



CONTRIBUTED PAPER

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

Sophie-lee Williams^{1,2} | Sarah E. Perkins^{1,2} | Roy Dennis^{2,3} |
James P. Byrne^{2,4} | Robert J. Thomas^{1,2,5}

¹School of Biosciences, Sir Martin Evans Building, Cardiff University, Cardiff, UK

²The Eagle Reintroduction Wales (ERW) Project, Cardiff, UK

³Roy Dennis Wildlife Foundation, Moray, UK

⁴Wildlife Trusts Wales, Cardiff, UK

⁵Eco-explore Community Interest Company, Nelson, UK

Correspondence

Sophie-lee Williams, School of Biosciences, Sir Martin Evans Building, Cardiff University, CF10 3AX Cardiff, UK.
Email: lanes6@cardiff.ac.uk

Funding information

Knowledge Economy Skills Scholarship (KESS); Welsh Government's European Social Fund; European Social Funds (ESF)

Abstract

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 prehistoric 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.

KEYWORDS

distribution, eagles and conservation, historic, reintroduction

1 | INTRODUCTION

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; Guisan et al., 2013; Kuemmerle, Hicker, Olofsson, Schurgers, & Radeloff, 2012; Yang et al., 2016). Historic data and

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2020 The Authors. Conservation Science and Practice published by Wiley Periodicals LLC. on behalf of Society for Conservation Biology

distribution modeling 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 (Guisan et al., 2013; Sinclair, White, & Newell, 2010; Syfert et al., 2014).

There are two eagles native to Britain, the Golden Eagle (*Aquila chrysaetos*) and White-tailed Eagle (*Haliaeetus albicilla*). Both eagles belong, in scientific terms, to the *Accipitridae* family (Mindell, Fuchs, & 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 behavior and ecology (Evans et al., 2010; Whitfield et al., 2013). In Wales, both the Golden Eagle (known in the Welsh language as Eyr Euriad) and the White-tailed Eagle (known in Welsh as Eyr y Môr) are currently regionally extinct. They are iconic and charismatic species of ecological, cultural and conservation importance across the British Isles. A reintroduction of either or both species would contribute to the Welsh, National and International aims of the Council Directive 92/43/EEC (Habitat Directive); 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, Dillion, Patrick, & Whitfield, 2007; Hayhow, Benn, Stevenson, Stirling-Airid, & Eaton, 2017). A pair returned to breed in England from 1969 until 2004 (Dennis & Ellis, 1984; Evans, O'toole, & Whitfield, 2012). Golden Eagles remained extant in parts of Scotland, where the population today stands at more than 500 breeding pairs (Whitfield & Fielding, 2017). White-tailed Eagles became extinct in England and Wales by 1860, and in Scotland by 1918 (Evans et al., 2012; Yalden, 2007). 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 (Bainbridge et al., 2003; Love, 1988), in Ireland (Nygard, Halley, & Mee, 2009), most recently in southern Scotland (Fielding & Haworth, 2014) and southern England, specifically the Isle of Wight (Dennis, Mackrill, & Sargeant, 2019).

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 in close proximity to their natal sites (Millsap, 2014; Whitfield et al., 2009; Whitfield & 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 (Dennis et al., 2019; Marquiss, 2005). Populations of both eagle species are subject to increasing environmental pressures in the UK (Sansom, Evans, & Roos, 2016; Whitfield & Fielding, 2017), and a reintroduction 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, in accordance with 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.

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 et al. (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 reintroduction.

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 categorized into three record types: (a) historic observational records—including ornithological literature, persecution records and museum specimens; (b) archaeological or palaeontological records; and (c) place-name records. We

utilize the increasing understanding of the habitat preferences of both species within the UK (Evans et al., 2010; Sansom et al., 2016; Whitfield et al., 2013) to maximize 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 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 | METHODS

2.1 | Collation of historic data

The historic distributions 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).

2.1.1 | Historic observational records

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.

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.

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	<i>Eagle</i>	English
	<i>Erne</i>	English (historic)
	<i>Eryr (heryr)</i>	Welsh (+mutated form)
	<i>Eryrod (heryrod)</i>	Welsh plural (+mutated form)
	<i>Aquila</i>	Latin
Species-specific records		
Golden eagle	<i>Golden Eagle</i>	English
	<i>Eryr Eurriad</i>	Welsh
	<i>Aquila chrysaetos</i>	Latin
White-tailed eagle	<i>White-tailed Eagle</i>	English
	<i>Sea Eagle</i>	English
	<i>Great Erne</i>	English (historic)
	<i>Eryr y Môr</i>	Welsh
	<i>Haliaeetus albicilla</i>	Latin

Museum specimens

In search of historic eagle records, 52 museums around Wales and neighboring parts of Britain were contacted regarding taxidermic 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.

