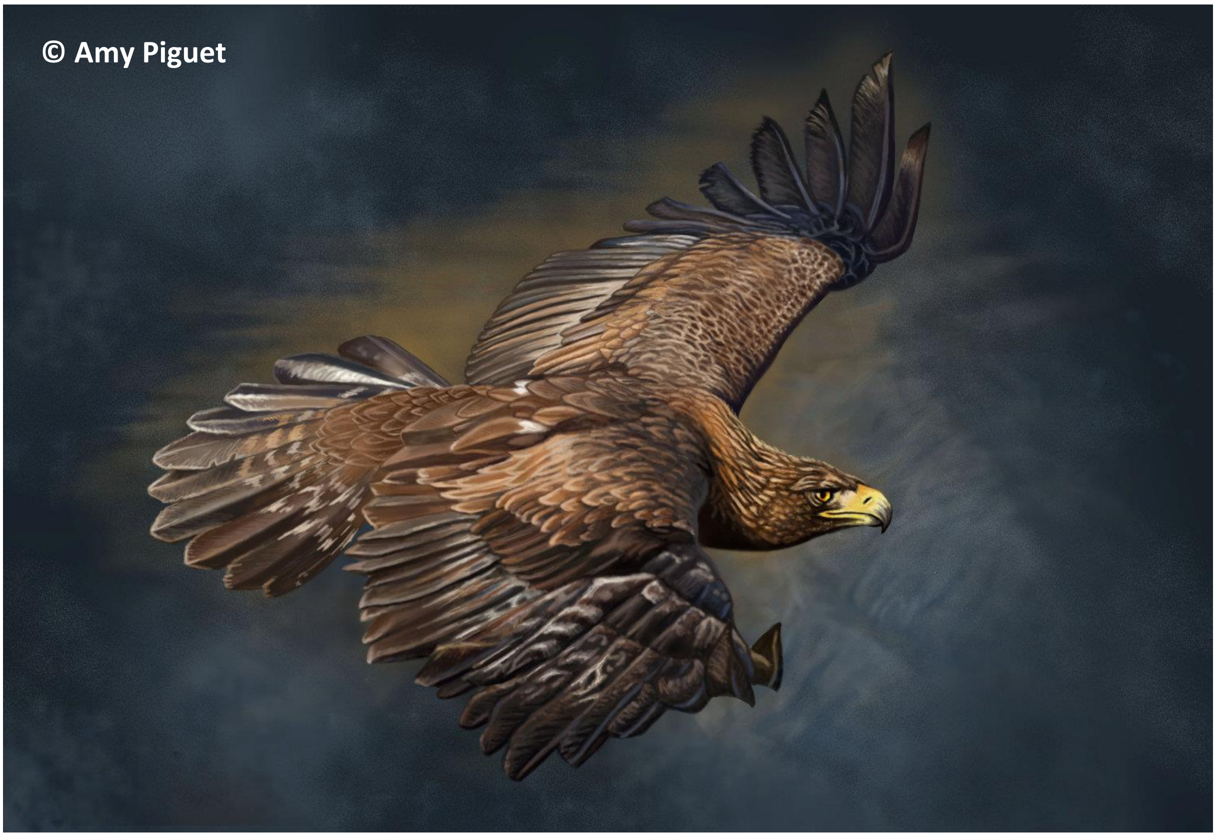
One land use characteristic for the majority of lowland and coastal Wales is the high proportion of livestock pastures. Many studies suggest that livestock pastures do not directly affect a region's potential to support breeding White-tailed Eagles (Love, 2013). This is particularly reflected in our results, as many Welsh lowland regions with high proportions of pasture also have numerous available nest sites available for eagles to occupy; such as the Ceredigion coast and the Isle of Anglesey. According to Love (2013), there are many examples of White-tailed Eagles breeding in close proximities to livestock pastures across Europe but heavily relies on the social attitude of local farmers and the general perceptions of the bird's behaviour and ecology (Mayhew *et al.*, 2016). The species capability to occupy coastal regions with intense live-stock pastures is significantly dependent on local public attitudes toward White-tailed Eagles in Wales. Our results suggested the Mawddach Estuary & Coed y Brenin Forests, Pembrokeshire National Park and Isle of Anglesey to be the best coastal breeding habitat for White-tailed Eagles in Wales and should be the focus of further feasibility assessments.

5.5. Conclusion

As set out by the IUCN reintroduction guidelines, matching and mapping of habitat suitability and availability of both eagle species and assessing anthropogenic land uses across empty breeding habitats are central to feasibility assessments, reintroduction design and implementation (IUCN/SSC, 2013). In this chapter, we evaluated the potential of the modern Welsh landscape to support breeding Golden and White-tailed Eagles. The results of this chapter conclude that there are substantial expanses of available breeding eagle habitat, including sufficient areas with available nest sites across Wales. However, further assessments are required to assess each region's potential, including assessments of; habitat quality, prey availability, and social attitudes of the public. Habitat availability for breeding eagles provides assurance that the potential release of eagles, and their subsequent movements, are compatible with current land uses in Wales. I discuss the potential land use issues for breeding eagles. The results of this chapter for breeding eagles, can also be tentatively applied to sub-adult birds, which are, more nomadic and tolerant of anthropogenic land uses than breeding eagles. Breeding eagles are territorial, and protect their territories year-round. Being central place foragers, breeding eagles are less tolerant of regional land use disturbances. Thus, the information in this chapter, can move forward the plans to restore eagles back to Wales.

Chapter Six

General Discussion



"Bydd ailgyflwyno Eryrod Cynffon Aur a Chynffon Gwyn i Gymru o bwysigrwydd cadwraeth Cenedlaethol a Rhyngwladol"

"The reintroduction of Golden and White-tailed Eagles to Wales will be of National and International conservation importance"

Roy Dennis, MBE, Pers. Comms (2019).

6.1. Discussion Summary

The notion of restoring eagles to Wales is not a novel concept and has been suggested for many years (Dennis and Ellis, 1984; Marquiss, 2005; Yalden, 2007; Evans, O'toole and Whitfield, 2012), but until now little scientific research has been conducted and no formal proposal developed. The overall aim of this thesis was to start addressing the IUCN reintroduction guidelines, and to fill knowledge gaps about the biological, ecological and environmental feasibility of restoring either or both the Golden and White-tailed Eagle to Wales. The primary objective of this work is to conclude whether '*a reintroduction of eagles is the most acceptable option for either species and for Wales*?'

Using a range of investigative methodologies to address IUCN reintroduction criteria (IUCN/SSC, 2013), this study examined: the historic distribution of both eagle species in Wales (***Chapter Two***); the distribution, habitat associations and avoidance of ecologically similar avian mesopredators in Wales (***Chapter Three***); the distribution of suitable habitat for both species across Britain, including Wales (***Chapter Four***); and the distribution of available nest sites across Wales, with consideration of possible land use and anthropogenic threats surrounding potential breeding habitats (***Chapter Five***). Combined, this work finds strong evidence that the Welsh landscape is compatible with the restoration of either/or both native eagles, but is particularly suitable for White-tailed Eagles. The biological, ecological and environmental evidence gathered in this thesis, provides the basic information to initiate restoration programmes, and further discusses additional regional assessments needed to be carried out to complete the license application to re-introduce either or both species to Wales.

6.2. History of Eagles in Wales and the UK

The history of eagles in Britain is well studied, and there is an abundance of historic records for both eagle species in Scotland, England and 25 well-known records for Wales (Yalden, 2007; Evans, O'toole and Whitfield, 2012). Both species were widespread across historic Britain, with populations estimated to be as high as 800 – 1,400 pairs for Golden Eagles and 1,000 – 1,500 pairs for White-tailed Eagles in 500 CE (Evans, O'toole and Whitfield, 2012). The historic records for eagles in Wales gathered in these previous studies were considered insufficient to provide the basis for a reintroduction programme, leading some to question whether Golden and White-tailed Eagles are native breeding species in Wales (Marquiss, 2005; Love, 2006). Following our analysis of the history of eagles in Wales (***Chapter Two***), there are now 151 eagle records archived for

Wales; 81 records attributed to Golden Eagle and 70 records attributed to White-tailed Eagle. These Welsh records contribute to the archived data for both species across Britain, and by including breeding records they effectively eliminate any doubt about the native status of these birds in Wales.

The analysis presented in ***Chapter Two*** demonstrates that both species were formerly widespread in Wales before suffering intense persecution during the Middle Ages, which led to their eventual extinction as breeding species by the early 1800s (Evans, 1974; Hurford and Lansdwon, 1995). A number of archaeological accounts were found indicating the early presence of both species in Wales, with Golden Eagles remains found at Cathole Cave, Gower, dating back to the Devensian period over 20,000 years ago (Harrison, 1980); and White-tailed Eagle remains at Port Eynon Cave, Gower, from the Mesolithic period, 6,000 – 9,000 years ago (Harrison, 1987). Our evidence from 69 Welsh Place-names are similarly suggestive, indicating that both species were likely present across most of the Welsh landscape in historic times, encompassing South, Mid and North Wales, highlighting the importance of eagles in the heritage and culture of Wales.

Like many birds of prey, both eagle species were relentlessly persecuted, which resulted in the sharp declines and local extinctions of both eagles in Wales during the 18th and 19th Centuries, parallel with the extinction of both eagles in England (Evans, O'toole and Whitfield, 2012). Both species were common breeders in Wales during the 16th and 17th Centuries (Johnson, 1644; Pennant, 1778), however, by the late 18th Century, we found that Golden Eagles displayed a limited distribution in the uplands of Snowdonia (***Figure 8, Chapter Two***). By contrast, White-tailed Eagles were still present in areas of Gwynedd, Dyfed and areas of Mid Glamorgan (***Figure 8, Chapter Two***). The last known breeding pair of Golden Eagles were recorded during the late 18th Century on the cliffs of Snowdonia (Evans, 1974) and during the same period the last, and only, breeding record for White-tailed Eagles was recorded in the Kenfig area of the south Wales coast east of Swansea (Welsh Online Newspaper Library, 2019b). By the mid-1800s, both species were extinct as breeding species in Wales, however, wandering young eagles were still observed -and persecuted until at least 1918 (Lovegrove et al., 2010).

6.2.1. Have the causes of extinction been reduced or eliminated?

There is strong historic evidence that the conflicts between eagles and farmers of livestock (e.g. sheep, lambs and gamebirds) gave rise to persecution, eventually resulting to the regional extinction of breeding eagles in Wales (Cambridge, 1899; Ingram, Salmon and Condry, 1966; Hope and Dare, 1976). Historic persecution records collated in ***Chapter Two*** reference detailed records of eagles being shot by landowners due to 'scavenging on sheep carcasses' or the belief that eagles 'killed sheep and lambs' (Welsh Online Newspaper Library 2019c, 2019d). This human-wildlife conflict was first recorded in Wales during the 17th Century and continued through the 19thth Century, eliminating all potential colonists until adjacent regions no longer held breeding eagles or young eagles dispersing from further north in Britain (Newton, 1979; Marquiss, 2005).

Persecution of raptors became illegal under the Protection of Birds Act (1954) which was superseded by the Wildlife and Countryside Act (1981), which unfortunately in Wales, was after many birds of prey suffered population declines and extinctions (Lovegrove, 2007). Under strict protection many birds of prey populations recovered during the 20th and 21st Centuries (Hawksworth, 2003). Illegal persecution of birds of prey is still sporadically recorded across the Welsh landscape, with 85 recorded incidents between 2007 and 2019 (RSPB Raptor Persecution, 2019). This RSPB data demonstrates poisoning to be the most common persecution method used in Wales, accounting for 69.6% of recorded persecution incidents, followed by shooting (22.8 %) and trapping (7.6 %). However, as shown in ***Chapter Three***, generalist avian mesopredators occur across large breeding ranges in Wales. The widespread modern distributions in Wales of Common Buzzards, Red Kites and Peregrine Falcons, and the ongoing population recoveries of breeding Ospreys and Hen Harriers (***Figure 9, Chapter Three***); there is no doubt that persecution rates have significantly decreased from historic levels, parallel to trends observed across Northern Ireland and Scotland (Park *et al.*, 2008; Musgrove *et al.*, 2013).

Both the Golden and White-tailed Eagle are now fully protected as "Schedule 1" species under the Wildlife and Countryside Act (1981), meaning that it is a crime to deliberately or recklessly disturb breeding eagles or shoot, poison or harm eagles at any time of the year. As illegal persecution is still recorded in Wales, an essential component of any future reintroduction is to enter into dialogue with key landowners and their employees, who may perceive eagles as an ongoing concern. A comprehensive risk assessment, a requirement of the IUCN reintroduction guidelines (IUCN/SCC, 2013), should be part of any reintroduction planning, to assess any potential threats that the released birds may face, and to identify effective measures by which these hazards could be mitigated.

6.3. The Environmental Feasibility of Eagle Reintroductions in Wales

As established, the Golden and White-tailed Eagle have been extinct as breeding species in Wales, for over 150 years. The historic landscape once familiar to these eagles has changed significantly over time. One of the main feasibility questions in this thesis for restoring eagles to Wales, is whether the modern-day Welsh landscape still holds the habitat requirements to sustain long-term populations of the Golden and White-tailed Eagle (***Chapter Four***). Both eagle species display a broad array of habitat preferences, which render them habitat generalists (Watson, 2010; Moss, 2011). The Golden Eagle is an elusive bird, wary of humans, and mostly inhabits upland habitats, utilising crags within 1.2 km from a mountain ridgeline for nesting (McLoed, Whitfield and McGrady, 2003; Fielding *et al*. 2019). The species can also nest in trees within lowland and upland habitats that enclose their main requirement of open-landscapes for hunting (Millsap *et al.*, 2015; Crandall, Craighead and Bedrosian, 2016). In Wales, over 44% of land cover meets the habitat requirements of breeding Golden Eagles (***Figure 12, Chapter Four***). From the comprehensive analysis of Golden Eagle breeding habitat across lowland Wales (***Chapter Five***), we predict that this species will primarily occur in upland Wales, in habitats similar to those occupied by Golden Eagle populations in Scotland, Ireland and western Scandinavia (Watson and Dennis, 1992; Moss, 2015; O'Toole pers. comm., 2019). ***Chapter Four*** concludes there are 12 mountainous bio-geographic areas of focus that are suitable for the Golden Eagle to return in Wales (***Figure 14, Chapter Four)***.

By contrast, the White-tailed Eagle is less elusive, more tolerable to humans, and can be expected to thrive in the maritime landscapes and climate of Wales. This species mostly prefers to nest in mature trees across lowland wooded habitats, close to the sea coast or freshwater sources (Evans *et al.,* 2010; Sansom, Evans and Roo, 2016), or position nests on coastal crags. In Wales, over 38% of land cover is a suitable breeding habitat for White-tailed Eagles (***Figure 13, Chapter Four***). The spatial analysis of land uses across Wales in ***Chapter Five***, revealed 14 coastal, wetland and estuarine bio-geographic areas to be best suited for breeding White-tailed Eagles in Wales, comparable to populations in Scotland, Ireland and the Netherlands (Halley, 1998; Whitfield et al., 2013; Mee, 2016). Wales also provides an abundance of inland habitats that meet the breeding requirements of White-tailed Eagles, parallel to populations in Germany, Siberia and Croatia (Mlíkovský, 2009; Radovic and Mikuska, 2009; Krone, Nadjafzadeh and Berger, 2013). ***Chapter 4*** concludes that there are 14 coastal bio-geographic and 3 inland bio-geographic areas of focus that are suitable for the White-tailed Eagle to return to Wales (***Figure 15, Chapter Four***).

The Welsh landscape, as described in **Chapters *Four and Five***, is suitable to support breeding Golden and White-tailed Eagles. The high proportion of land cover that is a suitable breeding habitat for either or both eagle species highlights the conservation importance of Wales as the next priority area in Britain to restore the Golden and White-tailed Eagle. In addition to this evidence, the '*habitats of principal importance'* to Wales, defined by Section 42 of the Natural Environment and Rural Communities (NERC) Wales Act (NERC, 2006), overlap with many of the habitat requirements for Golden Eagles and White-tailed Eagles (***Table 11***). From the list provided in ***Table 11***, the current conservation focuses on many Welsh coastal, wetland and upland habitats, an eagle reintroduction would place Wales as a leader in respect of its focus on and progressive stance towards biodiversity conservation and ecological restoration of these habitats, using eagles as flagship species.

Table 11*. The twenty-one Habitats of Principal Importance to Wales (NERC, 2006) are associated with the habitat requirements of Golden or White-tailed Eagles. Habitat types are given in English and Welsh.*

	Priority Habitats Across Wales
Golden Eagle Eryr Euraid (*Aquila chrysaetos*)	**Lowland calcareous grassland** - Glaswelltir calchaidd yr iseldir
	Upland calcareous grassland - Glaswelltir calchaidd tir uchel
	Lowland dry acid grassland - Glaswelltir asidaidd sych yr iseldir
	Lowland heathland - Gweundir yr iseldir
	Upland heathland - Gweundir yr ucheldir
	Purple moorgrass and rush pastures - Porfeydd brwyn a glaswellt y gweunydd
	Lowland raised bog - Cyforgors ar dir isel
	Blanket bog - Gorgors
	Mountain heaths and willow scrub - Gweundir a phrysgwydd helyg ar dir mynyddig
	Inland rock outcrop and scree habitats - Cynefinoedd brigiadau craig a sgri mewndirol
White-tailed Eagle Eryr y môr (*Haliaeetus albicilla*)	**Lowland Beech** - ffawydd coetir
	Wet Woodland - Coedwig wlyb
	Lowland mixed deciduous woodland - Coedwig gollddail gymysg ar dir isel
	Rivers - Afonydd
	Mesotrophic lakes - Llynnoedd mesotroffig
	Eutrophic standing waters - Dyfroedd llonydd ewtroffig
	Maritime cliff and slopes - Clogwyni a llethrau arforol
	Coastal sand dunes - Twyni tywod arfordirol
	Estuarine rocky habitats - Cynefinoedd creigiog aberol
	Coastal saltmarsh - Morfa heli
	Intertidal mudflats - Eangderau llaid yn y gylchfa rhyng-lanw

6.3.1. Available nest sites and breeding habitat

Nest site availability is an important resource consideration in terms of sustaining breeding populations of Golden and White-tailed Eagles in Wales. Previous studies have highlighted nest site availability as a major potential limiting factor across several avian breeding populations (Millsap et al., 2015; Crandall *et al.*, 2016; Jiménez-Franco *et al.*, 2018). While there is no strong evidence to suggest an abundance of potentially suitable eagle breeding habitats across Wales (***Chapter Four***), this does not necessarily mean that these areas are available for eagles to occupy today, due to lack of suitable nest sites or their sensitivity to human disturbance and the loss and/or degradation of habitat to human activities (Ruddock and Whitfield, 2007; Korsman *et al.,* 2012). Avian predators are sensitive to human disturbance and the loss and/or degradation of their natural habitats (Wong and Candolin, 2015). Thus, it is often good practice for feasibility studies to re-assess suitable areas with anthropogenic land uses that may cause additional environmental constraints that could influence the availability of these areas to be occupied (Byrne and Pritchard, 2016; Baker *et al.*, 2019). The temporal distribution of ecologically similar avian mesopredators to both eagles in ***Chapter Three*** revealed four main anthropogenic land-use types that influenced their Welsh breeding distributions, namely; windfarms, urban areas, persecution and livestock pastures. Windfarms, persecution and urban areas are recorded to displace breeding birds of prey (Rudock and Whitfield, 2007), while livestock pastures are responsible for the depletion/degradation of bird of prey habitats (Donzar *et al.,* 2016).

Taking these anthropogenic land uses into consideration, we re-evaluated suitable eagle breeding habitats in ***Chapter Five***, to reveal nest site availability, nesting compatibility and potential breeding constraints within key breeding areas across Wales. The average displacement of nesting eagles, a direct breeding constraint caused by anthropogenic land uses, suggested that 8% of Golden Eagle breeding habitat (***Figure 17, Chapter Five***) and 5.3% of White-tailed Eagle habitat (***Figure 18, Chapter Five***) may be lost due to modern-day land uses. The South Wales Valleys exhibited the greatest loss of potential Golden Eagle breeding habitat in Wales; undoubtedly attributed to the dense human populations and high numbers of windfarms (***Table 7, Chapter Five***). The Radnor Forests and Llangollen & Berwyn Mountains had the lowest availability of nest sites, while the Snowdonia National Park and Black Mountains had the highest number of, and most suitable nest sites in Wales for Golden Eagles (***Table 8, Chapter Five***).

By contrast, inland nest sites were much less abundant than coastal nest sites for White-tailed Eagles; primarily as a result of higher persecution incidents and windfarms in inland areas (***Table 9, Chapter Five***). Y Berwyn National Reserve, Cambrian Mountains and the Brecon Beacons National Park exhibited the lowest availability of nesting sites, whereas the Mawddach Estuary, Caerfyrddin Bay, and Pembrokeshire National Park exhibited the highest number and most suitable nesting sites for White-tailed Eagles in Wales (***Table 10, Chapter Five***).

Despite these 'modern' constraints on potential eagle breeding distribution, Wales still holds an abundance of available nest sites; leaving over 36% of land cover as suitable breeding habitat for Golden Eagles, and 33% for White-tailed Eagles. With this research, we can state with confidence that modern-day land uses in Wales are compatible with the restoration of Golden and White-tailed Eagles. Many available nesting areas for both species lie within already protected habitats in Wales. This is an extremely important result, as biodiversity conservation is a focus in Wales, with 30% of the terrestrial surface and 36% of territorial waters, supporting a rich variety of legally protected flora and fauna within nature reserves (Natural Resources Wales, 2017). If Golden and White-tailed Eagles were to be restored, they would integrate into and complement the existing conservation initiatives already underway in Wales (Future Generation Act, 2015).

6.4. The Ecological Feasibility of Eagle Reintroductions in Wales

The ecological niches and functions of both eagle species are covered in ***Chapter One***. From this information, we know that reintroduction to Wales complements National and International efforts to restore eagles to their historic native ranges (Convention on Biological Diversity, 2006; SCBC, 2010). Since the Welsh landscape can support populations of both species of eagles, understanding their negative and positive ecological roles after translocation is important (Weeks, 2011). In recent years, the positive ecological impacts of such species have become increasingly evident through the proposition of trophic cascades and mesopredator release effects (Prugh *et al.,* 2009; Terraube and Bretagnolle, 2018), and also via their sentinel species status as key indicators of overall environmental quality (Ross and Weber, 2008). Thus, a reintroduction would restore lost ecosystem functions over a range of Welsh habitats, compliant with the 'Well-being of Future Generation Wales Act' (2015), to enhance biodiverse natural environments with healthy functioning ecosystems. The Golden and White-tailed Eagle are also regarded as important flagship species for upland, coastal and wetland habitats (Thompson, 2008; Dennis *et al.,* 2019); supporting the view that the conservation of charismatic and iconic apex predators would bring wider biodiversity conservation benefits to Wales (Sergio *et al.*, 2006a; Albert, Luque and Courchamp, 2018). Thus, the main ecological reasoning to restore either/or both species assists Section 6 and Section 7 of the Environmental Wales Act (2016) to enhance biodiversity and build greater resilience into our ecosystems in Wales.

