An investigation into the possible cumulative impact of additional mortality on the Scottish White-tailed Eagle Population.

Report prepared for Galileo Empower UK

Alan Fielding BSc(Hons) MSc PhD FHEA FLS[1]

and

Matt Geary BSc(Hons) MRes PGCert PhD[2]

August 2026

[1] Independent Researcher and Data Analyst

[2] Associate Professor in Conservation Biology, Conservation Biology Research Group, School of Natural Sciences, University of Chester

Executive Summary

Overall conclusion

The clear conclusion from multiple strands of evidence in this report is that the current Collision Risk Assessment (CRA) methodology, and published CRA results, significantly overestimate the collision risk to the Scottish White-tailed Eagle *Haliaeetus albicilla*. Section 5 of this report demonstrates that in one long term Scottish case study, recorded collisions occurred at only 7% of the rates predicted by the CRA methodology; a 93% reduction. This discrepancy is consistent with the real population growth rate, as accepted by NatureScot (NS), which is only possible if historic collision rates have not been significant.

There is a potential counter argument that the CRAs for almost all operational wind farms demonstrate there was no risk to the White-tailed Eagle and thus it is unsurprising that population growth rate has not experienced a significant reduction. However, that argument is based on two false premises. First, almost all known collisions have occurred at wind farms where no collisions were predicted. Second, historic CRA estimates fail to take account of the expansion in the White-tailed Eagle population since the wind farm became operational and the significant expansion in the White-tailed Eagle population between the completion of pre-application bird surveys, on which the CRA estimate is based, and the start of wind farm operations. In the context of an expanding eagle population, almost all CRA estimates should be larger by the time a wind farm is operational. This observation partly explains why collisions have been recorded at wind farms where none were predicted.

The conclusion from the second false premise is that the impact of predicted wind farm collisions should be much larger than currently recorded. However, as no population-level impact has been observed, and recorded fatalities have been small, the number of predicted collisions - even before accounting for population expansion - has to be a significant overestimate. This finding is underlined by the apparently insignificant impact on the Scottish population resulting from the export of a large number of birds to England for the English reintroduction given these losses have occurred in addition to predicted collisions

More accurate and pragmatic assessments of risk, which recognise the many limitations of the current CRA method described in this report, are needed in order to assess the viability of the Scottish White-tailed Eagle population into the future as the current estimates of collision risk, even after taking the previously ignored elevated risk due to the numerical and spatial expansion of the population into account, cannot be reconciled with the observed population growth.

The report concludes with a number of recommendations about how CRAs could be improved; the most pragmatic of which suggests a change to the current White-tailed Eagle avoidance rate of 95%. Based on the analysis of this report, even an increase to 97.5% or 98% would still be precautionary and likely overestimate of the White-tailed eagle collision risk using existing CRA methods.

Background

NS is concerned about the impact of wind turbines on the future of the Scottish White-tailed Eagle population. The population has grown rapidly since its initial 1975 release on Rhum and

the 2026 population is ~220 pairs (~1,100 individual birds). NS collates the estimated White-tailed Eagle collision risk associated with each wind energy project irrespective of the project's progress through the planning process. In the first part of 2026, NS believe the annual cumulative collision is ~21-22 birds if all of these projects become operational and such an annual additional mortality could have a significant impact on the growth of the Scottish population. It is, therefore, important that the collision estimate is robust. This study examines the factors which feed into this cumulative collision total in order to understand the weight which should be applied to it. The study also examines population trends to determine if historic predicted collisions have had the expected impact on population numbers.

The NS concern about the potential threat to the future of Scotland's White-tailed Eagle population, as a result of collisions with wind turbines, is predicated on combining the results from two separate analyses: **Collision Risk Analysis** which estimates the number of collisions, both cumulatively and at individual wind farms; and **Population Viability Assessment** (PVA) of the Scottish White-tailed Eagle population's trajectory and what level of additional mortality the population can sustain. As the concern is a combination of results from two independent analyses each is examined separately to assess their robustness. In order to arrive at a legitimate conclusion both have to be unbiased and accurate. If either analysis results in an under- or over-estimate (of the number of collisions or the population growth rate) it is unclear if the overall conclusion will be valid as that depends on the magnitudes of the errors.

Section Summaries

Section 1 sets out the background to this report and shows how CRA and PVA are linked in a decision error matrix.

Section 2 outlines the format of a Collision Risk Analysis (CRA), particularly its separation into two components: the first concerns the bird, its density, size, flight speed and collision avoidance probability; the second relates to the wind farm, the number and spatial arrangement of the turbines, their size and operating characteristics. The turbine's size and rotation speed plus the bird's size and flight speed is used to estimate the probability that a bird flying through the swept area of a rotating turbine would be hit by a blade. This collision probability is combined with the bird's on-site density and its avoidance behaviour to estimate an annual collision rate (birds killed per year). Inconsistency in values used to describe the bird and the turbine introduces uncertainty into the modelling which makes the collision estimate less reliable. This inconsistency is investigated by extracting data from publicly available CRAs.

Section 3 examines how bird activity (density) is measured and what assumptions are made. The amount of bird activity recorded within a known sampling time over a known sampling area (the viewshed) are combined to produce the bird density. The main problem with this approach is that density is assumed to be even across the viewshed; which it never is. Examples are shown to illustrate this. The overall conclusion, from the evidence presented here, is that a sufficient level of confidence cannot be obtained using this method of estimating bird density. Section 8 has some suggestions for changes that could increase the level of confidence.

Section 4 investigates how the NS collision model has been used in CRAs and determines if there is bias in the assessed collision probabilities. Data were extracted from 114 CRAs in the public domain; 48 of the 114 CRAs estimated a White-tailed Eagle collision probability. There was great inconsistency in the bird and turbine metrics used, even for apparently very similar turbines. In many cases rotation speed was too fast, sometimes faster than the turbine

specifications. Overall, these CRAs entered values into the collision model which inflated the collision probability. There was also confusion between operational time and operational capacity. The wide range of values used, even for the same turbine specification, means the robustness of the collision estimates is questionable. Most consultants appear to err on the side of precautionary values, often exceeding what is feasible, resulting in a tendency to overestimate the number of predicted collisions.

Section 5 examines known collisions, particularly their relationships with the CRA predictions for the relevant wind farms. Two of 15 recorded collisions were on the Edinbane wind farm where, unusually, there are many years of post-construction VP monitoring combined with the neighbouring Ben Aketil wind farm. These monitoring data were used to derive annual collision estimates using standard methodology. Using these and other data, it is clear the current CRA tools lead to a large over-estimate of the number of collisions. In the case of White-tailed Eagles at two Skye wind farms, our analysis indicates that the real collision level is only 7% of the CRA predictions calculated whilst the turbines were operational. This reduction is despite the fact that the post-construction surveys at these two wind farms are likely to have produced a lower CRA than would be expected in normal circumstances given there would be some level of displacement from the operational wind farms.

Section 6 documents change in the number and spread of White-tailed Eagles and wind turbines across Scotland and attempts to understand how the two are linked. Both have shown significant expansion, but the rates differ within, and between, regions. Overall, there are now more than 200 pairs of White-tailed Eagles with a possible continuing expansion to ~350 pairs by 2030. There was no evidence that the recent outbreak of HPAI has had a significant long-lasting impact on the Scottish White-tailed Eagle population. In addition to data from the raptor study groups, there is indirect evidence for the scale and speed of the White-tailed Eagle's expansion from independent sources such as the Sea Eagle Management Scheme and data from the citizen science programme eBird and observations from Environmental Impact Assessments (EIA) to demonstrate the change in this distribution over time. Using mainland Argyll as a case study there is no evidence that the increasing number of turbines is restricting the White-tailed Eagle's expansion. The removal of birds for reintroduction of White-tailed Eagles into England is equivalent to losses due to collisions. The proposal to remove birds noted that "*The removal of 12 young each summer from 2019-2023 would have a negligible effect on overall productivity… would pose no risk to the donor population given the current and expected rate of population increase*". This is significantly more birds than are removed from the population by wind farms on an annual basis. The long interval between the end of bird surveys for a proposed wind farm and the date at which the wind farm becomes operational further reduces the value of original CRM as a predictive tool, unless a population is relatively stable.

Section 7 is concerned with the second set of analyses which model the population trajectory of the Scottish White-tailed Eagle and identify what level of additional mortality the population can sustain with the aim of understanding how a PVA can be used to investigate the evidence for a significant impact of collision mortality on the future of Scotland's White-tailed Eagle population. Our results suggest the observed growth in the Scottish White-tailed Eagle population could not have occurred if the calculated collision risks from EIAs were accurate. Indeed, if the previously modelled population trajectory by Sansom *et al* (2016) accurately represents the current status of the population, as acknowledged by NS, this can only have occurred if the number of collisions was very much smaller than calculated in EIAs. Our models suggest that the known losses associated with collisions and the intentional removals for eagle

reintroduction programmes, have so far had a very limited impact on population growth over the last twenty years despite the considerable expansions in the number of wind farms and the number of White-tailed Eagles.

The final **Section 8** lists the CRA problems identified in this report and, where possible, suggests possible solutions such as changes to how density is estimated, using satellite tracking data to better understand White-tailed Eagle behaviour and, not least, reviewing the current avoidance rate which appears too conservative given the results of the analyses in Sections 6 and 7.

1. Introduction

1.1 Approach

NatureScot (NS) is concerned about the impact of wind turbines on the future of the Scottish White-tailed Eagle *Haliaeetus albicilla* population. The population has grown rapidly since its initial 1975 release on Rhum and the 2026 population is ~220 pairs (~1,100 individuals of all ages and sexes). NS collates the estimated white-tailed eagle collision risk associated with each wind energy project irrespective of the project's progress through the process. Currently, NS believe the annual cumulative collision is ~21-22 birds if all of these projects become operational and such an annual additional mortality could have a significant impact on the growth of the Scottish eagle population. It is, therefore, important that the collision estimate is robust. This study examines the factors which feed into this cumulative collision total in order to understand the weight which should be applied to it. The study also examines eagle population trends to determine if historic predicted collisions have had the expected impact on population numbers.

1.2 Background

The NS concern about the potential threat to the future of Scotland's White-tailed Eagle population, as a result of collisions with wind turbines, is predicated on combining the results from two separate analyses.

1. **Collision Risk Analysis** (CRA) estimates the number of collisions, both cumulatively and at individual wind farms (Sections 2 – 5 of this report).
2. **Population Viability Assessment** (PVA) models the Scottish White-tailed Eagle population trajectory and what level of additional mortality the population can sustain (Sections 6 and 7 of this report).

As the concern is a combination of results from two independent analyses it is important to examine each separately to assess how robust they are. In order to arrive at a legitimate conclusion both have to be unbiased and accurate. If either analysis results in an under- or over-estimate (of the number of collisions or the population growth rate) it is unclear if the overall conclusion will be valid as that depends on the magnitudes of the errors (Table 1.1).

Table 1.1 Decision error risk matrix

		CRA-Turbine collision estimates		
		Under-estimate	**Accurate**	**Over-estimate**
PVA-Population model growth trajectory	**Under-estimate**	Potentially accurate	Over-estimates risk	Over-estimates risk
	Correct	Under-estimates risk	Accurate	Over-estimates risk
	Over-estimate	Under-estimates risk	Under-estimates risk	Potentially accurate

Appendix A discusses how the White-tailed Eagle's biology affects the probability that it will collide with a turbine and suggests some ways of reducing the chance of a collision.

2. Collision Risk Analysis Outline

2.1 Section Summary

This section outlines the format of a Collision Risk Analysis (CRA), particularly its separation into two components: the first concerns the bird, its density, size, flight speed and collision avoidance probability; the second relates to the windfarm, the number and spatial arrangement of the turbines, their size and operating characteristics.

The turbine's size and rotation speed plus the bird's size and flight speed is used to estimate the probability that a bird flying through the swept area of a rotating turbine would be hit by a blade. This collision probability is combined with the bird's on-site density and its avoidance behaviour to estimate an annual collision rate (birds killed per year).