2.1.2 | Place-name records

Place-names in Wales referring to eagles were collated from the Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMN, 2019); the "Archwilio" Historic Environment Records of Wales (Archwilio, 2019); the Melville Richards Archive Place-name Database (MRA, 2019); and Ordnance Survey Six Inch Maps of England and Wales, 1842–1952, supplemented by the National Library of Scotland (NLS, 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 Section 3).

2.1.3 | 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 (2007), Harrison (1987), Bramwell (1960), 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 such records found for Wales, of which only 8 were documented with sufficient information to be used in the analysis.

2.2 | Data preparation, modeling 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 13 old counties (i.e., Anglesey, Brecknockshire, Caernarfonshire, Ceredigion, Denbighshire, Glamorganshire, Flintshire, Gower, Gwent, Meirionnydd, Pembrokeshire, and 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 modeled. 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, 2017) were included (Evans et al., 2010; Hayhow et al., 2017; Moss, 2015; Sansom et al., 2016). 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 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, 2018) 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 (m²) were calculated in QGIS for each eagle record.

Quantitative data analysis was carried out using R (R Core Team, 2018), implemented in R-Studio (v 3.4.2, R Studio 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 & 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 utilization 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 “ade-habitatHR” package (v0.4.14; Calenge, 2006).

3 | RESULTS

3.1 | A review of eagle records for Wales

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 36 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 1a).

3.1.2 | Archaeological and paleontological records

Of the eight such records, four were identified as Golden Eagle, and four as White-tailed Eagle. These records were mainly distributed near coastal areas across Wales (Figure 1c).

3.1.3 | 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 “hybridized” Welsh and English components (e.g., Eryrys Mine and Cymery-Mawr Well), considered unlikely to indicate the past occurrence of eagles (Appendix S1). 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 1b).

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. The dataset comprised 80 “known ID” records, 40 representing Golden Eagles and

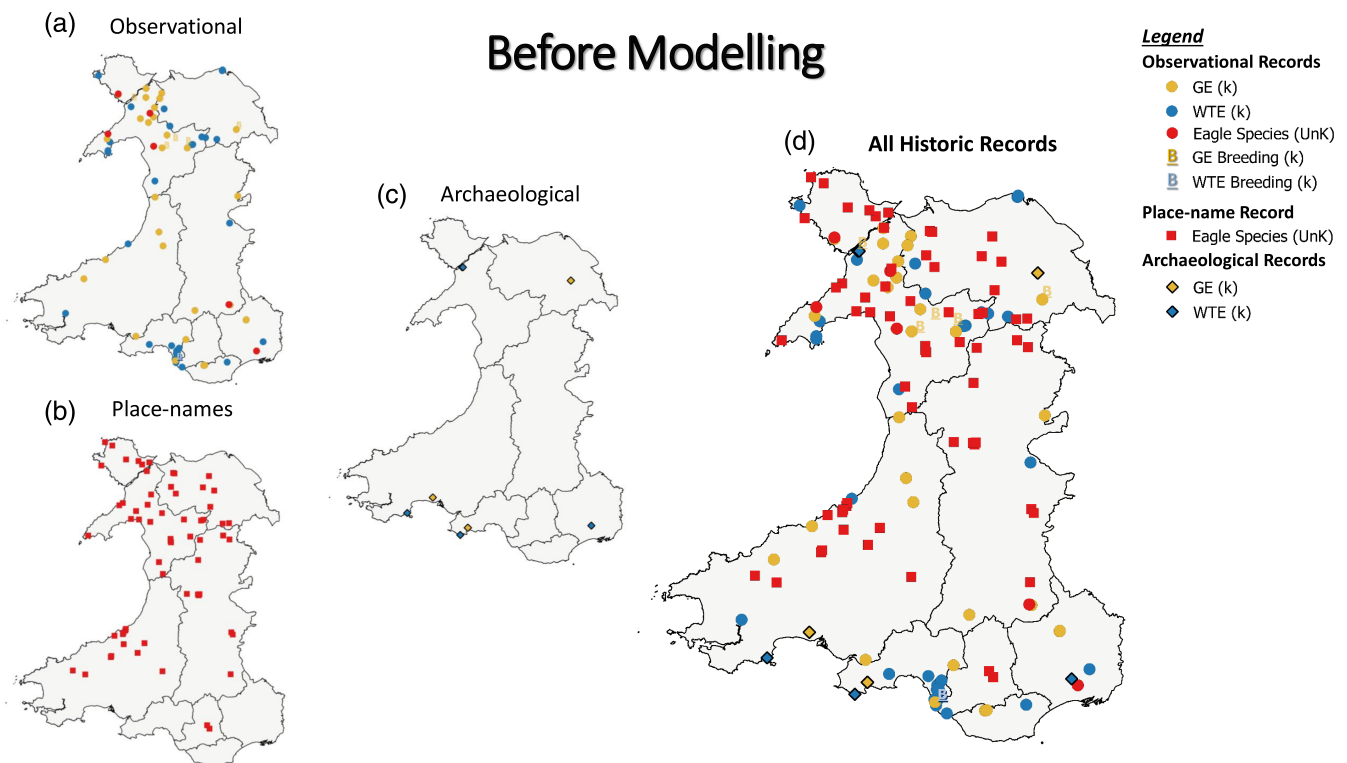


FIGURE 1 The historic distribution of known (k) and unknown (Unk) eagle records in Wales before modeling—(a) observational records; (b) place-name records; (c) archaeological records, and (d) all historic records together

40 representing White-tailed Eagles. The dataset also included 71 “Unknown ID” records which could indicate the historic occurrence of either species (Figure 1d). 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.

