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Birds Science People

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Report to RenewableUK Cymru

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Executive summary

The Welsh Red Kite population is currently in ongoing recovery after a historic decline driven by persecution, and a consequent population bottleneck during the first half of the 20th Century. Trends from the BTO/JNCC/RSPB Breeding Bird Survey (BBS; Heywood et al. 2023) show that the population has grown rapidly over the past few decades. Nonetheless, the Red Kite remains a conservation concern, in particular around two Special Protection Areas (SPAs) designated for the species' conservation: the Berwyn SPA and the Elenydd–Mallaen SPA. Wind turbines represent a known threat to Red Kite populations, causing additional mortality through collisions. A large number of wind farm sites are currently at various stages of development (ranging from aspirational schemes to proposals under assessment) in Wales, especially in Mid Wales where Red Kites are at their highest density and where the Elenydd-Mallaen SPA is situated. In this context, RenewableUK Cymru contracted BTO and BSG Ecology to undertake Population Viability Analysis (PVA) to model the potential impacts of current and proposed (including early concept) wind farm developments on the Welsh population of Red Kites.

Modelling used spatially-explicit Red Kite population estimates produced by combining data from (i) *Bird Atlas 2007–11* (Balmer et al. 2013), (ii) the BBS, and (iii) the Avian Population Estimates Panel (Woodward et al. 2020). PVAs were run using lower and upper bounds and intermediate values for published, calculated and estimated demographic parameters. All possible combinations of demographic parameter levels were modelled, and a rejection sampling procedure applied to retain a final 'baseline' model set whose range of population trajectories reflected the observed population trend of Red Kite in Wales. Scenarios of wind turbine collision mortality were applied to describe the impact of each developer's proposed sites in turn, as well as their combined impact, with outcomes assessed at the national (Wales) scale, at the scale of Natural Resources Wales' regional 'Area Statements', and on the population of each of the two focal SPAs. Model outcomes were assigned to five categories according to whether they predicted population decline, population stability, or three different levels of population growth.

From the initial set of 37,500 candidate models, rejection sampling retained 19,775 models that reflected the observed recent population growth. Under the baseline scenario (which includes all existing wind turbines but no further future developments), all models predicted population stability or increase at all spatial scales. Across virtually all combinations of impact scenarios and outcome scales, impacts are projected to be relatively small, even under the scenario where all developers' plans were modelled in combination. Under this scenario, the probability of the Welsh population of Red Kite stabilising is 28% (compared to 17% under the baseline scenario). There is also a small but non-zero probability of each SPA population declining under this scenario (Elenydd-Mallaen SPA: 4%; Berwyn SPA: 0.4%; compared to 0% in both SPAs under the baseline scenario). However, for every impact scenario, population decline is predicted to be less likely than continued growth, at all outcome scales; an average of 12% of the national Red Kite population could be killed per year in collisions with new wind turbines before our models would suggest population decline as being more probable than not (all else being equal). In general, modelled impacts were larger for spatially-smaller outcome scales with relatively high-density Red Kite populations (especially the two SPA populations). Thus, impacts were larger for the high-density Elenydd-Mallaen SPA population than for the Berwyn SPA population where the current density of Red Kites is lower.

Whilst impacts upon population trends may appear relatively small, these may propagate into substantial differences in population size given enough elapsed time. For example, the median population size estimate for the Elenydd-Mallaen SPA in the year 2050 is approximately half as large under the scenario where all developers' plans were modelled in combination than under the baseline scenario, even though both estimates are greater than the most recent (2022) population estimate and therefore represent population growth.

These results may provide reassurance that currently proposed levels of wind farm development are unlikely to prevent the continued growth of the Welsh Red Kite population, even in the most extreme scenario where all sites currently in development go ahead. However, they highlight that greater caution is justified for developments in proximity to the two SPAs designated for Red Kite, in order to minimise risk to the higher-density populations of these areas.

1. Introduction

Historic population change

The Red Kite (*Milvus milvus*) was historically widespread across Britain but by the 1930s and 1940s intense persecution had reduced the population to fewer than 10 breeding pairs, concentrated in a small area of Mid Wales. Careful conservation organised by a local 'Kite Committee' of conservationists and landowners restored the Welsh population to 100 pairs by 1993. Most birds were descended from a single female that had continued to breed successfully during the population bottleneck (Carter 2007). As a step towards restoring the original breeding range, birds were introduced in 1989 into the Chilterns (Oxfordshire and Buckinghamshire) and into the Black Isle in Easter Ross (Evans & Pienkowski 1991). Successful breeding populations quickly established in both areas. Further releases were begun in Northamptonshire in 1995, central Scotland in 1996, Yorkshire in 1999, Dumfries & Galloway in 2001, north-east England in 2004, Aberdeen in 2007 and County Down in 2008.

Each of these centres of reintroduction has given rise to a productive breeding group, in some cases benefiting from large-scale provision of food (e.g. Orros & Fellowes 2014, 2015), or the development of a well-established communal roost. Introduced birds and their offspring wander widely across Britain and Ireland but, as yet, pairs have been slow to set up breeding sites distant from the release areas (Balmer et al. 2013). Nonetheless, the BTO/JNCC/RSPB Breeding Bird Survey (BBS) has recorded a steep rise in abundance since 1995 (Heywood et al. 2023). At the UK national scale, there has been an increase of almost 2,000% over the last 25 years, and the population continues to increase rapidly. In Wales, the species has recovered to the point that population change can now be reported under the annual BBS. Results from a transect survey specifically targeting Buzzards and Red Kites in central-southern England between 2011 and 2016, showed a doubling of population in the area over that period, broadly in line with the BBS trend (Stevens et al. 2020).

Contemporary status and conservation action

In light of this sustained population growth, the Red Kite was moved to the UK Green List in 2015 (Eaton et al. 2015) and the Welsh Green list in 2022 (Johnstone et al. 2022). Nonetheless, a range of conservation issues remains relevant, particularly in the context of two Special Protection Areas (SPAs) in Wales which are designated under Article 4.1 of EC Directive 79/409 on the Conservation of Wild Birds for the protection of breeding Red Kite (an Annex 1 species). For this purpose, the SPA populations are considered by Natural Resources Wales (NRW; and its predecessor, the Countryside Council for Wales) to include "*all birds nesting within the SPA, or within 2 km of the boundary*" (CCW 2008a). The Elenydd-Mallaen SPA (site code UK9014111) was designated in 1996 for holding 9.3% of the breeding population of Great Britain (JNCC 2015a), and held 34 breeding pairs of Red Kite at the most recent formal assessment (JNCC 2015a). This is compared to a target of at least 15 pairs or at least 0.5% of the British population present, set as a Conservation Objective by the NRW Core Management Plan (CCW 2008a). The Berwyn SPA (site code UK9013111) was designated in 1998 for holding 1.2% of the breeding population of Great Britain (JNCC 2015b), and held two to three breeding pairs of Red Kite at the most recent formal assessment (JNCC 2015b). This is compared to a target of at least two breeding pairs set as a Conservation Objective by the NRW Core Management Plan (CCW 2008b).

Artificial feeding of Red Kites can help support populations, and inadvertent food provision through contemporary farming approaches (leaving of sheep afterbirth and fallen stock as carrion) may have contributed to supporting the remnant Red Kite population through its lowest point during the 20th century (Roger Buisson pers. comm.). However, there may be a risk that such food provision may artificially inflate populations to such an extent that if feeding was halted (or farming practices changed), there may be insufficient resources in the local area to continue to sustain the number of birds present (Orros & Fellowes 2014). There is also increasing concern that bird aggregations at artificial food supplies might facilitate the transmission of disease (Toms 2023). Some illegal killing of Red Kites continues, and in northern Scotland the use of poisoned baits deliberately to kill raptors has severely limited the growth of the population (Smart et al. 2010, Sansom et al. 2016). Poisoning also still occurs in England and Wales (RSPB 2023) and may have slowed the rate of expansion in some areas (Molenaar et al. 2017). Anticoagulant rodenticides have been found in some Red Kite carcasses in concentrations sufficient to be considered a contributory cause of death; there is no evidence so far to suggest that this might be affecting the population growth rate, but precautions such as prompt removal and safe disposal of poisoned rodents, as well as continued monitoring, would be prudent (Walker et al. 2013).