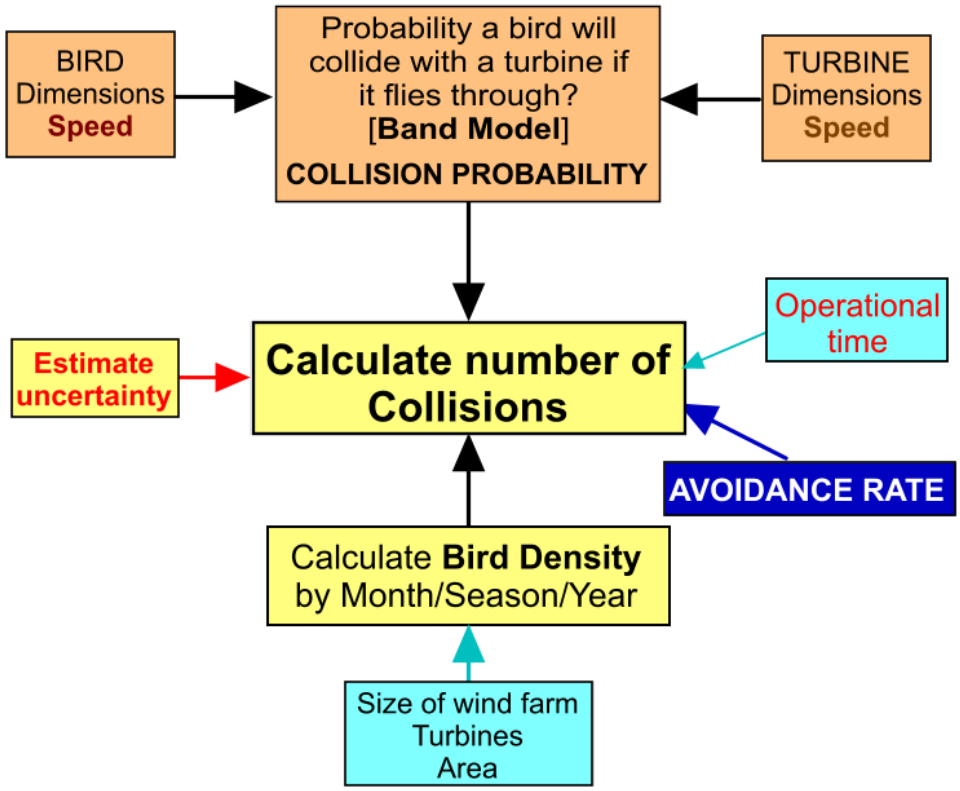
Inconsistency in values used to describe the bird and the turbine introduces uncertainty into the modelling which makes the collision estimate less reliable. This inconsistency is investigated by extracting data from publicly available CRAs.

2.2 Structure of a CRA estimate

Three components contribute to a CRA's estimate of the number of turbine collisions (Fig. 2.1):

a. **bird density** - the amount of bird activity within the proposed wind farm (Section 3);
b. **collision probability** - probability that a bird, flying through the rotating turbine blades, will be hit by a blade and killed (Section 4);
c. (a) and (b) are combined, with the bird's assumed collision avoidance behaviour, to estimate the number of birds killed each year.

Figure 2.1 Summary of the process by which the number of potential collisions is estimated



Bird density is estimated via field surveys which record the amount of flight activity and extrapolate from the samples to get annual or seasonal averages.

Collision probability plays a central role in converting flight density into to an estimated number of annual collisions. The number of estimated collisions reduces as the collision probability reduces. For all species, their characteristics (dimensions and flight speed) should have no freedom in the Band model (NS's collision probability Excel spreadsheet). Therefore, for any species, changes in the collision probability should be entirely a function of the turbine characteristics. Changes to these values change the collision probability and, in combination, they could increase or decrease the collision probability.

Collision probability is estimated using a spreadsheet (the 'Band' model) supplied by NS and now incorporated into a new comprehensive spreadsheet. The use of this model to estimate the predicted collision risk from a proposed wind farm is specified in official guidance but it should be recognised that it is unlikely to produce reliable collision estimates. Whitfield (*pers comm*), one of the authors of the original paper (Band *et al*., 2007), does not think its continued use is justified.

Ten values are needed to use the Band spreadsheet (Table 2.1). The first five relate to the turbines and are under the developer's control, although the first two are rarely changed. The last four relate to the species being modelled and these values are given in source references. In our review of publicly available White-tailed Eagle CRAs there was inconsistency in these bird measures as described in Section 4.

Table 2.1. Parameter values needed to run the Band collision probability model.

Values and units	Notes
K: 2D or 3D (0 or 1)	*0 implies a turbine that has only area and no depth.*
Number of blades	*3 except for smaller turbines unlikely to be used in large wind farms.*
Max Chord (m)	This varies between turbine types and is typically widest close to the hub and tapering towards the tip. When chord width is combined with the blade pitch the blade depth can be estimated, i.e. the distance that must be flown to pass through the turbines at right angles. This information is not always provided by manufacturers and an educated guess may be needed. There is inconsistency in the published CRAs for the same turbine.
Pitch (degrees)	Pitch is the turbine blade angle relative to the rotor plane and, as with the chord width, it varies along the blade. Pitch is rarely provided now that variable pitch turbines are common. Increases in the pitch increase the collision probability and *vice versa*. The collision probability is not particularly sensitive to this value and there was inconsistency in the published CRAs for the same turbine.
Diameter (m)	Larger turbines generally have reduced collision probabilities.
Rotation Period (s)	Time taken for one blade to make a complete revolution. Smaller times (faster blade speed) increase the collision probability all else being equal. Also expressed as RPM.

Bird Length (m)	*A source reference (e.g. Provan and Whitfield (2006) or BTO bird facts) must be provided. In the case of the White-tailed Eagle the NS recommended length is 0.8m.*
Wingspan (m)	*As above. The NS recommended wingspan is 2.2m.*
Flapping 0 or gliding +1	*Gliding reduces the collision probability but it is usual to assume birds use a flapping flight as they pass through the turbine. There was considerable inconsistency in the retrieved CRAs with some consultants opting for what they thought, incorrectly, to be the more conservative option. Often it was unspecified.*
Bird speed (m/s)	*As with the dimensions, a source reference is needed. In the case of the White-tailed Eagle the NS recommended speed is 12.0 m/s. Higher speeds reduce collision probability but this 'gain' is lost in later calculations as the number of transits (potential collisions) increases with flight speed. There was considerable inconsistency in flight speeds in the publicly available CRAs.*

The avoidance rate is an assumed behavioural response to the presence of the turbine. It plays a very important part of the calculations after the bird density and collision probability are combined (part c) to estimate how many times birds would fly through the rotating turbine (number of transits). Each transit has a probability of resulting in a collision. The avoidance rate reduces the number of transits through turbines.

The value of the avoidance rate has the largest impact on the estimated number of collisions. The recommended avoidance rate of 95% for White-tailed Eagles is the lowest (least avoidance) of the NS recommended rates. If it was increased to 97.5% the number of collisions would be halved. As such avoidance rates play an integral and dominating role in collision estimates, and therefore any assessment of the potential threats to Scottish White-tailed Eagle populations.

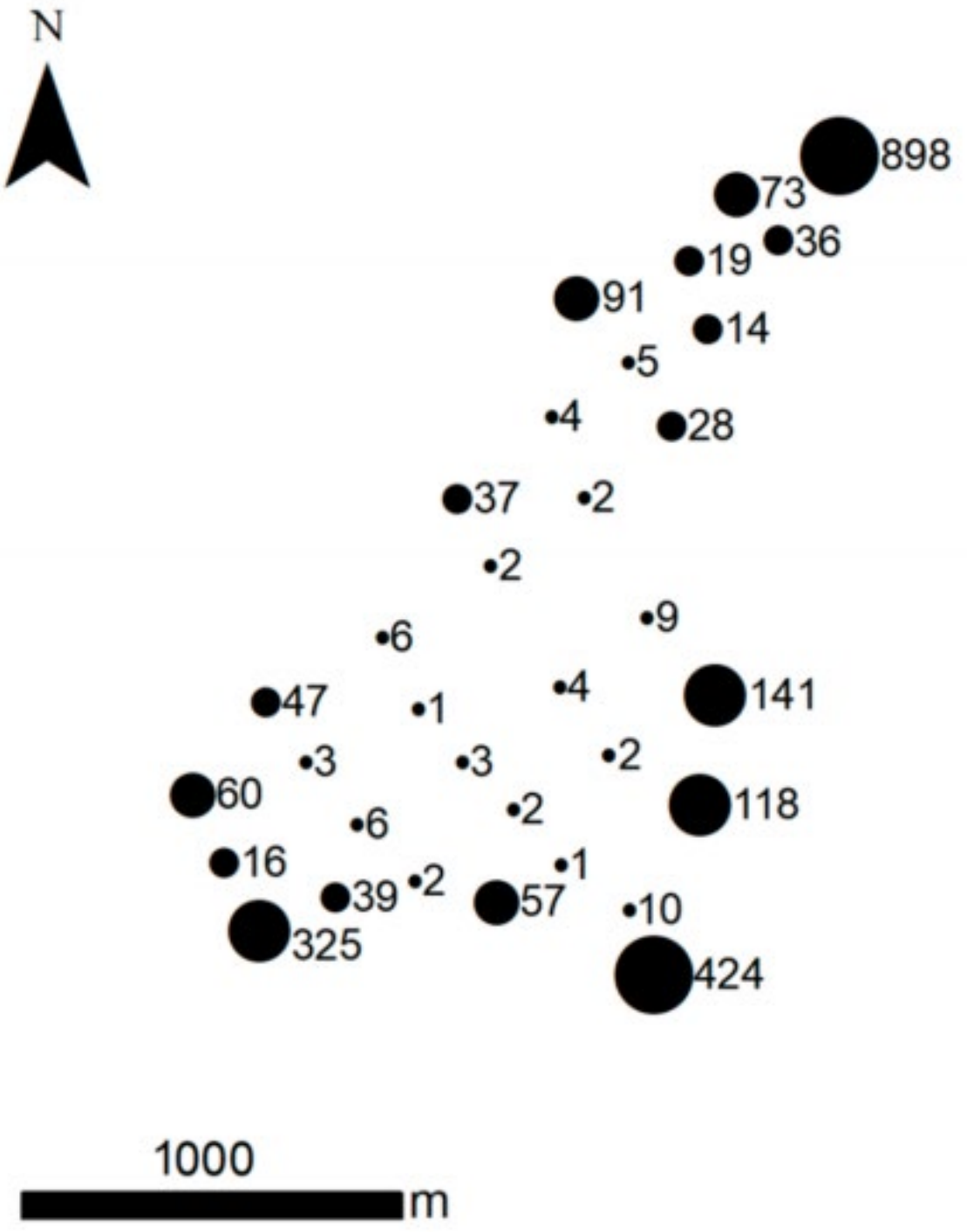
The collision estimate in part c is a single figure which is, in effect, a cumulative sum of the deaths associated with each turbine. Ferrer *et al* (2012) recognised that there was no clear relationship between predicted fatalities and the actual recorded bird mortality at wind farms. They suggested this discrepancy could be reduced if assessments focussed on the locations of proposed individual wind turbines.

This is illustrated in Fig. 1 in Fielding *et al*. (2024, reproduced below as Fig. 2.2)) for an example of unequal golden eagle activity around turbines recorded using satellite tracked birds; some turbines have much more activity close by while many have little. **This observation is important if the number of turbines has to be reduced if the collision risk is too high as it clearly demonstrates that individual turbines present different levels of risk**.

A recent study by García-Macía *et al* (in review) does not consider how a CRA should be changed but it is relevant to the criticisms made above and the suggestions for changes to how bird density could be estimated (Section 8). García-Macía *et al* (in review) note that CRAs have evolved towards increasingly sophisticated frameworks but there is a problem in that collision risk is frequently assessed using coarse, wind farm–level metrics based on overall activity patterns. They used a pre-operational study across four wind farms in southern Spain to evaluate the potential bias introduced by such generalized approaches. They collected fine-scale spatial data from 59 turbine locations during pre-operation phases and quantified flight activity and

collision risk of soaring-gliding birds at the turbine level. As in Fig. 2.2, both flight activity and estimated risk were highly heterogeneous among turbines and followed a strongly right-skewed distribution, with a small subset of turbines disproportionately contributing to overall risk. Wind farm identity explained only a low-to-moderate proportion of the variance, whilst fine-scale, site-specific factors accounted for a larger share. They suggest that their results highlight the importance of incorporating fine-scale spatial variability into EIAs.

Figure 2.2. The number of golden eagle flight line records associated with each of the 35 turbines at the Cruach Mhor wind farm (taken from Figure 1 in Fielding et al. (2024)).



3. Bird Activity

3.1 Summary

This section examines how bird activity (density) is measured and what assumptions are made.

Bird density is estimated from field surveys conducted from fixed locations (Vantage Points). The amount of bird activity recorded within a known sampling time over a known sampling area (the viewshed) are combined to produce the bird density. The main problem with this approach is that density is assumed to be even across the viewshed; but it never is. Examples are shown to illustrate this.