While the positive ecological effects for Wales are important to argue the value of restoring eagles, their potential negative ecological effects are equally important. To cover all the potential positive and negative effects of eagles, further comprehensive analysis of their prey species is further required. For example, eagles may have a positive effect by limiting the population growth of species that are non-native, invasive or particularly abundant, such as; American Mink (*Neovison vison*), Canada Geese (*Branta canadensis*), Red Foxes (*Vulpes vulpes*), and Corvids (McWilliams, Dunn and Raveling, 1994; Salo *et al.,* 2008; Roemer, Donlan and Courchamp, 2002); but may have a negative effect on small vulnerable native populations.

6.4.1. Prey Availability in Wales

6.4.1.1. The Golden Eagle (Eryr Euraid)

As generalist avian predators, both eagle species have broad diets and their distribution across Wales would be dependent on prey abundance and availability (Whitfield *et al.,* 2009; Schweiger, Fünfstück and Beierkuhnlein, 2015). While prey availability is not yet considered in this thesis, preliminary analyses on the spatial distribution of key prey densities across Wales have been estimated. To establish that there is sufficient prey availability in Wales, species densities have been calculated for every 10 km² across Wales and each biogeographic region suitable for Golden eagles (***Table 12***); providing compelling evidence that there are fragmented, but abundant, populations of prey sources for Golden Eagle all year round.

While many studies have reported the specialised diet of Golden Eagles in Scotland (Rollie et al, 1994; Shaw 1994; Mcgrady 1994). Haworth 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. The variation in diet, in accordance to prey availability, has been further observed across Europe (Pendrini and Segio, 2001;Clouet et al. 2017; Health et al. 2021) and America (Bedrosian et al. 2017; Preston, 2017).

***Table 12**. Golden Eagle mammal and bird prey densities per 10 km² across Wales*

Species Density per 10 km2		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13 (Lowland)	All Wales
Mammals (Family)															
Leporidae	Hares/Rabbits	10.0	6.0	1.8	4.7	4.0	5.4	4.8	7.8	10.3	6.5	8.2	5.9	10.8	8.6
Cervidae	Deer	0.7	1.5	1.1	1.9	1.3	0.8	0.4	1.1	0.4	1.8	1.8	1.3	0.4	0.7
Bovidae	Goats	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.9	12.7	0.0	0.0	0.5
Carnidae	Fox	8.0	5.6	1.7	1.3	0.8	2.1	2.6	3.6	3.7	5.3	4.3	1.0	4.7	4.0
Muridae	Rats/mice/voles	13.4	8.2	1.7	6.5	10.5	2.0	4.4	10.4	5.6	16.6	13.6	4.8	17.4	12.2
Mutelidae	Weasels/Badgers	11.3	13.1	5.5	9.5	7.5	3.8	3.6	13.5	6.2	14.6	11.5	4.9	8.7	8.2
Birds (Family)															
Phasianidae	Grouse/Pheasant/partrige/quail	11.4	6.5	9.1	36.8	8.6	8.7	7.2	9.4	38.1	4.6	7.8	15.3	37.2	25.0
Anatidae	Ducks/Geese/Swans	201.7	143.3	81.2	133.5	19.3	25.7	53.1	49.1	31.3	30.8	98.7	27.0	375.5	217.7
Rallidae	Rails/Crakes/Coots	28.0	40.9	17.1	21.8	4.4	7.2	5.3	2.1	5.5	0.8	16.4	2.4	80.5	45.1
Ardeidae	Herons/Bitterns	58.0	37.3	15.5	29.6	5.5	5.1	14.1	12.7	8.4	12.1	24.6	4.7	107.8	61.5
Charadriidae	Plovers/Dottrel/Lapwings	12.4	27.8	7.2	21.6	5.2	2.4	11.3	9.2	4.7	5.5	18.3	4.5	105.6	56.7
Scolopaciidae	Pipers/Curlew/Snipe	38.1	55.2	22.0	36.3	16.8	16.4	26.4	22.9	17.3	26.0	42.2	20.3	265.3	143.2
Laridae	Gulls/Turns	136.5	59.0	15.1	19.1	2.0	4.0	9.9	19.5	7.3	19.6	40.6	27.1	229.6	124.8
Columbidae	Pigeon/Doves	337.9	136.2	32.2	73.2	28.5	40.9	37.1	23.8	62.6	19.4	76.4	31.8	234.9	150.4
Alaudidae	Larks	33.0	31.7	21.5	15.6	15.0	6.9	8.2	7.4	9.1	8.8	11.8	17.2	32.4	22.9
Motacillidae	Pipits/Wagtails	115.2	84.8	59.3	55.2	41.6	21.3	40.7	38.8	43.3	43.9	77.7	48.4	134.4	92.4
Turdidae	Thrushes/Chats	433.1	225.6	88.8	150.8	79.3	64.5	84.8	55.4	99.7	56.3	163.8	61.8	289.3	204.1
Corvidae	Crows/Raven/Magpies	801.9	415.8	135.5	183.6	100.0	87.8	116.0	84.4	147.8	82.1	250.3	112.5	538.5	363.0

* Zone 1 - South Wales Valleys (East); Zone 2 - South Wales Valleys (West); Zone 3 - Brecon Beacons National Park; Zone 4- Black Mountains; Zone 5 - Hay-on-Wye; Zone 6 - Radnor Forests; Zone 7 - Cambrian Mountains; Zone 8 - Lower Snowdonia National Park; Zone 9 - Llangollen & Berwyn Mountains; Zone 10 - Central Snowdonia National Park; Zone 11 - Upper Snowdonia National Park; & Zone 12 - Pentre-llyn-Cymmer.

While mammals are an important component of the Golden Eagle diet, Wales is void of Mountain Hares (*Lepus timidus*) but does have sufficient fragmented populations of Brown Hares (*Lepus europaeus)* and European rabbits (*Oryctolagus cuniculus*). While both species are more abundant in Lowland areas of Wales (Zone 13; 10.8 individuals per 10km2), there is also sufficient rabbit/hare populations in upland habitats such as; the Berwyns and Llangollen (Zone 9; 10.3 individuals per 10km2), South Wales Valleys (Zone 1; 910 individuals per 10km2) and Upper Snowdonia National Park (Zone 11; 8.2 individuals per 10km2). There are also other mammal species available in these regions to prey upon including small populations of deer (*Cervidae*) and goats (*Bovidae*) and more abundant species like Fox (*Canidae*), Rats, Mice and Voles (*Muridae*) and Weasels and Badgers (*Mustelidae*).

Birds are also a big component of the Golden Eagle diet, with medium-sized ground-dwelling birds (i.e. *Phasianidae*) being a staple diet. While Red Grouse (*Lagopus Lagopus scotica*) are in low numbers across Wales, there seem to be high densities of Pheasants (*Phasianus colchicus*) and Red-legged Partridges (*Alectoris rufa*), estimated to be 25 individuals per 10 km2 across Wales; with the highest densities in the Berwyns and Llangollen (Zone 9; 38.1 individuals per 10km2) and the Black Mountains (Zone 4; 36.8 individuals per 10km2). Crows, Raven and Magpies (*Corvidae*) seem to be the highest bird population across Wales, followed by Ducks Geese and Swans (*Anatidae*), Thrushes and chats (Turdidae), Pigeon and Doves (Columbidae) and Gulls (Laridae). All of these bird species will provide plenty of prey variation for Golden Eagles in Wales.

Carrion is also a big part of the Golden Eagle's diet (Sánchez-Zapata *et al.*, 2010), especially during the winter months and there is a year-round abundance of sheep/lamb carcasses in Wales. The combination of live prey and carrion may be sufficient to sustain a small breeding population of Golden Eagles in Wales (Lockie, 1964). The diet of Welsh Golden Eagles could be projected to broadly resemble the diets of their European relatives from Sweden, Norway, the French Alps and the Pyrenees Mountains (Pedrini and Sergio, 2001; Nystrom, *et al.,* 2006; Gjershaug *et al*., 2018).

6.4.1.2. The White-tailed Eagle (Eryr y môr)

White-tailed Eagles choice of habitat, like that of the Golden Eagle, reflects its diet. These birds are highly versatile in their choice of prey and are opportunistic feeders. The diet of White-tailed Eagles in a given location tends to be much broader than that of the Golden Eagle (Unwin, 2016) and are specialists in catching aquatic prey. They have been reported to take a wide variety of prey species across their range and combines fish, sea birds, waterfowl, mammals with plentiful scavenging (Wille and Kampp, 1983; Whitfield *et al.,* 2013). To understand if there is sufficient prey available in Wales, key mammal and bird population densities per 10 km² have been estimated across Wales and each biogeographic region suitable for White-tailed Eagles (*Table 12).* Fish and carrion densities were not included due to a lack of data availability. Further insight to estimate fish and carrion numbers will be drawn, in due course, from fallen stock and fish catch rates across Wales. Despite fish and carrion not being quantified, the preliminary analysis provides compelling evidence for abundant bird and mammal prey sources for White-tailed Eagles all year round.

Birds tend to be the dominant part of the White-tailed Eagle diet in many regions (Sulkava et al. 1997; Dementavicius et al. 2020). Halley (1998) found 64% of the Norwegian White-tailed Eagle diet comprised of birds and 33.3% fish. Waterfowl are a staple item on the menu including, ducks, geese, swans (i.e. from the family *Anatidae*), coots, rails (*Rallidae*) and grebes (*Podicipedidae*); and seabirds such as gulls (Laridae) and auks (Alcidae). Local preference depends on the season and what is most easily available (Nadjafzadeh, Hofer and Krone, 2015). Wales supports abundant waterfowl populations, with an estimated 178.9 ducks, geese and swan species (*Anatidae*) per 10 km², with the highest densities found in Zone 1 (879.4 individuals per 10 km²) and Zone 14 (522 individuals per 10 km²). For wintering eagles on the Danube Delta, coots are a favourite prey item (Sandor et al. 2014), on Mull in Scotland Shags are important (Whitfield et al. 2013) and in Estonia eagles mainly target Cormorants (Mlikovsky, 2009). On average across Wales rails, crakes and Coots (*Rallidae*) are in abundant numbers with 36.9 individuals per 10 km² reaching the maximum of 197.4 individuals in some regions (***Table 13***). Cormorants and shags are also plentiful with on average 25.2 individuals per 10 km² across inland and coastal Wales with a maximum of 84.9 individuals in parts of Wales. Other bird species have been recorded including, crows, magpies, thrush and game birds, but to a much smaller extent to aquatic bird species (Ekblad et al. 2020). There is no doubt plenty of bird prey items across all seasons in Wales for White-tailed Eagles.

Mammals are also incorporated into the diet of White-tailed Eagles, although large parts of their mammalian diets are taken as carrion. White-tailed Eagles are not as adept as the Golden Eagle in pursuit of hunting their prey but have been recorded to prey upon rabbits, hares (i.e. from the family *Leporidae*), voles, mice rats (*Muridae*) and Roe deer (*Cervidae;* (Yurko, 2016; Ekblad *et al.*, 2020). Mammalian prey is present in good numbers in Wales and staple prey items such as Rabbits and Hares are more abundant in lowland areas than upland areas – providing higher densities to sutain a small White-tailed Eagle population. Rabbits and Hares seem to be abundant in lowland areas across Wales with Zone 11, 14, and 1 presenting the highest population densities.

Marine fish species such as Pollock (*Theragra Chalcogramma),* Grey mullet (*Mugil cephalus)* and Lumpsucker (*Cyclopteridae*) and freshwaters species such as Pike (*Esox lucius*), Perch (*Perca*) and Salmon (*Salmo salar*) also play big parts in the diet of White-tailed Eagles (Willw and Kempp, 1983; Whitfield et al. 2013). Available terrestrial and marine carrion will also play a big part in this bird's diet including, dead fish, seals, livestock and cetaceans (Marquiss, 2005). With the broad array of prey items in the Welsh landscape The diet of Welsh White-tailed Eagles is projected to be similar to their British and European relatives from Norway, Scotland, Ireland, Germany and Sweden (Willie and Kampp, 1983; Halley, 1998; Kruger *et al*., 2010; Whitfield *et al.,* 2013).

***Table 13**. White-tailed Eagle mammals and bird prey densities per 10 km² across Wales.*

Species Density per 10 km2		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15 (Upland)	Zone 16 (Upland)	Zone 17 (Upland)	All Wales
Mammals (Family)																			
Leporidae	Hares/Rabbits	9.8	9.1	6.1	2.3	6.3	6.7	6.7	7.5	6.9	8.3	25.9	9.7	9.5	17.4	10.0	3.7	10.9	7.1
Cervidae	Deer	0.5	1.1	0.3	0.3	0.3	0.4	0.3	1.5	0.2	0.1	0.2	0.2	0.7	0.1	0.3	0.3	1.2	0.4
Bovidae	Goats	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	2.1	0.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.1
Carnidae	Fox	9.4	5.7	5.4	1.6	5.4	4.2	2.3	5.7	3.6	0.7	3.1	5.6	1.8	8.3	3.8	2.0	4.4	3.5
Muridae	Rats/mice/voles	38.1	45.1	9.0	1.7	3.2	6.9	10.4	21.2	14.2	8.5	19.9	19.8	8.9	10.7	7.9	5.0	14.2	11.1
Mutelidae	Weasels/Badgers	18.7	11.6	11.7	5.0	13.4	6.0	10.5	13.7	10.2	4.3	7.0	12.1	5.2	5.4	7.0	4.7	24.4	8.3
Birds (Family)																			
Anatidae	Ducks/Geese/Swans	879.4	423.7	497.1	59.9	163.7	43.4	178.1	36.3	133.2	56.4	397.1	478.3	130.7	522.0	27.9	14.8	203.1	178.9
Phalacrocoracidae	Cormorants/Shags	84.9	49.3	68.9	14.4	44.0	9.6	23.6	4.8	15.6	21.8	53.9	44.9	19.1	47.9	2.7	0.9	20.5	23.2
Rallidae	Rails/Crakes/Coots	197.4	107.3	69.2	8.1	37.0	7.7	11.0	0.7	6.3	8.5	98.4	97.4	33.3	95.1	4.0	1.5	54.4	36.9
Procellariidae	Petrels/Sheerwaters	1.3	6.9	14.2	4.1	27.9	1.4	1.0	0.3	0.9	7.6	15.1	7.2	1.7	0.1	0.0	0.0	0.0	4.7
Ardeidae	Herons/Bitterns	256.5	92.7	184.7	21.2	50.6	20.3	44.9	13.7	51.8	28.9	135.6	180.1	32.4	153.8	7.4	3.7	49.8	54.5
Charadriidae	Plovers/Dottrel/Lapwings	164.7	83.8	168.7	31.3	56.4	13.2	52.6	9.1	24.8	37.2	110.5	145.6	28.3	143.8	3.8	1.0	28.5	44.4
Scolopaciidae	Pipers/Curlew/Snipe	446.6	180.1	396.9	47.3	159.3	49.2	105.9	27.4	114.2	94.8	387.9	399.7	92.8	361.3	14.9	7.5	60.2	119.7
Laridae	Gulls/Turns	389.8	253.6	220.2	51.9	174.4	47.4	60.6	21.3	127.4	115.3	268.1	325.8	129.1	125.3	5.9	2.2	61.0	103.1
Corvidae	Crows/Raven/Magpies	#####	603.4	576.2	200.9	384.8	223.5	174.5	87.3	363.3	235.7	555.5	686.3	339.5	673.1	121.1	75.3	437.6	309.1
Gaviidae	Divers	1.9	6.1	14.2	2.1	6.0	1.1	2.5	0.6	3.9	8.1	15.3	10.7	5.3	0.2	0.4	0.0	0.8	3.2
Podicipedidae	Grebes	170.5	67.5	68.2	9.6	30.0	5.8	14.5	3.3	26.5	5.1	97.0	110.1	23.7	73.1	3.3	2.0	43.3	32.0
Salidae	Gannets	1.4	4.1	14.9	2.7	20.4	2.5	2.9	0.7	1.8	8.4	22.5	9.3	1.5	0.7	0.0	0.0	0.1	4.4
Threskiornithidae	Ibis/Spoonbill	2.9	0.6	8.6	0.4	0.5	0.1	0.1	0.0	0.1	2.2	1.2	0.3	0.1	1.4	0.0	0.0	0.0	0.7
Recurvirostridae	Advocet/Stilts	10.0	0.3	0.6	0.3	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.4	0.0	6.9	0.0	0.0	0.0	0.8
Alcidae	Auks	0.4	3.4	12.8	2.7	45.3	2.5	1.7	0.5	3.4	16.1	58.0	25.0	2.4	0.5	0.0	0.0	0.0	8.3

*Zone 1 - The Severn Estuary; Zone 2 - Swansea Bay & Afon Forests; Zone 3 - The Gower Peninsula ; Zone 4 - Caerfyrddin Bay; Zone 5 - Pembrokeshire National Park ; Zone 6 - Ceredigion Bay; Zone 7 - Dyfi Estuary & Dyfi Forests; Zone 8 – Mawddach Estuary & Coed y Brenin Forests; Zone 9 - Glaslyn Estuary & Snowdonia National Park; Zone 10 – Lyn Peninsula; Zone 11 - Isle of Anglesey; Zone 12 - Conwy Estuary & Gwydir Forests; Zone 13 - Clwyd Estuary & Clocaenog Forests; Zone 14 - Dee Estuary & Pen y Maes Woods; Zone 15 (upland) - Y Berwyn National Reserve; Zone 16 (upland) - Cambrian Mountains; and Zone 17 (upland) - Brecon Beacons National Park.

6.4.2. Ecological Risk Assessments

The diets of European Golden and White-tailed Eagles are well studied (Nystrom, *et al.,* 2006; Kruger *et al*., 2010; Whitfield *et al.,* 2013; Gjershaug *et al*., 2018), and, no quantifiable negative effects of either species on wild prey populations have been demonstrated (Miller *et al.,* 2006; Whitfield et al., 2013). This is likely because both eagle species target the most seasonally abundant food source and are facultative scavengers that readily take advantage of carrion (Sánchez-Zapata *et al*., 2010; Nadjafzadeh, Hofer and Krone, 2013). Nevertheless, further ecological risk assessments need to consider all key local issues concerning any potential negative effects on species of conservation concern (Wolf and Ripple, 2018). Species of conservation importance in Wales that need to be taken into consideration for future ecological risk assessments to restore both Golden and White-tailed Eagles to Wales are detailed in ***Table 14*.** Species listed in ***Table 14*** highlighted in green are not predicted to be at risk from eagles due to habitat differences; species highlighted in amber are small populations and to rare for eagles to regularly prey upon, thus, there will be no/minimum predicted risks; and species highlighted in red are global staple prey items and may be exposed to regular predation if populations numbers are sufficient.

Table 14. *Species of Principal Importance enlisted under the NERC Wales Act (2006) for consideration and further ecological risk assessments to restore Golden and White-tailed Eagles to Wales. Species names are given in English, Welsh and Latin.*

Species Groups	Open Lowland and Upland Species	Coastland, Wetland and Estuarine Species
Birds / Adar	**European Nightjar** - Troellwr mawr *(Caprimulgus europaeus)*	**Greenland White-fronted Goose** - Gŵydd Gwyn yr Ynys Las *(Anser albifrons)*
	Corncrake - Crex crex *(Rhegen yr ŷd)*	**Dark-bellied Brent Goose** - Gwydd ddu Siberia *(Branta bernicula)*
	Common Cuckoo - Cog *(Cuculus canorus)*	**Ringed Plover** - Cwtiad torchog *(Charadrius hiaticula)*
	Great Bittern - Aderyn y bwn *(Botaurus stellaris)*	**Bewick's Swan** - Alarch Bewick (Cygnus columbianus)
	Red Grouse - Grugiar goch *(Lagopus lagopus)*	**Herring Gull** - Gwylan y penwaig *(Larus argentatus)*
	Eurasian Curlew – Gylfinir *(Numenius arquata)*	**Black-headed Gull** - Gwylan benddu *(Larus ridibundus)*
	Grey Partridge – Petrisen *(Perdix perdix)*	**Bar-tailed Godwit** - Rhostog gynffonfraith *(Limosa lapponica)*
	Golden Plover - Cwtiad aur	**Common Scoter** - Môr-hwyaden ddu

	(Pluvialis apricaria)	*(Melanitta nigra)*
	European Turtle Dove – Turtur *(Stretopelia turtur)*	**Balearic Shearwater** - Aderyn drycin y Balearig *(Puffinus mauretanicus)*
	Black Grouse - Grugiar ddu *(Tetrao tetrix)*	**Chough** - Brân goesgoch *(Pyrrhocorax pyrrhocorax)*
	Ring Ouzel - Mwyalchen y mynydd *(Turdus torquatus)*	**Roseate Tern** - Môr-wennol wridog *(Sterna dougallii)*
Mammals / Mamaliad	**Brown Hare** – Ysgyfarnog (*Lepus europaeus*)	**Otter** – Dyfrgi (*Lutra lutra*)
	Pine Marten - Bele'r coed (*Martes Martes*)	**Water Vole** - Llygoden bengron y dŵr (*Arvicola terrestris*)
Fish / Pysgod	/	**European Eel** – Llysywen (*Anguilla anguilla*)
	/	**River Lamprey** - Llysywen bendoll yr a (*Lampetra fluviatilis*)
	/	**Sea Lamprey** - Llysywen bendoll y môr (*Petromyzon marinus*)
	/	**Atlantic salmon** – Eog (*Salmo salar*)
	/	**Brown / Sea Trout** - Brithyll / Siwin (*Salmo trutta*)
	/	**Arctic Char** – Torgoch (*Salvelinus alpinus*)

Thus, while the restoration of both eagle species will ultimately contribute to restoring ecological functions to priority habitats and improving ecosystem resilience across Wales, there is now a duty to carry out Habitat Regulation Assessments (HRA's) on all local SPAs and SACs that may be affected either positively or negatively by eagles, before any possible reintroduction programme.