3.3 | Habitat features associated with White-tailed and Golden Eagle species identity

The binomial GLM model to explain species identity of Known-ID eagle records, identified altitude (m asl; LRT = 8.9, d.f. = 1, $p = .01$) and distance to the nearest coast (m; LRT = 6.4, d.f. = 1, $p = .003$) 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: $9,039.4 \pm 1,935.4$ 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: $17,383.6 + 2,127.8$ m). Altitude and distance to nearest coast were themselves positively correlated (Pearson's correlation coefficient: $r = 4.3$, d.f. = 80, $p \leq .001$).

Species identity was also significantly associated with distance to nearest waterbodies (m; LRT = 8.6, d.f. = 1, $p = .003$) and the area of such water bodies (m^2 ; LRT = 7.1, d.f. = 1, $p = .007$). As expected, White-tailed Eagle records were associated with closer proximity to waterbodies (average distance to waterbody: $2,120.5 \pm 259.4$ m) than Golden Eagles (average distance to waterbody: $2,254.9 \pm 308.7$ m). White-tailed Eagles were also associated with smaller waterbodies (average waterbody area: $131,080.3 \pm 58,604.5$ m^2), whereas Golden Eagles were associated with larger waterbodies (average waterbody area: $202,758.9 \pm 71,597.6$ 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: $4,372.5 + 3,701.3$ m) and White-tailed Eagle records (average settlement distance: $4,198.8 + 3,610.6$ m). Initially, this variable was eliminated from the model as the variable was marginally nonsignificant. 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) as well as 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 model. The six habitat features retained in the final GLM model were incorporated into the Discriminant Function Analysis used to assign likely species identities to the “Unknown” species records.

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 151 species-specific eagle records for Wales—81 Golden Eagle and 70 White-tailed Eagle records (Figure 2d).

3.5 | Where were eagles formerly distributed in Wales?

All eight modern counties in Wales hold historic records of at least one eagle species, with the north western parts of Wales holding over half of the records (Figure 3). 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 3a).

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 3b). The north-western core range held