The overall conclusion, from the evidence presented here, is that a sufficient level of confidence cannot be obtained using this method of estimating bird density. Section 8 has some suggestions for changes that could increase the level of confidence.

3.2 How is bird activity measured?

3.2.1 Wind farm boundary and vantage point (VP) surveys

First, the wind farm's boundary is determined as the area within a radius of all proposed turbines. There does not appear to be a defined radius but 500 m from the turbine tip is the NS default although most assessments use 500 m from the turbine towers. Some of the White-tailed Eagle CRAs obtained from web searches, and used in this report, use smaller areas.

Five hundred metres was adopted as a way of dealing with the inevitable inaccuracies involved when a surveyor records a bird's flight path on to a map. One overlooked problem is that the amount of recorded flight activity is an estimate, based on a sample, with the associated sampling error that is rarely considered (Douglas *et al*., 2012). Bird surveys are rarely, if ever, random samples of all bird activity and it is unclear if this introduces a positive or negative bias. This is compounded by errors recording flight locations on to a map and the flight's changing altitude, particularly if the topography is complex.

3.2.2 Vantage Point (VP) surveys

Flight activity is usually recorded by surveyors from specific VPs that fulfil the regulatory requirements of total watched time and area. Only flights in the Rotor Swept Volume (RSV, between the maximum and minimum heights swept by the rotating turbine), or risk window, contribute to the collision risk. Flights outside of the RSV are either below or above the rotating blades so they would not result in a collision. However, recording the instantaneous height of a bird above the ground surface is impossible so compromises are needed such as recording an 'average' flight height in 15 second intervals. Even then, flight height is recorded in height bands which, hopefully, match the turbine specifications used in subsequent calculations.

The amount of flight activity is related to the habitat (land cover), topography, season and proximity to breeding sites or roosts. In the case of White-tailed Eagle, carrion could vastly increase flight activity resulting in peaks in the bird density.

3.3 What assumptions does the Band model make about bird activity?

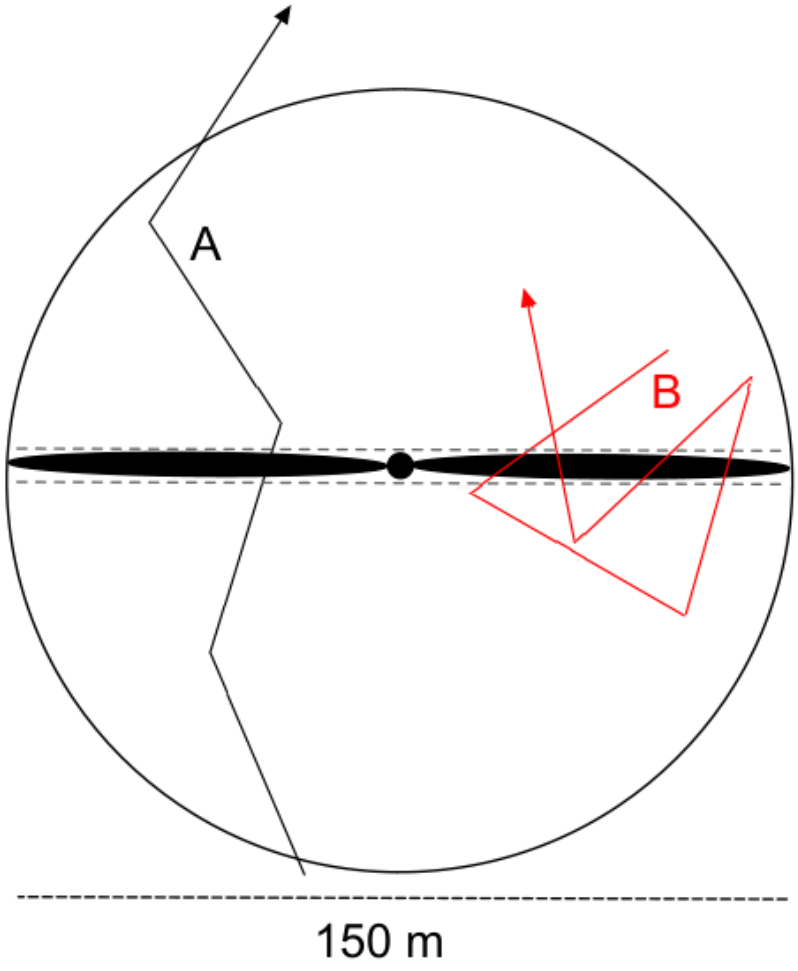
Imagine a simple scenario with a single turbine wind farm (Fig. 3.1) with a 150 m diameter turbine. The viewshed covers a circle with a radius of 75 m. The turbine has a 3.7 m maximum chord, 15° pitch and a rotation time of 8.8 rpm. The bird has the recommended values of length = 0.8 m, wingspan = 2.2 m and a flapping flight speed of 12 m/s. The Band model collision

probability for these values is 6.74%. This means that for every 100 flights through the rotating turbines there will be 6.74 collisions.

The turbine is assumed to operate for 100% of the time and there are six hours of VP survey per month from the single VP. Each month an identical single flight is observed, always with 25 s in the RSV. However, there are two flight scenarios which reflect different flight patterns, at the scale of the turbine (Fig. 3.1), but result in 25 s of activity within the surveyed area. Flight line A is a directional flight but only at the scale of the turbine, across the landscape there is no prevailing directional flight (not shown in Fig. 3.1). A different calculation is required for regular directional flight such as seen in migration flights.

Using the updated NS CRA spreadsheet the bird density (0.1308 birds km^{-2}) is the same each month for flights A and B. The number of turbine transits per month is the same for flights A and B, varying from 156.2 - 352.6 (2,996 per year), reflecting the changes in daylength. The number of collisions per month, before avoidance is included, is 6.74% of the transits at 10.5 - 23.8 collisions per month (202 per year) which reduces to 0.53 - 1.19 with 95% avoidance. The result is a predicted 10.10 collisions per year. Clearly this cannot be true for both flights, flight B has four times more transits than flight A so the risk to this flight should be four times larger.

Figure 3.1. A simplified collision calculation scenario with a 150 m diameter turbine and two flights, each lasting 25 s in the risk window.



This illustrates one of the fundamental challenges with the NS collision model which is separate from how individual changes in parameters change the collision probability (see Section 4).

The NS collision model averages flight activity across the site, with all points in a viewshed having equal activity. This is clear from how bird density is calculated as the flight time (seconds within the RSV) divided by the survey effort (hours spent watching each km^2). After conversions between seconds and hours are carried out, time is cancelled out leaving a bird density per km^2. But this is an even density which is not justified even if topography and land cover were identical across the surveyed area (an extremely rare event). This is partly recognised in the updated guidance but only with respect to inter-VP differences rather than intra-VP differences "*Where the conditions are such that it is likely to be a notable difference, for example because the underlying habitat is different, either the bird density should be calculated separately for each watch area and applied to calculate collision risks within that area, or a turbine-weighted average bird density should be used, i.e. weighting the bird density for each watch area by the number of turbines within that watch area.*"

The assumed even density of flight activity, at least within a viewshed (also termed 'watch area'), is used to estimate the number of turbine transits which is fundamental to the estimated number of collisions, albeit mediated by the collision probability during a transit (Section 4) and the avoidance factor.

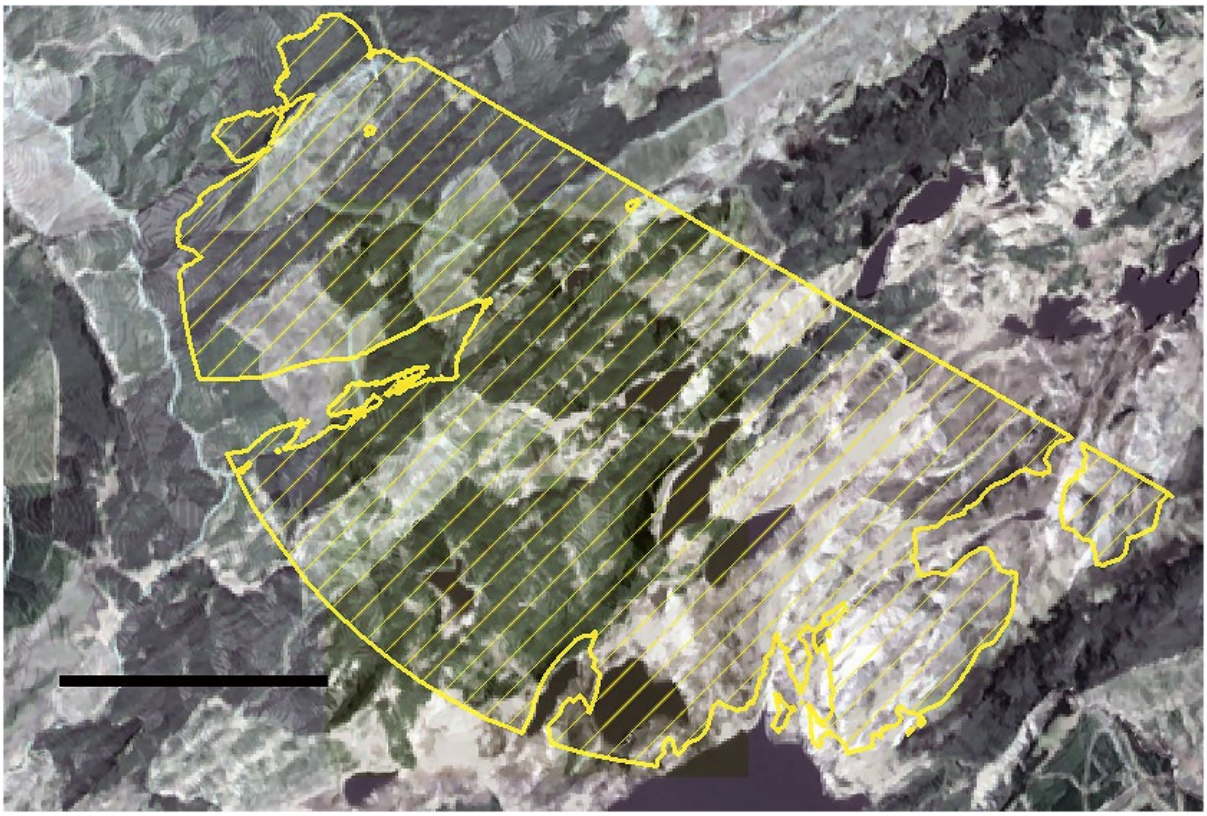
The number of turbine transits is estimated using the simple ratio of the volume occupied by the turbines (turbine swept area multiplied by turbine depth plus the length of the bird) and the volume of the wind farm which, in the guidance, is assumed to be the volume of land within the RSH (rotor swept height = turbine diameter) and a 500 m buffer extending from the turbine tips but is almost universally calculated as a 500 m buffer from the turbine towers. Whether the buffer radius matters depends on the distribution of flights within the viewshed and wind farm; it could lead to both increases and reductions in the estimated number of collisions, i.e. there is no systematic bias resulting from the distance used.

Consider the VP and its viewshed in Fig. 3.2, there are clear differences in the topography and land cover within the viewshed which must affect the density of flights by a target species but the NS collision model spreads all activity within the viewshed evenly across the viewshed, irrespective of land cover or topography, to create a single flight density across the viewshed.

An underlying problem is that a bird cannot be everywhere; not least the probability of being somewhere is related to where it was a second ago i.e. there is spatial and temporal autocorrelation in flight activity which is not captured by this even-density model and changes in the land cover and topography alter the probability of a bird being at any point.

Grünkorn *et al's.* (2016) in-depth study, is critical of the Band model, other than using it to standardise comparisons of relative risks. They considered the stochastic and mechanistic nature of the Band model a big limitation and, as such, it is not a behavioural model. Grünkorn *et al.* (2016) were also particularly critical of the assumption that an avoidance rate is constant over all individuals of a species (regardless of age). The main problem with the Band model, identified by Grünkorn *et al.* (2016), was the vague relationship between the observable flight activity and the collision risk. The model assumes a linear relationship between the length of time in the view shed and danger, which does not appear to be the empirical case. For example, De Lucas *et al*. (2008) found no relationship between raptor abundance in wind farms and the number of collisions.

Figure 3.2. An example viewshed (yellow hatched, 2 km radius) and the landscape it covers (Sentinel 2 April 2025 image).



As shown in Section 4, Grünkorn *et al.* (2016) also note the sensitivity of the Band model's predictions to the various turbine technical parameters (e.g. rotor speed, angle of the tilt of blades) and that it is very difficult to account for bird behaviour such that the proportion of activity in the danger zone, flight speed, flight height and wind direction which are all subject to high levels of uncertainty.