6.5. The Socioeconomic Feasibility of Eagle Reintroductions in Wales

This thesis has provided an assessment of the ecological feasibility of restoring eagles to Wales. One of the main next steps is to develop the proposal in line with the socio-economic circumstances, public attitudes, values and expectations (Scottish Reintroduction Forum, 2014). One of the main socio-economic benefits that have been reported for other reintroduction programmes is the added benefit of increased tourism following eagle reintroduction, resulting in regional boosts to the economy (Molloy, 2011; MacPherson *et al.,* 2014; Hamilton and Morgan, 2015). The natural environment is a significant driver of tourism in Wales and visitor-spend contributes more than £6.3 billion annually and supports 206,000 jobs (Welsh Government, 2020). Many protected areas bring significant economic contributions, for example, Sites of Special Scientific Interest (SSSI) are estimated to generate £128 million per annum, while the Wales Heritage Coast brings £32 million to the Welsh economy per annum (Wildlife Trust Wales, 2013).

Wildlife viewing and information platforms are also common approaches used to boost local tourism in Wales. For example, the Dyfi Osprey Project attracts 40,000 visitors per year, bringing up to £500,000 to the local economy annually (Wildlife Trust Wales, 2013). In a study carried out by the RSPB, the reintroduction of White-tailed Eagles to the Isle of Mull is estimated to account for up to £5 million of tourist spend each year, supporting 110 jobs and £1.4 million of local economic income (Molloy, 2011). Species conservation and our Welsh natural environments are important to the economy of Wales. As analysed in ***Chapter Five***, there is a large proportion of suitable eagle habitat, particularly White-tailed Eagle habitat, within protected areas within Wales; there is little doubt that eagles would create additional interest and increase visitor numbers to Wales. The reintroduction of either/or both of these charismatic and iconic species can play vital roles in regenerating and diversifying rural economies in Wales.

6.5.1. Socioeconomic risks

6.5.1.1. Sheep Farming

Wales is dominated by grassland pasture, which accounts for 75% of land use in Wales (***Chapter Five***). Cattle and sheep grazing account for 35% of active farm holdings in Wales (Armstrong, 2016). One of the main social-economic conflicts over restoring eagles to Wales will likely be the concerns by farmers over lamb predation. Although both eagles take a wide array of prey types, there has been a long-standing debate about the extent to which Golden and White-tailed Eagles prey upon live, healthy, viable lambs (Marquiss *et al*, 2004). In Scotland, lambs are incorporated into the diets of both eagle species during the breeding season; lambs found at nest sites offer irrefutable evidence of this (Whitfield *et al.,* 2013). Nevertheless, the majority (up to 75%) of such remains found at nests, were found to have been scavenged rather than taken live (Marquiss et al, 2004; Simms *et al.,* 2010).

One study in Scotland, reported Golden Eagles to be responsible for predating on less than 3% of lambs, later concluding lamb predation to be insignificant to the total number of lamb mortalities attributed to other factors (Campbell and Hartley, 2004). Furthermore, across Scotland there was circumstantial evidence that many of the lambs killed by eagles were not healthy or viable (i.e. sick, injured or diseased) because, compared to live lambs, they were often small for their age and of similar size to lambs that died from natural causes (Wiley and Bolen, 1971; Marquiss et al, 2004). This scavenging or opportunistic behaviour in Britain is not a surprise, some 30% of lambs in the Scottish Highlands fall victim of bad weather or disease in the lambing season (SHAWG, 2019); this behaviour will almost certainly be observed in Wales as similarly, there is a 15 - 20% lamb mortality rate (SHAWG, 2019).

Any proposal to reintroduce eagles to Wales is likely to concern some farmers, as seen in Ireland (Burke *et al.,* 2014). The Golden Eagle and White-tailed Eagle reintroductions to Ireland were met with considerable opposition by the farming communities when first proposed (O'Toole, Fielding, and Haworth, 2002; Mee, 2016). Due to, significant efforts were made to address concerns by meeting with farming groups and working with local farmers where eagles took up residence. It is now 12-years since the first release of both species of eagles in Ireland and both species are now seen by farmers as part of the landscape, with no lamb predation recorded (Lorcan O'Toole and Roy Dennis pers. comms). Across Europe, lamb predation is not a significant problem. In Norway, the Norwegian Sea Eagle Project has been involved in a carcass autopsy scheme over the last 33 years (1987 - 2019) and have found no lamb predation by White-tailed Eagles (Alv Otter Folkestad pers. comms). On par with Scotland, Norwegian Golden Eagles were found to be responsible for under 3% of lamb predations over this 33-year period (Rovbasen, 2020).

There is no evidence across Britain or Europe that suggest the killing of viable lambs, by either the Golden or White-tailed Eagle, represents habitual predation. More likely, it represents infrequent opportunism. Furthermore, even in Scotland where this socio-economic conflict seems to be an increasing issue, Scottish Natural Heritage conclude that eagle predation accounts for 0.5 to 2.4 % of lamb fatalities and has concluded such predation as 'minimum impact' on the general income of livestock farming (Scottish Natural Heritage, 2010); a consensus that exists across most of Europe (Bautista *et al.,* 2019). Attributed to the perceived perception of increasing lamb predation in Scotland, a recent Sea Eagle Management Scheme has been launched (Scottish Natural Heritage, 2019) to offer payment subsidies for lamb losses by White-tailed Eagles, but despite evidence connecting Golden Eagle with lamb predation in similar areas, there are no subsidies offered for Golden Eagles. On behalf of the Eagle Reintrodcution Wales project I have discussed aneagle reintroduction with the National Farmers Union for Wales (Rachel Lewis-Davies, NFU Cymru, National Environment and Land Use Advisor, pers. comm), and they are content with a slow and considered approach to assess the feasibility and concerns around this topic, moving forward.

6.5.1.2. Game Shoots

At present, there is conflict between British eagles, particularly the Golden Eagle, and private landowners assigning their land to densely stocked game (particularly Red Grouse) for recreational shooting (Whitfield *et al.*, 2007; Whitfield and Fielding, 2017). Across Scotland, Red Grouse shooting estates are a common countryside land use, while Red Grouse and Pheasant shoots are common across England. Shooting estates in rural Wales are not widely distributed compared to England and Scotland. There are only 56 official shooting estates in Wales, plus an unknown number of unofficial, small-scale farm shoots, largely Pheasants shoots; 29 of these estates are found within Powys and Gwent (Evans, 2016). In Western Scotland gamebirds were found to consist of only 0.4% of White-tailed Eagle diets, compared to 7.6% of the diet of Golden Eagles (Whitfield et al. 2013). Nevertheless, research shows a strong association between the persecution of Golden Eagles and land managed for game shooting (Whitfield and Fielding, 2017).

In the Welsh landscape, there are high levels of stocking of captive-bred Pheasants and Red-legged Partridges, in some areas, and such species are a key alternative prey item for eagles across Europe (Tjernberg, 1981; Clouet *et al.*, 2017). As a result, a socio-economic conflict with Golden Eagle reintroduction to Wales may arise. It has been estimated that 2 million Pheasants and 0.4 million Red-Legged Partridges are released for recreation shooting in the Wales each year (Bicknell et al., (2010). In a similar manner to sheep farming, it will be important to maintain a close dialogue with game shooting interests across the Welsh landscape prior to any reintroduction. On the other hand, White-tailed Eagles are not agile hunters, and they are therefore not inclined to catch game birds. I, therefore, project there to be minimum realised conflicts between reintroduced White-tailed Eagles and game shoots in Wales. In Romania, Pheasants comprises <5% of the diet of breeding White-tailed Eagles, and this was reported to only include birds killed on roads and taken as carrion (Sandor et al., 2014). With the Pheasant being the most likely bird species to fall victim to car collision across England and Wales (Madden and Perkins, 2017) and the proportion of game carrion across rural landscapes, White-tailed Eagles would certainly take advantage by scavenging on such carrion.

6.5.2. Social attitudes in Wales

Historically, the reintroduction of apex predators only considered the comprehensive biology, ecology and environmental feasibility of the focal species and its release area (Marshall et al. 2007; O'Rourke 2014). It is now a crucial part of the IUCN reintroduction criteria (IUCN/SSC, 2013) that species restoration outcomes are shaped around the attitudes and behaviour of the public and regional stakeholder groups (Consorte-McCrea and Thompson, 2014). This can be achieved for proposed eagle reintroductions in Wales by consultations, to reveal and acknowledge contentious concerns surrounding reintroductions, and to identify solutions and mitigation plans that fit into regional social and socio-economic structures in Wales (Mayhew *et al.*, 2016). Over the last three years, the ERW project has been engaging with the Welsh public and key stakeholder groups. This experience has been broadly positive with no clear objections.

Recently, the ERW project collaborated with the University of the West of England (Bristol) for a humanities study assessing the general public's perceptions of White-tailed Eagles in South Wales. Reese's (2020), found that 65.6% of people who took part in the survey in South Wales were familiar with - or had previously heard of - the White-tailed Eagle, even though 63.4% of people had never encountered or observed this species in the wild or captivity. A large proportion of people in this study had a positive attitude towards White-tailed Eagles; 80.3% felt the species would pose no threat to their small pets and/or children, and 90.5% had never experienced or knew of someone who had experienced livestock loss by an eagle before, due to there being no eagles in Wales. One interesting result from this study is that 69.1% of people in South Wales did not feel responsible for the future conservation of White-tailed Eagles in Wales. A high proportion of people may feel like the conservation of the species is the remit of a conservation group, however, this attitude does not mean they do not support the conservation of White-tailed Eagles in Wales.

While Reese (2020) was a small-scale study, it has given insight and direction on how to plan and conduct extensive public consultation programmes across Wales. , Wide-spread public surveys and consultations will need to be conducted to gauge public perceptions towards the Golden and White-tailed Eagle and to extend consultation efforts to the farming, game-shooting, fishing and commercial forestry industries in Wales.

6.5.3. Source Population Considerations

Source population selection is an important consideration for reintroduction programmes. Two essential requirements of any reintroduction programme are to, first, ensure there will be no impact on the source population and, secondly, to select the most genetically compatible population (IUCN/SSC, 2013). For sourcing Welsh Golden and White-tailed Eagles, population size, geography and genetics were all key considerations of source population selection.

Both Golden and White-tailed Eagle are monotypic across Europe, meaning that there is one species or sub-species known to these geographic areas (Hailer et al, 2006; Ogden et al. 2019). Thus, the historic Welsh population of Golden Eagles were from the European race *Aquila chrysaetos* and White-tailed Eagle was presumably from the nominate race *Haliaetus albicilla*. As a result, any European population of breeding eagles would likely be suitable as a source population.

With the nearest geographic breeding population of both species being in Scotland, the most suitable source stock would be from Scotland. While this is true for sourcing Welsh Golden Eagles, the Scottish population of White-tailed Eagles will not be a viable source population due to population size (n=130 breeding pairs) and this population already sourcing youngsters (n=50 in total) to Isle of Wight, Southern England (Dennis et al. 2019). It can be suggested that taking a further 50 young birds would bring concern over an imminent decline in the near future. By contrast, Scotland holds the fourth largest population of Golden Eagles in Europe, with over 530 breeding pairs of this population is the most genetically and geographically suitable source population for Wales (Haworth and Fielding, 2018).

An essential requirement of any reintroduction is to ensure there is no impact on source populations. The most suitable geographical population to source Welsh White-tailed Eagles is from Norway, this population is the largest and most genetically viable breeding population in Europe (n=2,800-4,200 pairs; Birdlife International, 2015). As both Norwegian and Scottish populations are considered highly genetically diverse (Hailer et al, 2006; Ogden et al. 2019), it complements IUCN guidelines by reducing the risk of inbreeding, genetic deterioration, outbreeding depression & genetic drift; Vali et al, 2019). The best conservation programme to translocate eagles is to reintroduce them at regular periods to avoid genetic deterioration (Mee et al, 2003; Haworth and Fielding, 2018; Dennis et al, 2019). Best practice has been shown to reintroduce a number (n=6-15) of unrelated individuals per year, over a 5-year translocation period.

6.6. Thesis Conclusion

6.6.1. Are Eagle Reintroductions an Acceptable Option for Wales?

Throughout this thesis, the main research objective was to assess if eagle reintroductions are an acceptable option for Wales. It has been established that the restoration of White-tailed Eagles to Wales, in concordance with their UK Species Action Plan (SAPs), would have International conservation significance. The restoration of Golden Eagles would be of National conservation significance in the UK and Wales. ***Chapter Two*** after reviewing the literature the extinction of both species in Wales can be attributed to human persecution, thus a reintroduction would be the most acceptable option for restoring the species' to Wales; due to the Golden and White-tailed Eagles' unlikely ability to naturally colonise Wales for the foreseeable future, due to limited dispersal from their current core breeding ranges. The analysis of ecologically similar bird of prey species, in ***Chapter Three,*** suggests that the cause of eagle extinctions has significantly reduced since the extirpation of eagles from Wales; the wide distribution of generalists and the re-colonisation of specialist mesopredators in Wales offers strong evidence of this reduction in persecution threats.

This thesis demonstrates that there is a great proportion of suitable habitat and available nesting locations for both species in Wales (***Chapter Four and Five***), which appear to be compatible with many modern-day conservation initiatives and land uses in Wales. This enables us to conclude that the restoration of both the Golden and White-tailed Eagle has a very good chance of success, especially given the success of the well-established eagle translocation programmes conducted across the UK (Mee *et al.*, 2003; Scottish National Heritage, 2009; Burke *et al.*, 2014; Fielding and Haworth, 2014); all of which have offered their expertise to help further design the practicalities of translocation to Wales.

While studies of regional prey availability and public attitudes are yet to be completed, this thesis presents the starting procedure of gathering feasibility evidence to restore either/or both species of eagles to Wales. Wales would benefit from the restoration of either/or both the Golden and White-tailed Eagle by restoring former biodiversity, heritage and culture, enhancing environmental education, eco-tourism and building greater resilience into our Welsh ecosystems. T the status of any eagle reintroduction would designate Wales as a leading country in respect to its progressive stance towards biodiversity conservation and ecological restoration.

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Appendix 1

The historic records gathered for Golden and White-tailed Eagles in Wales.

Table A1: The past records of Golden and White-tailed Eagles gathered for Wales

Written Observational Records				
Record type	**Name**	**County**	**Species** (k: known or p: predicted)	**Reference**
Ornithological Literature	Aberaeron (1910 AD)	Dyfed	WTE (k)	Forrest, H. E. 1907. The Vertebrate Fauna of North Wales. London: Witherby & Co.
Ornithological Literature	Abersoch (1910 AD)	Gwynedd	WTE (k)	Forrest, H. E. 1907. The Vertebrate Fauna of North Wales. London: Witherby & Co.
Ornithological Literature	Beddgelert 1859 AD)	Gwynedd	GE (k)	Pritchard, R. (2012). Birds of Meirionnydd. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Beguildy (1835 AD)	Powys	WTE (k)	Jennings, P., and Harris, A. (2013). Birds of Radnorshire. London: Ficedula Books.
Ornithological Literature	Blaen Llia (1867 AD)	Powys	GE (k) Adult	Pritchard, R. (2012). Birds of Merionydd. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Caernarfon (1789 AD)	Gwynedd	GE (k) Breeding	Pennant, T. (1778) A Tour in Wales. London: Henry Hughes and Son Limited
Ornithological Literature	Carnedd Llewelyn	Gwynedd	GE (k) Breeding	Johnson, Thomas (1644). Dictionary of National Biography, edited by Sidney Lee. London: Smith, Elder & Co. 30: 47–48.
Ornithological Literature	Clocaenog (1688 AD)	Clwyd	GE (k)	Bewick, T., Beilby, R., Cotes, H. et al. (1885) A History of British Birds. London, pp. 17-20.
Ornithological Literature	Clyne Woods (1817 AD)	West Glamorgan	WTE (k)	Saunders, D. (1974). A Guide to the Birds of Wales.London: Constable.
Ornithological Literature	Coed-y-prior (1885 AD)	Gwent	GE (k)	Venables, W.A. et al. (2008). Birds of Gwent. Newport: Gwent Ornithological Society.
Ornithological Literature	Coed-y-prior (1985 AD)	Gwent	GE (k) Juvenile	Tyler, S. et al. (1987). The Gwent Atlas of Breeding Birds. Newport: Gwent Ornithological Society.
Ornithological Literature	Cors Caron (1890 AD)	Dyfed	GE (k)	Lovergrove, R. et al. (2010). Birds on Wales. London: Poyser, pp. 56-84
Ornithological Literature	Craig yr Aderyn (1880 AD)	Gwynedd	WTE (k)	Jones, H.P. (1974). Birds of Merioneth. Cambria: Cambria Ornithological Society.
Ornithological Literature	Crogen (1863 AD)	Gwynedd	WTE (K) Juvenile	Pritchard, R. (2012). Birds of Merionydd. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Cwm Bychan (1909 AD)	Gwynedd	GE (k)	Lovergrove, R. et al. (2010). Birds on Wales. Poyser, pp. 56-84
Ornithological Literature	Dinas (1907 AD)	Gwynedd	WTE (k)	Ingram, G.C.S., Salmon, H.M., and Condry, W.M. (1966). The birds of Cardiganshire. Bridgend: West Wales Naturalists' Trust.
Ornithological Literature	Foel (1965 AD)	Powys	GE (k)	Holt, B., and Williams, G. (2008). Birds of Montgomeryshire. Brayton Halt and Graham Williams.
Ornithological Literature	Glyder Fawr (1639 AD)	Gwynedd	GE (k)	Matheson (1932) Changes in the Fauna of Wales, p.53; Foster Evans (2006) 'Cyngor y Bioden', pp.52-3.
Ornithological Literature	Kenfig Burrows (1816 AD)	West Glamorgan	WTE (k)	Hurford, C. and Lansdown, P (1995) The Birds of Glamorgan. D. Brown & Sons Ltd, pp. 61--68.
Ornithological Literature	Kenfig Burrows (1816 AD)	West Glamorgan	WTE (k) x2	Hurford, C., and Lansdown, P. (1995) Birds of Glamorgan. Cardiff: Department of Zoology, National Museum of Wales.
Ornithological Literature	Kenfig Burrows (1818 AD)	West Glamorgan	WTE (k) x2	Heathcote, A., Griffin, D., & H. L. Salmon (1967). The birds of Glamorgan. Cardiff: Cardiff Naturalist Society.
Ornithological Literature	Landrillo (1862 AD)	Gwynedd	WTE (k)	Hope, P. and Dave, P. (1976) Birds of Caernarfonshire. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Llandderfel (1990 AD)	Gwynedd	WTE (k)	Pritchard, R. (2012). Birds of Meirionnydd. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Llangollen Dinas Bran (1540AD)	Clwyd	GE (k) Breeding	Forrest, H. E. 1907. The Vertebrate Fauna of North Wales. London: Witherby & Co.
Ornithological Literature	Llangower (1889 AD)	Gwynedd	WTE (k) Adult	Hope, P. and Dave, P. (1976) Birds of Caernarfonshire. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Llangower (1899 AD)	Gwynedd	WTE (k)	Jones, E.B., and Thomas, G.E. (1976). Birdwatching in Snowdonia. Cardiff: John Jones.
Ornithological Literature	Llanuwchllyn (1823 AD)	Gwynedd	GE (k)	Jones, P.H. (1974). Birds of Merioneth. Cambria: Cambrian Ornithological Society.

Appendix 1: Welsh Historic Eagle Records

Ornithological Literature	Llanuwchllyn (1867 AD)	Gwynedd	GE (k)	Jones, P.H. (1974). Birds of Merioneth. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Llyn Conwy (1832 AD)	Gwynedd	GE (k)	Jones, H.P. (1974). Birds of Merioneth. Cambria: Cambria Ornithological Society.
Ornithological Literature	Llyn Cwm Bychan (1909 AD)	Gwynedd	GE (k)	Forrest, H. E. 1907. The Vertebrate Fauna of North Wales. London: Witherby & Co.
Ornithological Literature	Llyn Peninsula (1910 AD)	Gwynedd	WTE (k)	Lovergrove, R. et al. (2010). Birds on Wales. Poyser, pp. 56-84
Ornithological Literature	Llynnau Mymbyr (1900 AD)	Gwynedd	GE (p)	Pritchard, R. (2012). Birds of Meirionnydd. Cambria: Cambrian Ornithological Society.
Ornithological Literature	Margam (1810 AD)	West Glamorgan	WTE (k)	Hurford, C. and Lansdown, P (1995) The Birds of Glamorgan. D. Brown & Sons, pp. 61--68.
Ornithological Literature	Margam (1825 AD)	West Glamorgan	WTE (k)	Hurford, C., and Lansdown, P. (1995) Birds of Glamorgan. Cardiff: Department of Zoology, National Museum of Wales.
Ornithological Literature	Margam (1828 AD)	West Glamorgan	WTE (k)	Heathcote, A., Griffin, D., & H. L. Salmon (1967). The birds of Glamorgan. Cardiff Naturalist Society
Ornithological Literature	Margam (1828 AD)	West Glamorgan	WTE (k)	Hurford, C. and Lansdown, P (1995) The Birds of Glamorgan. D. Brown & Sons, pp. 61--68.
Ornithological Literature	Margam (1831 AD)	West Glamorgan	WTE (k)	Hurford, C., and Lansdown, P. (1995) Birds of Glamorgan. Cardiff: Department of Zoology, National Museum of Wales.
Ornithological Literature	Margam (1839 AD)	West Glamorgan	WTE (k)	Hurford, C., and Lansdown, P. (1995) Birds of Glamorgan. Cardiff: Department of Zoology, National Museum of Wales.
Ornithological Literature	Margam (1840 AD)	West Glamorgan	WTE (k)	Saunders, D. (1974). A Guide to the Birds of Wales. London: Constable.
Ornithological Literature	Margam (1859 AD)	West Glamorgan	WTE (k)	Hurford, C., and Lansdown, P. (1995) Birds of Glamorgan. Cardiff: Department of Zoology, National Museum of Wales.
Ornithological Literature	Margam (1860)	West Glamorgan	WTE (k)	Jones, R (1977). Birds of the Welsh coast. Norwich: Jarrold Colour Publications.
Ornithological Literature	Montgomerys (1887 AD)	Powys	GE (k)	Mullens, W.H. et al. (1919). A Geographical Bibliography of British ornithology. London: Witherby.
Ornithological Literature	Neath Port Talbort (1938 AD)	West Glamorgan	WTE (p)	Heathcote, A., Griffin, D., & H. L. Salmon (1967). The birds of Glamorgan. Cardiff: Cardiff Naturalist Society.
Ornithological Literature	Nefyn (1880 AD)	Gwynedd	GE (p)	Jones, H.P. (1974). Birds of Merioneth. Cambria: Cambria Ornithological Society.
Ornithological Literature	Newton (1833 AD)	West Glamorgan	WTE (k)	Hurford, C. and Lansdown, P (1995) The Birds of Glamorgan. D. Brown & Sons, pp. 61--68.
Ornithological Literature	Pentir Pumlumon (1887 AD)	Dyfed	WTE (k)	Holt, B., and Williams, G. (2008). Birds of Montgomeryshire. Brayton Halt and Graham Williams.
Ornithological Literature	Preton/Slebech (1851 AD)	Dyfed	WTE (k)	Mullens, W.H. et al. (1919). A Geographical Bibliography of British ornithology. London: Witherby.
Ornithological Literature	Snowdon (1677 AD)	Gwynedd	GE (k) Breeding	Bolam, G. 1913. Wildlife in Wales. London: Frank Palmer.
Ornithological Literature	Snowdon National Park (1676 AD)	Gwynedd	GE (k)	Forrest, H. E. 1907. The Vertebrate Fauna of North Wales. London: Witherby & Co.
Ornithological Literature	Snowdon National Park (1800 AD)	Gwynedd	GE (k) Breeding	Evans, G. (1974). History of Wales: Gwynfor Evans Tells the Story of his Country. Cardiff: South Wales Echo.
Ornithological Literature	Tap y Gigfran	Powys	GE (k)	Pritchard, R. (2012). Birds of Meirionnydd. Cambrian Ornithological Society.
Ornithological Literature	Trawsfynydd (1865 AD)	Gwynedd	GE (k) Juvenile	Jones, E.B., and Thomas, G.E. (1976). Birdwatching in Snowdonia. Cardiff: John Jones.
Ornithological Literature	Tre'r-ddol (1865 AD)	Dyfed	GE (k) Juvenile	Lovergrove, R. et al. (2010). Birds on Wales. Poyser, pp. 56-84
Ornithological Literature	Tretwr (1838 AD)	Powys	GE (k)	Lovergrove, R. et al. (2010). Birds on Wales. Poyser, pp. 56-84
Ornithological Literature	Wentwood Forest (1881 AD)	Gwent	WTE (k)	Cramp. S. et al. (1982). British Birds: Volume 75. London: National History Museum Library.
Persecution Record	Abersoch (1810 AD)	Gwynedd	WTE (k) Killed	Hope, P. and Dave, P. (1976) Birds of Caernarfonshire. Cambria: Cambrian Ornithological Society.
Persecution Record	Bangor (1884 AD)	Gwynedd	GE (k)	https://newspapers.library.wales/view/3026425/3026428/33/
Persecution Record	Bodorgan (1838 AD)	Isle of Anglesey	WTE (p)	https://newspapers.library.wales/view/3393090/3393094/43/
Persecution Record	Bodorgan (1839 AD)	Isle of Anglesey	GE (k)	https://newspapers.library.wales/view/4461790/4461793/21/
Persecution Record	Cwm Malog (1828 AD)	West Glamorgan	WTE (k) Shot	https://newspapers.library.wales/view/3391059/3391060/3/
Persecution Record	Eglwyswrw (1908 AD)	Dyfed	GE (k) Shot	https://newspapers.library.wales/view/4185796/4185798/28/
Persecution Record	Glyder Fawr (1886 AD)	Gwynedd	GE (k) x 2	https://newspapers.library.wales/view/4452749/4452754/32/
Persecution Record	Gorddinog (1804 AD)	Gwynedd	GE (k)	https://newspapers.library.wales/view/4452749/4452754/32/
Persecution Record	Holyhead Harbour (1822 AD)	Isle of Anglesey	WTE (k)	https://newspapers.library.wales/view/3677796/3677799/16/
Persecution Record	Kenfig (1816 AD)	Mid Glamorgan	WTE (k) Breeding	https://newspapers.library.wales/view/3794505/3794508/19/