An additional potential threat is posed by an increasing drive to expand renewable energy generation in Wales through the development of onshore wind capacity. Red Kites are known to fall victim to collisions with wind turbines (Schaub 2012), including occasionally in Wales (BSG Ecology 2022, Cross 2023). Modelling suggests that the spatial distribution of wind turbines can significantly shape their impact upon Red Kite populations (Schaub 2012, Bellebaum et al. 2013), such that assessing environmental impact of wind power plants collectively at regional scale, rather than on a case-by-case basis, is justified (Schaub 2012). However, at this stage it is unclear what impact the current suite of proposed wind energy developments is likely to have on the continued growth of the Red Kite population in Wales, both at national scale and regionally, and with particular reference to the two designated SPAs.

Background to the modelling project: industry need

A large number of wind farms are being proposed in Wales (with details of at least 50 supplied confidentially to this project), especially in Mid Wales, at present. Many of these are sufficiently close to the two SPAs that impacts on local Red Kite populations must legally be considered. To date, NRW has requested detailed consideration of impacts on SPA Red Kite populations for proposed wind farms, in some cases where the proposed developments are in excess of 8 km from SPA boundaries.

To be able to complete robust assessments of the impact of wind farm-related mortality on SPA populations from individual developments, population modelling is typically required. This is specialist work that most commercial consultancies are not equipped to do. Completing this on a site-by-site basis, and often under time constraints in the lead up to Environmental Impact Assessment (and Habitats Regulations Assessment) submission, is likely to result in inconsistent approaches in different applications, to both the modelling itself and the interpretation of findings. A more consistent and strategic approach is therefore needed. It is also inevitable that in the absence of an overarching study, and as more wind farm proposals come forward, NRW will become more concerned about cumulative impacts from multiple wind farms proposed by multiple developers on SPA populations, and potentially also about impacts on the wider Welsh population. This is likely to result in requests for additional survey, delays in the planning process, and complicated hearings. There is also the clear potential for proposed schemes to be turned down based on the precautionary principle, as Planning & Environmental Decisions Wales (PEDW) place a great deal of weight on NRW's views.

It follows that, to understand the capacity of Red Kite populations to absorb current and future collision fatalities, and thereby give NRW the confidence to provide a more informed view on the impacts of wind farm proposals on the SPAs, a strategic study is required. An independently conducted modelling exercise by a collaboration of experienced researchers was considered to be more influential than a consultancy-led piece of work in this regard. A study building understanding of Red Kite population resilience at local and national scales would be timely and informative.

BSG Ecology, on behalf of several member organisations of RenewableUK Cymru, approached BTO Cymru to deliver a population viability analysis (PVA) for the Welsh Red Kite population, for which the Berwyn and Elenydd-Mallaen SPAs are designated. The renewable energy generation industry's objective was to better understand the resilience of the Red Kite population to additional mortality through collision with wind turbines; and the vulnerability of the SPA populations to development sites outside of, but close or adjacent to, their boundaries. Although new wind farms may not be located within the SPAs (which are generally considered a hard constraint to development), they may be located close to SPA boundaries. There is therefore potential for Red Kite populations within an SPA to be impacted both by mortality of individuals breeding within, but ranging outside, the SPA boundary (for example to forage, both during the breeding season and when they range more widely outside the breeding season), and by mortality of individuals breeding outside the SPA boundary but providing young birds that recruit into the SPA population (preventing breeding isolation of the SPA population, and consequent genetic bottlenecks).

The rapid increase in Red Kite numbers in Wales over recent decades will have resulted in far more pairs breeding within and close to the SPAs than were present when the sites were designated. Welsh Red Kites are also likely to have higher breeding productivity than has historically been the case, due to recent genetic mixing with birds from the reintroduced populations in England, as well as occasional immigrating Scottish and Irish birds (Skujina 2013). The population may therefore be resilient to a certain amount of increased mortality from wind turbine collisions. Demographic modelling provides a quantitative framework for examining the sensitivity of the Red Kite population to altered survival risk, under a range of impact scenarios and at a range of spatial scales.

Population models: general approach

Population Viability Analysis (PVA) has become a commonly used tool in conservation biology and in the management of threatened or endangered species (Keedwell 2004). PVA is a general term for demographic predictive models which forecast the robustness of a population to scenarios of impact compared to an unimpacted baseline (Beissinger et al., 2006). Robust PVAs are contingent upon sufficient demographic data (e.g. population estimates, breeding success, juvenile and adult survival) for the target species (Keedwell 2004). Natural England (NE) have developed a PVA modelling framework (Searle et al. 2019) as a front-end, interactive web application user interface allowing users to set-up, apply and run their own PVA models without the need for access to specific software. Although this application was developed within the context of modelling mortality of seabirds as a consequence of collisions with offshore wind turbines, the modelling tool can be used to assess any type of impact that changes the survival or productivity rates of any avian species (Searle et al. 2019). In other words, the generic nature of the tool is such that it can be applied to other groups of birds. The NE seabird modelling tool is available to other users under an Open Government Licence. In order to meet BTO internal standards of reproducibility and accuracy, BTO staff developed the capacity to use the underpinning tools for the NE web application within the R programming environment (R Core Team 2022) as part of previous work developing PVAs for Great Cormorant *Phalacrocorax carbo* and Goosander *Mergus merganser* (Macgregor et al. 2022).

PVAs are parameterised using a range of demographic metrics (e.g. brood size, adult and immature mortality); which need to be evidence-based. In addition to evidence from the published literature (much of which will refer to Red Kite populations outside Wales), two long-term datasets have been collected that contain demographic information on the Welsh population. Firstly, nest records collated by the Welsh Kite Trust over the period 2000–13 (Welsh Kite Trust 2023) have enabled a detailed understanding of productivity in the population, and can permit the estimation of 'skip rate' (i.e. the likelihood of an adult Red Kite not attempting to breed in any given breeding season). Secondly, recoveries and resightings of birds ringed under license over the period 1994 to present as part of the BTO Ringing Scheme, many of which have also been colour-marked with wing tags and/or leg rings (Cross 2023), can provide an understanding of typical intra- and inter-annual movements made by individual Red Kites.

Aims

In this study, we employ a PVA approach to model and predict the impacts of currently-planned wind farm developments on the Welsh Red Kite population. We present results in comparison to a baseline scenario, which effectively incorporates existing wind turbines in Wales while assuming no further wind turbines are commissioned, at a range of spatial scales to aid interpretation of impacts upon national, regional and SPA-level populations. We attempt to identify the level of additional mortality that, all else being equal, would be required to halt population growth in the Welsh population of Red Kite.

METHODS

Impact scenarios and outcome scales

Throughout this study, we aimed to test the impacts of a range of wind farm development scenarios, and to describe these across a range of informative spatial scales. Our input scenarios were: (i) the most extreme case, in which every development currently in planning (across every developer involved in the study) is implemented, and (ii) the total impact of each individual development. We described the outcome of each of these scenarios: (i) nationally, (ii) for each NRW Area Statement area (a subdivision of Wales into six terrestrial zones, allowing regionally-important environmental issues, priorities and opportunities to be identified and incorporated into NRW's work), and (iii) for the population associated with the two respective SPAs designated for Red Kites. Because the SPA populations of Red Kites are often considered to include all individuals within a 2 km zone surrounding the SPA, we tested impacts on SPA populations both solely within the SPA boundary, and within the SPA boundary plus a 2 km buffer.

We additionally aimed to identify the national-scale rate of additional mortality from wind turbine collisions that would result in the current growth of the Welsh Red Kite population ceasing (i.e. population stabilisation of the median population trend estimate).

Data requirements for Population Viability Analysis

All analyses were conducted in R version 4.2.2 (R Core Team 2022).

Population Viability Analysis (PVA) models require detailed demographic data, which was collated from BTO data, published literature, Welsh Kite Trust reports and data held by individual ringers. Final data sources are listed and referenced below, and for each data source, any initial selection and/or filtering process applied before analytical selection is briefly summarised. In-study analysis included **dispersal ranges** split between two age classes and lifetime **skip rate** for breeding attempts.