The inevitable consequence of the unrealistic assumptions about bird density is that the real uneven distribution of flight activity results in collisions and bird activity being unequally distributed across a site (see Fig. 3.1 and any VP survey map of flight lines). Fig. 3.3 shows actual White-tailed Eagle flight lines collected from VP surveys for an un-named proposed development.

Fig. 3.4 shows golden eagle flights recorded in a viewshed for another un-named proposed development. The background is the GET model (Fielding *et al.,* 2020) in which darker colours indicate a greater probability of use by golden eagles. It is clear that flight activity is not spread evenly across the viewshed and this is largely related to the landscape. It is reasonable to assume that there will be some relationships between White-tailed Eagle flight activity and topography and land cover. Such relationships could be identified once there is sufficient satellite tracking data for White-tailed Eagles.

Figure 3.3. Example White-tailed Eagle flight lines recorded from VPs. The square has 1 km sides, for context.

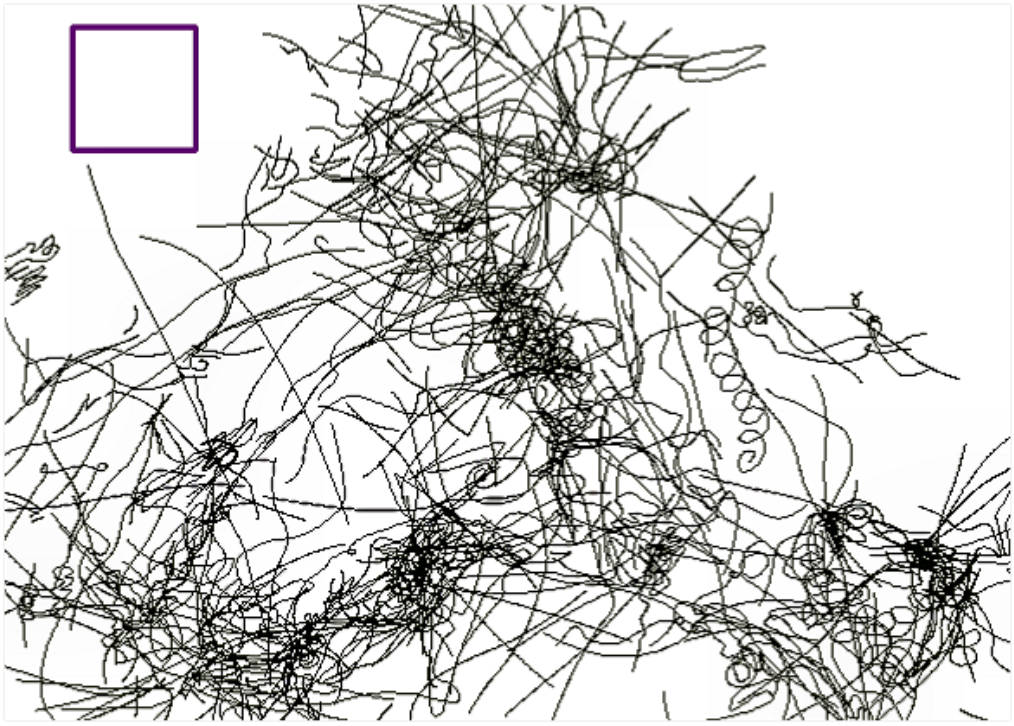
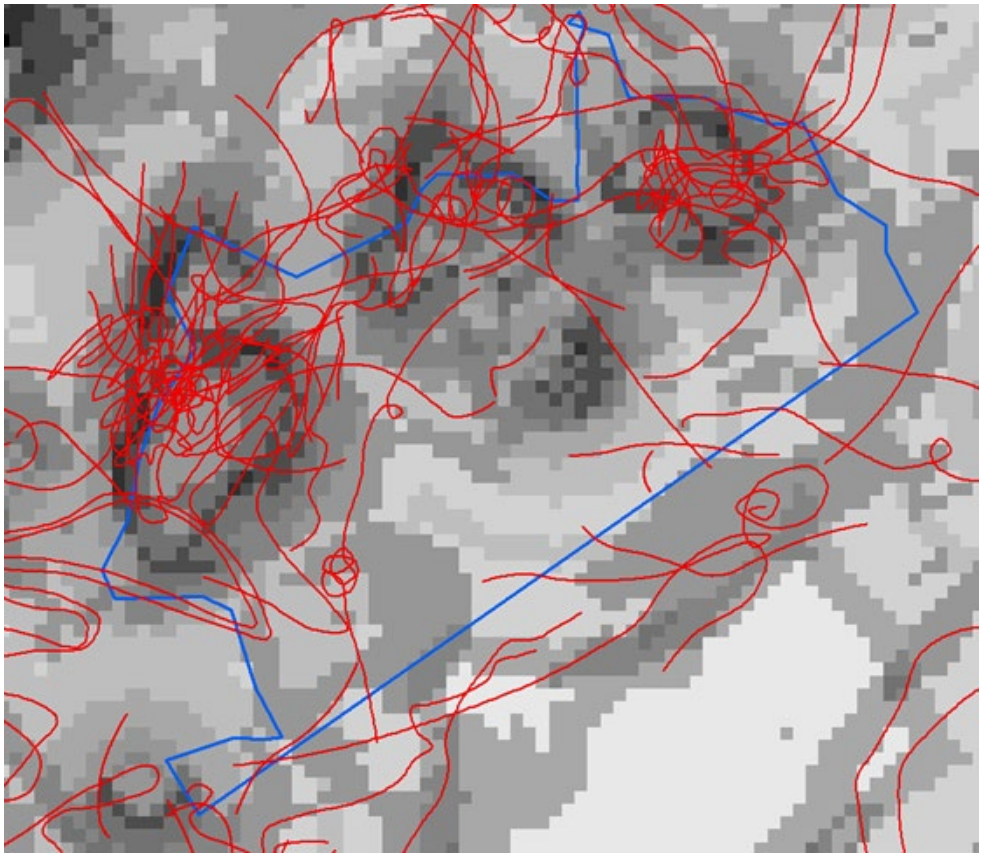


Figure 3.4. Golden eagle flight lines (red) in viewshed A (blue outline) with the GET model background. Contains Ordnance Survey data © Crown copyright and database right 2020



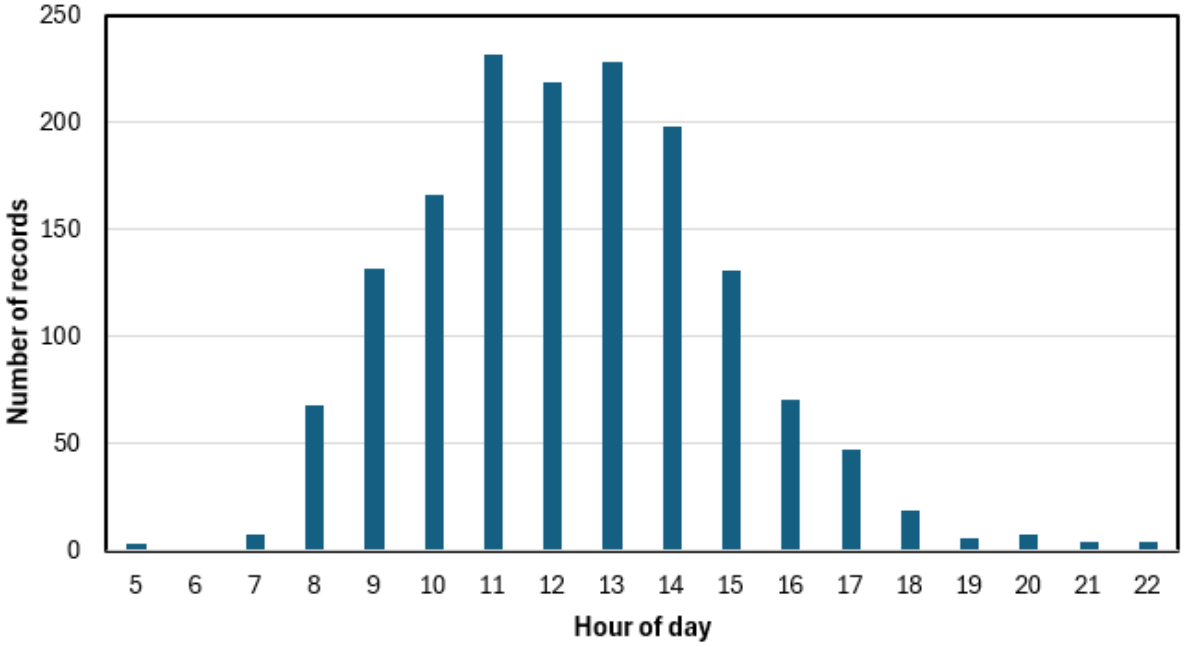
3.4 What is the evidence from flight activity to support the assumptions and how might this affect the CRA calculations?

The updated NS collision guidance suggests that, where possible, bird density should be calculated separately for each month. This is justified if, as seems likely, activity varies across a year (excluding migratory birds). If total bird activity is spread evenly across the year, or even within a breeding/non-breeding season, this runs the risk of inflating the number of collisions in some months simply because the days have different lengths. In the Section 3.2 hypothetical example, the number of turbine transits per month varied between 156.2 to 352.6 despite no changes in the amount of flight activity recorded each month.

NS guidance of White-tailed Eagle surveys notes that "*Soaring and display often peaks during the warmer part of the day but can occur throughout the day. …. There are seasonal variations in activity levels, e.g. late winter/early spring period has increased territorial behaviour and nest-building prior to breeding Immatures and non-breeding birds can visit breeding territories. Breeding season is defined as February- August inclusive*." We now examine what evidence exists to support the view that flight activity varies systematically with time of day and/or time of the year?

Data were extracted from wind farm bird surveys from 22 wind farm proposals[1] in the public domain (not all proposals had been determined at the time of our data collection). Only surveys which included VP dates and times plus the dates and times of all white-tailed flights recorded from those VPs were used. One thousand five hundred and fifty-four White-tailed Eagle flight records were available. There was a clear midday peak in White-tailed Eagle records (Fig. 3.5) but this pattern could simply reflect VP survey times, for example if most surveys were between 11 am and 2 pm.

Figure 3.5. Frequency of White-Tailed Eagle records by survey hour in 22 wind farm assessments.



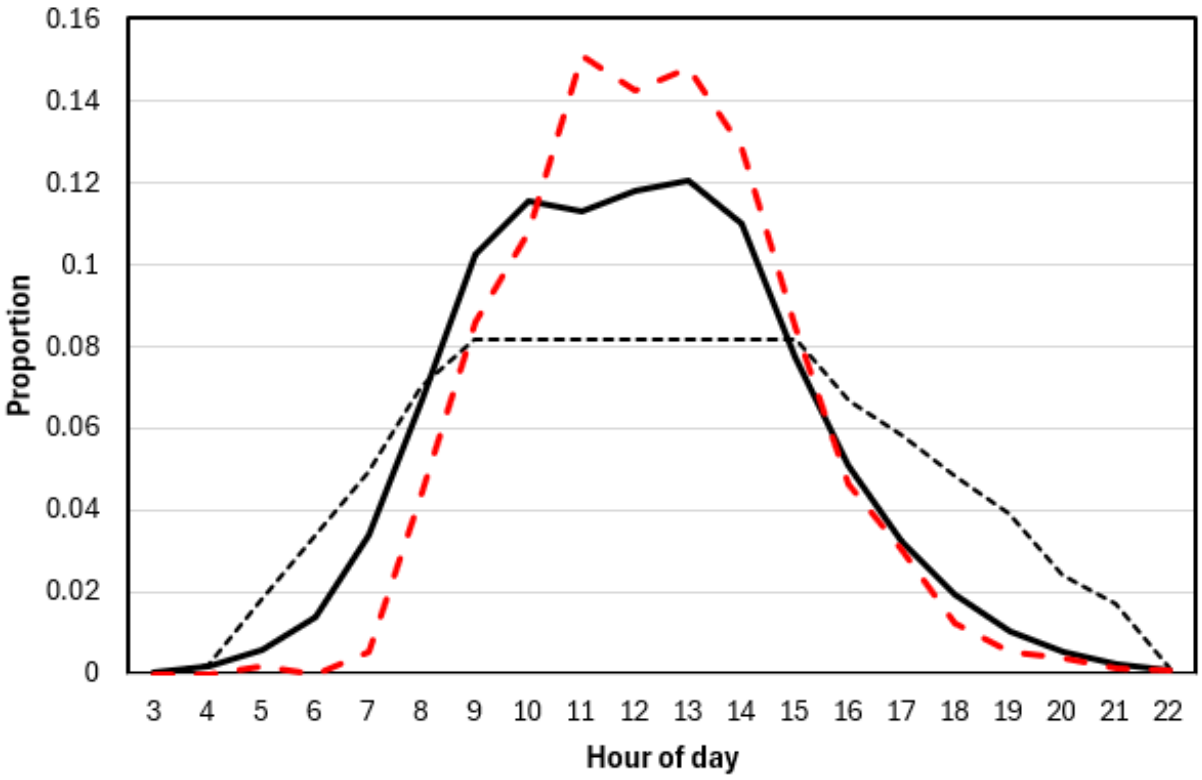
[1] Acheilidh, Allt an Tuir, Allt Domhain, An Carr Dubh, Beinneum 2, Ben Aketil Repower, Bhlaraidh Ext, Clachaig, Cloiche, Clune, Cnoc Buidhe, Corr Chnoc, Corriegarth 2, Eredine, Ullinish (New), Glentarken, Highland, Inveroykel, Ladyfield, Lynemore, Meall Dearg and Ounack

Understanding the relationship between the number of records and time of day is complicated not just by VP timing but also by the changes in daylength across the year. For example, there is daylight between 9am and 3pm on 365 days of the year whilst between 7-8 am and 7-8 pm there is daylight on only 220 and 174 days respectively. Inevitably this means there will be fewer VP surveys before 8 am and after 6 pm.