Persecution Record	Llanelli (1908 AD)	Dyfed	GE (k) Killed	Ingram, G.C.S., Salmon, H.M., and Condry, W.M. (1966). The birds of Cardiganshire. Bridgend: West Wales Naturalists' Trust.
Persecution Record	Llanelli (1908 AD)	Dyfed	GE (k) Shot	https://newspapers.library.wales/view/4195305/4195307/22/
Persecution Record	Llansanwr (1779 AD)	South Glamorgan	GE (k) Killed	Phillips, E. Cambridge. 1899. The Birds of Breconshire. Brecon: Edwin Davies
Persecution Record	Llanwern (1898 AD)	Gwent	GE (p)	https://newspapers.library.wales/view/3426388/3426392/95/
Persecution Record	Llyn peninsula (1910 AD)	Gwynedd	GE (k) Shot	https://newspapers.library.wales/view/4226260/4226262/55/
Persecution Record	Nant Ffrancon (1886 AD)	Gwynedd	GE (k) x 2	https://newspapers.library.wales/view/4452749/4452754/32/
Persecution Record	Neath (1884 AD)	Mid Glamorgan	WTE (k)	https://newspapers.library.wales/view/3026425/3026428/33/
Persecution Record	Newport (1896 AD)	Gwynedd	WTE (p) Shot	https://newspapers.library.wales/view/3426388/3426392/95/
Persecution Record	Penbont (1859 AD)	Powys	GE (k) Young eagle killed	Phillips, E. Cambridge. 1899. The Birds of Breconshire. Brecon: Edwin Davies.
Persecution Record	Plynlimon (1887 AD)	Dyfed	GE (k) Shot	https://newspapers.library.wales/view/4408986/4408988/25/
Persecution Record	Snowdon National Park (1822 AD)	Gwynedd	GE (p)	https://newspapers.library.wales/view/3325080/3325084/18/
Persecution Record	Talacre (1810 AD)	Clwyd	WTE (k) Shot	https://newspapers.library.wales/view/3784538/3784546/97/
Persecution Record	Talacre (1884 AD)	Clwyd	WTE (k) Shot	https://newspapers.library.wales/view/3784538/3784546/197/
Persecution Record	Whitechurch (1829 AD)	Gwent	WTE (k) Killed	Donovan, J., & Rees, G (1994). Birds of Pembrokeshire: status and atlas of Pembrokeshire birds. Pembrokeshire: Dyfed Wildlife Trust
Place-name Records				
Record type	**Name**	**County**	**Species** (k: known or p: predicted)	**Reference**
Place-name Record	Allt yr Eryr (1564 AD)	Dyfed	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Allt yr Eryr (1599 AD)	Dyfed	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Allt yr Eryr (1838 AD)	Powys	GE (p)	Archwilio & Place-name Research Centre: Archif Melville Richards
Place-name Record	Allt-pant-eryrod (1134 AD)	Dyfed	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Bryn Eryr (1564 AD)	Dyfed	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn Eryr (800 BC)	Isle of Anglesey	WTE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Bryn Eryr (1637 AD)	Isle of Anglesey	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn Eryr (1668 AD)	Isle of Anglesey	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn Eryr (1751 AD)	Isle of Anglesey	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn Eryr (1776 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn Eryr (1805 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn Eryr (1805 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Bryn yr Eryr (1838 AD)	Clwyd	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Bryn-yr-eryr (1539 AD)	Clwyd	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Cae Carreg Yr Eryr (1840 AD)	Isle of Anglesey	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Cae Eryrych (1840 AD)	Mid Glamorgan	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Carreg Yr Eryr (1602 AD)	Gwynedd	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Carreg Yr Eryr (1898 AD)	Gwynedd	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Cefin-cwmeryr (1891 AD)	Powys	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Cefn-Yr-Eryr (1838 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Cefn-Yr-Eryr (1849 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Cefn-Yr-Eryr (1879 AD)	Gwynedd	GE (p)	Archwilio: The Historic Environmental Records of Wales

Appendix 1: Welsh Historic Eagle Records

Place-name Record	Clogwyn'r Eryr (411 AD)	Gwynedd	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Coed Cwmeryr (1898 AD)	Powys	GE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Coed Eryr (1899 AD)	Gwynedd	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Coed Garth-Eryr (1898 AD)	Powys	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Craig-yr-eryr (1889 AD)	Dyfed	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Crug Eryr (1535 AD)	Dyfed	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Crug Eryr (1191 AD)	Powys	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Crugerydd (1744 AD)	Powys	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Crug-yr-eryr-isaf (1889 AD)	Dyfed	GE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Cwm Eryr (1836 AD)	Powys	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Cwmeryr-mawr (1539 AD)	Powys	WTE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Cwm-pant-eryod (1876 AD)	Dyfed	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Eryri (1840)	Isle of Anglesey	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Ffridd Carreg Eryr (1602 AD)	Gwynedd	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Ffridd Cefn Yr Eyry (1614 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Ffynnon Moel Eryr (1700 AD)	Clwyd	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Foel Eryr (411 AD)	Dyfed	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Garth yr eryr (1591 AD)	Clwyd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Gartheryr (1599 AD)	Dyfed	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Graig Eryrod (1838 AD)	Clwyd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Gwaun Yr Eryr (1810 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Llanerch-yr-eryr (1539 AD)	Gwynedd	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Llanerch-yr-eryr (1874)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Llyn-Yr-Eryr (1838 AD)	Gwynedd	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Moel Erydd (1839 AD)	Clwyd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Moel Graig Eryr (1631 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Nant Eryr (1700 AD)	Dyfed	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Nant-yr-Eryr (1603 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Nant-yr-Eryr (1539 AD)	Powys	GE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Nant-yr-Eryr (1552 AD)	Powys	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Pant Eryrod (1534 AD)	Dyfed	WTE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Pant Eryrod (1837 AD)	Dyfed	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Pen Allt yr Eryr (1651 AD)	Dyfed	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Pen Graig ty Eryr (1697 AD)	Clwyd	WTE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Pen yr Eryr (1838 AD)	Clwyd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Pen-yr-Eryr (1539 AD)	Gwynedd	GE (p)	Place-name Research Centre: Archif Melville Richards
Place-name Record	Tal Eryr (1539 AD)	Gwynedd	WTE (p)	Archwilio: The Historic Environmental Records of Wales
Place-name Record	Tap Nyth-yr-eryr (1889 AD)	Gwynedd	GE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Trwyn Cerig-yr-eryr (1868 AD)	Isle of Anglesey	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names

Place-name Record	Tryn-yr-eryrod (1689 AD)	Powys	WTE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Twr yr Eryr (1839 AD)	Gwynedd	GE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	Twyn-yr-eryod (1604 AD)	Mid Glamorgan	GE (p)	Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names
Place-name Record	*Crug-Yr-Eryr Wollen Factory (1865 AD)*	*Gwynedd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Cymmeryr-Bach Quarry (1765 AD)*	*Powys*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Cymeryr Mawr Well (1506 AD)*	*Clwyd*	*Not Included*	*Place-name Research Centre: Archif Melville Richards*
Place-name Record	*Eagle Tower (1643 AD)*	*Gwynedd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Llanercheryr Well (1832 AD)*	*Dyfed*	*Not Included*	*Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names*
Place-name Record	*Eryrys Mine (2001)*	*Powys*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Bryn Eryr Settlement (1804 AD)*	*Gwynedd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Eryrys Church (1862 AD)*	*Clwyd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Coed Eryr Enclosure (1999 AD)*	*Gwynedd*	*Not Included*	*Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names*
Place-name Record	*Cwmeryr Bach House (1872 AD)*	*Powys*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Yr Eryr House (1887 AD)*	*Gwynedd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Pen-yr-Eryr Trackway (1800 AD)*	*Clwyd*	*Not Included*	*Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names*
Place-name Record	*Cwmeryr Pond (1891 AD)*	*Powys*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Nant-yr-Eryr Fishpond (1997)*	*Powys*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Eryrs Hill Cave*	*Clwyd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*
Place-name Record	*Nant-yr-Eryr Quarry (1994 AD)*	*Gwynedd*	*Not Included*	*Rhestr o Enwau Lloedd Hanesyddol (RCAHMW): List of Historic Place-names*
Place-name Record	*Gartheryr House (1998 AD)*	*Gwynedd*	*Not Included*	*Archwilio: The Historic Environmental Records of Wales*

Archaeological Records

Record type	Name	County	Species (k: known or p: predicted)	Reference
Archaeological record	Caerleon Well	Gwent	WTE (k)	Zienkiewicz, J.D. (1993) Excavations in the Scamnum Tribunorum at Caerleon: The Legionary Museum Site 1983-5. Britannia XXIV (1993), 135
Archaeological record	Cat Hole Cave	West Glamorgan	GE (k)	Harrison 1980: A Re-examination of British Devensian and Earlier Holocene Bird Bones in the British Museum (Natural History). Journal of archaeol-ogical Science. 7, pp 53-68
Archaeological record	Port Eynon Cave	West Glamorgan	WTE (k)	Harrison 1987: Pleistocene and prehistoric birds of south-west Britain. Proc. Univ. Bristol Spelaeol. Soc. 18, pp. 81-104.
Archaeological record	Longbury Bank Cave	Dyfed	WTE (k)	Bell, A. 1915. Pleistocene and later birds of Great Britain and Ireland. Zoologist. 19, pp 401–412. & Tyrberg, T. 1998. Pleistocene Birds of the Palearctic: a catalogue. Nuttall Ornithological Club, Cambridge.
Archaeological record	Perthi-Chwarau Farm Cave	Clwyd	GE (k)	Bramwell, D. 1960. Some research into bird distribution in Britain during the Late Glacial and Post-glacial periods. Bird Report of Merseyside Naturalists Association: 51–58
Archaeological record	Pontnewydd Cave	Clwyd	GE (k)	Adlhouse-Green, S., Peterson, R., and Walker, E.A (2012) Neanderthals in Wales: Pontnewydd and the Elwy Valley Caves. Oxford Books.
Archaeological record	Coygan Cave	Dyfed	GE (k)	Lovergrove, R. et al. (2010). Birds on Wales. Poyser, pp. 56-92
Archaeological record	Segontium Fort	Gwynedd	WTE (k)	Mulkeen, S., & O'Connor, T. P. 1997. Raptors in towns: towards an ecological model. International Journal of Osteoarchaeology 7: 440–449.

Appendix 2

The Habitat Associations of Breeding Avian Mesopredators in Wales.

Table A2: The abundance of observations within habitat types across Wales for the Hen Harrier, Common Buzzard, Peregrine Falcon, Osprey and Red Kite; in relation to the proportion of habitats available across the Welsh landscape.

Hen Harrier, Hen Tinwyn (*Circus cyaneus*)						
Habitat	**No. Observations**	**Null**	**Lower 95% CI**	**Upper 95% CI**	**Test**	**SES**
Arable land	0	/	/	/	/	/
Bare rock	6	0.98	0.08	2.59	Stronger	7.34
Beaches, dunes & sands	4	1.30	0.20	3.11	Stronger	3.39
Broad-leaved forests	2	8.82	5.34	13.45	Weaker	-2.94
Coastal lagoons	0	/	/	/	/	/
Conifer forests	1	19.36	14.53	25.36	Weaker	-5.58
Estuaries	0	/	/	/	/	/
Heterogeneous agricultural areas	2	28.67	22.63	34.94	Weaker	-8.57
Inland marshes	17	1.01	0.06	2.50	Stronger	22.04
Intertidal flats	0	/	/	/	/	/
Mixed forests	1	11.70	7.52	16.48	Weaker	-4.51
Moors and heathland	121	28.54	20.96	34.86	Stronger	24.88
Natural grassland	44	42.60	34.83	50.29	ns	0.32
Pastures	12	184.02	169.64	197.65	Weaker	-23.45
Peat bog	139	9.45	6.18	13.61	Stronger	66.15
Salt marsh	0	/	/	/	/	/
Scrub and herbaceous vegetation	14	6.68	3.45	9.91	Stronger	4.12
Sea and ocean	0	/	/	/	/	/
Sparsely vegetated areas	6	4.00	1.23	7.23	ns	1.23
Urban	0	/	/	/	/	/
Waterbodies	1	0.89	0.03	2.34	ns	0.16
Watercourses	0	/	/	/	/	/
Common Buzzard, Bwncath Gyffredin (*Buteo buteo*)						
Habitat	**No. Observations**	**Null**	**Lower 95% CI**	**Upper 95% CI**	**Test**	**SES**
Arable land	1110	495.35	471.55	532.03	Stronger	40.02
Bare rock	5	13.17	8.71	18.74	Weaker	-2.89
Beaches, dunes & sands	44	19.23	14.45	27.51	Stronger	7.61
Broad-leaved forests	130	119.18	106.39	133.54	ns	1.55
Coastal lagoons	21	3.04	1.26	5.39	Stronger	16.06
Conifer forests	274	283.24	264.55	305.25	ns	-0.82
Estuaries	4	10.32	5.23	14.32	Weaker	-2.67
Heterogeneous agricultural areas	415	395.54	369.81	418.61	ns	1.50

Inland marshes	15	15.50	10.61	21.19	ns	-0.18
Intertidal flats	49	51.51	41.68	63.29	ns	-0.46
Mixed forests	109	160.88	143.20	179.91	Weaker	-5.17
Moors and heathland	372	390.26	367.66	415.46	ns	-1.32
Natural grassland	392	590.54	562.99	620.05	Weaker	-12.86
Pastures	1323	2545.16	2490.13	2594.88	Weaker	-42.69
Peat bog	29	132.34	119.75	147.03	Weaker	-12.96
Salt marsh	16	21.70	16.53	27.18	Weaker	-2.01
Scrub and herbaceous vegetation	86	87.01	75.44	101.49	Ns	-0.14
Sea and ocean	1	22.04	16.34	27.40	Weaker	-6.78
Sparsely vegetated areas	105	52.37	44.74	61.39	Stronger	11.12
Urban	1192	312.15	287.63	331.38	Stronger	71.03
Waterbodies	38	11.38	6.38	15.85	Stronger	10.70
Watercourses	8	6.08	3.25	9.91	ns	1.16

Peregrine Falcon, Hebog Tramor (*Falco peregrinus*)

Habitat	No. Observations	Null	Lower 95% CI	Upper 95% CI	Test	SES
Arable land	286	139.10	123.80	152.79	Stronger	20.18
Bare rock	1	3.65	0.85	6.11	ns	-1.94
Beaches, dunes & sands	12	5.46	2.64	9.39	Stronger	3.74
Broad-leaved forests	17	33.40	26.76	41.56	Weaker	-4.14
Coastal lagoons	9	0.82	0.03	2.30	Stronger	12.82
Conifer forests	76	78.28	67.16	91.21	ns	-0.40
Estuaries	4	2.85	0.89	5.24	ns	0.94
Heterogeneous agricultural areas	94	11.15	97.38	123.48	Weaker	-2.19
Inland marshes	14	4.26	1.72	7.25	Stronger	6.31
Intertidal flats	55	14.23	9.73	20.79	Stronger	15.08
Mixed forests	16	45.01	35.21	56.32	Weaker	-5.51
Moors and heathland	107	109.24	94.59	124.15	ns	-0.31
Natural grassland	127	165.56	150.61	182.83	Weaker	-4.20
Pastures	213	712.56	682.33	737.26	Weaker	-35.57
Peat bog	12	36.68	28.60	44.57	Weaker	-5.57
Salt marsh	84	6.17	3.34	9.18	Stronger	48.86
Scrub and herbaceous vegetation	22	24.59	18.85	31.45	ns	-0.76
Sea and ocean	57	6.29	3.07	10.11	Stronger	27.72
Sparsely vegetated areas	18	14.88	9.80	19.49	ns	1.21
Urban	368	87.86	74.77	99.57	Stronger	42.86
Waterbodies	11	3.24	1.09	5.63	Stronger	6.57
Watercourses	3	1.75	0.37	3.41	ns	1.45

Osprey, Gweilch (*Pandion haliaetus*)

Habitat	No. Observations	Null	Lower 95% CI	Upper 95% CI	Test	SES
Arable land	0	/	/	/	/	/
Bare rock	0	/	/	/	/	/
Beaches, dunes & sands	0	/	/	/	/	/
Broad-leaved forests	13	12.86	8.16	17.55	ns	0.05
Coastal lagoons	0	/	/	/	/	/
Conifer forests	4	31.81	24.11	40.21	Weaker	-6.80
Estuaries	0	/	/	/	/	/
Heterogeneous agricultural areas	227	44.68	35.89	54.09	Stronger	39.19
Inland marshes	1	1.66	0.42	3.39	ns	-0.79
Intertidal flats	14	5.83	3.06	9.59	Stronger	4.93
Mixed forests	2	17.80	12.63	24.54	Weaker	-5.35

Moors and heathland	21	25.28	35.00	54.53	Weaker	-5.07
Natural grassland	35	66.58	55.40	76.86	Weaker	-5.64
Pastures	214	289.40	272.76	308.39	Weaker	-8.01
Peat bog	1	15.03	9.72	20.46	Weaker	-5.25
Salt marsh	312.	2.70	1.27	4.89	Stronger	27.11
Scrub and herbaceous vegetation	2	10.27	6.10	14.82	Weaker	-3.72
Sea and ocean	5	2.40	0.65	4.73	Stronger	2.26
Sparsely vegetated areas	4	6.12	3.21	9.09	ns	-1.21
Urban	8	35.79	27.53	44.40	Weaker	-6.28
Waterbodies	0	/	/	/	/	/
Watercourses		0.76	0.03	2.15	Stronger	10.20

Red Kite, Barcud Coch (*Milvus milvus*)

Habitat	No. Observations	Null	Lower 95% CI	Upper 95% CI	Test	SES
Arable land	160	234.09	209.54	250.05	Weaker	-6.97
Bare rock	3	6.24	3.60	9.72	Weaker	-1.96
Beaches, dunes & sands	8	9.15	5.67	14.21	ns	-0.54
Broad-leaved forests	37	56.98	43.99	86.94	Weaker	-3.41
Coastal lagoons	6	1.47	0.28	3.24	Stronger	5.50
Conifer forests	141	133.08	116.36	150.30	ns	0.95
Estuaries	0	/	/	/	/	/
Heterogeneous agricultural areas	315	186.21	169.90	203.80	Stronger	14.02
Inland marshes	11	7.16	4.12	10.93	Stronger	2.17
Intertidal flats	15	23.74	18.24	30.66	Weaker	-2.76
Mixed forests	57	74.73	64.19	87.41	Weaker	-2.53
Moors and heathland	172	184.58	166.81	204.72	ns	-1.25
Natural grassland	348	276.84	253.79	297.31	Stronger	6.08
Pastures	928	1201.11	1174.29	1235.59	Weaker	-14.95
Peat bog	71	62.51	52.18	73.02	ns	1.44
Salt marsh	78	10.55	6.47	14.61	Stronger	28.31
Scrub and herbaceous vegetation	16	41.39	33.45	50.47	Weaker	-5.46
Sea and ocean	2	10.44	6.61	14.73	Weaker	-3.58
Sparsely vegetated areas	11	24.52	18.58	33.62	Weaker	-3.59
Urban	298	145.97	130.58	160.63	Stronger	19.14
Waterbodies	19	5.17	2.55	8.36	Stronger	8.97
Watercourses	0	/	/	/	/	/

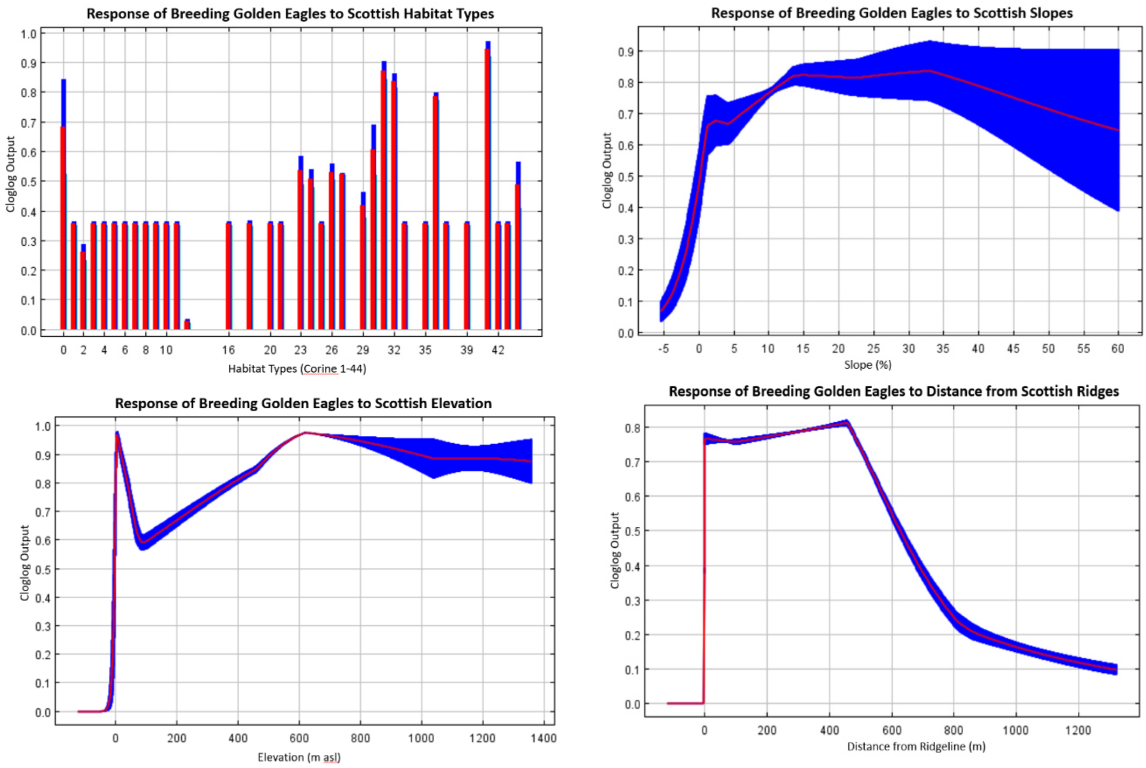
Appendix 3

Environmental Variables Influencing the Distribution of Breeding Golden Eagles in Britain.