Population and distribution estimates

Distribution estimates for Red Kite, in the form of interpolated population density, were sourced from *Bird Atlas 2007–11* (Balmer et al. 2013). Estimates are at tetrad-resolution (i.e. 2 x 2 km grid squares) and represent the relative density of individuals during the breeding and winter seasons; for this study, we used the winter estimates since individual Red Kites are expected to range further (and potentially encounter more wind farms) during winter. Fieldwork for the *Bird Atlas 2007–11* took place across the entire period 2007 to 2011, so estimates are nominally centred on the year 2009. Given the time elapsed since this survey period, and the status of Red Kite as a [re-]colonizing species within Wales, we cross-referenced these distribution estimates against up-to-date observation data for Red Kite, supplied by Cofnod and collated by Local Environmental Records Centres Wales (www.lercwales.org.uk). Specifically, we overlaid *Bird Atlas 2007–11* distribution maps with maps of observations, and by visual inspection, ensured that there were no regions which had had few Red Kites during the *Bird Atlas 2007–11* survey period, but had had many subsequent observations.

National-scale population estimates for Red Kite were sourced from the Avian Population Estimates Panel (APEP)'s fourth report (Woodward et al. 2020), referring to populations in the year 2016. Estimates for Great Britain only (rather than for the entire UK) were used. Contemporary population estimates were produced by adjusting the APEP4 population estimates according to population trends for Red Kite in the intervening years, using annual population indices for Wales from the BBS (Heywood et al. 2023).

Broadly, population estimates from APEP4 (provided in numbers of breeding pairs, and doubled where necessary to represent numbers of breeding individuals) were used to calibrate the interpolated density surface derived from *Bird Atlas 2007–11*, such that a population estimate could be derived for each GB tetrad. These estimates were extrapolated using the annual BBS index for Red Kite in Wales to provide a population estimate for 2022. This approach assumes that local population trends — for example, those at tetrad-scale or within any other spatial boundary — reflect national population trends.

Population estimates for each individual tetrad could then be summed to provide baseline population estimates for different spatial boundaries (Table 1), including a national estimate, and estimates for each NRW Statement Area, for each of the two SPAs with Red Kite listed in their designations, and for the area potentially impacted by each proposed wind farm development (which was the footprint of the site itself, plus a buffer zone related to the dispersal distances of juvenile and adult Red Kites; see below). This approach generated a population estimate for Red Kite in Wales in 2022 of 2,117 breeding pairs, which is not dissimilar from the 2,500 pairs estimated by the Welsh Kite Trust in 2019 (Jenks 2020).

Population estimates for the two SPAs were larger than the maximum number of nests recorded in these areas during the 14 years of intense nest recording (2000–13) undertaken by the Welsh Kite Trust (Elenydd-Mallaen SPA: 18 nests in 2011; Berwyn SPA: zero nests in all years monitored), which is to be expected since Red Kite nests can be hard to detect, so there are likely to be more pairs present than nests recorded. For both SPAs, we estimated that there were at least as many Red Kites present within a 2 km buffer surrounding the SPA than in the entire SPA itself (Table 1). This was also the case among nests recorded by the Welsh Kite Trust, with a peak of 88 nests recorded in 2011 in the Elenydd-Mallaen SPA plus a 2 km buffer (of which 70 nests were in the buffer zone), and a peak of four nests recorded in 2006 in the Berwyn SPA plus a 2 km buffer (of which all four nests were in the buffer zone).

Table 1: Baseline (2022) Red Kite population estimates for relevant spatial areas, estimated using data from *Bird Atlas 2007–11*, APEP4 and BBS, and used as a starting point in PVA modelling.

Category	Spatial boundary	Population estimate	
		(pairs)	(adults)
Wales	Wales national boundary	2,117	4,234
Wales SPA	Berwyn SPA boundary	4	8
	Berwyn SPA plus 2 km buffer	10	19
	Elenydd-Mallaen SPA boundary	79	158
	Elenydd-Mallaen SPA plus 2 km buffer	179	359
Area Statement areas	North West Wales	99	198
	North East Wales	3	5
	Mid Wales	1,488	2,975
	South West Wales	468	937
	South Central Wales	22	45
	South East Wales	9	18

Demographic rates from the published literature

Most demographic parameters for Red Kite were sourced from the published literature. We required estimates of the range of plausible values for the population mean in Wales for each of several parameters: maximum brood size, age at first breeding, (annual) productivity, breeding skip rate, and annual survival rates of four age classes (adults, first-, second- and third-year immatures respectively). We collated published estimates of all variables and determined plausible ranges for each (Table 2).

Table 2: Demographic parameters used in Population Viability Analysis models. Parameters derived in the present study, rather than sourced from the literature, are in bold italics.

Parameter	Plausible range	Sources
Maximum brood size	2–3	Pfeiffer & Mayberg (2015), Davis & Newton (1981), Jorgensen (1989), Evans et al. (1999)
Age at first breeding	2–3	Davis & Newton (1981), Evans et al. (1999), Smart et al. (2010), Tenan et al. (2012), Bellabaum et al. (2013), Ceccolini et al. (2013), Mammen et al. (2014)
Productivity	1–2	Annual reports of the Welsh Kite Trust (e.g. Welsh Kite Trust, 2017)
Adult annual survival	0.75–0.95	Newton et al. (1989), Evans et al. (1999), Desholm (2006), Schaub (2012), Katzenberger et al. (2019), Pfeiffer & Schaub (2023)
Immature survival first-year	0.516–0.804	Carter (2007), Evans et al. (1999), Carter & Grice (2000)
Immature survival second-year	0.65–0.944	Duffy & Urquhart (2014), Evans et al. (1999), Carter & Grice (2000)
Immature survival third-year	0.73–0.927	Evans et al. (1999), Carter & Grice (2000)
Breeding deferral/skip rate	0.085–0.185	**Calculated in this study from territory monitoring data (Welsh Kite Trust, 2023)**

Breeding skip rate

Data from the Welsh Kite Trust's long-term nest monitoring dataset (Welsh Kite Trust 2023) were used to estimate skip rates in Red Kites in Wales. Skip rate is the proportion of breeding individuals that do not make a breeding attempt in any given year; this variable is required by PVA models. The data consisted of annual recording at known territories, with survey effort recorded such that years in which surveys took place, but no active nest could be identified, are distinguishable from years in which surveys did not take place. We first filtered the dataset to identify territories which had been continuously monitored for at least four years. Since the first and last year of recording at any given territory could not be confidently labelled as a 'skip', we then restricted the data further, to a 10-year period between 2002 and 2011 that was internal to the overall data range. For each year in this period, we calculated the proportion of established territories that had been monitored, but where no active nest was identified. We used these annual estimates of skip rate to determine a plausible range for PVA modelling (Table 2).

Spatial ranges

Data from a long-running ringing and colour-marking project (Cross 2023) were used to estimate dispersal distances in Red Kites in Wales. This dataset consisted of resightings/recoveries for 1,082 individual Red Kites ringed under license in Wales as part of the BTO Ringing Scheme (Robinson et al. 2023). Dispersal distance, for the purposes of this project, was defined as the typical maximum distance travelled by either (a) a juvenile Red Kite from its natal nest, or (b) an adult Red Kite from its nest site. For this project, dispersal distances were required to determine the spatial area across which each wind farm proposal could impact upon resident Red Kites. To this end, we calculated the distances between each resighting/recovery for a bird and (a) its original ringing location, for resightings of juveniles (i.e. less than one year after ringing as an unfledged pullus in the nest), or (b) each other resighting/recovery, for adults. For each age group, we filtered out resightings that were less than 1 km apart (and therefore may have been associated with repeated sightings at the same location), and then calculated the 75th percentile of between-points distances; we considered this to strike a balance between capturing the typical distances between locations that might realistically be travelled by a majority of individuals, yet excluding the extreme distances travelled by a very small subset of individuals. We repeated this process twice, first excluding resightings at Red Kite feeding stations, and second including all resightings for birds that had been seen at least once at a feeding station. This enabled us to estimate the dispersal distance of Red Kites in a typical landscape, but also to understand whether birds may fly further in order to access feeding stations (with implications for proposed developments in the vicinity of such feeding stations).

Spatial boundary data

We obtained a range of spatial boundaries (in GIS formats) to facilitate analysis and reporting at different scales. Spatial boundaries for the two SPAs designated for Red Kites, and for the NRW Area Statement areas, were downloaded directly from Datamap Wales (datamap.gov.wales).