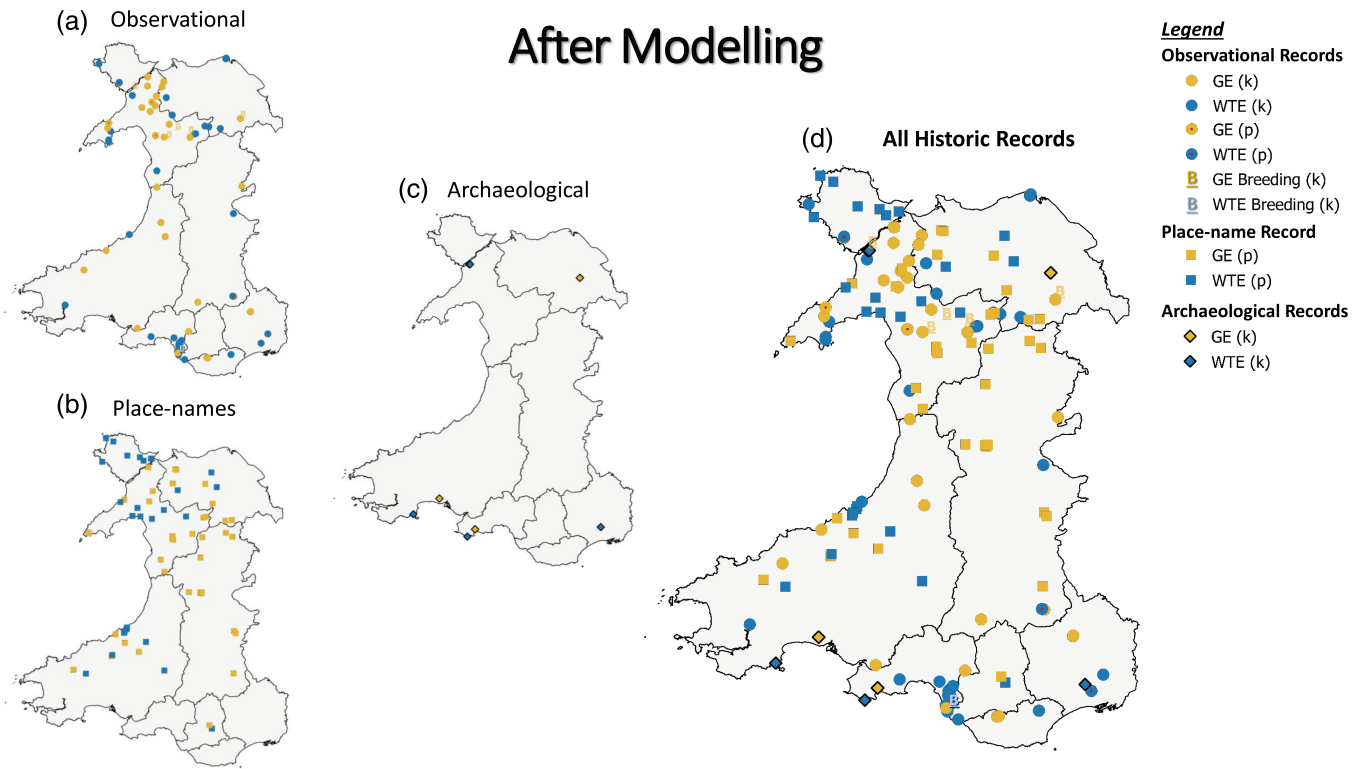


FIGURE 2 The historic distribution of known (k) and predicted (p) eagle records in Wales after modeling—(a) observational records; (b) place-name records; (c) archaeological records, and (d) all historic records

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

(b) **White-tailed Eagle, Eyr y Môr (*Haliaeetus albicilla*)**

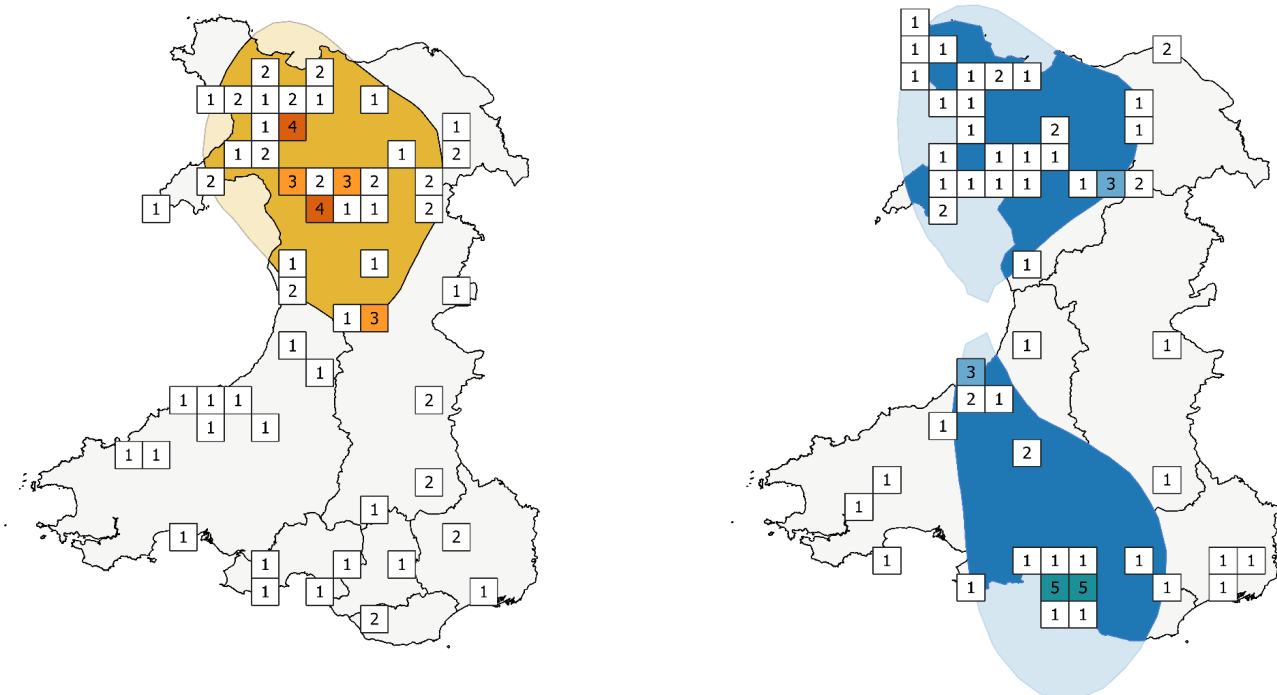


FIGURE 3 10 × 10 km distribution of eagle records in Wales: Historic record abundance and core historic distribution for; (a) Golden Eagle, Eyr Euriad (*Aquila chrysaetos*) and (b) White tailed Eagle, Eyr y môr (*Haliaeetus albicilla*)

36.4% of records and the south-eastern core range held 42.9% of records.

4 | DISCUSSION

The historic and pre-historic presence of Golden and White-tailed Eagles across England, Scotland and Ireland is well understood (Evans et al., 2012; Yalden, 2007), but the historic evidence for these two species in Wales has, until now, been sparse (Lovegrove, Williams, & Graham, 2010). Our collation, modeling 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.