The number of survey hours per hour of the day, in the 22 assessments, broadly follows the number of days with daylight for that hour (expressed as proportions to simplify comparisons) but the proportion of White-tailed Eagle records has a different distribution (Fig. 3.6) with a deficiency in the morning and an excess around midday.

Interestingly, this mirrors the pattern of activity seen from millions of golden eagle satellite tracking records collected in Scotland, Greece and Spain (López-Peinado *et al.,* 2024 and unpublished, ongoing research in which AF is involved) so it is probable that the pattern seen across the day is real and not a sampling artefact. However, if surveys were biased towards particular times of day the estimated bird density estimate would be biased. If surveys were biased towards early mornings and late afternoons this would under-record the average bird density while it would be over-recorded if surveys are biased towards the middle of the day. **In Fig. 3.6 there is evidence that the middle of day is over-sampled meaning that density estimates are artificially high and the collision estimate will be incorrectly inflated.**

Figure 3.6 Proportions of VP survey hour records (solid black line); White-tailed Eagle VP records (dashed red line) and the proportion of the year that hour is daylight (dotted black line)[2].



[2] Note – the proportion of the year that an hour is daylight is not the same as the number of daylight hours per day. For example, the hours between 10 am and 2 pm are daylight in all months whilst the hour between 6 and 7 am is daylight in only in six months.

Possible biases introduced when surveys are undertaken is complicated by the larger annual pattern in activity. There was a marked pattern in White-tailed Eagle records by month (Fig. 3.7) with a late spring peak and a possible smaller autumn peak. March, April and May are notable for having a larger proportion of records compared with the proportion of daylight hours. July, November, December and January show the opposite pattern.

As with the daytime activity, this mirrors what has been found for golden eagles across Europe (López-Peinado *et al.,* 2024 and unpublished, ongoing analyses of several million records from Scotland, Greece and Spain). This has implications for when collisions are likely to occur but also on how the estimated number of collisions is obtained if bird density is not estimated separately for each month. However, within a single wind farm survey period there is unlikely to be sufficient survey effort to robustly capture these trends, assuming they are general. This would add greatly to the lack of precision in the collision estimate.

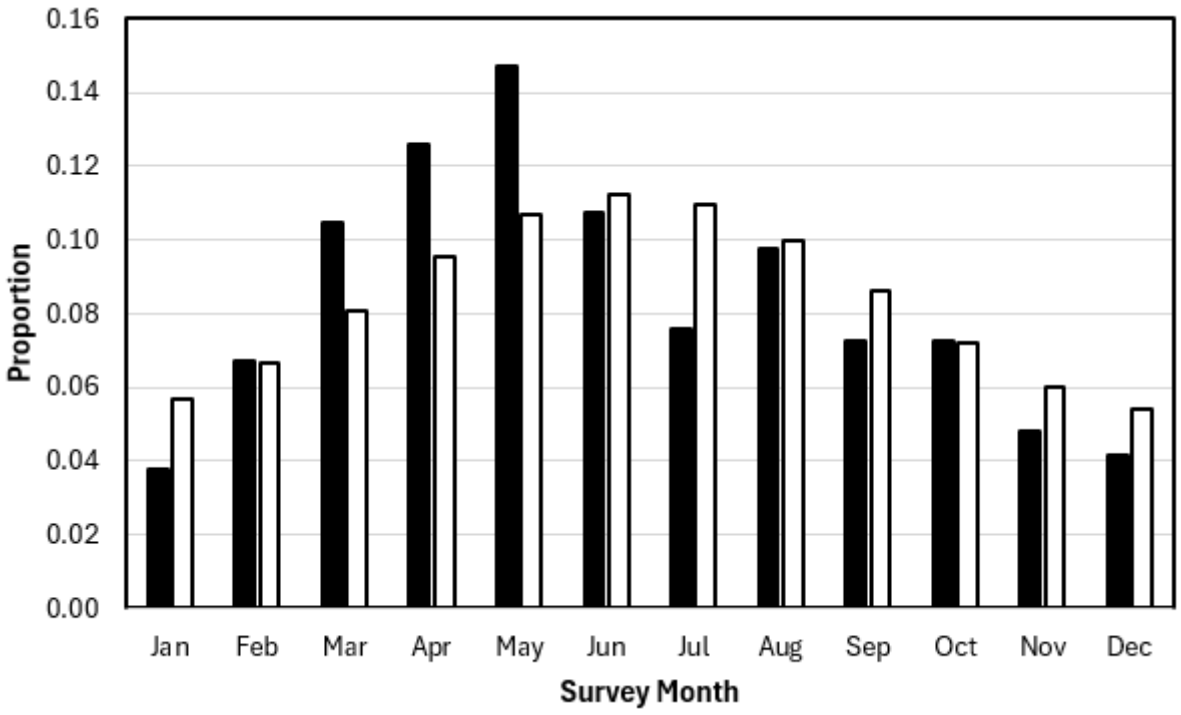
3.5. Conclusion

A high level of confidence in collision estimates cannot be obtained using this method of estimating bird density for the following key reasons:

1) The discrepancy between real White-tailed Eagle flight activity (flight patterns and spatial use) and the Band model density assumptions produces unrealistic collision outputs.
2) A disproportionate survey effort during periods of the day when birds are most active overestimates collision outputs.

Even treating the collisions estimates as qualitative, for example to rank the impact of wind farms, is questionable as so many factors contribute to the unreliability of the estimate. This conclusion is further supported by the analyses in Section 5.

Fig. 3.7. Proportion of White-tailed Eagle records by survey month in 22 wind farm assessments (black bars). Also shown is the proportion of annual daytime hours by month (white bars).



4. The Band collision probability model

4.1 Summary

This section investigates how the NS collision model has been used in CRAs and determines if there is bias in the assessed collision probabilities.

The three most important turbine specifications, with respect to the collision probability, are related: blade length and chord width; and rotation time. Both chord width and rotation time increase as blades get longer.

Data were extracted from 114 CRAs in the public domain; 48 of the 114 CRAs estimated a White-tailed Eagle collision probability. There was great inconsistency in the bird and turbine metrics used, even for apparently very similar turbines. In many cases rotation speed was too fast, sometimes faster than the turbine specifications. Overall, these CRAs entered values into the collision model which inflated the collision probability.

There was also confusion between operational time and operational capacity.

The wide range of values used, even for the same turbine, means the robustness of the collision estimates is questionable. Most consultants appear to err on the side of precautionary values, often exceeding what is feasible, resulting in a tendency to overestimate the number of collisions. Subsequent analysis presented in this report indicate that these overestimates are both consistent and significant.

4.2 Turbine specifications

Changes to the four turbine specifications (Table 2.1) alters the collision probability but the relative magnitude of change differs between them.

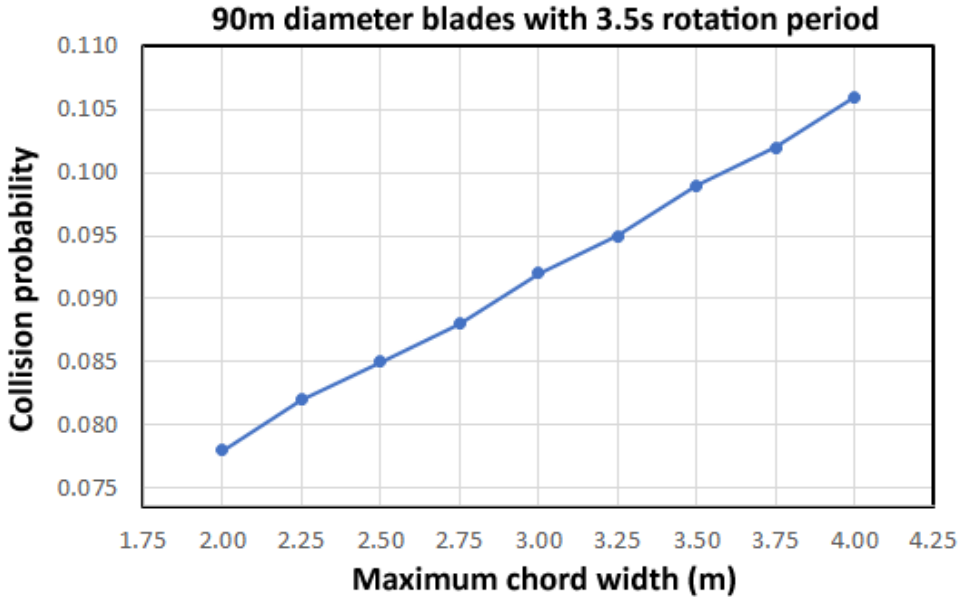
Data were extracted from 114 collision calculations (Appendix 1) found on the Scottish Government Energy Consents Unit web site[3] and web searches to investigate the consistency of values used in collision modelling; 48 were for White-tailed Eagle collision calculations. Some of the 116 calculations included only partial information so not all subsequent analyses apply to all assessments.

4.2.1 Maximum turbine blade chord width

Collision probability increases with increasing maximum turbine blade chord width as this is the distance a bird must fly to clear the rotating blades. In general, chord width will increase with blade length. For a fixed blade length, the collision probability is a linear function of the maximum chord width; with the collision probability increasing at a rate of approximately 0.1% per 0.1m (Fig. 4.1).

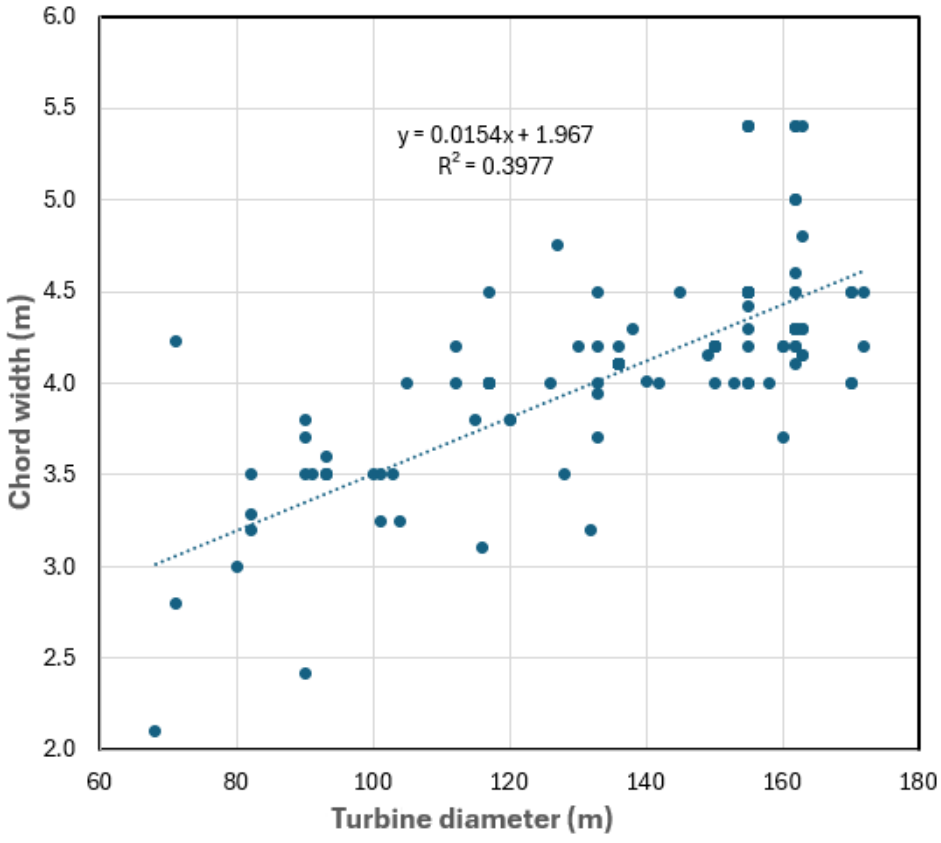
[3] https://www.energyconsents.scot/ApplicationSearch.aspx

Figure 4.1. Relationship between the collision probability and the maximum chord width for a 90m diameter turbine with 3.5 s rotation period.