Each wind farm developer involved in the project was asked to provide (under a Non-Disclosure Agreement) the locations of their current in-development projects (preferably as a GIS shapefile of each proposed site's boundary), along with metadata including the number of turbines proposed for each site, and the outcome of a Collision Risk Model (CRM) if one had been undertaken to date. Some developers also supplied this information for already-operational sites to support the imputation of collision risk at proposed sites where CRM has not yet been undertaken (see below). We analysed data from all developers in combination, and also on a developer-by-developer basis. Summary metrics for each developer are reported non-identifiably.

Impacts on survival using Collision Risk Model data

To predict the impact of wind farm developments upon Red Kite populations, it was necessary to understand the rate of additional expected mortality (above and beyond natural mortality rates) associated with each proposed development in the study. Some developments had already undertaken CRM, a standard model typically based on site-specific field observation data (Band et al. 2007; e.g. Urquhart & Whitfield 2016). However, many proposed developments had not yet reached this stage. Additionally, the outputs of standard CRMs are expressed as absolute numbers of birds expected to collide with turbines per year, whereas PVA requires this to be expressed as a risk of collision per exposed bird.

To translate absolute collision risk (CR) into a risk of collision per exposed bird, we divided the CR value for each site at which an estimate was available (15 sites in total, which included several already-operational sites that were otherwise outside the scope of this study) by the estimated baseline population for the site's impacted area. This yielded a CR value per exposed bird that was directly equivalent to a rate of additional mortality expected as a result of exposure to the development.

To estimate the risk of collision for developments where no CRM had yet been undertaken, we fitted a simple linear model with the risk of collision per exposed bird predicted by the number of turbines in the development (excluding two sites that were clearly outliers in terms of their CR value per exposed bird). We found there was no significant relationship between development size (expressed as number of turbines) and the per-bird additional mortality rate (Figure S1), even though larger developments tend to have higher absolute CR values, probably because larger developments also had a higher number of exposed birds (i.e. absolute CR values were correlated with number of exposed birds). Therefore, we deemed it appropriate to apply an average value for the CR per exposed bird of 0.0027 to all developments, regardless of the number of turbines (i.e. roughly one bird per 400 exposed, on average, is expected to collide with a development each year, where larger developments tend to have a greater number of birds exposed).

In some cases, there was spatial overlap between the impacted areas (based on Red Kite dispersal distances) of multiple proposed developments. To allow us to model the population impacts of multiple developments, each with its own unique impacted area, on regional populations, we calculated a collision-risk estimate for each individual tetrad in Wales under each modelled scenario. For each tetrad, this collision-risk estimate was the multiplicative combination of collision risk for all developments expected to impact upon that tetrad; for example, a tetrad within the impacted area of two developments would have a collision-risk estimate of 1–(1–0.0027)2 = 0.0054 (i.e. 0.54% of that tetrad's population are expected to collide with a wind turbine per year).

Population Viability Analysis

Overview

Population Viability Analysis was conducted using the NEPVA R package (Searle et al. 2019), version 4.17, following the multi-model approach of Macgregor et al. (2022). In brief, we fitted a large number of deterministic models (using different combinations of plausible values for the various demographic parameters), and used a rejection sampling procedure to filter these models according to how well their predicted population trend matched the recent Red Kite population trend in Wales, to generate a set of accepted baseline models. We then applied a range of impact scenarios to each baseline model to estimate the full range of possible outcomes arising from different starting population trends affected by different numbers of wind farm developments. Finally, we combined the most relevant set of population trends with starting populations at tetrad-level, in order to make population predictions that incorporated spatially-explicit variation in both Red Kite starting populations and impacts of proposed wind turbine developments.

Modelling environment

A range of options are available within the NEPVA package to conduct PVAs in different ways. Following Macgregor et al. (2022), the following options were employed in this study. Environmental and demographic stochasticity were eliminated from models (by setting model.envstoch = 'deterministic' and model.demostoch = FALSE), because it was considered that too little data were available to make accurate estimates of intra- and inter-annual variability in productivity and survival. Instead, estimation of model uncertainty was conducted by modelling large numbers of combinations of input parameter levels and inspecting variation between outcomes (see below). Models were constructed without density dependence (model.dd = 'nodd') because Red Kite is still recolonizing in Wales, and with productivity constrained by brood size (model.prodmax = TRUE). It was deemed not possible to model the potential onset of density dependence as the population approaches its carrying capacity, due to a lack of evidence to suggest what the carrying capacity for Red Kite in Wales is likely to be. The option to include a number of 'burn-in' years to allow age structure within the model to settle was used, because the existing age structure of the Red Kite population is unknown; a value of five burn-in years was used because preliminary model runs showed this was sufficient to allow age structure in the models to stabilise. Because each model was fully deterministic, there was no need for multiple simulations of each model (sim.n = 1 and sim.seed = NULL). Like Macgregor et al. (2022), we treated breeding skip rate as a modifier to per-nest productivity since the skip rate argument 'demobase.bskippc' did not appear to be functioning as intended. Therefore, for each model, productivity rate was multiplied by (1 – skip rate) to determine the modelled productivity rate.

Models were fitted with a starting population size of 2,117 (breeding pairs), based on the estimated Welsh population size, but this was effectively arbitrary because tetrad-specific starting population sizes would be applied at a later stage in analysis. Impacts (of collisions with new wind turbine developments) were modelled to begin in 2025 and continue annually. The population trend of each model was calculated using a generalised linear model (Poisson error distribution with log link function).

Model construction and rejection sampling

The above procedure generated a total of 37,500 possible combinations of parameters to be modelled. Each model parameter provided five input levels — upper bound, lower bound, median, upper and lower quartile values, based on the plausible ranges in Table 2. We modelled all possible combinations of these values for all parameters except maximum brood size and age at first breeding, for which we modelled only the lower and upper bounds (since non-integers are nonsensical for these parameters).

Wind turbine mortality associated with new/future developments was applied as a modifier to survival of all age classes. In reality, it is possible that juveniles have a higher risk of colliding, since they may range further than territory-holding adults, but there are currently no data on age-specific collision risks in Red Kite with which to assess this. For every baseline model, we applied a broad range of survival modifiers as follows (all values represent an additional percentage of the population killed by collisions with new wind turbines per year): increments of 0.025 between 0 and 0.1; increments of 0.25 between 0 and 1; increments of 0.5 between 1 and 9; increments of 1 between 10 and 20; and an additional 30% scenario. These modifiers were intended to encompass the full range of tetrad-level collision risk estimates (calculated as above) under all development scenarios, with the higher-mortality modifiers ensuring that the rate of additional mortality that would result in stabilisation (i.e. population growth halting) of the Welsh population of Red Kite could be identified. Note that collisions with existing, already-operational wind turbines are considered to be encompassed within the 'baseline' case where no additional survival modifier was applied.

Some combinations of parameters (e.g. if the upper bounds were used for all three of productivity, adult and immature survival) produced population estimates in the baseline (0% additional mortality) case that were clearly not consistent with observed population trends for Red Kite in Wales (e.g. population explosion or decline). Although each parameter within these models was individually plausible, in such cases the overall combination was not plausible. To narrow down the total set of 37,500 candidate models to a set of models that could plausibly explain observed population trends, we calibrated baseline models against population trends from the BBS, using Approximate Bayesian Computation (Hartig et al. 2011). We used 10-year trends calculated over the period 2012–22 for all BBS squares in Wales where Red Kite was observed, and applied a rejection sampling approach whereby the probability of each model's acceptance was determined by the Probability Distribution Function (PDF) of the 10-year trend estimates, which was approximated by bootstrapping (Heywood et al. 2023). See Macgregor et al. (2022), Figure 1, for a visual representation of this process. This means that models predicting a rate of population change similar to the central BBS trend estimate (67% increase over 10 years; 95% confidence interval 32–112%) were relatively more likely to be accepted, and models predicting a rate of change far from the central BBS trend estimate (i.e. the extremes of the PDF) were more likely to be rejected.

Spatially-explicit population predictions

To translate population trend projections from our set of accepted generic PVA models into population trend projections that incorporate spatially-explicit variation in both starting populations and wind turbine impacts, we first extrapolated the population of each individual tetrad under each scenario. Selecting a model at random from the accepted set (see below), we selected the survival modifier that was the closest match to each tetrad's individual collision risk estimate and used the relevant modelled population trend to project that tetrad's starting population forward in time over 10 years. We summed the annual tetrad populations for all tetrads in each outcome scale (e.g. for the national-scale outcomes, we summed annual population estimates for all tetrads in Wales to generate a prediction of the Red Kite population in each year for 10 years). We then fitted a generalised linear model (Poisson error distribution with log link function) to these summed annual population estimates to identify the overall population trend within each outcome scale. We applied this procedure to all accepted PVA models in order to describe 95% confidence intervals for population projections under each impact scenario and at each outcome scale.