Table A3: *The relative contributions of what environmental variables are contributing to fitting the Golden Eagle MAXENT model to assess suitable breeding areas across Britain.*

Species	Environmental variable	AUC	Percent contribution	Permutation importance
Golden Eagle	Habitat type	0.8	57.9	73.9
	elev	0.8	28.7	16.4
	rdge	0.6	9.1	3.9
	Slop	0.7	3.1	3.9
	aspt	0.7	1.2	1.9

Figure A3: *Response curves indicating how the four top environmental variables effect the Golden Eagle MAXENT model that were responsible for the projection of suitable breeding areas across Britain.*



Appendix 4

Descriptive Statistics of Environmental Variables within the Breeding Territories of Golden Eagles in Britain.

***Table A4:** Summary of the environmental variable descriptive statistical outputs that were incorporated into the Golden Eagle MAXENT model to assess suitable breeding areas across Britain.*

Environmental Variables	Predictor Description	Descriptive Stats	Breeding Outputs
elev	Elevation (m asl)	Minimum	0
		Maximum	620
		Mean	356
		Median	342
		Standard Deviation	245
slop	Slope (%)	Minimum	0
		Maximum	46.7
		Mean	10.6
		Median	8.7
		Standard Deviation	8.4
aspt	Slope aspect (˚)	Minimum	3.2
		Maximum	360
		Mean	192.6
		Median	177.9
		Standard Deviation	99
rdge	Distance from ridgeline (m)	Minimum	0
		Maximum	1124
		Mean	218.6
		Median	160.8
		Standard Deviation	226
Corine habitat types (%)			
Habitat Variables	**Habitat Description**	**Descriptive Stats**	**Breeding Outputs**
hab1	Artificial surfaces	n = %	1.5
hab2	Arable land	n = %	0.7
hab3	Pastures	n = %	10.9
hab4	Heterogeneous agricultural areas	n = %	0.2
hab5	Broad-leaved woodland	n = %	2.2
hab6	Coniferous forest	n = %	6.9
hab7	Mixed forest	n = %	0.0

hab8	Natural Grassland	n = %	9.6
hab9	Moors and heathland	n = %	13.7
hab10	Scrub and herbaceous areas	n = %	1.4
bab11	Beaches, dunes and sands	n = %	0.4
hab12	Bare rock	n = %	1.1
hab13	Open spaces with little vegetation	n = %	9.2
hab14	Inland marshes	n = %	0.0
hab15	Peat bogs	n = %	40.1
hab16	Salt marsh	n = %	0.0
hab17	Intertidal flats	n = %	0.1
hab18	Water courses	n = %	0.0
hab19	Waterbodies	n = %	1.7
hab20	Coastal lagoons	n = %	0.0
hab21	Estuaries	n = %	0.1
hab22	Marine waters	n = %	0.3

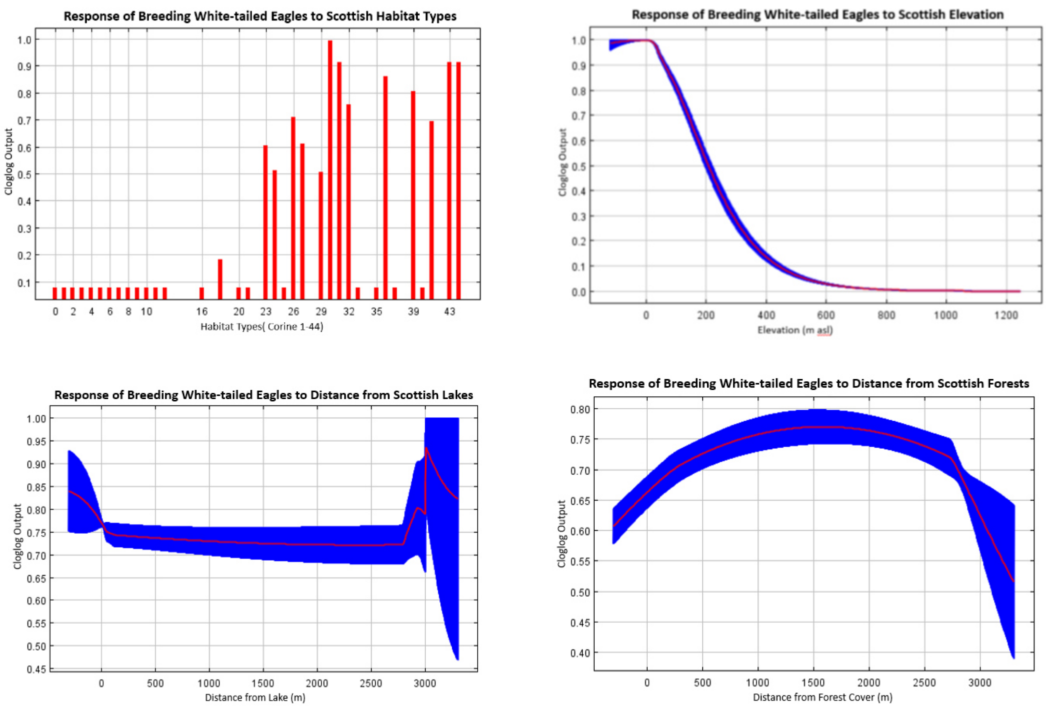
Appendix 5

Environmental Variables Influencing the Distribution of Breeding White-tailed Eagles in Britain.

Table A5: *The relative contributions of what environmental variables are contributing to fitting the White-tailed Eagle MAXENT model to assess suitable breeding areas across Britain.*

Species	Environmental variable	AUC	Percent contribution	Permutation importance
White-tailed Eagle	Habitat type	0.8	53.7	59.7
	elev	0.6	29.2	25.9
	coas	0.7	14.3	12.2
	frst	0.6	0.7	0.6
	aspt	0.5	0.5	0.5
	lake	0.5	0.9	0.6
	Slop	0.7	0.5	0.5

Figure A5: *Response curves indicating how the four top environmental variables effect the White-tailed Eagle MAXENT model that were responsible for the projection of suitable breeding areas across Britain.*



Appendix 6

Descriptive Statistics of Environmental Variables within the Breeding Territories of White-tailed Eagles in Britain.

Table A6: *Summary of the environmental variable descriptive statistical outputs that were incorporated into the White-tailed Eagle MAXENT model to assess suitable breeding areas across Britain.*

Environmental Variables	Predictor Description	Descriptive Stats	Breeding Territories
elev	Elevation (m asl)	Minimum	0
		Maximum	911
		Mean	124.6
		Median	72
		Standard Deviation	146.2
slop	Slope (%)	Minimum	0
		Maximum	46.7
		Mean	10.1
		Median	7.8
		Standard Deviation	9.4
aspt	Slope aspect (˚)	Minimum	2
		Maximum	360
		Mean	193.3
		Median	200.4
		Standard Deviation	102.8
lake	Distance from lake (m)	Minimum	0
		Maximum	3000
		Mean	431.6
		Median	0
		Standard Deviation	821.8
coas	Distance from Coast (m)	Minimum	0
		Maximum	3000
		Mean	700
		Median	0
		Standard Deviation	751.7
frst	Distance from Forest cover (m)	Minimum	0
		Maximum	2943.8
		Mean	629.1
		Median	100
		Standard Deviation	849.2
Corine habitat types (%)			

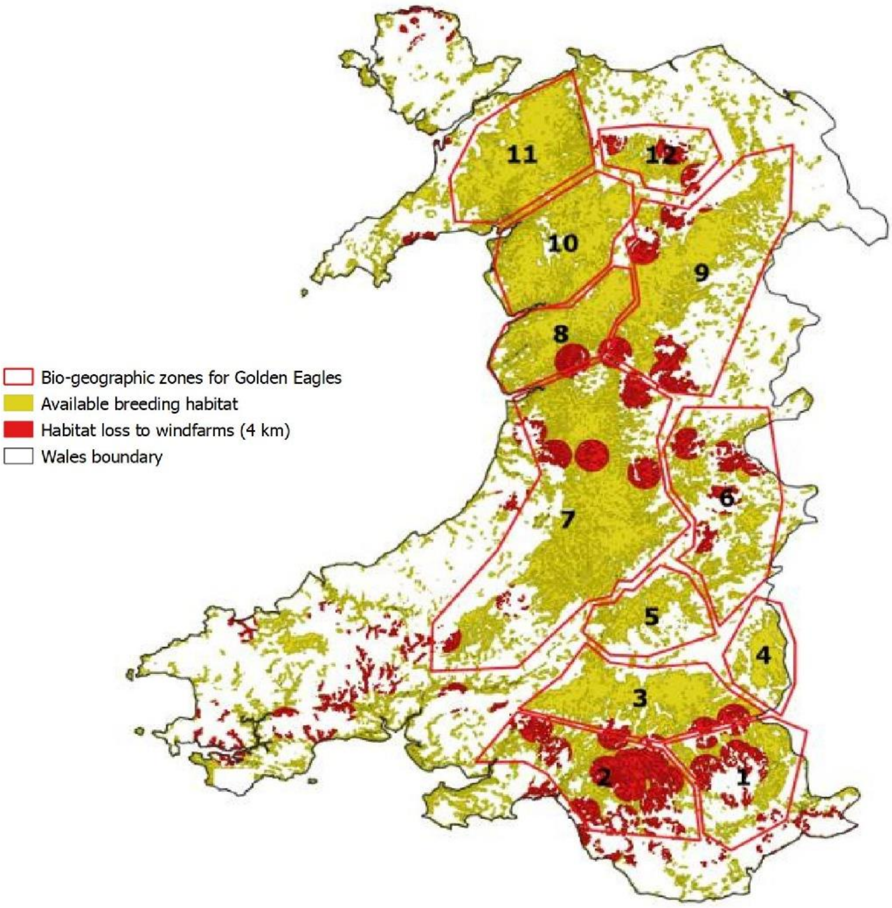
Appendix 6: White-tailed Eagle Breeding Territories

Habitat Variables	Habitat Description	Descriptive Stats	Breeding Territories
hab1	Artificial surfaces	n = %	0.3
hab2	Arable land	n = %	0.0
hab3	Pastures	n = %	2.5
hab4	Heterogeneous agricultural areas	n = %	0.0
hab5	Broad-leaved woodland	n = %	2.7
hab6	Coniferous forest	n = %	8.8
hab7	Mixed forest	n = %	0.0
hab8	Natural Grassland	n = %	9.9
hab9	Moors and heathland	n = %	9.1
hab10	Scrub and herbaceous areas	n = %	1.1
bab11	Beaches, dunes and sands	n = %	16.5
hab12	Bare rock	n = %	12.9
hab13	Open spaces with little vegetation	n = %	0.0
hab14	Inland marshes	n = %	0.0
hab15	Peat bogs	n = %	9.6
hab16	Salt marsh	n = %	0.0
hab17	Intertidal flats	n = %	6.0
hab18	Water courses	n = %	0.0
hab19	Waterbodies	n = %	4.1
hab20	Coastal lagoons	n = %	0.0
hab21	Estuaries	n = %	8.5
hab22	Marine waters	n = %	8.0

Appendix 7

The Predicted Loss of Golden Eagle Breeding Habitat from 4 km Buffers Representing Wind-turbine Displacement.

Figure A7: *The estimated loss of Golden Eagle breeding habitat attributed to the plausible displacement by modern-day Windfarms (4 km) across Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



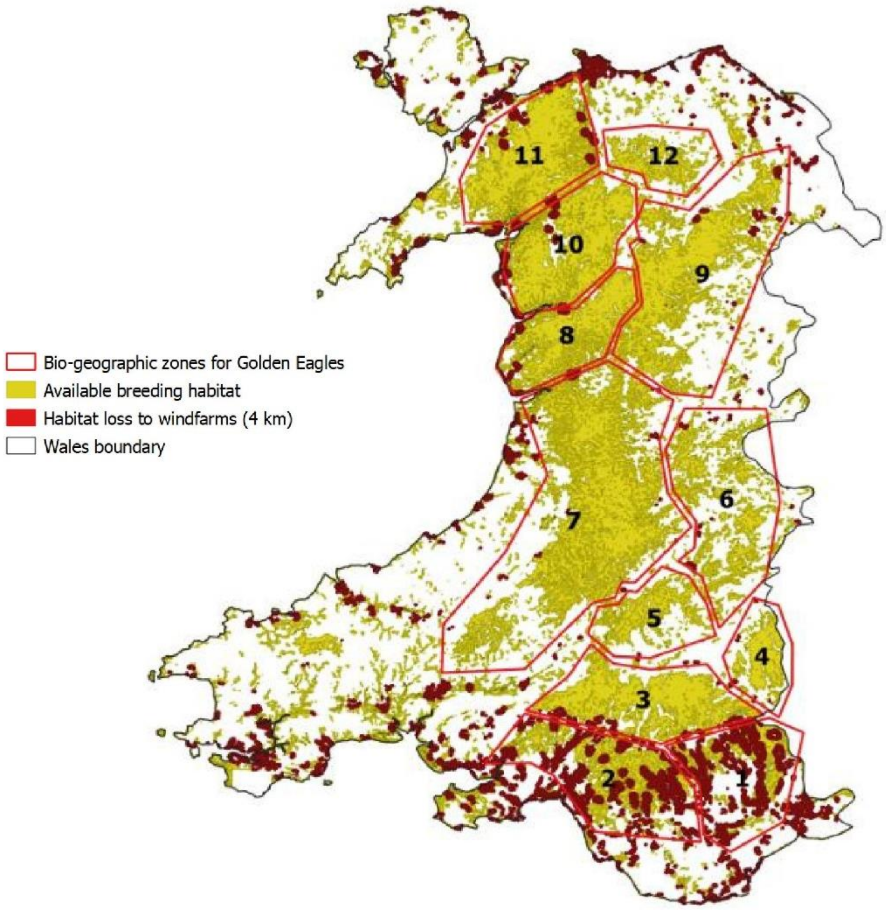
Golden Eagle Bio-geographic Zones and Habitat Loss to Windfarms in Wales:

	% loss to Windfarms	Windfarm loss rank		% loss to Windfarms	Windfarm loss rank
(1) – South Wales Valleys (East)	14.1	11	**(8)** – Lower Snowdonia National Park	6.0	7
(2) – South Wales Valleys (West)	32.3	13	**(9)** – Llangollen & Berwyn Mountains	9.3	9
(3) – Brecon Beacons National Park	5.3	6	**(10)** – Central Snowdonia National Park	0.0	1
(4) – Black Mountains	0.0	1	**(11)** – Upper Snowdonia National Park	0.0	1
(5) – Hay-on-Wye	0.0	1	**(12)** – Pentre-llyn-Cymmer	31.5	12
(6) – Radnor Forests	10.1	10	***(13)*** *– Other Lowland Areas*	2.5	5
(7) – Cambrian Mountains	6.7	8			

Appendix 8

The Predicted Loss of Golden Eagle Breeding Habitat from 1 km Buffers Representing Urban Area Displacement.

Figure A8: *The estimated loss of Golden Eagle breeding habitat attributed to the plausible displacement by modern-day urban areas (1 km) across Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



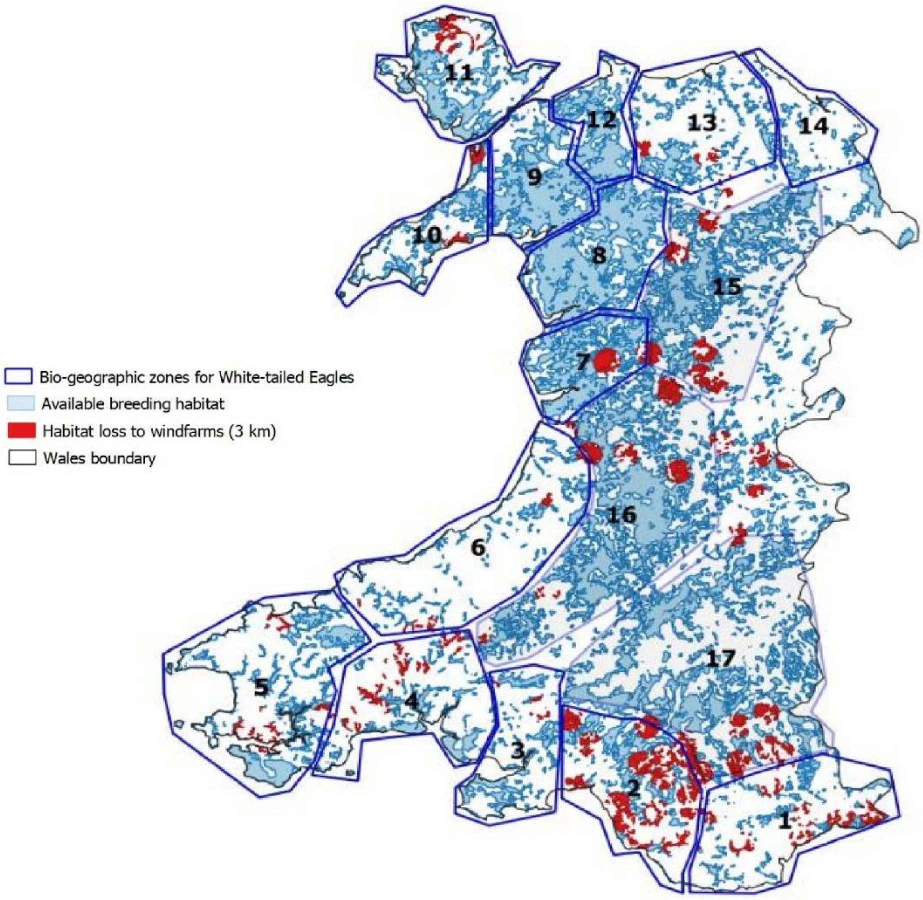
Golden Eagle Bio-geographic Zones and Habitat Loss to Urban Areas in Wales:

Zone	% loss To urban area	Urban loss rank	Zone	% loss To urban area	Urban loss rank
(1) – South Wales Valleys (East)	0.7	12	**(8)** – Lower Snowdonia National Park	0.1	8
(2) – South Wales Valleys (West)	0.5	11	**(9)** – Llangollen & Berwyn Mountains	0.0	7
(3) – Brecon Beacons National Park	0.1	9	**(10)** – Central Snowdonia National Park	0.0	6
(4) – Black Mountains	0.0	5	**(11)** – Upper Snowdonia National Park	0.1	10
(5) – Hay-on-Wye	0.0	1	**(12)** – Pentre-llyn-Cymmer	0.0	2
(6) – Radnor Forests	0.0	4	***(13)*** *– Other Lowland Areas*	5.8	13
(7) – Cambrian Mountains	0.0	3			

Appendix 9

The Predicted Loss of White-tailed Eagle Breeding Habitat from 3km Buffers Representing Wind-turbine Displacement.