There was considerable variation in the chord width used for the same turbine diameter in the 114 collision calculations (Fig. 4.2). There was a general trend for increasing chord width as turbine diameter increased but for some diameters there was an almost 2 m difference in the chord width for the same diameter. Some differences result from differences in manufacturer specifications but other differences appear to be due to different estimates by the consultants.

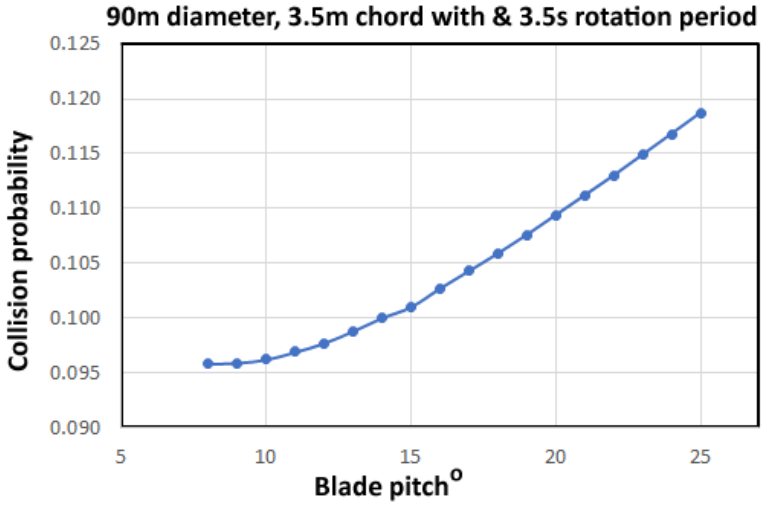
Figure 4.2. Relationship between the turbine chord width and turbine diameter in 114 collision assessments.



4.2.2 Blade pitch

Blade pitch is the angle of the blade relative to the rotor plane and, as with chord width, it varies along the blade's length. This information is rarely provided now that variable pitch turbines are common. Increases in the pitch increase the collision probability and *vice versa*. Collision probability is not particularly sensitive to this value (Fig. 4.3), for example between 5° & 15° it increases from 9.6% to 10.1% in the illustrated example; 15° appears to be an acceptable value.

Figure 4.3. Relationship between the collision probability and blade pitch for a 90m diameter turbine with 3.5 m chord width and a 3.5 s rotation period.



Pitch information was given in 114 of the calculations and it varied from 5° to 30°. The two most frequent pitch angles were 6° (n = 18) and 15° (n = 70) with a mean of 12.9° and a median of 15°.

4.2.3 Turbine diameter and rotation time

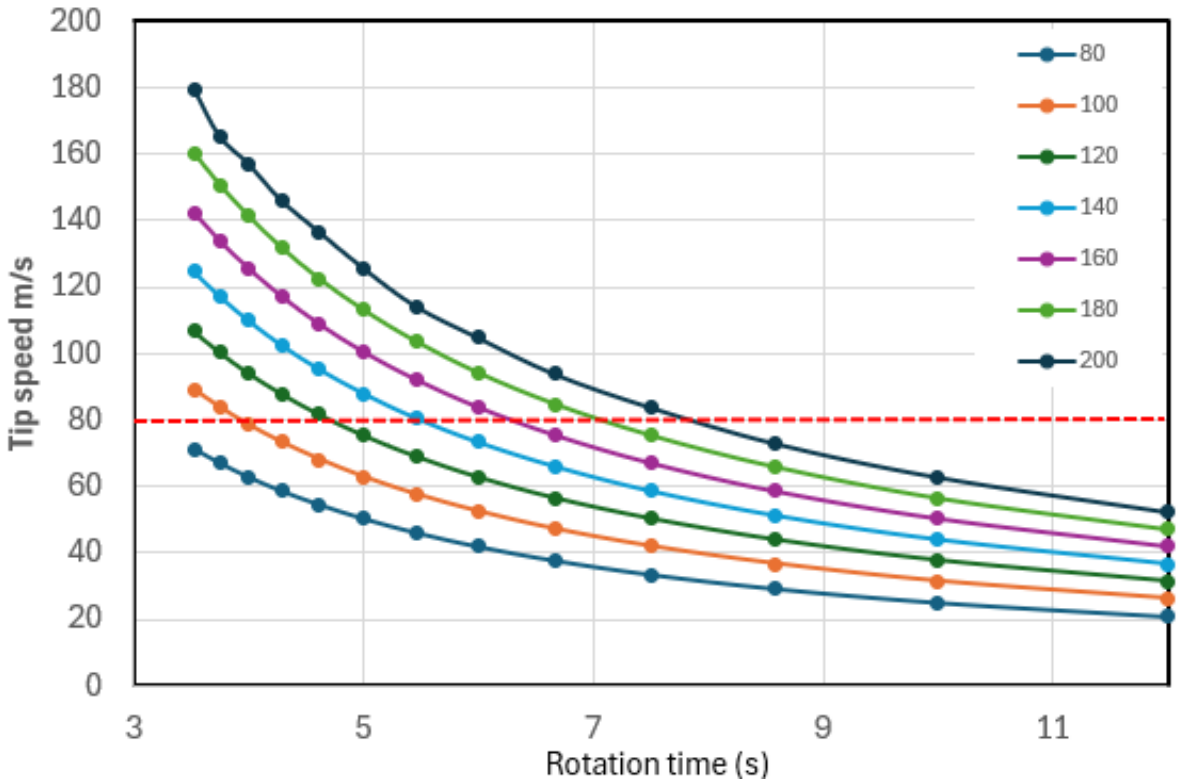
These two are considered jointly as the rotation time is closely related to turbine diameter.

Turbines do not rotate at constant speeds but there are upper limits created by the tip speed. If rotation time is kept constant, for example 10 rpm (6 s per rotation), the tip speed increases as the turbine diameter increases (Fig. 4.4) because the tips have to travel further in the same time. The tip speed (m/s) of turbine can be calculated from its diameter and rotation time. Tip speed (m/s) = circumference (m) /rotation time (s) where the circumference is π.diameter.

There is a useful explanation[4] of how the maximum tip speed is related to turbine diameter: "*to maintain noise within strict regulatory limits, the tip of the blade must travel below a maximum speed, typically about 80 meters per second. This is one reason modern turbines with long blades turn slowly - increasing the blade length means the rotation speed must decrease accordingly. For the largest turbines, with blades around 80 meters in length, typical rotation speeds might not exceed 10 rpm*". Fig. 4.4 shows the blade tip speed relationship between rotation period and turbine diameter and rotation periods producing a maximum tip speed of 80m/s are where the dashed red line crosses the curves. As these are the maximum tip speeds they are conservative and their use in the Band model produces over cautious higher collision probabilities.

[4] Article 5 from the Andlinger Centre for Energy and Environment (The Single Wind Turbine: From the Wind to the Blades) https://acee.princeton.edu/wp-content/uploads/2019/04/AndlingerDistillate_Article5.pdf

Fig. 4.4. The effect of rotation time on the tip speed (m/s) for seven turbine diameters. The dashed red line is at a tip speed of 80 m/s.



Saint-Drenan *et al* (2020) used data from 600 turbines to deduce two equations which make reasonable estimates of the minimum and maximum rotation times (rpm) from the blade diameter (Fig. 4.5, also and see Fig. 11 in Saint-Drenan *et al*., 2020). They also looked at the cut-in and cut-out wind speeds and advised that, when information on the cut-in and/or cut off wind speeds are unavailable, values of respectively 3 and 25 m/s are recommended. Ninety percent of cut-in values were 2 – 4 m/s. The range of cut-off wind speed were 15 - 30 m/s but the most frequent values were 20 and 25 m/s, (12 % and 70 % of values respectively). Figure 4.5 demonstrates that, on average, Scottish collision calculations are assuming unrealistically high RPM values which have the effect of artificially increasing predicted collision risk.

In Annex 8 of the updated NS collision guidance, it is noted that the mean rotor speed used to estimate the collision probability is "*not just a mean as between minimum and maximum operational speeds*", rather it depends on four factors.

- expected wind speed frequency distribution for the site;
- the range of wind speeds over which the turbine will operate;
- the rotor speed range for the turbine and;
- the rated wind speed for the turbine, i.e. the minimum wind speed at which full power is generated

There is a worked example in Annex 8 of the updated NS collision guidance (see Fig. A8-3) which relies on having a wind profile (annual wind speed frequency curve) and the turbine's operational characteristics. The worked example has a range from 7 to 12.1 rpm for a 3.2 MW turbine (not specified but assumed to be 130 m diameter). The maximum predicted by the equation in Saint-Drenan *et al* (2020) for a 130 m diameter turbine is the same at 12.1 rpm. Combining the wind profile with the turbine's rpm range Annex 8 produces a mean rotation time of 9.87 rpm (6.1 s). Using a rotation time of 81.5% of the maximum predicted by the equation in Saint-Drenan *et al*

(2020) the suggested rotation time for a 130 m diameter turbine would be almost identical at 9.86 rpm.

Figure 4.5. Turbine maximum (dashed red) and minimum (dashed blue) rotation times using the equations from Saint-Drenan et al (2020). $r_{min} = 1046.5577 . diameter^{-1.0911}$ *and* $r_{max} = 705.406 . diameter^{-0.8349}$*. Also shown (black dots) are the turbine rotation times used in 46 white-eagle collision calculations and a suggested rotation time (green line) for use in the Band model (81.5% of the maximum), see below.*