Summarising outcomes
To aid with interpretation, we summarised outcomes in several ways. First, we depicted the 95% confidence intervals for population projections under each impact scenario, at each outcome scale, as population trend lines on graphs in direct comparison to the baseline (unimpacted) scenario.

In addition to describing the 95% confidence intervals of projected trends as above, we categorised models according to which of five outcomes they resulted in, over a five-year timescale: decline (< 0% increase), stability (0–25% increase), low growth (25–50% increase), medium growth (50–100% increase), and high growth (> 100% increase). We then calculated the proportion of all models under each impact scenario, at each outcome scale, which resulted in each category, presenting these in direct comparison to the baseline (unimpacted) scenario in each case.

Lastly, we projected the 95% confidence interval for the size of the Welsh population of Red Kite by the year 2050, under each scenario and at each outcome scale, presenting scenarios in direct comparison to each other, as well as the baseline (unimpacted) scenario.

RESULTS

Breeding skip rate
The annual average breeding skip rate based on site occupancy varied between 8.6% (2004) and 18.2% (2003), with no apparent trend over time (Table S1). This is broadly comparable to the 9% skip rate estimated by Pfeiffer & Schaub (2023). Based on this, a skip rate range of 0.085–0.185 was used in PVA modelling, to encapsulate annual variation in the recorded range. This is likely to represent an overestimate of real skip rate to some extent, because Red Kite nests can be hard to detect even within known territories.

Spatial ranges
On average, we found that immature Red Kites ranged further than adults. There was little difference between (i) the distances ranged by all immature Red Kites, with resightings at feeding stations excluded from the dataset, and (ii) those ranged by the subset of immatures that visited feeding stations, with all resightings included. However, the distances ranged by all adults, with resightings at feeding stations excluded from the dataset, were half those ranged by the subset of adults that visited feeding stations, with all resightings included (Table 3).

Table 3: Average distances between resightings of individually-marked Red Kites originally marked in Wales, split by age category and, respectively, for all birds with visits to feeding stations excluded, and for all resightings of birds that visited feeding stations.

Age category	Distance between resightings (km)			
	n observations	25th percentile	50th percentile (median)	75th percentile
Immature (exc. feeding stations)	499	4.3	8.3	21.7
Immature (using feeding stations)	2,275	2.6	5.6	22.7
Adult (exc. feeding stations)	585	2.1	4.2	16.3
Adult (using feeding stations)	657	7.1	13.7	33

The 75th percentile of between-resighting distances for immatures and adults respectively were 21.7 km and 16.3 km (in other words, only 25% of all immature Red Kites range further than 21.7 km from their natal nest during their first year, and only 25% of all adult Red Kites range further than 16.3 km from their nest site). Based on these distances, we conservatively assigned a buffer distance of 22 km around all proposed development sites in order to determine the potentially impacted area. Whilst this is a relatively large buffer given the outcomes of this analysis, it represents a cautious approach through which we capture the vast majority of plausible mortality associated with each wind farm development.

Population Viability Analysis

In total, the rejection sampling procedure selected 19,775 plausible accepted models for Red Kite (53% of the 37,500 candidate models). The vast majority of baseline models predicted population stability or increase.

Impacts of wind farm development on Red Kite population trends

Modelled impacts on the mean Red Kite population trend from all the sites provided by developers are presented in Figures 1 to 3. Across virtually all combinations of impact scenarios and outcome scales, impacts are projected to be relatively small, even under the scenario where all developers' plans were modelled in combination (Figure 1). Every impact scenario is predicted to be less likely to result in population decline than continued growth at all outcome scales. In general, modelled impacts were larger for spatially-smaller outcome scales with relatively high-density Red Kite populations (e.g. the two SPA populations). Thus, impacts were larger for the high-density Elenydd-Mallaen SPA population than for the Berwyn SPA population (in both cases taken to include birds within a 2 km buffer zone around the SPA boundary), where the current density of Red Kites is lower.

Impacts for the all-developers scenario were substantially larger than for any one developer taken in isolation, but there was also significant variation between the projected impacts of different developers' plans. Developers projected to have the largest impacts were those with large numbers of developments in proposal (or spatially large developments), and as above, where those developments are located in areas with high densities of Red Kites (e.g. in the vicinity of the Elenydd-Mallaen SPA).

These patterns are also evident when considering the relative probabilities of different population outcomes under different impact scenarios compared to the unimpacted baseline (Figure 2). The implementation of all development sites in combination would increase the probability of the Welsh population of Red Kite stabilising from 17% to 28% (Figure 2a), and even introduce a possibility of population decline in each SPA population where none exists under the baseline scenario (0.4% probability of decline in the Berwyn SPA population; 4% probability of decline in the Elenydd-Mallaen SPA population; Figure 2b to 2e). Note, however, that in all cases there remains a greater than 50% probability of continued population growth. Again, each individual developer's portfolio has a lesser impact than the combined effect, with substantial variation between developers.

Whilst impacts upon population trends may appear relatively small, these may propagate into substantial differences in population size given enough elapsed time (Figure 3). For example, the median population size estimate for the Elenydd-Mallaen SPA in the year 2050 under the all developers scenario is approximately half of the equivalent estimate under the unimpacted baseline, even though both estimates are greater than the current (2022) population estimate, and therefore represent population growth. Note that our modelled scenarios effectively assume the Red Kite population does not reach carrying capacity by 2050 (and therefore there is no onset of density dependence).

Figure 1: Projected impacts of all currently proposed wind farm developments in combination at a range of outcome scales. The recent Red Kite population trend (from BBS trend for Wales) is shown in blue. Baseline (unimpacted) population projections are shown in yellow, and the impacted population projections are shown in grey. For all line colours, dotted/dashed lines and shading (blue and yellow only) show 95% confidence intervals. Panels show projections at different outcome scales: a) all Wales; b) Berwyn SPA; c) Berwyn SPA plus 2 km buffer; d) Elenydd-Mallaen SPA; e) Elenydd-Mallaen SPA plus 2 km buffer; f) North West Area Statement (AS); g) North East AS; h) Mid Wales AS; i) South West AS; j) South Central AS; and k) South East AS. Note the y-axis is shown on a logarithmic scale.