4.1 | Temporal distribution of records

We found that 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 ninth 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). We found that 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 strong historic evidence for breeding Golden Eagles in Wales, with nests being recorded in Castell Dinas Brân in Denbighshire (Forrest, 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 1850s, 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 1800s. 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 (Heathcote, Griffin, & Salmon, 1967; Hurford & Lansdown, 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 in an attempt to protect domestic livestock; not only in Wales, but also across Britain and Europe (Newton, 1979). Persecution was encouraged and subsidized by bounty payments, recorded in Britain as early as the 16th Century (Newton & 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.

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 (Evans et al., 2010; Evans et al., 2012; Radović & Mikuska, 2009; Sansom et al., 2016; Whitfield & 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 (Evans et al., 2010; Krone, Nadjafzadeh, & Berger, 2013; Radović & Mikuska, 2009).

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 (*Hieraetus pennatus*) and Lesser-spotted Eagles (*Clanga pomarina*), where DFA yielded on average a 60–82% prediction accuracy (Galanaki, 2004; Poirazidis, Goutner, Tsachalidis, & Kati, 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., 2020). 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 et al., 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.

4.3 | Core historic distributions

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, centered 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. Most of the records within these core ranges are dated within the 16th, 17th and 18th Centuries, providing an insight into the core distribution prior to the extinctions of both species as breeding birds in Wales.

5 | CONCLUSION

IUCN guidelines (IUCN/SSC, 1998, 2013) state that the reintroduction of a species should be carried out within its historic indigenous 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; Dennis et al., 2019; Nygard et al., 2009), European Beaver, *Castor fiber* (Gaywood, Batty, & Galbraith, 2008; Kitchener & Conroy, 1997) and Pine Marten, *Martes martes* (Macpherson, 2014).

It has previously been suggested the reintroduction 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 a reintroduction of either or both eagle species to Wales is a realistic possibility.

ACKNOWLEDGMENTS

We thank the historians and museum curators who supplied us with information, the volunteer contributors to the Eagle Reintroduction Wales (ERW) project (www.eaglereintroductionwales.com), and the British Trust for Ornithology for the use of their library. This work was part-funded by a Knowledge Economy Skills Scholarship (KESS) to Sophie-lee Williams, supported by European Social Funds (ESF) through the Welsh Government. Knowledge Economy Skills Scholarships (KESS) is a pan-Wales higher level skills initiative, led by Bangor University on behalf of the HE sector in Wales. It is part funded by the Welsh Government's European Social Fund (ESF) convergence programme for West Wales and the Valleys. We thank ERW project collaborators, also Cardiff University and our KESS partner companies Eco-Explore (<http://www.eco-explore.co.uk/>) and Wildlife Trusts Wales (<http://www.wtwales.org/>), for co-funding this KESS studentship. Data used in this study is available in the online supporting information.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors participated in the design and theory of the study. Sophie-lee Williams and Rob Thomas were responsible for data collection and analysis, and with Sarah Perkins all three participated writing the preliminary manuscripts. All authors were involved in implementing feedback on the analysis and revising the manuscript. All authors approved the final submission.

DATA AVAILABILITY STATEMENT

The references for historic data gathered for this research is available in the online supporting information. Spatial data used are available at the Lle Geo-Portal for Wales (<https://lle.gov.wales/home?lang=en>), under the Open Government License for Public Sector Information. Code to reproduce the analysis is available from the corresponding author upon request.

ETHICS STATEMENT

No animals were used in this study.