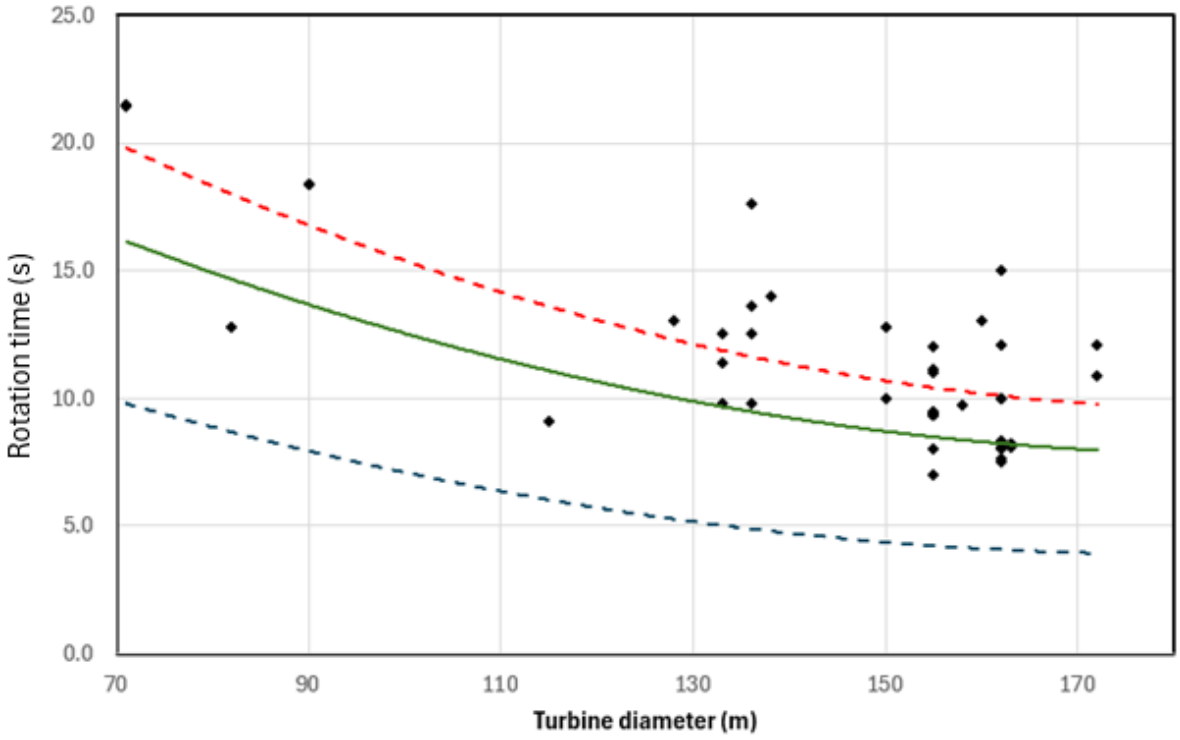


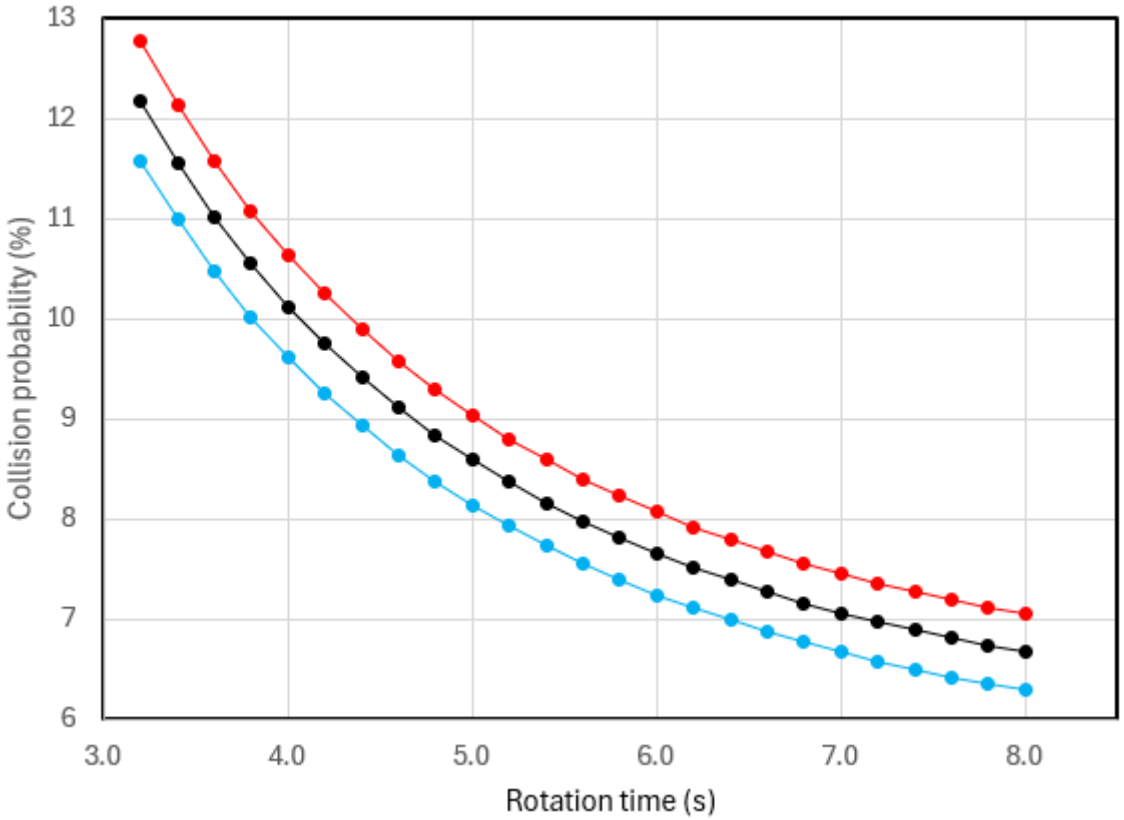
Fig. 4.6 shows the non-linear relationship between the turbine rotation time and the probability of a collision for a 160 m diameter turbine for White-tailed Eagles using the Band model. As the time needed for one turbine rotation increases the probability of a collision declines, but asymptotically. Clearly, the rotation time affects the estimated number of collisions. As the chord width increases there is an increase in the collision probability because it takes longer for the bird to transit the turbines but the effect is small compared with changes in the rotation time. Other turbine diameters have similar relationships although the collision probabilities differ.

The estimated number of annual collisions (before the avoidance factor and operational time are applied) is estimated from the *number of transits through the turbines x probability of a collision*

Using the example data in Fig. 4.6, this would mean a 34% decrease in the estimated number of collisions if the rotation time was reduced from 4 s to 8 s (4.5 m chord width). Collision probabilities are 0.1012 @ 4 s and 0.0667 @ 8 s meaning that the number of collisions is reduced by 34% ((0.1012 – 0.0667)/0.1012).

If rotation times are applied incorrectly this has a significant impact on the estimated collision mortality.

Figure 4.6. Relationship between the White-tailed Eagle collision probability, using the Band model, and turbine rotation time (seconds for one rotation) for a 160 m diameter turbine. All other parameters of the Band model are fixed except for the maximum chord width, three values were used: 4.0m (blue); 4.5 m (black); and 5.0 m (red)



4.2.4 Mean rotation time in relation to the operational time and capacity

Mean rotation time is related to the operational time and operational capacity. In some of the assessments reviewed for these analyses operational time[5] and operational capacity were confused. A 40% capacity factor does not mean a turbine operates for only 40% of the time. A turbine could operate at 40% capacity factor but spin all day, every day throughout the year.

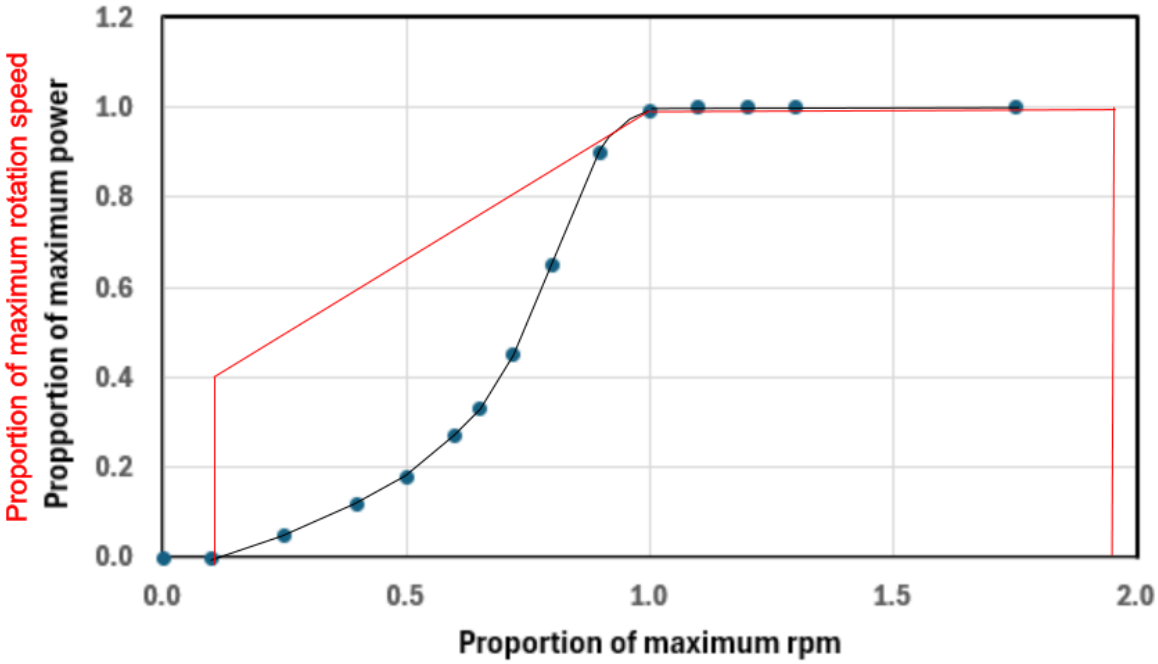
A turbine's maximum output is only achieved in certain wind conditions (higher speeds). At lower wind speeds, it will turn but at a lower speed which produces a fraction of its maximum possible output.

An 85% capacity factor is a turbine is generating 85% of its maximum all day every day but this does not reflect commercial reality based on empirical data. There is a general relationship between a turbine's rotation time (rpm) and its energy generation (Fig. 4.7). There are low wind speeds (typically < 3m/s) when a turbine does not turn and wind speeds when the maximum energy generation is achieved (typically ~12 m/s). Above this wind speed the turbine blade pitch

[5] The October 2024 revised collision guidance suggests calculating an operational time per month. However, this is an extremely unrealistic calculation. When questioned about this the normal response from an operational team is that predicting monthly operational periods is unrealistic, as downtime is inherently unpredictable—both over a project's lifetime and on a month-to-month basis.

is altered to maintain the rotation time at its maximum until a threshold is reached when the wind speed is so high that the turbine stops generating to avoid damage to its components.

Figure 4.7. Generic relationships between turbine power output and turbine rotation time.



The five-year rolling average load factor calculated by RenewableUK between 2019-2023 was 40.6% for onshore wind projects. As turbine designs have evolved load factors have increased such that the load factor for new build for onshore wind projects (2026-2029 delivery) is 44.8%. It is not simple to translate a 45% load factor into an average turbine rpm. However, an empirical figure of ~0.8 of the maximum rpm appears conservative (i.e. it would not underestimate the collision risk) and produces a similar estimate derived in Annex 8 of the updated NS guidance.

Using this method the mean rotation time for a 130 m diameter turbine would be 9.88 rpm (6.07 s) which is almost identical to the worked example in Annex 8 of the updated NS collision guidance which produced a mean rotation time of 9.87 rpm (6.1 s).

4.2.5 What values have been used in collision assessments?

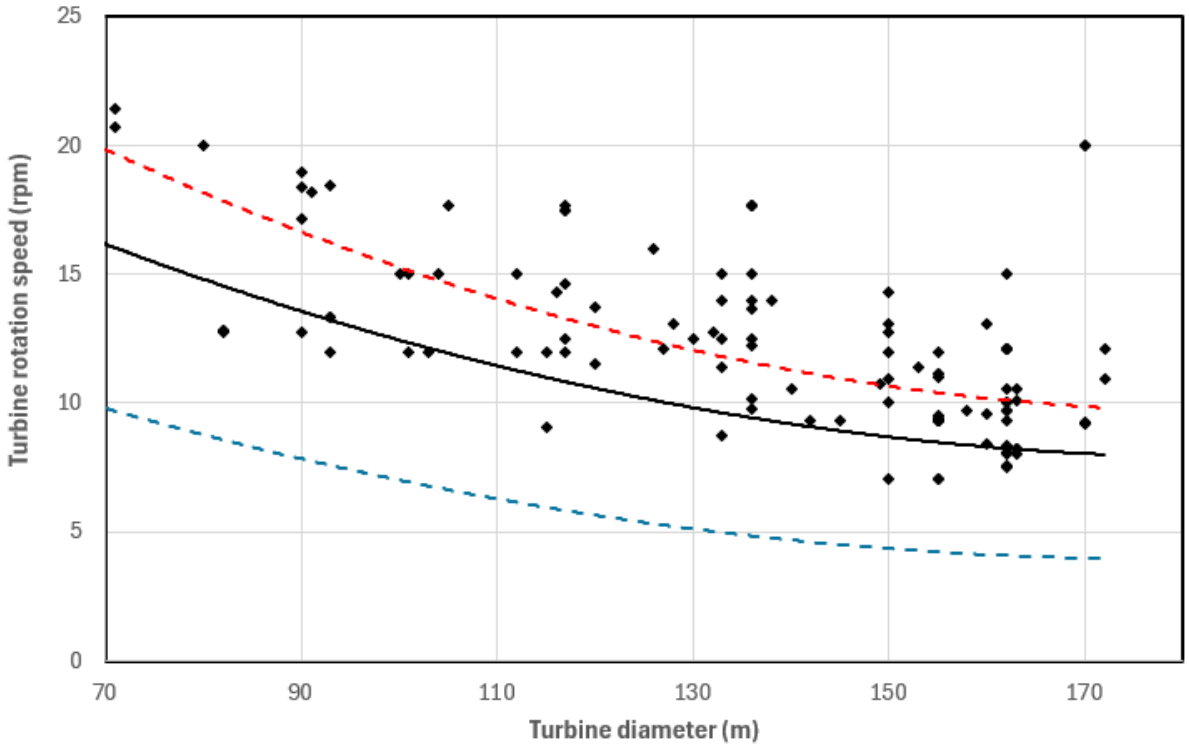
It is clear from Fig. 4.8 that almost all Scottish assessments used rotation times that were too fast for the candidate turbine which would inflate the collision probability and, subsequently, the estimated number of collisions.