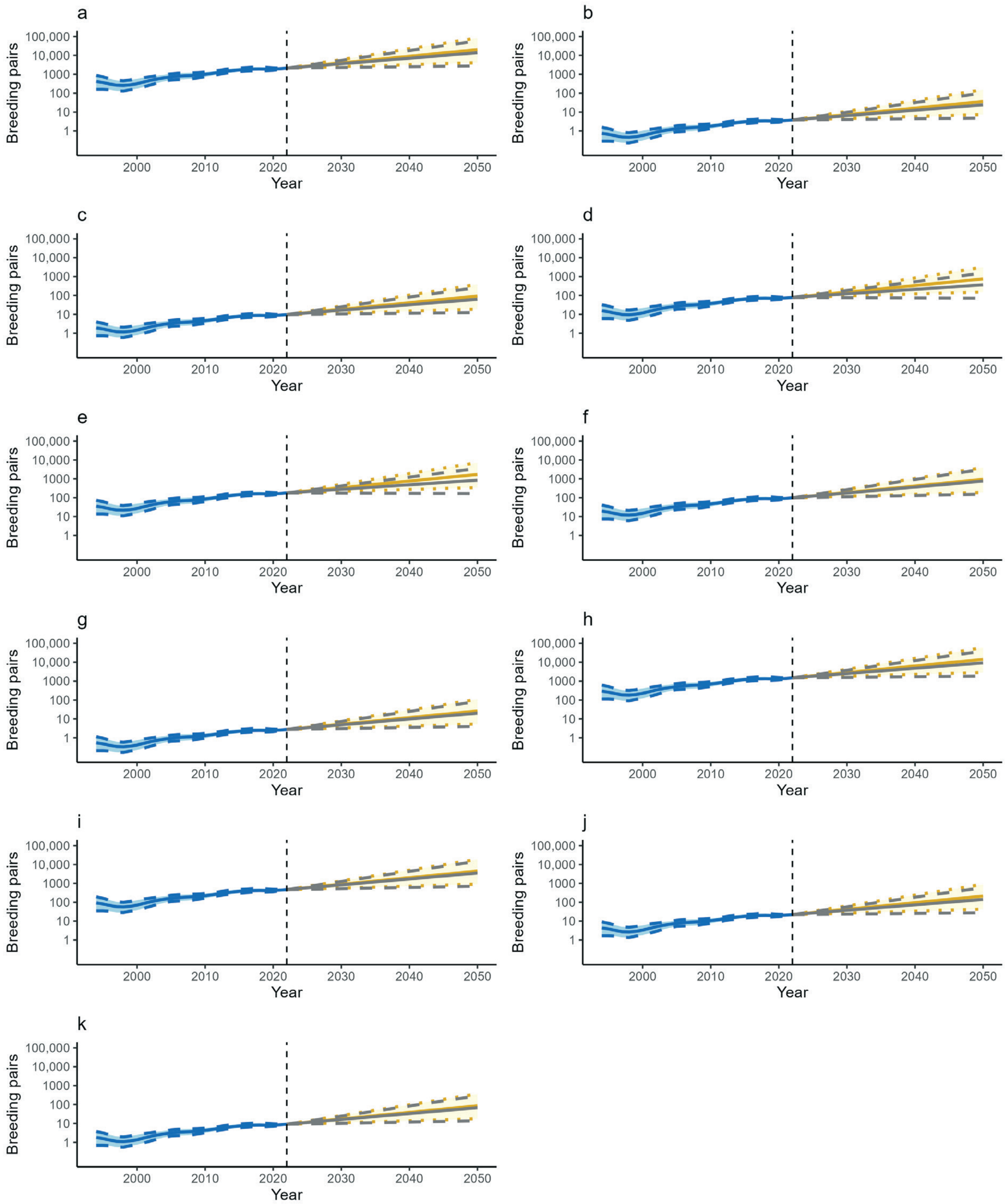


Figure 2: Relative probabilities of different population outcomes for all currently proposed wind farm developments in combination at a range of outcome scales. In each panel, the impacted scenario (right) is compared to the unimpacted baseline (left). Outcomes are grouped into high, medium and low rates of population increase (shaded in dark green, light green and yellow respectively); population stability (shaded blue) and population decline (shaded grey). Panels show probabilities at different outcome scales: a) all Wales; b) Berwyn SPA; c) Berwyn SPA plus 2 km buffer; d) Elenydd–Mallaen SPA; e) Elenydd–Mallaen SPA plus 2 km buffer; f) North West Area Statement (AS); g) North East AS; h) Mid Wales AS; i) South West AS; j) South Central AS; and k) South East AS.

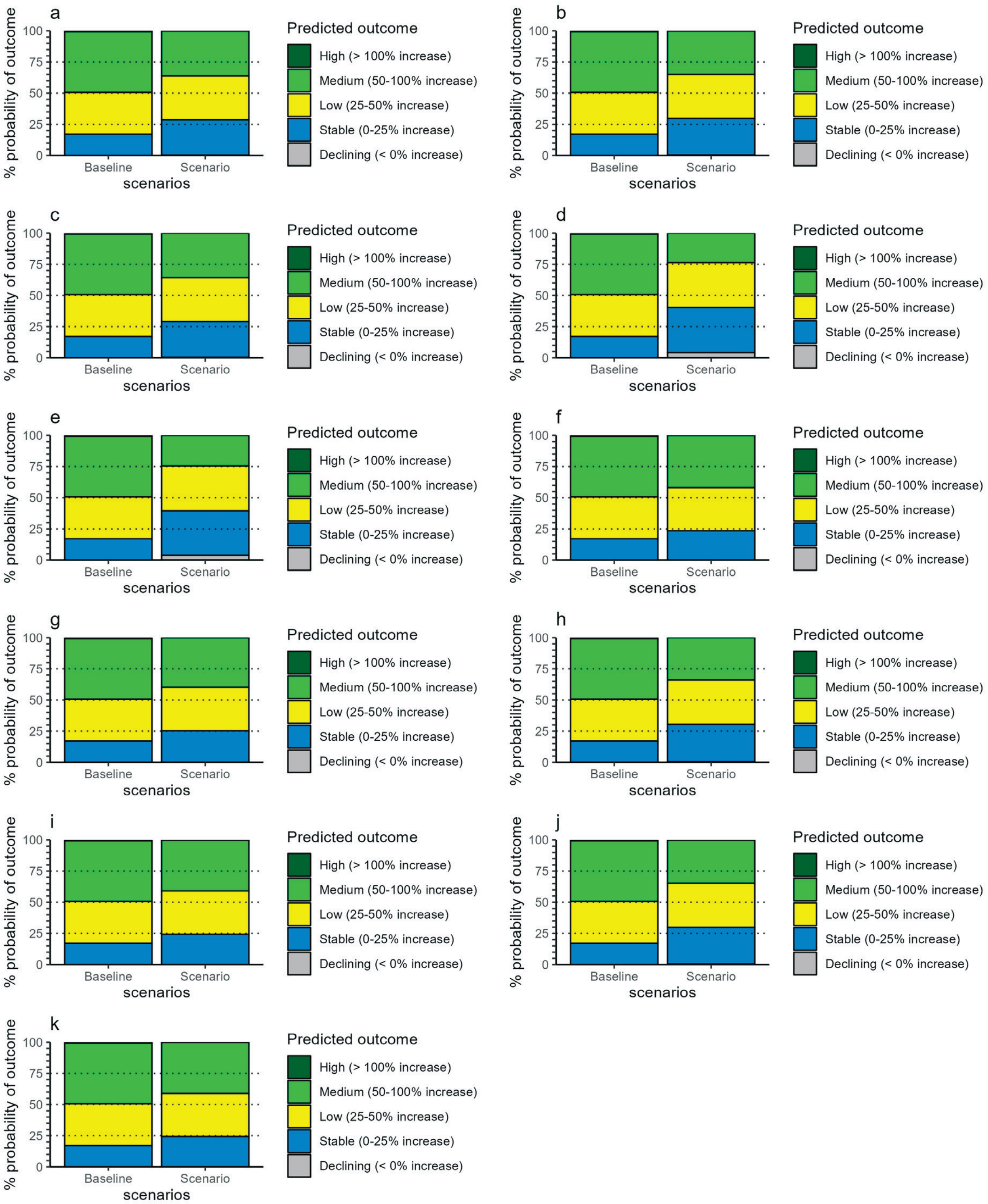
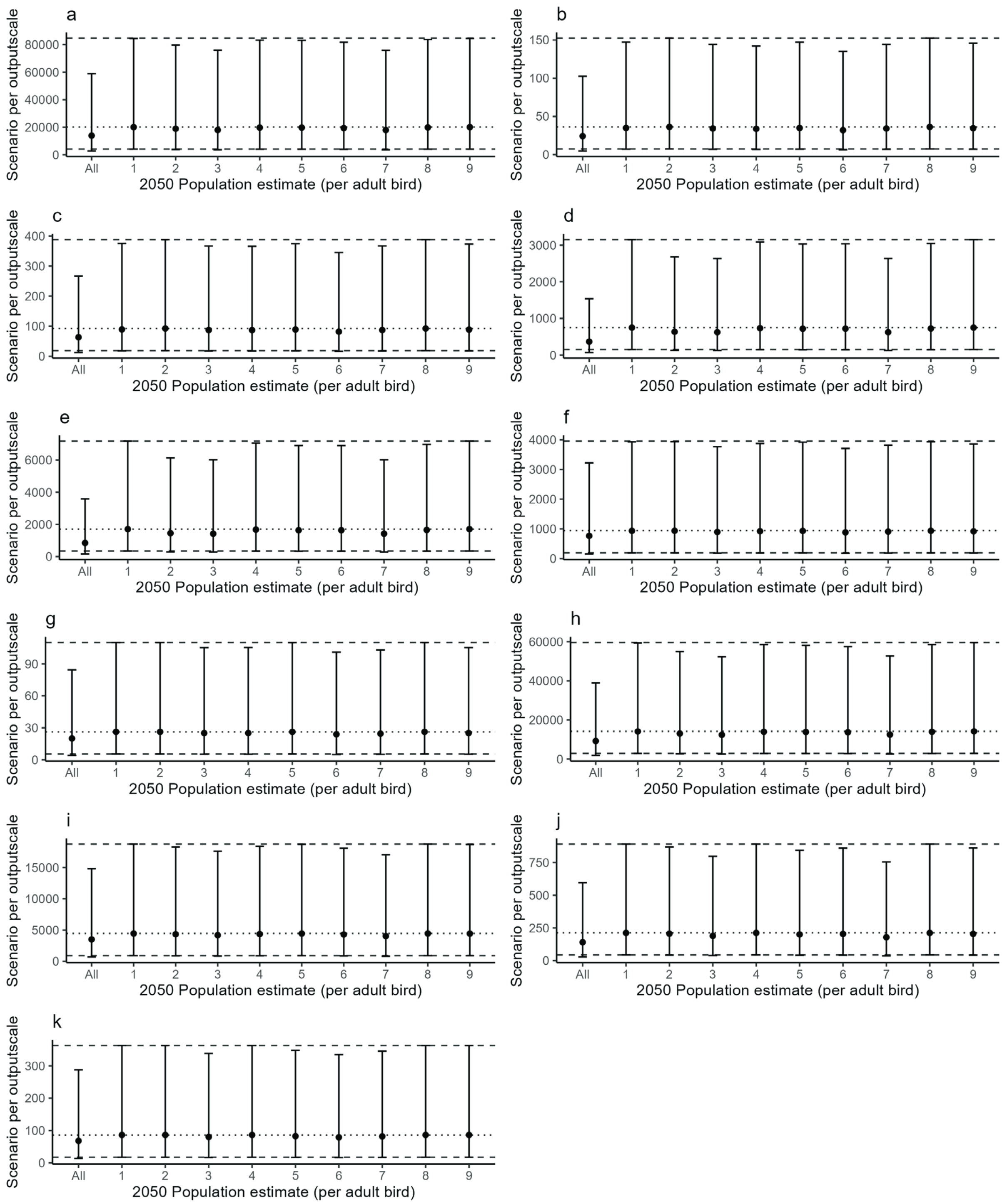