ORCID

Sophie-lee Williams  <https://orcid.org/0000-0003-3937-8329>

REFERENCES

- Ancient Woodland Inventory. (2011). *Lle: A geo-portal for Wales: Ancient Woodland Inventory 2011*. Natural Resources Wales. Retrieved from <https://lle.gov.wales/catalogue/item/AncientWoodlandInventory2011/?lang=en>.
- Archwilio. (2019). *Records on scheduled monuments, listed buildings, registered landscapes of historic interest*. Retrieved from <https://www.archwilio.org.uk/her/chi1/arch.html>.
- Bainbridge, I. P., Evans, R. J., Broad, R. A., Vrooke, C. H., Duffy, K., Green, R. E., et al. (2003). Re-introduction of white-tailed eagles (*Haliaeetus albicilla*) to Scotland. In D. B. A. Thompson, S. M. Redpath, A. H. Fielding, M. Marquiss, & C. A. Galbraith (Eds.), *Birds of prey in a changing environment* (pp. 393–406). Edinburgh: The Stationary Office.
- Bell, A. (1915). Pleistocene and later birds of Great Britain and Ireland. *Zoologist*, 19, 401–412.
- Bramwell, D. (1960). *Some research into bird distribution in Britain during the Late Glacial and Post-glacial periods* (pp. 51–58). Arbroath, Scotland: Bird Report 1956-60 of Merseyside Naturalists' Association.
- Calenge, C. (2006). The package adehabitat for the R software: A tool for the analysis of space and habitat use by animals. *Ecological Modelling*, 197, 516–519.
- CPAT. (2017). *Chwyd-Powys archaeological trust*. Retrieved from <http://www.cpat.org.uk/>.
- DAT. (2017). *Dyfed archaeological trust*. Retrieved from <http://www.dyfedarchaeology.org.uk/>.
- Dennis, R. (2003). Re-introduction of birds and mammals to the British Isles. *Biologist*, 50, 20–24.
- Dennis, R., Mackrill, T., & Sargeant, L. (2019). *The feasibility of reintroducing White-tailed Eagles Haliaeetus albicilla to the Isle of Wight and the Solent*. Bristol: Forestry Commission England.
- Dennis, R. H., & Ellis, P. M. (1984). The status of the Golden Eagle in Britain in 1992. *British Birds*, 77, 592–607.
- Eaton, M., Dillion, I. A., Patrick, K. S.-A., & Whitfield, D. (2007). Status of Golden Eagle *Aquila chrysaetos* in Britain in 2003. *Bird Study*, 54(2), 212–220. <https://doi.org/10.1080/00063650709461477>
- Elith, J. H., Graham, C. P., Anderson, R., Dudík, M., Ferrier, S., Guisan, A. J., ... Zimmermann, N. E. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29, 129–151. <https://doi.org/10.1111/j.2006.0906-7590.04596.x>
- Evans, G. (1974). *History of Wales: Gwynfor Evans tells the story of his country* (pp. 6–98). Cardiff: South Wales Echo.
- Evans, R. J., O'toole, L., & Whitfield, D. P. (2012). The history of eagles in Britain and Ireland: An ecological review of place-name and documentary evidence from the last 1500 years. *Bird Study*, 59(3), 335–349. <https://doi.org/10.1080/00063657.2012.683388>
- Evans, R. J., Pearce-Higgins, J., Whitfield, D. P., Grant, J. R., MacLennan, A., & Reid, R. (2010). Comparative nest habitat characteristics of sympatric White-tailed *Haliaeetus albicilla* and Golden Eagles *Aquila chrysaetos* in western Scotland. *Bird Study*, 57, 473–482. <https://doi.org/10.1080/00063657.2010.489317>
- Fielding, A. H., & Haworth, P. F. (2014). *Golden eagles in the south of Scotland: an overview*. Inverness: Scottish Natural Heritage, Commissioned Report No. 626, pp. 82.
- Fielding, A. H., Haworth, P. F., Anderson, D., Benn, S., Dennis, R., Weston, E., & Whitfield, D. P. (2020). A simple topographical model to predict Golden Eagle *Aquila chrysaetos* space use during dispersal. *Ibis*, 162, 400–415. <https://doi.org/10.1111/ibi.12718>
- Forrest, H. E. (1907). *The vertebrate Fauna of North Wales*. London: Witherby & Co.
- Galanaki, A. (2004). *Using habitat-based models to assess the distribution of raptor nesting areas on the Island of Kythera, SW Greece*. Manchester: Master's thesis. Manchester Metropolitan University.
- GAT. (2017). *Gwynedd archaeological trust*. Retrieved from <http://www.heneb.co.uk/>.
- Gaywood, M., Batty, D., & Galbraith, C. (2008). Reintroducing the European Beaver in Britain. *British Wildlife*, 19, 381–391.
- GGAT. (2017). *Glamorgan-Gwent archaeological trust*. Retrieved from <http://www.ggat.org.uk/>.
- Guisan, A., Tingley, R., Baumgartner, J. B., Naujokaitis-Lewis, I., Suttle, P. R., Tuloch, A. I. T., ... Buckley, Y. M. (2013). Predicting species distributions for conservation decisions. *Ecology Letters*, 16(12), 1424–1435. <https://doi.org/10.1111/ele.12189>
- Harrison, C. J. O. (1980). A re-examination of British Devensian and Earlier Holocene bird bones in the British Museum (natural history). *Journal of Archaeological Science*, 7, 53–68.
- Harrison, C. J. O. (1987). Pleistocene and prehistoric birds of south-west Britain. *Proceedings of the University of Bristol Speleological Society*, 18(1), 81–104.
- Hayhow, D. B., Benn, S., Stevenson, A., Stirling-Airid, P. K., & Eaton, M. A. (2017). Status of Golden Eagle *Aquila chrysaetos*