***Figure A9:** The estimated loss of White-tailed Eagle breeding habitat attributed to the plausible displacement by modern-day wind-turbines (3 km) across Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



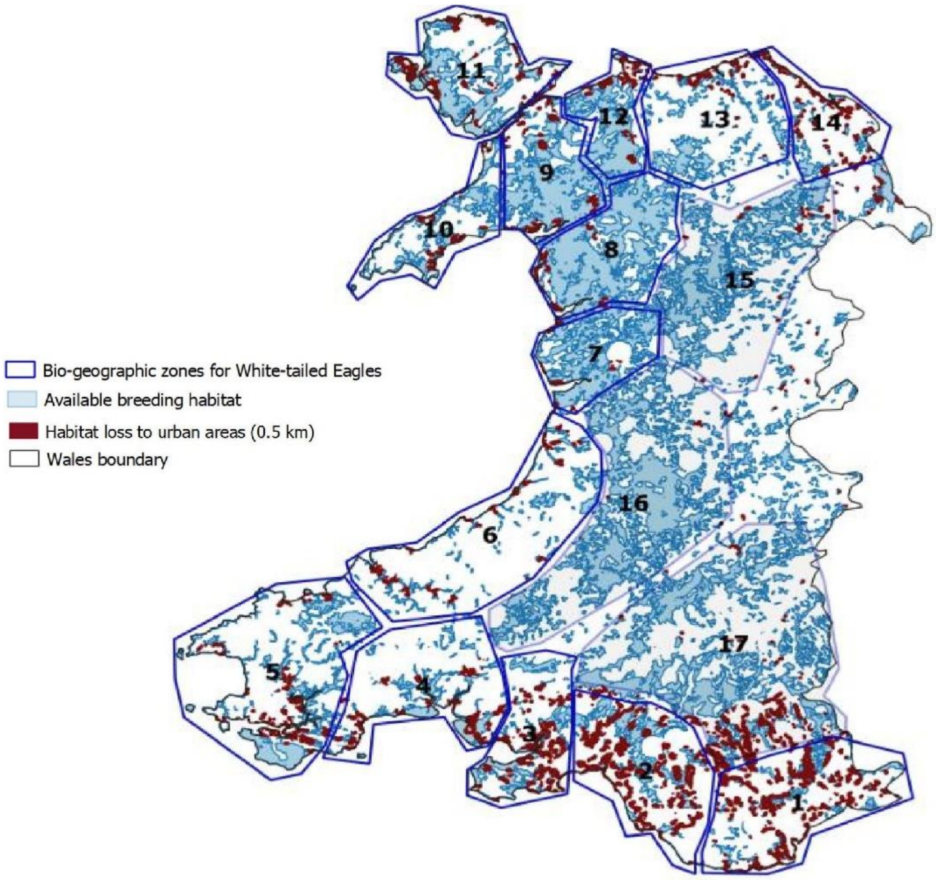
White-tailed Eagle Bio-geographic Zones and Habitat Loss to Windfarms in Wales:

Zone	% loss to windfarms	Windfarm Loss rank	Zone	% loss to windfarms	Windfarm Loss rank
(1) - The Severn Estuary	3.0	13	**(10)** - Llyn Peninsula	2.5	12
(2) - Swansea Bay & Afon Forests	13.0	17	**(11)** - Isle of Anglesey	2.3	10
(3) - The Gower Peninsula	0.5	5	**(12)** - Conwy Estuary & Gwydir Forests	0.0	3
(4) - Caerfyrddin Bay	2.3	9	**(13)** - Clwyd Estuary & Clocaenog Forests	1.2	8
(5) - Pembrokeshire National Park	0.9	7	**(14)** - Dee Estuary & Pen y Maes Woods	0.0	4
(6) - Ceredigion Bay	0.6	6	***(15)*** *- Y Berwyn National Reserve*	3.9	15
(7) - Dyfi Estuary & Dyfi Forests	5.1	16	***(16)*** *– Cambrian Mountains*	3.2	14
(8) - Mawddach Estuary & Coed y Brenin Forests	0.0	1	***(17)*** *- Brecon Beacons National Park*	2.4	11
(9) - Glaslyn Estuary & Snowdonia National Park	0.0	2			

Appendix 10

The Predicted Loss of White-tailed Eagle Breeding Habitat from 0.5 km Buffers Representing Urban Area displacement.

Figure A10: *The estimated loss of White-tailed Eagle breeding habitat attributed to the plausible displacement by modern-day urban areas (0.5 km) across Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



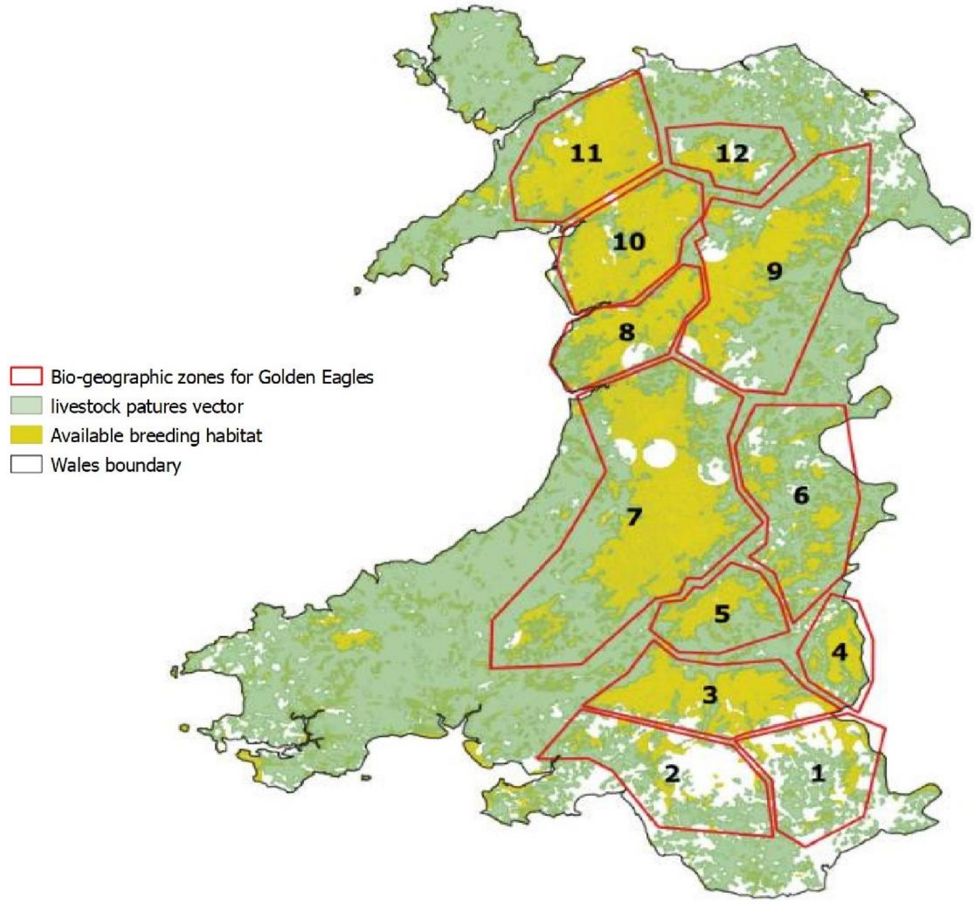
White-tailed Eagle Bio-geographic Zones and Habitat Loss to Urban Areas in Wales:

	% loss to Urban areas	*Urban Loss rank*		*% loss to Urban areas*	*Urban Loss rank*
(1) - The Severn Estuary	6.7	16	**(10) -** Llyn Peninsula	1.7	6
(2) - Swansea Bay & Afon Forests	10.0	17	**(11) -** Isle of Anglesey	5.1	14
(3) - The Gower Peninsula	6.5	15	**(12) -** Conwy Estuary & Gwydir Forests	2.5	8
(4) - Caerfyrddin Bay	2.9	10	**(13) -** Clwyd Estuary & Clocaenog Forests	1.5	4
(5) - Pembrokeshire National Park	1.6	5	**(14) -** Dee Estuary & Pen y Maes Woods	4.9	13
(6) - Ceredigion Bay	1.2	3	***(15) -*** *Y Berwyn National Reserve*	0.4	1
(7) - Dyfi Estuary & Dyfi Forests	4.0	12	***(16)*** *- Cambrian Mountains*	0.6	2
(8) - Mawddach Estuary & Coed y Brenin Forests	2.2	7	***(17) -*** *Brecon Beacons National Park*	2.8	9
(9) - Glaslyn Estuary & Snowdonia National Park	3.7	11			

Appendix 11

Golden Eagle Breeding Habitat and Livestock Pastures Across Wales.

Figure A11: *The proportion of livestock pastures across Golden Eagle bio-geographic breeding zones in Wales.; depicted by percentage habitat loss by bio-geographic breeding zones.*



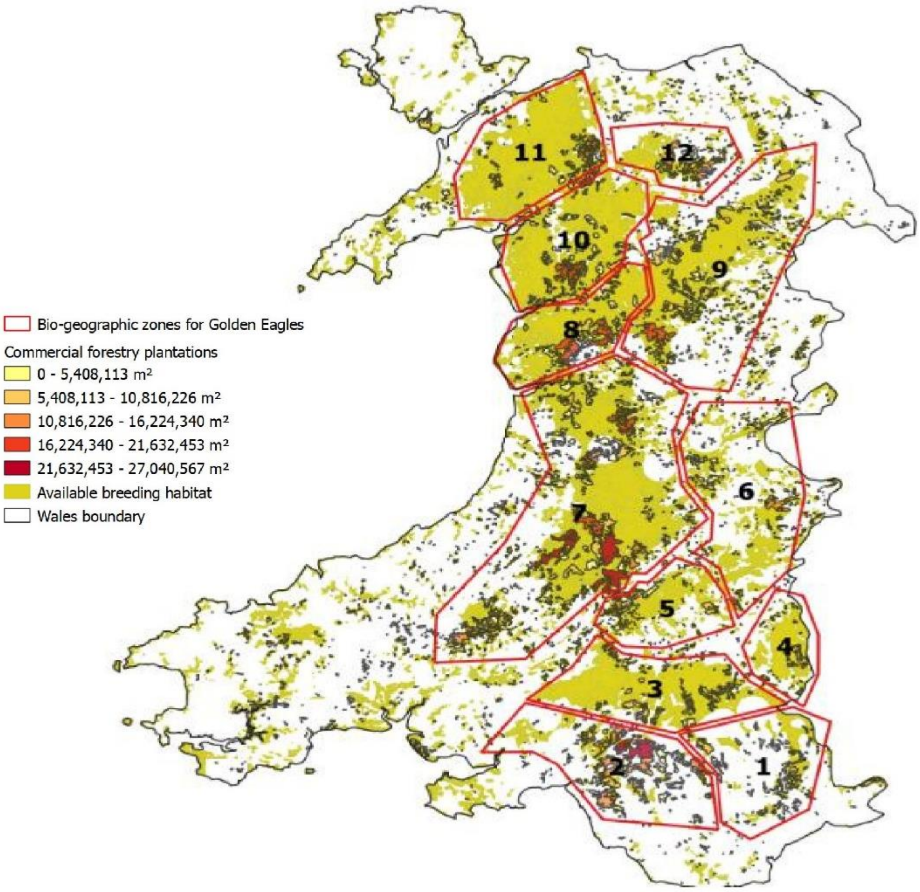
Golden Eagle Bio-geographic Zones and Livestock Pasture in Wales:

Zone	% Pasture	Pasture rank	Zone	% Pasture	Pasture rank
(1) – South Wales Valleys (East)	53.3	8	**(8)** – Lower Snowdonia National Park	34.6	3
(2) – South Wales Valleys (West)	63.0	12	**(9)** – Llangollen & Berwyn Mountains	49.7	7
(3) – Brecon Beacons National Park	45.4	6	**(10)** – Central Snowdonia National Park	24.2	2
(4) – Black Mountains	41.6	4	**(11)** – Upper Snowdonia National Park	18.3	1
(5) – Hay-on-Wye	57.9	11	**(12)** – Pentre-llyn-Cymmer	55.8	9
(6) – Radnor Forests	57.6	10	***(13)*** *– Other Lowland Areas*	65.4	13
(7) – Cambrian Mountains	43.5	5			

Appendix 12

Golden Eagle Breeding Habitat and Commercial Forestry Plantations Across Wales.

Figure A12: *The proportion of commercial forestry plantations across Golden Eagle bio-geographic breeding zones in Wales.; depicted by percentage habitat loss by bio-geographic breeding zones.*



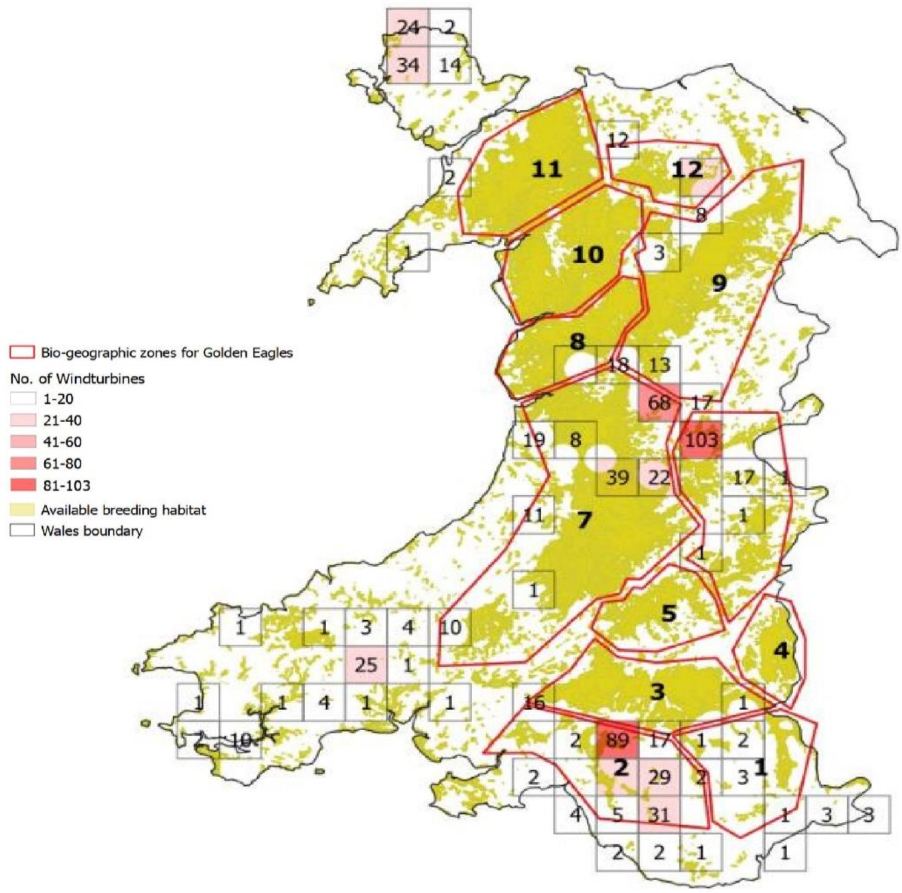
Golden Eagle Bio-geographic Zones and Commercial Forestry in Wales:

	% Com. forestry	*Com. Forestry rank*		*% Com. forestry*	*Com. Forestry rank*
(1) – South Wales Valleys (East)	**19.7**	**9**	**(8)** – Lower Snowdonia National Park	**31.8**	**11**
(2) – South Wales Valleys (West)	**36.6**	**13**	**(9)** – Llangollen & Berwyn Mountains	**17.9**	**8**
(3) – Brecon Beacons National Park	**14.4**	**6**	**(10)** – Central Snowdonia National Park	**16.1**	**7**
(4) – Black Mountains	**11.9**	**3**	**(11)** – Upper Snowdonia National Park	**12.9**	**4**
(5) – Hay-on-Wye	**13.7**	**5**	**(12)** – Pentre-llyn-Cymmer	**24.6**	**10**
(6) – Radnor Forests	**10.2**	**2**	***(13)*** *– Other Lowland Areas*	**2.4**	**1**
(7) – Cambrian Mountains	**36.5**	**12**			

Appendix 13

Golden Eagle Breeding Habitat and the Spatial Intensity and Distribution of Wind-turbines.

***Figure A13:** Atlas map highlighting the intensity of wind turbines across Golden Eagle bio-geographic breeding zones in Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



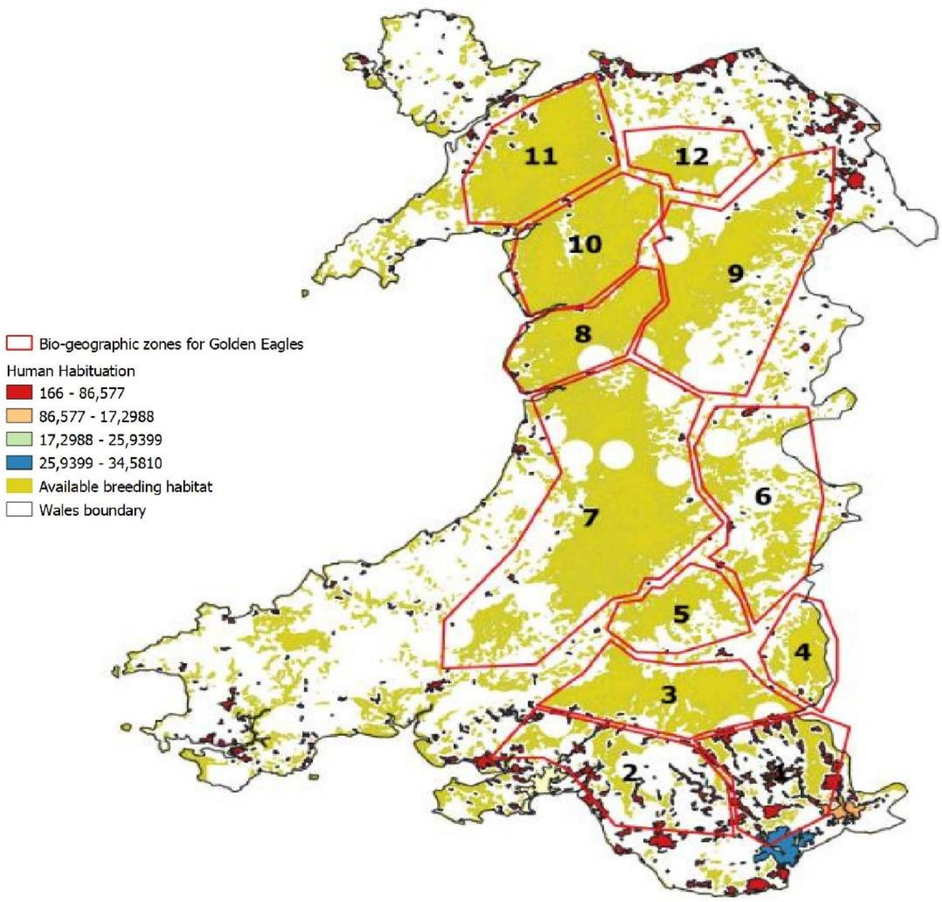
Golden Eagle Bio-geographic Zones and Wind-turbines in Wales:

	No. Wind-turbines	Wind-turbine rank		No. Wind-turbines	Wind-turbine rank
(1) – South Wales Valleys (East)	8	7	**(8)** – Lower Snowdonia National Park	2	6
(2) – South Wales Valleys (West)	204	13	**(9)** – Llangollen & Berwyn Mountains	58	9
(3) – Brecon Beacons National Park	1	5	**(10)** – Central Snowdonia National Park	0	1
(4) – Black Mountains	0	1	**(11)** – Upper Snowdonia National Park	0	1
(5) – Hay-on-Wye	0	1	**(12)** – Pentre-llyn-Cymmer	38	8
(6) – Radnor Forests	123	10	***(13)** – Other Lowland Areas*	176	12
(7) – Cambrian Mountains	167	11			

Appendix 14

Golden Eagle Breeding Habitat and the Spatial Intensity and Distribution of Urban Areas Across Wales.

***Figure A14**: The intensity of human habituation across Golden Eagle bio-geographic breeding zones in Wales.; depicted by percentage habitat loss by bio-geographic breeding zones.*



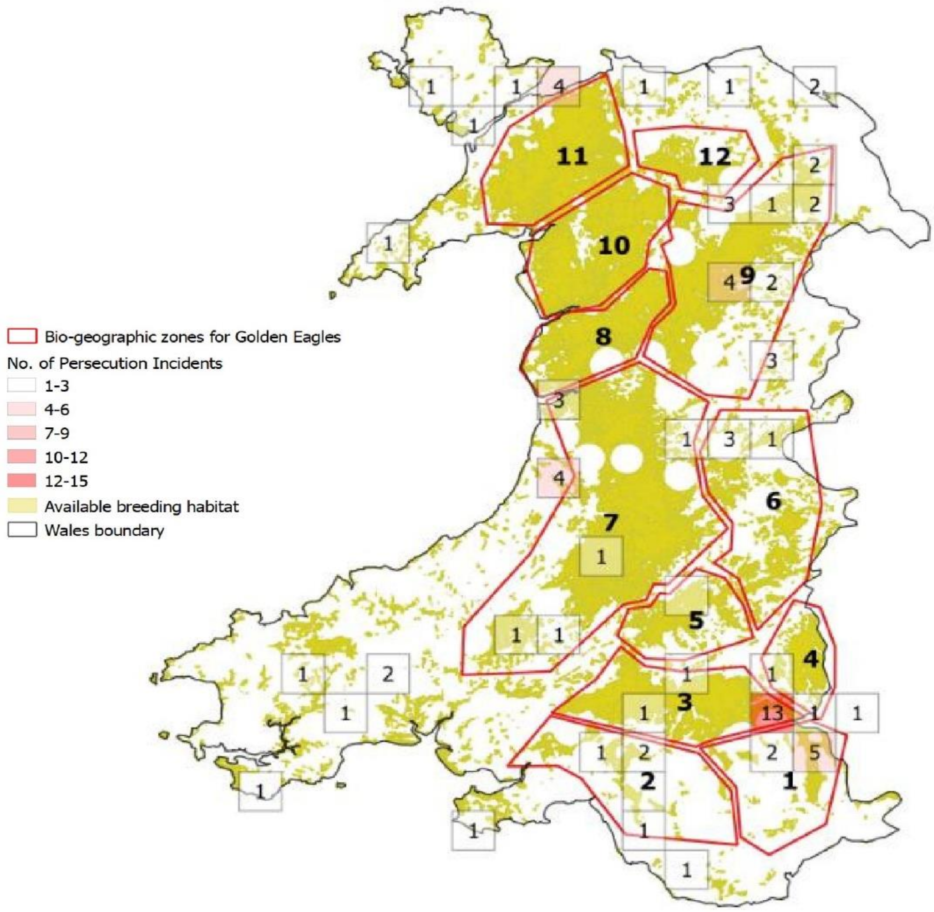
Golden Eagle Bio-geographic Zones and Human Habituation in Wales:

	Urban population no.	*Urban population rank*		*Urban Population no.*	*Urban population rank*
(1) – South Wales Valleys (East)	973,898	12	**(8)** – Lower Snowdonia National Park	8,274	3
(2) – South Wales Valleys (West)	689,530	11	**(9)** – Llangollen & Berwyn Mountains	107,302	10
(3) – Brecon Beacons National Park	103,493	9	**(10)** – Central Snowdonia National Park	11,600	5
(4) – Black Mountains	11,349	4	**(11)** – Upper Snowdonia National Park	28,215	8
(5) – Hay-on-Wye	205	1	**(12)** – Pentre-llyn-Cymmer	5,975	2
(6) – Radnor Forests	22,015	7	***(13)** – Other Lowland Areas*	1,907,194	13
(7) – Cambrian Mountains	17,227	6			

Appendix 15

Golden Eagle Breeding Habitat and the Spatial Intensity and Distribution of Raptor Persecution Incidents Across Wales.