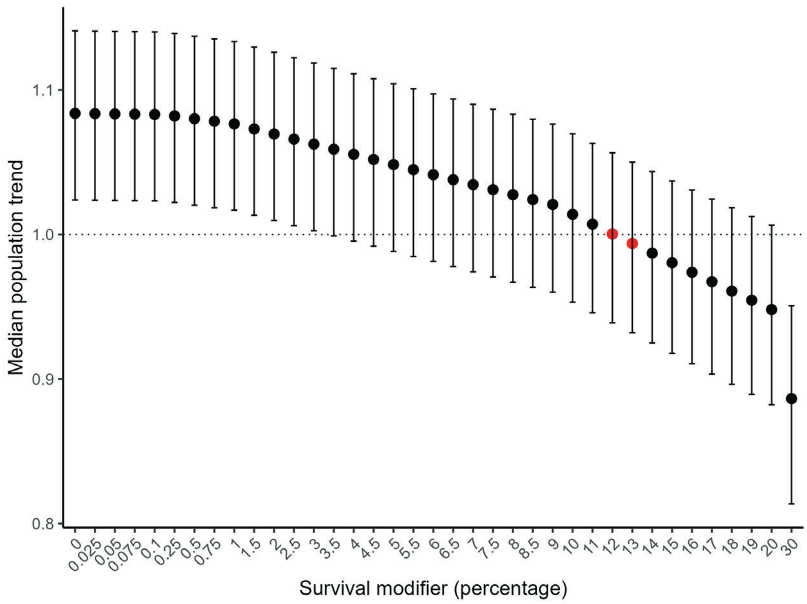
Figure 3: Projected Red Kite populations in the year 2050 under each impact scenario, at each outcome scale, with no onset of density dependence. Horizontal lines show projected populations under the unimpacted baseline scenario (dotted: median, dashed: 95% confidence interval). Points show median estimates and lines indicate 95% confidence intervals for each impact scenario. Panels show projected population sizes at different outcome scales: a) all Wales; b) Berwyn SPA; c) Berwyn SPA plus 2 km buffer; d) Elenydd-Mallaen SPA; e) Elenydd-Mallaen SPA plus 2 km buffer; f) North West Area Statement (AS); g) North East AS; h) Mid Wales AS; i) South West AS; j) South Central AS; and k) South East AS. In each panel, a population size is shown for the 'all developers' impact scenario, as well as for each developer (1–9) in turn along the x-axis.



Red Kite population tolerance to decreased adult survival

None of the scenario-focused analyses resulted in a prediction whereby population decline was more likely than increase. Analysis of more extreme survival modifiers suggests that an additional 12–13% mortality per year would be necessary to lead to the median population model projecting a decline (Figure 4). This is far in excess of the levels associated with current proposed developments, even at very local scales, let alone as a national average.

Figure 4: Population trends projected using each survival modifier modelled using PVA. Points show the trend of the median model, with lines indicating the 95% confidence interval. Red points highlight the values between which the median model projections transition below 1 (dotted line), where a population trend of 1 indicates population stability. Note that the x-axis is categorical rather than continuous.



DISCUSSION

Implications of modelled results

The key finding of this study is that Red Kite population stabilisation or decline in Wales, solely as a consequence of wind energy development, is unlikely. Even under the most extreme scenario tested, where every project currently in development by all nine collaborating developers is ultimately approved and commissioned, our modelling suggests that there is approximately a 28% probability of population stabilisation, and virtually no chance of decline (Figure 2a). An average of 12% of the national population could be killed per year in collisions with new wind turbines before our models would suggest population decline as being more probable than not, all else being equal (Figure 4).

Nevertheless, our models suggest that more caution is warranted with respect to developments in close proximity to the Berwyn and Elenydd-Mallaen SPAs. The impacts of additional mortality from new wind turbines adjacent to the relatively small, high-density populations of these protected sites were distinctly greater. In particular, decline of the Elenydd-Mallaen SPA population was assessed to have a probability of approx. 4% under the all-developers scenario (Figure 2e), with a lower probability of 0.4% for decline of the Berwyn SPA population (Figure 2c); these were the only analyses in the entire study to produce a non-zero probability of population decline. Each individual developer scenario forecast a zero probability of decline, emphasising the importance of evaluating impacts of multiple developments in the round. This caution extends some distance beyond the boundary of each SPA, given that at least as many Red Kites are present within the 2 km buffer zone around the SPAs as within the designated areas themselves, for both the Berwyn and Elenydd–Mallaen (Table 1). Predicted impacts were in all cases comparable when considering Red Kites within the SPA boundary itself, or when considering the 'SPA population' including a 2 km buffer zone around each SPA.

Predicting impacts using an extrapolated population trend

Predicting population trends from historic survey data (in this case, with rejection sampling of candidate models calibrated using trends from the BBS) assumes that conditions in the future apply exactly the same positive and negative pressures on a species as have been applied in the past. Although most ecological pressures will act at local scales, and therefore have only weak effects on national populations, it is possible that new and unforeseen pressures may act on the Red Kite population and weaken model performance against the surveyed population trend in future. In order to illustrate this issue, we present three different potential scenarios likely to modify the population trend in future, that cannot, at present, be incorporated into the demographic modelling exercise.

First, the Welsh Red Kite population is still recovering from historic catastrophic decline to near-extinction, and has not yet reached its carrying capacity (the maximum population that can be supported by contemporary landscapes). As the population approaches this ecological limit in future, density-dependent effects may come into force, such that some demographic parameters will change as they become limited by available resources. For example, if the limiting resource is food availability in winter, we might see a decline in immature survival, perhaps followed by a decline in adult survival. Under such a scenario of density-dependent effects on survival, it is possible that some level of mortality associated with wind turbine collisions could be sustainably offset by increased survival among the remaining birds. If food resources during the breeding season become limiting, we might see decreased nest productivity, chick survival or clutch sizes. If nest-site availability decreases and/or becomes limiting, we might see increases in age at first breeding, or larger spatial movements from immature birds because all available territories around their natal sites are occupied. The most likely scenario is that all of these parameters would change to a greater or lesser extent as the population continues to grow; an adjustment that is impossible to predict from current data. There is also likely to be considerable regional variation in the timing of when different stages of this recovery-adjustment process are reached. At the centre of their range, local populations may already be stable or nearly so, while at the range margins in North and South Wales the species is still expanding and recolonizing landscapes where resources are less limited. One of the benefits of a multi-model approach is that there are individual models within the thousands of plausible models for the population that reflect all these possibilities, from the core (stable) sub-populations to the rapidly increasing ones.