- in Britain in 2015. *Bird Study*, 64(3), 281–294. <https://doi.org/10.1080/00063657.2017.1366972>
- Heathcote, A., Griffin, D., & Salmon, H. L. (1967). *The birds of Glamorgan* (pp. 34–64). Cardiff: Bird Report of Cardiff Naturalists' Society.
- Hendricks, S. A., Clee, P. R. S., Harrigan, R. J., Pollinger, J. P., Freedom, A. H., Callas, R., ... Wayne, R. K. (2016). Re-defining historical geographic range in species with sparse records: Implications for the Mexican wolf reintroduction program. *Biological Conservation*, 194, 48–57. <https://doi.org/10.1016/j.biocon.2015.11.027>
- Historic LandMap Wales. (2017). *Lle: A geo-portal for Wales: Landmap historic landscape*. Natural Resources Wales. Retrieved from <https://lle.gov.wales/catalogue/item/LandmapHistoricLandscape/?lang=en>.
- Hurford, C., & Lansdown, P. (1995). *The birds of Glamorgan* (pp. 61–68). Cowbridge: D. Brown & Sons.
- IUCN/SSC. (1998). *IUCN guidelines for re-introductions*. Gland, Switzerland: International Union for Conservation of Nature Retrieved from <http://www.iucn-whsg.org/node/1471>
- IUCN/SSC. (2013). *Guidelines for reintroductions and other conservation translocations*. Gland, Switzerland: International Union for Conservation of Nature Retrieved from <https://www.iucn.org/content/new-guidelines-conservation-translocations-published-iucn>
- Johnson, T. (1644). *Dictionary of National Biography, edited by Sidney Lee* (pp. 47–48). London: Smith, Elder & Co.
- Kitchener, A. C., & Conroy, J. W. H. (1997). The history of the Eurasian Beaver *Castor fiber* in Scotland. *Mammal Review*, 27(2), 95–108. <https://doi.org/10.1111/j.1365-2907.1997.tb00374.x>
- Krone, O., Nadjafzadeh, M., & Berger, A. (2013). White-tailed Sea Eagles (*Haliaeetus albicilla*) defend small home ranges in north-east Germany throughout the year. *Journal of Ornithology*, 154, 55–64. <https://doi.org/10.1007/s10336-013-0951-6>
- Kuemmerle, T., Hicker, T., Olofsson, J., Schurgers, G., & Radeloff, V. C. (2012). Reconstructing range dynamics and range fragmentation of European bison for the last 8000 years. *Diversity and Distributions*, 18, 47–59. <https://doi.org/10.1111/j.1472-4642.2011.00849.x>
- Love, J. A. (1988). The reintroduction of the white-tailed sea eagle to Scotland, 1975–1987. *Proceedings of the International Symposium on Raptor Reintroduction*. Peterborough: Nature Conservation Council.
- Lovegrove, R., Williams, I., & Graham, W. (2010). *Birds in Wales* (pp. 56–84). London: Poyser.
- Macpherson, J. (2014). *Feasibility assessment for reinforcing pine marten numbers in England and Wales*. Herefordshire: The Vincent Wildlife Trust.
- Marquiss, M. (2005). *Scoping study for the possible re-introduction of Golden Eagle and White-tailed Eagle to Wales*. Bangor: Countryside Council for Wales.
- Millsap, B. A. (2014). Natal dispersal distance of bald and Golden eagles originating in the coterminous United States as inferred from band encounters. *Journal of Raptor Research*, 48, 13–23. <https://doi.org/10.3356/JRR-13-00005.1>
- Mindell, D., Fuchs, J., & Johnson, J. A. (2018). Phylogeny, taxonomy, and geographic diversity of diurnal raptors: Falconiformes, Accipitriformes, and Cathartiformes. In J. Sarasola, J. Negro, & J. Grande (eds.), *Birds of prey* (pp. 3–32). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-73745-4_1
- Moss, E. (2015). *Habitat selection and breeding ecology of Golden Eagles in Sweden*. (PhD thesis). Swedish University of Agricultural Science.
- MRA. (2019). *Place-name Research Centre: Melville Richards Archive (MRA)*. Retrieved from http://www.e-gymraeg.co.uk/enwaulleoedd/amr/cronfa_en.aspx.
- National Library of Scotland (NLS). (2019). *Ordnance Survey Maps: Six-inch England and Wales, 1842–1952*. Retrieved from <https://maps.nls.uk/os/6inch-england-and-wales/>.
- Newton, I. (1979). Effects of human persecuting on European raptors. *Raptor Research*, 13(3), 65–75.
- Newton, I., & Rothery, P. (2001). Estimation and limitation of numbers of floaters in a Eurasian Sparrowhawk population. *Ibis*, 143, 442–449. <https://doi.org/10.1111/j.1474-919X.2001.tb04945.x>
- Nygaard, T., Halley, D., & Mee, A. (2009). *The reintroduction of the white-tailed eagle to Ireland*. Norwegian Institute for Nature Research; NINA report 583, pp. 30.
- OS Terrain 50. (2017). *Ordnance survey: OS Terrain 50*. Retrieved from <https://www.ordnancesurvey.co.uk/business-and-government/products/terrain-50.html>.
- Poirazidis, K., Goutner, V., Tsachalidis, E., & Kati, V. (2007). Comparison of nest site selection patterns of different sympatric raptor species as a tool for their conservation. *Animal Biodiversity and Conservation*, 2(30), 131–145.
- QGIS Development Team. (2018). *QGIS geographic information system. Open source geospatial foundation project*. Retrieved from <http://qgis.osgeo.org>.
- R Core Team. (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing Retrieved from <http://www.R-project.org/>
- R Studio Team. (2019). *R Studio: Integrated Development for R*. Boston: R Studio, Inc. Retrieved from <http://www.rstudio.com/>
- Radović, A., & Mikuska, T. (2009). Population size, distribution and habitat selection of the white-tailed eagle *Haliaeetus albicilla* in the alluvial wetlands of Croatia. *Biologia*, 64, 156–164. <https://doi.org/10.2478/s11756-009-0011-0>
- Rowland, R. (1990). *Early welsh Saga poetry: A study and edition of the Englynion*. Suffolk, England: D. S. Brewer Publishing.
- Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW). (2019). *List of historic place names*. Retrieved from <https://rcahmw.gov.uk/discover/list-of-historic-place-names/>.
- Sansom, A., Evans, R., & Roos, S. (2016). *Population and future range modelling of reintroduced Scottish white-tailed eagles (Haliaeetus albicilla)*. Inverness: Scottish Natural Heritage Commissioned Report No. 898, (898).
- Sinclair, S. J., White, M. D., & Newell, G. R. (2010). How useful are species distribution models for managing biodiversity under future climates? *Ecology and Society*, 15, 24–39.
- Syfert, M. M., Joppa, L., Smith, M. J., Coomes, D. A., Bachman, S. P., & Brummit, N. A. (2014). Using species distribution models to inform IUCN Red List assessments. *Biological Conservation*, 177, 174–184. <https://doi.org/10.1016/j.biocon.2014.06.012>
- Taylor, P. (2011). Big birds in the UK: The reintroduction of iconic species. *Ecos*, 32(1), 74–80.