***Figure A15**: Atlas map highlighting the intensity of recorded raptor persecution incidents across Golden Eagle bio-geographic breeding zones in Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



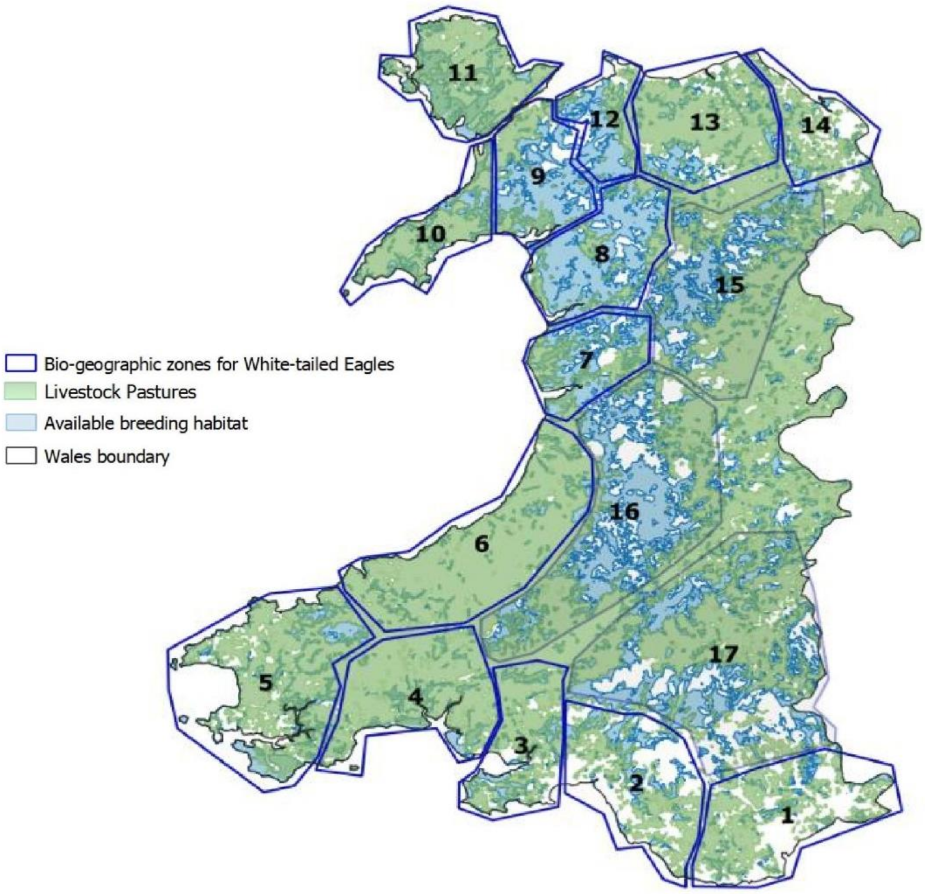
Golden Eagle Bio-geographic Zones and Persecution in Wales:

	No. persecuted raptors	Persecuted raptor rank		No. persecuted raptors	Persecuted raptor rank
(1) – South Wales Valleys (East)	7	8	**(8)** – Lower Snowdonia National Park	0	1
(2) – South Wales Valleys (West)	7	8	**(9)** – Llangollen & Berwyn Mountains	11	11
(3) – Brecon Beacons National Park	15	12	**(10)** – Central Snowdonia National Park	0	1
(4) – Black Mountains	2	6	**(11)** – Upper Snowdonia National Park	0	1
(5) – Hay-on-Wye	1	5	**(12)** – Pentre-llyn-Cymmer	0	1
(6) – Radnor Forests	4	7	***(13)** – Other Lowland Areas*	25	13
(7) – Cambrian Mountains	7	8			

Appendix 16

White-tailed Eagle Breeding Habitat and Livestock Pastures Across Wales.

Figure A16: *The proportion of livestock pastures across White-tailed Eagle bio-geographic breeding zones in Wales.; depicted by percentage habitat loss by bio-geographic breeding zones.*



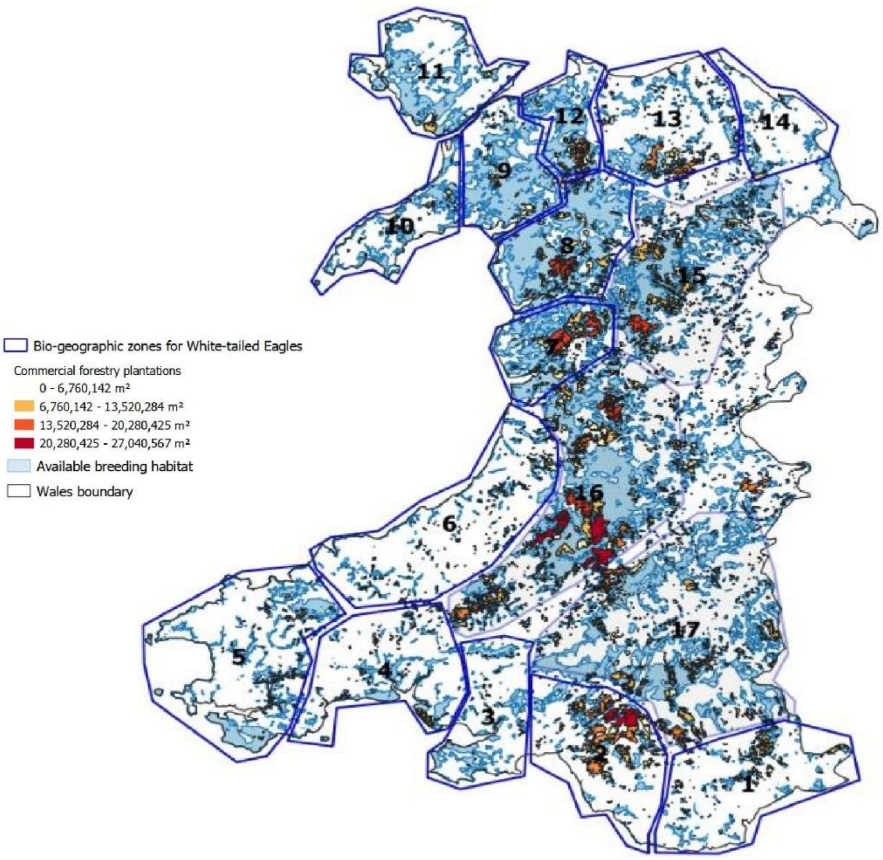
White-tailed Eagle Bio-geographic Zones and Livestock Pastures in Wales:

Zone	% Pasture	Pasture rank	Zone	% Pasture	Pasture rank
(1) - The Severn Estuary	59.7	12	**(10) -** Llyn Peninsula	56.4	11
(2) - Swansea Bay & Afon Forests	40.5	6	**(11) -** Isle of Anglesey	64.3	15
(3) - The Gower Peninsula	60.5	14	**(12) -** Conwy Estuary & Gwydir Forests	25.0	1
(4) - Caerfyrddin Bay	76.4	16	**(13) -** Clwyd Estuary & Clocaenog Forests	60.1	13
(5) - Pembrokeshire National Park	48.3	9	**(14) -** Dee Estuary & Pen y Maes Woods	43.5	7
(6) - Ceredigion Bay	82.5	17	***(15) -*** *Y Berwyn National Reserve*	48.3	10
(7) - Dyfi Estuary & Dyfi Forests	34.3	4	***(16) -*** *Cambrian Mountains*	34.8	5
(8) - Mawddach Estuary & Coed y Brenin Forests	32.5	3	***(17) -*** *Brecon Beacons National Park*	45.5	8
(9) - Glaslyn Estuary & Snowdonia National Park	27.5	2			

Appendix 17

White-tailed Eagle Breeding Habitat and Commercial Forestry Plantations Across Wales.

***Figure A17:** The proportion of commercial forestry plantations across White-tailed Eagle bio-geographic breeding zones in Wales.; depicted by percentage habitat loss by bio-geographic breeding zones.*



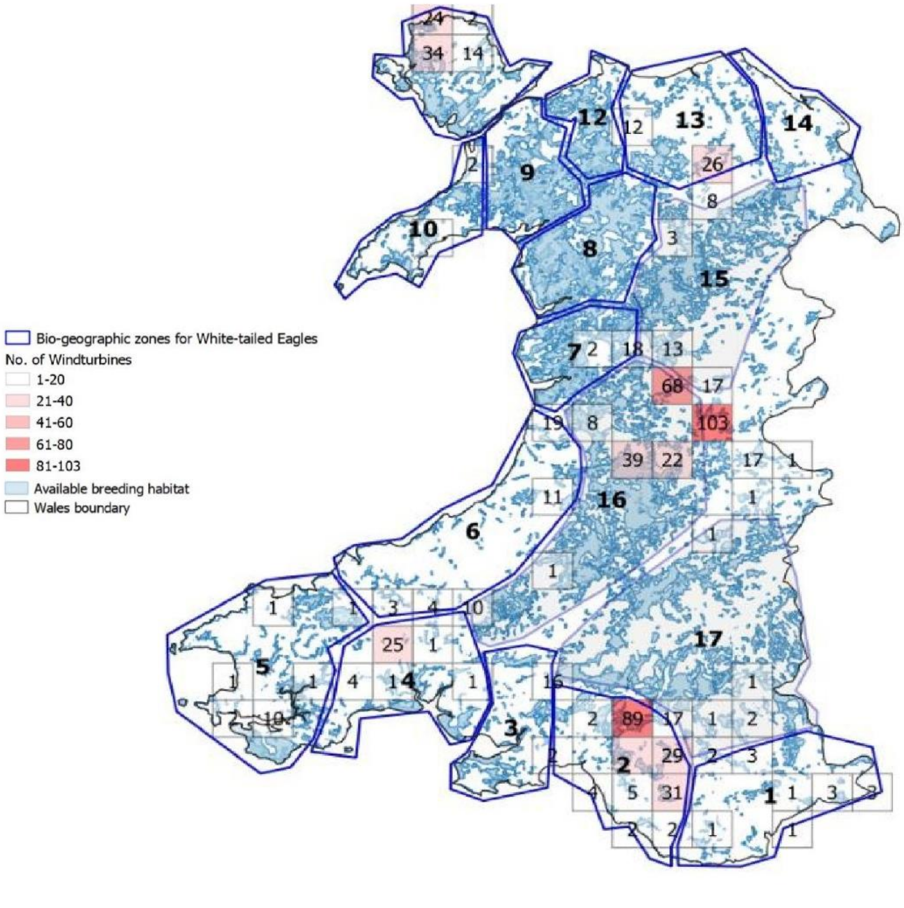
White-tailed Eagle Bio-geographic Zones and Commercial Forestry in Wales:

Zone	*% Com. forestry*	*Com. forestry rank*	Zone	*% Com. forestry*	*Com. forestry rank*
(1) - The Severn Estuary	3.4	10	**(10) -** Llyn Peninsula	0.6	3
(2) - Swansea Bay & Afon Forests	9.8	15	**(11) -** Isle of Anglesey	0.5	2
(3) - The Gower Peninsula	0.3	1	**(12) -** Conwy Estuary & Gwydir Forests	3.0	9
(4) - Caerfyrddin Bay	1.9	7	**(13) -** Clwyd Estuary & Clocaenog Forests	3.8	11
(5) - Pembrokeshire National Park	1.3	6	**(14) -** Dee Estuary & Pen y Maes Woods	0.6	4
(6) - Ceredigion Bay	2.4	8	***(15) -*** *Y Berwyn National Reserve*	9.3	14
(7) - Dyfi Estuary & Dyfi Forests	6.1	13	***(16) -*** *Cambrian Mountains*	28.8	17
(8) - Mawddach Estuary & Coed y Brenin Forests	5.2	12	***(17) -*** *Brecon Beacons National Park*	11.7	16
(9) - Glaslyn Estuary & Snowdonia National Park	1.3	5			

Appendix 18

White-tailed Eagle Breeding Habitat and the Spatial Intensity and Distribution of Wind-turbines.

***Figure A18:** Atlas map highlighting the intensity of wind turbines across White-tailed Eagle bio-geographic breeding zones in Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



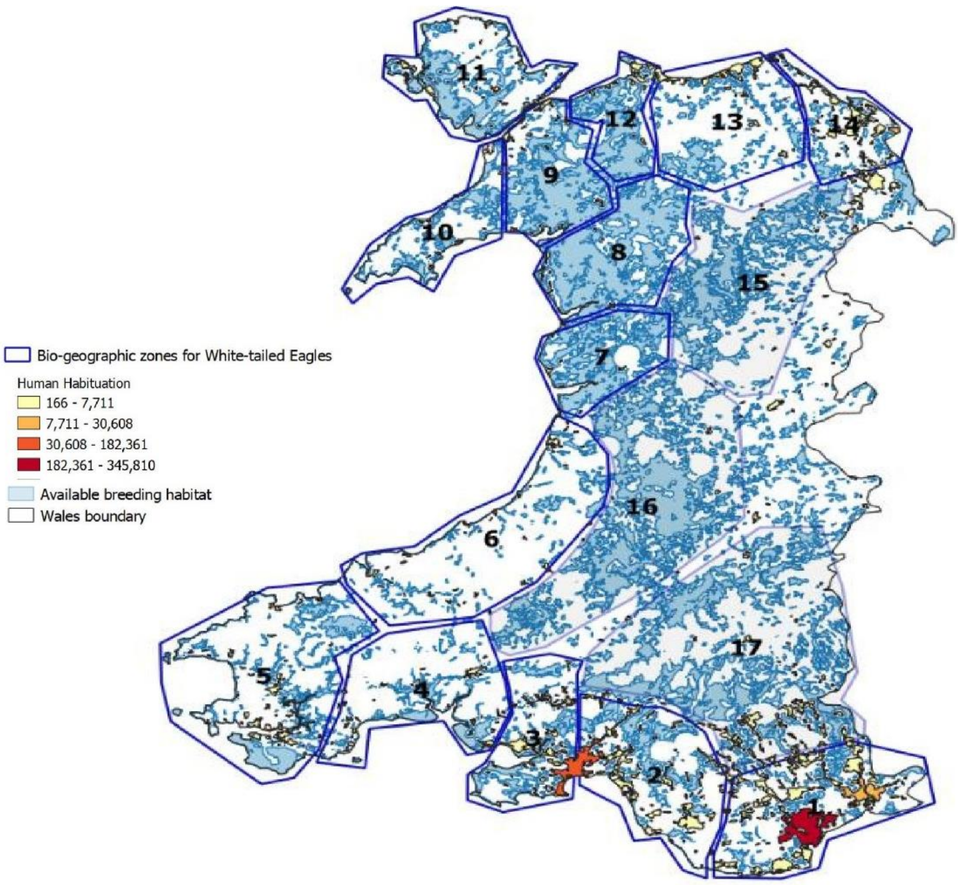
White-tailed Eagle Bio-geographic Zones and Wind-turbines in Wales:

Zone	No. wind turbines	Wind turbine rank
(1) - The Severn Estuary	10	9
(2) - Swansea Bay & Afon Forests	198	17
(3) - The Gower Peninsula	1	5
(4) - Caerfyrddin Bay	33	12
(5) - Pembrokeshire National Park	15	10
(6) - Ceredigion Bay	15	10
(7) - Dyfi Estuary & Dyfi Forests	2	6
(8) - Mawddach Estuary & Coed y Brenin Forests	0	1
(9) - Glaslyn Estuary & Snowdonia National Park	*0*	1
(10) - Llyn Peninsula	3	7
(11) - Isle of Anglesey	74	15
(12) - Conwy Estuary & Gwydir Forests	0	1
(13) - Clwyd Estuary & Clocaenog Forests	37	14
(14) - Dee Estuary & Pen y Maes Woods	0	1
***(15)** - Y Berwyn National Reserve*	36	13
***(16)** - Cambrian Mountains*	128	16
***(17)** - Brecon Beacons National Park*	8	8

Appendix 19

White-tailed Eagle Breeding Habitat and the Spatial Intensity and Distribution of Urban Areas Across Wales.

***Figure A19**: The intensity of human habituation across White-tailed Eagle bio-geographic breeding zones in Wales.; depicted by percentage habitat loss by bio-geographic breeding zones.*



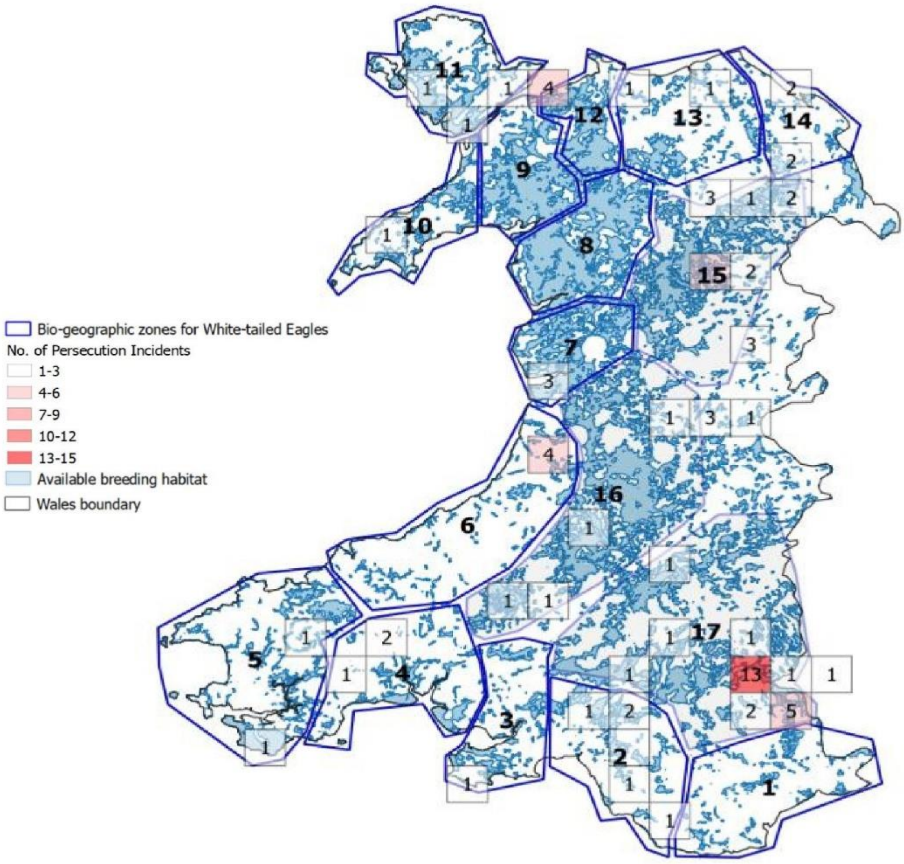
White-tailed Eagle Bio-geographic Zones and Human Habitation in Wales:

	Urban Population No.	*Urban population rank*		*Urban Population No.*	*Urban population rank*
(1) - The Severn Estuary	986,078	17	**(10) -** Llyn Peninsula	12,609	4
(2) - Swansea Bay & Afon Forests	524,573	16	**(11) -** Isle of Anglesey	49,678	6
(3) - The Gower Peninsula	320,677	14	**(12) -** Conwy Estuary & Gwydir Forests	79,409	11
(4) - Caerfyrddin Bay	58,853	8	**(13) -** Clwyd Estuary & Clocaenog Forests	126,091	12
(5) - Pembrokeshire National Park	73,131	10	**(14) -** Dee Estuary & Pen y Maes Woods	306,571	13
(6) - Ceredigion Bay	49,988	7	***(15) -*** *Y Berwyn National Reserve*	38,139	5
(7) - Dyfi Estuary & Dyfi Forests	8,942	2	***(16) -*** *Cambrian Mountains*	6,657	1
(8) - Mawddach Estuary & Coed y Brenin Forests	9,930	3	***(17) -*** *Brecon Beacons National Park*	330,634	15
(9) - Glaslyn Estuary & Snowdonia National Park	63,699	9			

Appendix 20

White-tailed Eagle Breeding Habitat and the Spatial Intensity and Distribution of Raptor Persecution Incidents Across Wales.

***Figure A20**: Atlas map highlighting the intensity of recorded raptor persecution incidents across White-tailed Eagle bio-geographic breeding zones in Wales; depicted by percentage habitat loss by bio-geographic breeding zones.*



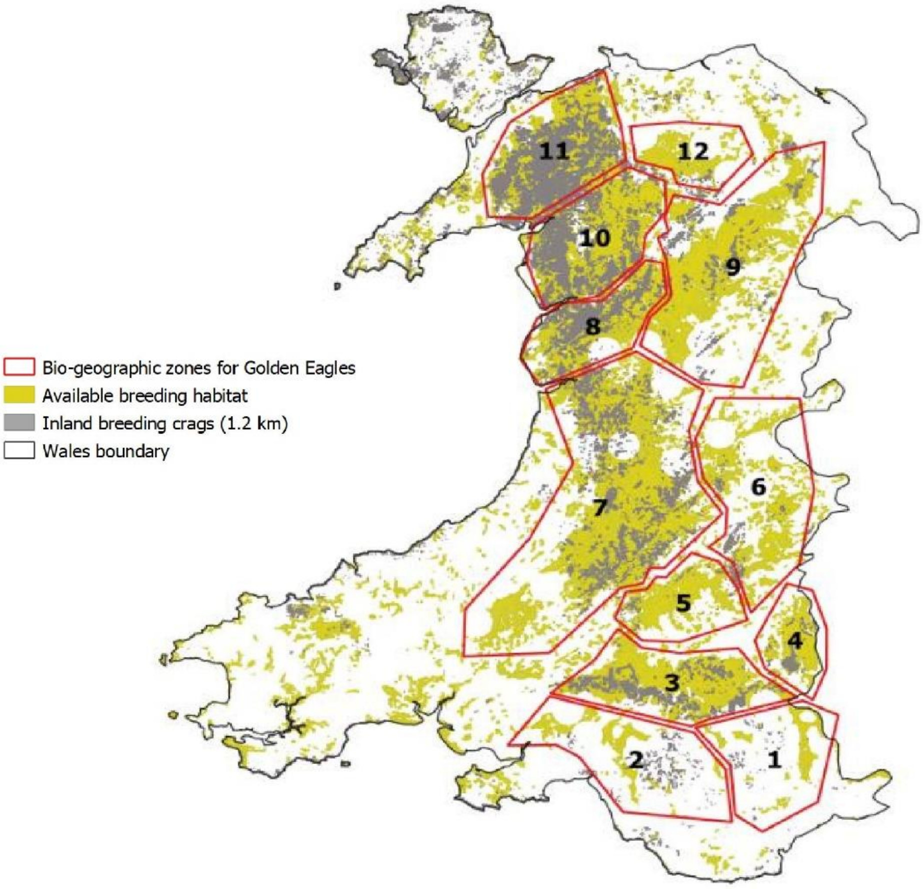
White-tailed Eagle Bio-geographic Zones and Persecution in Wales:

Zone	No. Persecuted raptors	Persecuted raptor rank	Zone	No. Persecuted raptors	Persecuted raptor rank
(1) - The Severn Estuary	0	1	**(10) -** Llyn Peninsula	1	4
(2) - Swansea Bay & Afon Forests	7	15	**(11) -** Isle of Anglesey	3	8
(3) - The Gower Peninsula	1	4	**(12) -** Conwy Estuary & Gwydir Forests	4	11
(4) - Caerfyrddin Bay	3	8	**(13) -** Clwyd Estuary & Clocaenog Forests	2	6
(5) - Pembrokeshire National Park	2	6	**(14) -** Dee Estuary & Pen y Maes Woods	4	11
(6) - Ceredigion Bay	4	11	***(15) -** Y Berwyn National Reserve*	12	16
(7) - Dyfi Estuary & Dyfi Forests	3	8	***(16) -** Cambrian Mountains*	4	11
(8) - Mawddach Estuary & Coed y Brenin Forests	0	1	***(17) -** Brecon Beacons National Park*	26	17
(9) - Glaslyn Estuary & Snowdonia National Park	*0*	1			

Appendix 21

Golden Eagle Breeding Habitat and the Proportion of Available Upland Nest Sites within 1.2 km of a Mountain Ridgeline Across Wales.