Another likely future includes new pressures associated with large-scale processes such as climate change, novel tree diseases, and land-use change. We are already seeing changes in weather patterns, seasonality and phenology, and in some species there are clear links between, for example, stormy weather in the breeding season and years of poor productivity (c.f. high rates of nest failure in Osprey *Pandion haliaetus* attributable to storm events; Forys et al. 2021), novel tree diseases and colonial behaviour change (for example, the impact of Dutch elm disease on spatial distribution of Rookeries; Brenchley 1986), and of course agriculture and bird population changes (Burns et al. 2020). The impacts of these pressures on Red Kite are difficult to predict in detail — we might hypothesise that a trend of increasing winter rainfall might reduce the survival of immature Red Kites, but not be able to predict either the climatic trend or its impact on Red Kites accurately enough to include it in a demographic model. An additional possible scenario that could lead to food limitation is the removal or closure of feeding stations; this would also likely result in changes to Red Kite dispersal and ranging behaviour, given that adults appear to travel further than normal in order to access feeding stations (Table 3).

A final pressure worth considering, although impossible to anticipate in detail, is any effect of a specific novel disease outbreak in Red Kite. Scavenging and predatory species are, for example, notably vulnerable to transmissible diseases, such as the recent multi-species epizootic of highly pathogenic avian influenza (HPAI). HPAI has had major impacts in the UK on seabirds, particularly colonial species (e.g. terns), scavenging species (Great Skua *Stercorarius skua* and some of the large gull *Larus* species) and large raptors, particularly Golden Eagle *Aquila chrysaethos* and White-tailed Eagle *Haliaeetus albicilla* (Falchieri et al. 2022, Wilson et al. 2023). There is evidence of HPAI incidence in Scottish populations of Red Kite (Wilson et al. 2023), but as yet, no data with which to explicitly parameterise the impacts of a disease outbreak in the demographic model. Nonetheless, our models suggest that any driver causing an additional 12% mortality in Red Kites could lead to decline in the Welsh population; although the context of this study is wind turbine collisions, this additional mortality could, in principle, come from any source or combination of sources. This percentage is directly comparable to, for example, the percentage of Great Skua known to have died during the recent HPAI epizootic (Falchieri et al. 2022). Therefore, the possibility exists that a significant disease outbreak could markedly change future population trends in this species, and this must be taken into consideration when interpreting the results of our study on the impacts of wind farms.

Conservative modelling of spatial movement data

Individual birds' movement patterns vary with a number of ecological and environmental factors, including age, sex, time of year, landscape structure, availability of (and dependence on) key resources such as feeding stations, and local population density. In general, individuals are most mobile during post-fledging dispersal when young birds are looking for territories of their own (Table 3). Individuals are also expected to be more mobile outside the breeding season (when breeding adults' movements are less constrained by nest location and landscape quality), but it is challenging to quantify such seasonal patterns using ring recovery data since there are often long time intervals between consecutive resightings of a bird, obscuring any information about when (in the year) movements between locations have taken place. GPS-tracking datasets would therefore be better suited to understanding seasonal variation in Red Kite movements. Adult Red Kites also travel further (likely in all seasons) when they are able to take advantage of permanent feeding stations (Table 3), suggesting that greater caution may be justified when considering developments within approximately a 30 km radius of a feeding station. Our modelling approach has a minimum time-step for population impacts of one year, so that mortality in immature or wintering birds is calculated as an impact on the following breeding season. It is therefore necessary to consider the distances travelled by individual birds during their most mobile life-stage and period of the year in order to adequately assess their risk of interacting with wind farms.

It is likely that this approach somewhat over-estimates mortality risk in territorial adult birds during the breeding season, since there is some evidence that individuals learn to avoid turbines even when entering the site footprint of an established wind farm (Duffy & Urquhart 2014, Urquhart & Whitfield 2016). Since underestimating wind farm impacts carries more risk into decision-making than overestimating them, we elected to use the larger spatial scale of immature and winter distance movement to model impacted areas around development sites.

An additional caveat with use of PVA is the core assumption that the population being modelled is a closed population of breeding individuals. This assumption is likely violated for Red Kite in Wales, since there is known migration of some individuals to and from the English and other regional populations. Nevertheless, genetic studies (Skujina 2013) suggest that this movement still represents a relatively small proportion of Welsh breeding birds, which are therefore somewhat reproductively isolated and distinct from the (reintroduced) English populations. It does, however, introduce a note of caution, because of the possibility of asymmetric dispersal into and out of Wales leading to outcomes beyond those predicted by our PVA; for example, if immigration from the expanding English populations was sufficient to offset wind turbine mortality of Welsh birds. This raises the importance of understanding known movement patterns (from ring and colour-mark recoveries, and potentially GPS tracking) of Welsh birds.

Habitat-specific variation in collision risk

Collision risk modelling often predicts lower risk to Red Kites from turbines constructed in afforested locations. We were unable to incorporate this into our models since all sites for which CRM data were available to us were on open or mixed ground (none were purely afforested when overlaid with land-cover data from Marston et al. (2022). Our analysis therefore effectively assumes that all future developments are on open ground, in a setting where they may have the most impact. As above, this is an appropriately conservative approach since underestimating impacts carries more risk into decision-making than overestimating them.

Breeding skip rate

Our analysis of breeding skip rate in the Welsh population of Red Kite relied on repeated monitoring of known territories over the period of several years in order to distinguish established pairs that skipped breeding for a year and then resumed from those that had permanently abandoned their territory or died. Whilst we believe this to be a robust approach, it is contingent on the assumption that surveyors for the

Welsh Kite Trust were able to identify the majority of nesting attempts within known territories in any given year. Since Red Kites, despite being territorial, do not consistently return to the same precise nest location every year, and tend to build their nests high up in trees, it is quite likely that some recorded absences that we considered to be 'skips' for analytical purposes were in fact non-detections of pairs that did attempt breeding. Therefore, our estimates of skip rate are likely to be a little higher than the true value. Indeed, the one previous estimate of skip rate in Red Kite of which we are aware, 9% (from Pfeiffer & Schaub 2023), falls near to the extremes of, but still within, the 8.5–18.5% range that we applied to our models. Since the rejection sampling approach calibrated our final model set against BBS trends, models may have been selected with higher skip rates than reality, compensated for by, for example, higher productivity or survival rates than reality. However, since the change in survival rate that we modelled is the same, whichever survival rate underpins a model, we believe the conclusions of our PVA are robust to this caveat.

Conclusions

The results of this Population Viability Analysis suggest that whilst collisions with wind turbines may be a cause of mortality in Red Kites, this mortality alone is unlikely to prevent the continued recovery of the Red Kite population in Wales. These results may provide some reassurance to policy makers, given significant concerns around the conservation implications of commissioning new onshore wind energy. Given that climate change is itself a significant conservation issue with the potential for difficult-to-predict, and in some cases severe, impacts upon a wide range of species, this issue represents a conservation trade-off between, on the one hand, the potential mitigating effects of increasing the renewable energy capacity of the national grid to reduce demand for fossil fuels, and on the other hand, the threat posed by wind turbine collisions to Red Kite populations. Our findings, that this risk is relatively low (albeit non-zero), may support decision-making in this sector.

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Modelling population-level impacts of wind farm collision risk on Welsh Red Kites

The Welsh Red Kite population is currently in ongoing recovery after a historic decline driven by persecution, and a consequent population bottleneck during the first half of the 20th Century. Trends from the BTO/JNCC/RSPB Breeding Bird Survey show that the population has grown rapidly over the past few decades. Nonetheless, the Red Kite remains a conservation concern, in particular around two Special Protection Areas (SPAs) designated for the species' conservation: the Berwyn SPA and the Elenydd–Mallaen SPA.

Wind turbines represent a known threat to Red Kite populations, causing additional mortality through collisions. A large number of wind farm sites are currently at various stages of development (ranging from aspirational schemes to proposals under assessment) in Wales, especially in Mid Wales where Red Kites are at their highest density and where the Elenydd-Mallaen SPA is situated

The aim of this analysis is to model the potential impacts of current and proposed wind farm developments on the Welsh population of Red Kites, using a Population Viability Analysis.

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