- Thomas, R., Lello, J., Medeiros, R., Pollard, A., Robinson, P., Seward, A., et al. (2017). *Data analysis with R statistical software*. Caerphilly: Eco-explore. www.eco-explore.co.uk
- Venables, W. N., & Ripley, B. D. (2002). *Modern Applied Statistics with S* (4th ed.). New York, NY: Springer.
- Watson, J. (2010). *The Golden Eagle* (2nd ed.). London: T & AD Poyser, Bloomsbury Publishing.
- Welsh Online Newspaper Library. (2019a). *Welsh Newspapers Online: The National Library of Wales*. Retrieved from <http://newspapers.library.wales>.
- Welsh Online Newspaper Library. (2019b). *Welsh Newspapers Online: The National Library of Wales – Article 19*. Retrieved from <https://newspapers.library.wales/view/3794505/3794508/19/Eagle>.
- Welsh Online Newspaper Library. (2019d). *Welsh Newspapers Online: The National Library of Wales – Article 113*. Retrieved from <https://newspapers.library.wales/view/3738798/3738804/113/eagle%20sheep%20carcass>.
- Whitfield, D. P., Douse, A., Evans, R., Grant, J., Love, J., McLoed, D. R. A., ... Wilson, J. D. (2009). Natal and breeding dispersal in a reintroduced population of White-tailed Eagles *Haliaeetus albicilla*. *Bird Study*, 56(2), 177–186. <https://doi.org/10.1080/00063650902792023>
- Whitfield, D. P., & Fielding, A. H. (2017). *Analyses of the fates of satellite tracked golden eagles in Scotland*. Inverness: Scottish Natural Heritage, report no. 982, p. 285. Retrieved from http://www.snh.org.uk/pdfs/publications/commissioned_reports/982.pdf.
- Whitfield, D. P., Marquiss, M., Ried, R., Grant, J., Tingey, R., Evans, J., & Evans, E. (2013). Breeding season diets of sympatric white-tailed eagles and golden eagles in Scotland: No evidence for competitive effects. *Bird Study*, 60, 67–76. <https://doi.org/10.1080/00063657.2012.742997>
- Yalden, D. W. (2007). The older history of the White-tailed Eagle in Britain. *British Birds*, 100(8), 471–480.
- Yang, L., Huang, M., Zhang, R., Lv, J., Ren, Y., Jiang, Z., ... Luan, X. (2016). Reconstructing the historical distribution of the Amur leopard (*Panthera pardus orientalis*) in Northeast China based on historical records. *ZooKeys*, 592, 143–153. <https://doi.org/10.3897/zookeys.592.6912>

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Williams S, Perkins SE, Dennis R, Byrne JP, Thomas RJ. An evidence-based assessment of the past distribution of Golden and White-tailed Eagles across Wales. *Conservation Science and Practice*. 2020;2:e240. <https://doi.org/10.1111/csp2.240>