***Figure A21**: The proportion of mountain crags available within 1.2km of a mountain ridgeline across Golden Eagle bio-geographic breeding zones in Wales: depicted by percentage habitat loss by bio-geographic breeding zones.*



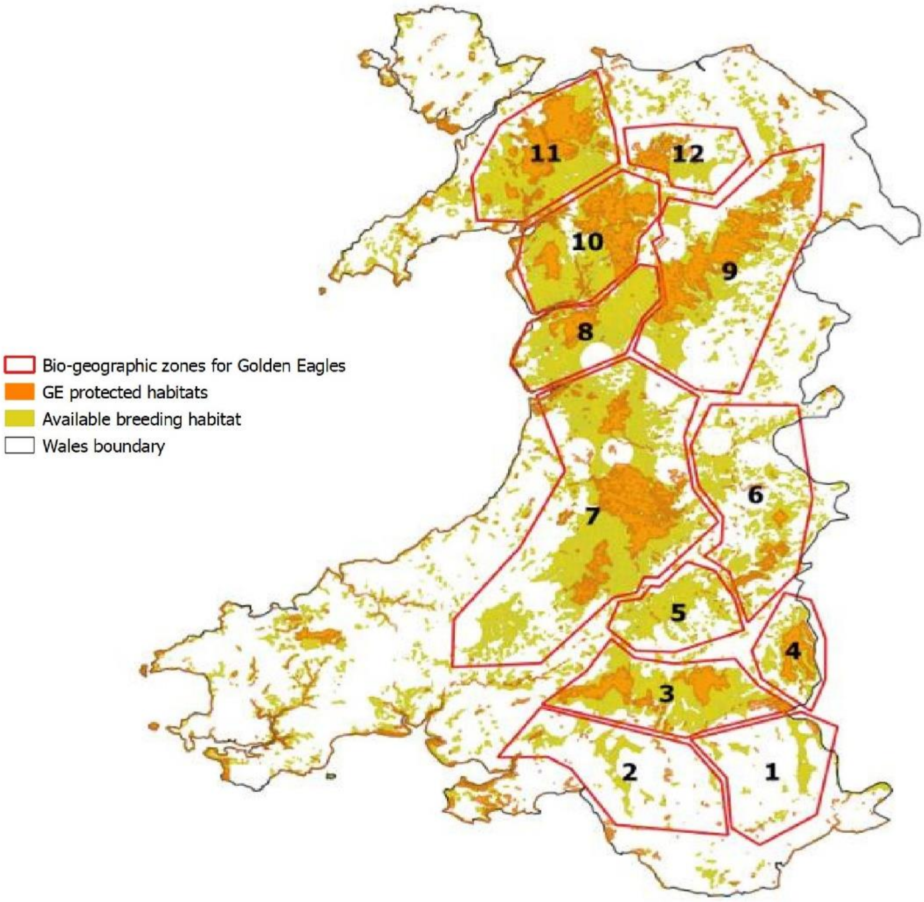
Golden Eagle Bio-geographic Zones and Breeding Inland Crags in Wales:

	% Inland crags	Inland crag rank		% Inland crags	Inland crag rank
(1) – South Wales Valleys (East)	0.2	13	**(8)** – Lower Snowdonia National Park	9.1	4
(2) – South Wales Valleys (West)	0.9	9	**(9)** – Llangollen & Berwyn Mountains	4.3	6
(3) – Brecon Beacons National Park	7.3	5	**(10)** – Central Snowdonia National Park	12.9	2
(4) – Black Mountains	1.0	8	**(11)** – Upper Snowdonia National Park	26.9	1
(5) – Hay-on-Wye	0.2	11	**(12)** – Pentre-llyn-Cymmer	0.2	12
(6) – Radnor Forests	0.6	10	***(13)** – Other Lowland Areas*	3.7	7
(7) – Cambrian Mountains	10.8	3			

Appendix 22

Golden Eagle Breeding Habitat and the Proportion of Breeding Habitats within Protected Areas Across Wales.

***Figure A22**: The proportion of protected breeding habitat across Golden Eagle bio-geographic breeding zones in Wales: depicted by percentage habitat loss by bio-geographic breeding zones.*



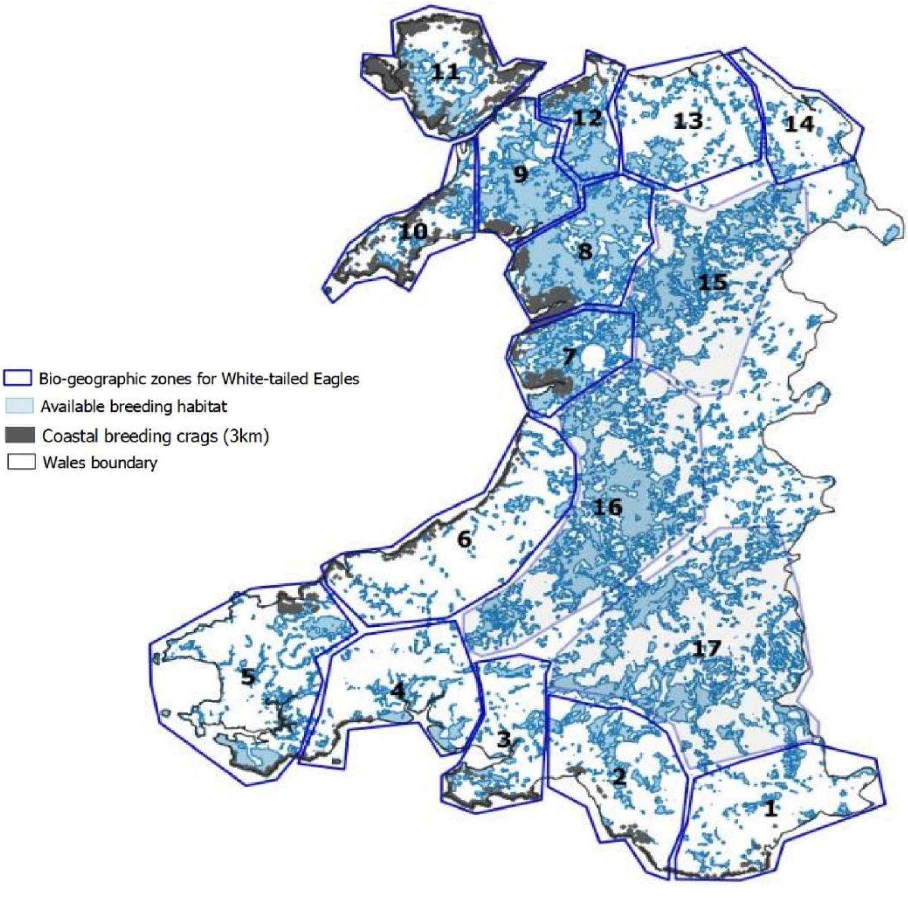
Golden Eagle Bio-geographic Zones and Protected Areas in Wales:

	No. protected habitats	Protected habitats rank		No. protected habitats	Protected habitats rank
(1) – South Wales Valleys (East)	1.1	12	**(8)** – Lower Snowdonia National Park	3.4	10
(2) – South Wales Valleys (West)	1.2	11	**(9)** – Llangollen & Berwyn Mountains	16.2	3
(3) – Brecon Beacons National Park	8.7	7	**(10)** – Central Snowdonia National Park	13.6	4
(4) – Black Mountains	10.2	6	**(11)** – Upper Snowdonia National Park	13.3	5
(5) – Hay-on-Wye	0.1	13	**(12)** – Pentre-llyn-Cymmer	8.4	8
(6) – Radnor Forests	6.6	9	***(13)** – Other Lowland Areas*	24.0	1
(7) – Cambrian Mountains	20.2	2			

Appendix 23

White-tailed Eagle Breeding Habitat and the Proportion of Available Coastal Nest Sites within 3 km from a Welsh Coastline.

***Figure A23**: The proportion of nesting crags available within 3km of a coastline across White-tailed Eagle bio-geographic breeding zones in Wales.: depicted by percentage habitat loss by bio-geographic breeding zones.*



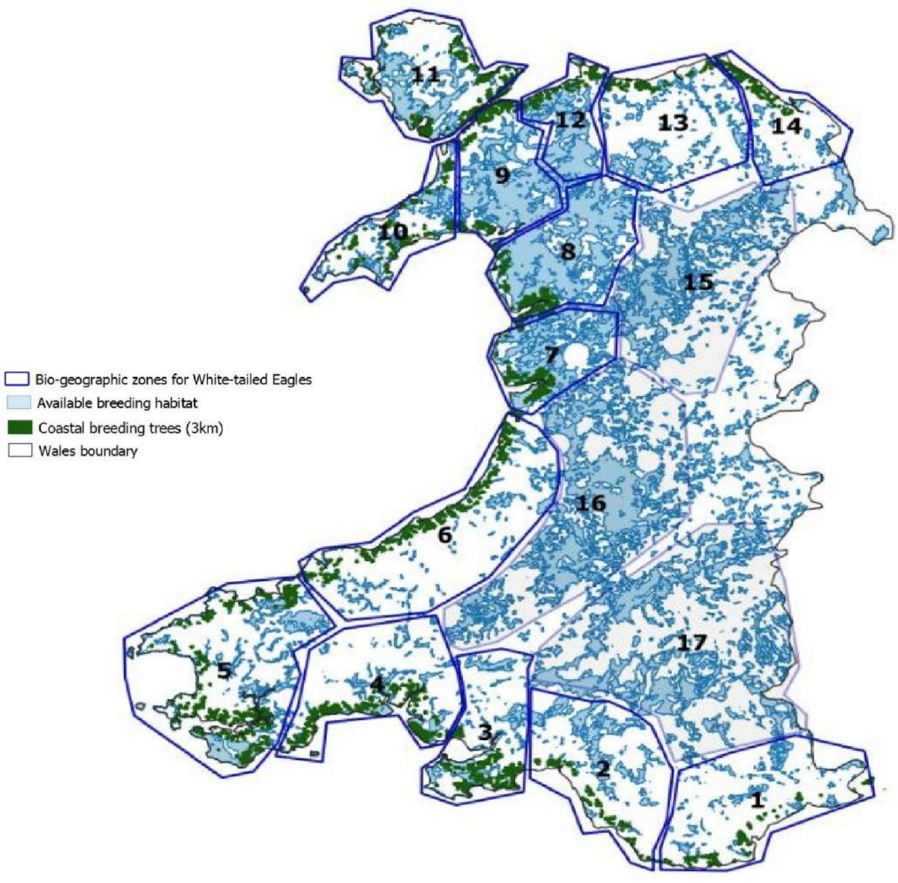
White-tailed Eagle Bio-geographic Zones and Breeding Coastal Crags in Wales:

	% Coastal crags	Coastal crag rank		% Coastal crags	Coastal crag rank
(1) - The Severn Estuary	1.0	12	**(10)** - Llyn Peninsula	32.3	2
(2) - Swansea Bay & Afon Forests	3.3	10	**(11)** - Isle of Anglesey	48.5	1
(3) - The Gower Peninsula	19.1	5	**(12)** - Conwy Estuary & Gwydir Forests	3.1	11
(4) - Caerfyrddin Bay	4.5	9	**(13)** - Clwyd Estuary & Clocaenog Forests	0.0	13
(5) - Pembrokeshire National Park	19.5	4	**(14)** - Dee Estuary & Pen y Maes Woods	0.0	13
(6) - Ceredigion Bay	27.4	3	***(15)*** - *Y Berwyn National Reserve*	/	/
(7) - Dyfi Estuary & Dyfi Forests	13.9	6	***(16)*** - *Cambrian Mountains*	/	/
(8) - Mawddach Estuary & Coed y Brenin Forests	12.3	7	***(17)*** - *Brecon Beacons National Park*	/	/
(9) - Glaslyn Estuary & Snowdonia National Park	8.8	8			

Appendix 24

White-tailed Eagle Breeding Habitat and the Proportion of Available Coastal Nest Sites within 3 km from a Welsh Coastline.

***Figure A24**: The proportion of nesting trees available within 3km of a coastline across White-tailed Eagle bio-geographic breeding zones in Wales.: depicted by percentage habitat loss by bio-geographic breeding zones.*



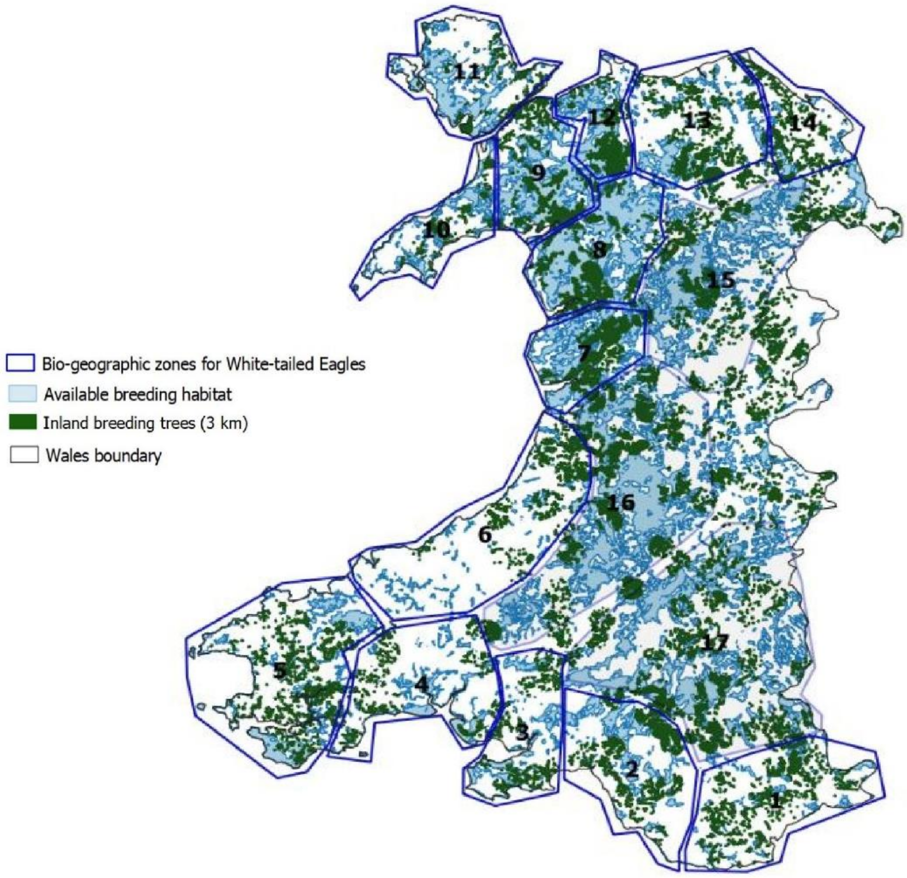
White-tailed Eagle Bio-geographic Zones and Breeding Coastal Trees in Wales:

Zone	% Coastal trees	Coastal tree rank
(1) - The Severn Estuary	3.3	12
(2) - Swansea Bay & Afon Forests	3.5	11
(3) - The Gower Peninsula	9.3	4
(4) - Caerfyrddin Bay	12.9	2
(5) - Pembrokeshire National Park	13.3	1
(6) - Ceredigion Bay	8.7	6
(7) - Dyfi Estuary & Dyfi Forests	7.4	7
(8) - Mawddach Estuary & Coed y Brenin Forests	9.3	5
(9) - Glaslyn Estuary & Snowdonia National Park	4.6	9
(10) - Llyn Peninsula	4.8	8
(11) - Isle of Anglesey	9.8	3
(12) - Conwy Estuary & Gwydir Forests	3.5	10
(13) - Clwyd Estuary & Clocaenog Forests	2.5	14
(14) - Dee Estuary & Pen y Maes Woods	3.1	13
***(15) -** Y Berwyn National Reserve*	/	/
***(16) -** Cambrian Mountains*	/	/
***(17) -** Brecon Beacons National Park*	/	/

Appendix 25

White-tailed Eagle Breeding Habitat and the Proportion of Available Inland Nest Sites within 3 km from an Inland Fresh Water Source.

***Figure A25**: The proportion of nesting trees available within 3km of a lake across White-tailed Eagle bio-geographic breeding zones in Wales: depicted by percentage habitat loss by bio-geographic breeding zones.*



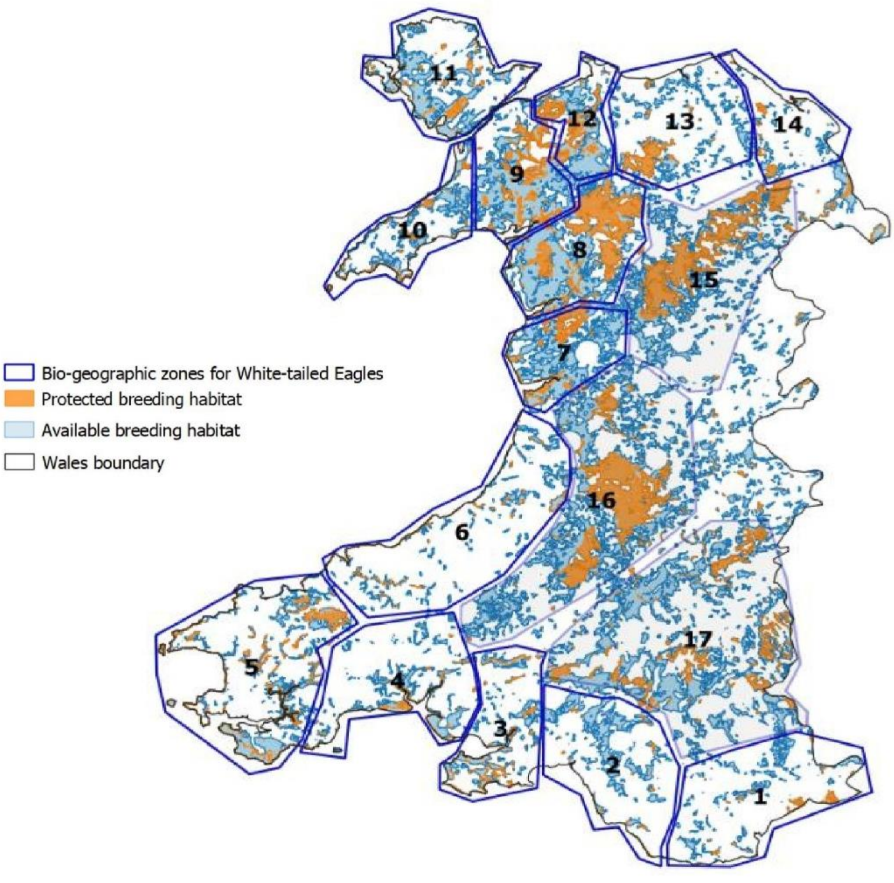
White-tailed Eagle Bio-geographic Zones and Breeding Inland Trees in Wales:

Zone	% Inland trees	Inland tree rank
(1) - The Severn Estuary	3.1	11
(2) - Swansea Bay & Afon Forests	1.8	15
(3) - The Gower Peninsula	2.1	13
(4) - Caerfyrddin Bay	1.6	16
(5) - Pembrokeshire National Park	5.1	8
(6) - Ceredigion Bay	4.0	10
(7) - Dyfi Estuary & Dyfi Forests	6.5	5
(8) - Mawddach Estuary & Coed y Brenin Forests	9.0	3
(9) - Glaslyn Estuary & Snowdonia National Park	5.1	7
(10) - Llyn Peninsula	1.3	17
(11) - Isle of Anglesey	2.0	14
(12) - Conwy Estuary & Gwydir Forests	4.7	9
(13) - Clwyd Estuary & Clocaenog Forests	5.7	6
(14) - Dee Estuary & Pen y Maes Woods	2.2	12
(15) *- Y Berwyn National Reserve*	6.6	4
(16) *- Cambrian Mountains*	14.2	1
(17) *- Brecon Beacons National Park*	12.2	2

Appendix 26

White-tailed Eagle Breeding Habitat and the Proportion of Breeding Habitats within Protected Areas Across Wales.

***Figure A26**: The proportion of protected breeding habitat across White-tailed Eagle bio-geographic breeding zones in Wales: depicted by percentage habitat loss by bio-geographic breeding zones.*



White-tailed Eagle Bio-geographic Zones and Protected Areas in Wales:

	% Protected habitat	Protected habitat rank		% Protected habitat	Protected habitat rank
(1) - The Severn Estuary	1.9	15	**(10) -** Llyn Peninsula	4.7	9
(2) - Swansea Bay & Afon Forests	1.1	16	**(11) -** Isle of Anglesey	9.2	5
(3) - The Gower Peninsula	3.0	12	**(12) -** Conwy Estuary & Gwydir Forests	2.5	13
(4) - Caerfyrddin Bay	2.2	14	**(13) -** Clwyd Estuary & Clocaenog Forests	6.2	7
(5) - Pembrokeshire National Park	15.7	3	**(14) -** Dee Estuary & Pen y Maes Woods	0.2	17
(6) - Ceredigion Bay	5.9	8	***(15) -** Cambrian Mountains*	20.6	2
(7) - Dyfi Estuary & Dyfi Forests	8.6	6	***(16) -** Y Berwyn National Reserve*	4.4	11
(8) - Mawddach Estuary & Coed y Brenin Forests	21.9	1	***(17) -** Brecon Beacons National Park*	13.9	4
(9) - Glaslyn Estuary & Snowdonia National Park	4.4	10			