Forty-eight of the assessments in Fig. 4.8 and Appendix 1 were for White-tailed Eagle collision probabilities in which all parameters used in the Band model were specified. The CRA values specified in the assessments were entered into the Band model but also with a rotation time based on 81.5% of maximum obtained using the method of Saint-Drenan *et al* (2020) [black curve in Fig. 4.8].

The estimated annual number of collisions could then be corrected for the recalculated collision probability (note – only the rotation time was changed, all other values were as specified for the assessment). A majority (41) of assessments reported an inflated collision probability. The mean collision probability across the 48 assessments was 8.054% compared with 7.232% with the adjusted rpm (range difference -1.91% - 4.48 %). Overall, corrections made relatively little

difference to the individual wind farm specific collision estimate (mean decrease 0.058 collisions per year per wind farm) but cumulatively the effect was significant because the estimated number of collisions decreased in 41 of the 48 assessments (range 0.001 to 0.454 collisions per year) reducing the cumulative total from 22.55 collisions per year to 19.62. The size of the change in the estimated number of collisions reflected the magnitude of the original collision estimate which is itself partly a function of the number of turbines.

Figure 4.8. Black dots are turbine rotation times and diameters used in 114 collision risk assessments. The dashed red line is the maximum rotation speeds for a turbine and the dashed blue line is the minimum rotation speeds suggested speeds based on operating factors. The solid black line is the suggested rpm. Values above the maximum and suggested rotation speeds have would generate collision probabilities that were too high.



In six assessments the collision probability was less so the estimated number of collisions was increased compared with the published assessment (range 0.001 to 0.015).

Notes about the 48 collision assessments

- Not all assessments are for approved wind farms, some are still in the planning process and some were refused. The aim of the exercise was to identify if there was systematic bias and, overall, there was a tendency to inflate the annual number of collisions.
- Values were obtained from the collision reports. In a minority of cases there was no indication if flapping or gliding flight was assumed. In those cases, it was assessed based on other values and the reported collision probability.
- These calculations were not standardised for other values in the Band calculation. For example: the pitch angle varied from 0 to 15 degrees; chord width varied for the same turbine diameter; bird length varied from 0.8 m to 0.92 m; wingspan varied from 2.2 m to 2.45 m and the flight speed ranged from 7 m/s to 15 m/s. All of these add additional noise to the estimated collisions, some inflate it and some reduce it. For example, using a 0.9 m length increases the collision probability relative to a 0.8 length (Section 4.3).

4.3 Band Model Bird Characteristics

Symbol	Description	Units	Notes
L	Length of bird	m	These should be drawn from standard reference works or NatureScot guidance on flight speed and biometrics.
W	Wingspan of bird	m	As above.
v	Bird flight speed	m s^{-1}	This value will already have been entered in Stage B.
F	Flight type	-	Either 'flapping' or 'gliding' - the spreadsheet then applies the relevant factor
-	Proportion of flights upwind	%	This should be set to 50% unless survey indicates a predominant direction relative to wind, e.g. for large-scale migration flights.

4.3.1 What values should be used to describe the size of a White-tailed Eagle?

NS recognises that natural variability in bird sizes cannot be incorporated directly, so mean values for 'typical' individuals must be used. They advise that biometric data should be obtained from reputable sources such as Birds of the Western Palearctic, (Snow & Perrins, 1998), online resources such as BTO BirdFacts or recommended values in what NS calls a 'key report' (Provan and Whitfield, 2006) but which appears to be unavailable despite being cited in their guidance notes.

In Table 3 of Provan and Whitfield (2006) the 'average' White-tailed Eagle biometric measures of length and wingspan for use in the NS CRA are length = 80 cm and wingspan = 220 cm. In one Norwegian sample (Willgohs, 1961) five male White-tailed Eagles had an average wingspan of 2.26 m while eight females had a larger average of 2.37 m. In another sample of wild birds of unspecified origin, five males were found to have a wingspan average of 2.1 m and seven females averaged 2.3 m (Brown and Amadon, 1968). In Raptors of the World and Birds of the Western Palearctic the White-tailed Eagle had a typical wingspan of 1.78 to 2.45 m and a wider range of lengths of 0.66 to 0.94 m (Ferguson-Lees and Christie, 2001 and National Geographic Field Guide to the Birds of North America, 2002).

4.3.2 What values should be used to describe the flight speed of a White-tailed Eagle?

Flight speed is important in the calculations because it affects two parts of the collision calculations. In the calculation of the collision probability a faster flight speed reduces the probability of a collision because the bird spends less time in the volume of air occupied by the turbine blades. However, in the part of the calculations concerned with bird density (Section 4.1) a faster flight speed increases the estimated number of turbine transits and, therefore, the number of collisions. This is part of the false logic of these calculations (see Section 4.1). On balance, a faster flight speed results in more predicted collisions even if the probability of a collision during a single transit is reduced.

NS state that a typical mean flight speed as given in standard references will usually be adequate but warn that sometimes it may be necessary to consider different speeds if a bird's behaviour results in very different flight speeds, e.g. pursuit or foraging.

In Table 4 of the NS's 'key report', Provan and Whitfield (2006) recommend a typical White-tailed Eagle flight speed of 12 m/s (43.2 kph) as this was calculated directly from observations at proposed wind farm sites. NS also cite Bruderer and Bolt (2001) and Alerstam *et al*. (2007).

It is also important to note that collision risk will vary according to whether a bird is considered to use predominantly flapping or gliding flight as this can make a significant difference to collision risk calculations.

Where a bird uses both types of flight a weighted average of the two flight behaviours could be used although we have never come across such an analysis. If flapping and gliding flight is to be considered it will also be necessary to take account of their different flight speeds. Bruderer and Boldt (2001, p189) state that the speed in flap/gliding flight is 13.7/13.1 m/s which is intermediate between the speeds of other eagles. However, this estimate appears to be based on a single observation. They also note that pure flapping speed is probably lower.

It would be interesting to estimate flight speed using data from recent satellite tags which have a short interval between records. May *et al* (2010) obtained the bird speed from 26 GPS tracked White-tailed Eagles and derived an average bird speed of 10.2 m/s ± 4.6 sd. Using a sample of 167 records from one individual during active flight, we found that the distance travelled was 84.9 km in 197.1 mins at an overall mean of 7.2 m/s. Only 17 of the 167 (10.1%) flight segments had a speed > 12 m/s. It would be inappropriate to change the recommended speed based on a sample of data from one individual but the limited evidence suggests that recommended flight speeds are too fast and a more detailed analysis could be undertaken. If the average flight speed in Scotland is ~7 m/s this would reduce the average number of collisions. For example, using the example in Section 3.3 the number of collisions at a flight speed of 12 m/s was 10.1 but this would be reduced to 8.3 collisions at a flight speed of 7.2 m/s, an 18% reduction. The work to estimate a flight speed from satellite tracking data could be undertaken by the recently established sea eagle research group, which NS is a member of.

4.3.3 How the bird's characteristics affect the probability of a collision?

Changes in **wing span** have minor effects on the probability of a turbine collision while changes in **body length** have a larger effect which is related to the time taken to pass through a turbine. For example, estimated probability of a collision with a turbine is 6.74% with the following assumptions:

- a 150 m diameter turbine, with a 3.7 m maximum chord, 15° pitch and a rotation time of 8.8 rpm (6.82 s);
- bird has a length of 0.8 m, wingspan 2.2 m and a flapping flight speed of 12 m/s.

If everything is kept unchanged and the wingspan is increased to 2.4 m (9.1% increase) the collision probability increases to 6.85% from 6.74%. However, if the body length is increased to 0.9 m (wingspan assumed to be 2.2 m), a 12.5% increase in body length, increases the collision probability from 6.74% to 7.05%. If both wingspan and body length are increased at the same time (to 2.4 m and 0.9 m) the collision probability increases from 6.74% to 7.16%. Therefore, the collision calculations are relatively immune to the effects of the estimated wingspan (within reason) but more sensitive to the body length, particularly when combined with changes in flight speed.

The type of flight, **gliding v flapping**, has an impact on the collision probability. For example, consider the 150 m diameter turbine described above; with flapping flight the collision probability is 6.74% but this falls to 6.28% if gliding flight is assumed. This is a significant 7% reduction.

4.3.4 What values have been used in collision assessments?

Data were extracted from 48 published White-tailed Eagle collision assessments in which bird dimensions and flight speed were specified. Wingspan varied from 2.15 m (n = 1) to 2.45 m (n = 2). Most (32/48) used a wingspan of 2.2 m but 12/48 used a wingspan of at least 2.4 m. Body length varied from 0.8 to 0.92 m with most (35/48) using 0.8 m but 12/48 used a body length of 0.9+ m. These were the same 12 assessments as those using the wider wingspan. Therefore, 12/48 (25%) will have produced collision probabilities at least 5% larger than expected if NS recommended values had been used.

Flight speed varied from 6 m/s (n = 1) to 15 m/s (n = 2), mean = 12.6 m/s, with two speeds dominating: 12.0 m/s, n = 9; 13.6 m/s, n = 19; four with speeds between 13.0 and 13.4 m/s; and eight with a flight speed between 6 m/s and 12 m/s.

Eighteen of the 48 White-tailed Eagle collision assessments specified flapping flight while 18 specified gliding flight. One assessment specified flapping flight but the collision probability was for gliding flight. The remainder did not specify the type of flight but they could be estimates from the collision probabilities and the other specified values; on this basis it was assumed that six used flapping flight and five used gliding flight. Overall, this implies an almost equal split between flapping and gliding flight implying that around half of the collision assessments have resulted in an incorrect number of collisions. The values obtained from the 48 published White-tailed Eagle collision assessments are summarised in Tables 4.1 – 4.3.

It is too complicated to assess what the combined impact of this variation in assessment parameters had on the cumulative number of collisions but it is certain that the cumulative total is imprecise. Table 4.3 shows the range of collision probabilities (6.95 – 7.66 %) for a single turbine and the range of values used. Flapping flight was assumed in these calculations. **Most of the 48 published White-tailed Eagle collision assessments over-estimated collision probabilities, resulting in inflated collision estimates.**

4.3.5 Conclusions

The wide range of values used, even for the same turbine, means there cannot be a high degree of confidence in the robustness of the collision estimates. Most consultants appear to err on the side of precautionary values, often exceeding what is feasible, resulting in a tendency to overestimate the number of collisions. It is impossible to place a value on the extent of the cumulative overestimate given the number of permutations of values used in the collision calculations. However, the subsequent analysis presented in this report indicate that the overestimate is both consistent and significant.

Table 4.1 Frequencies of wingspan (cm) and body length (cm) used in 48 published White-tailed Eagle collision assessments

	Wing span						
Length	215	220	230	232	240	245	All
80		32	2	1			35
87	1						1
90					10		10
92						2	2
All	1	32	2	1	10	2	48

Table 4.2 Mean flight speed (m/s) for different combinations of wingspan (cm) and body length (cm) used in 48 published White-tailed Eagle collision assessments

	Wing span						
Length	215	220	230	232	240	245	All
80		12.4	10.4	10.2			12.4
87	13.6						13.6
90					13.5		13.5
92						13.6	13.6
All	13.6	12.4	10.4	10.2	13.5	13.6	12.6

Table 4.3. Collision probabilities for a 150 m diameter, 4.2 m chord, 6.82 s (8.8 rpm rotation), 15° pitch, flapping flight at 12 and 13.6 m/s.

12 m/s	**Wing span**					
Length	215	220	230	232	240	245
80		7.15	7.21	7.22		
87	7.34					
90					7.57	
92						7.66
13.6 m/s	215	220	230	232	240	245
80		6.80	6.87	6.88		
87	6.95					
90					7.18	
92						7.26

5 Known White-tailed Eagle collisions and insights from their locations and timing

5.1 Summary

The section examines known collisions, particularly their relationships with the CRA predictions for the relevant wind farms.

Two of the 15 recorded collisions were on the Edinbane wind farm on Skye. Unusually there are many years of post-construction VP monitoring of the Edinbane, and neighbouring Ben Aketil wind farms, which can be used to derive annual collision estimates using standard methodology. Using these and other data, it is clear the current CRA tools lead to a large over-estimate of the number of collisions. In the case of White-tailed Eagles at two Skye wind farms, our analysis indicates that the real collision level is only 7% of the CRA predictions calculated whilst the turbines were operational. This reduction is despite the fact that the post-construction surveys are likely to have produced a lower CRA than would be expected in normal circumstances given there would be some level of displacement from the operational wind farms.

5.2 Known collisions

Twelve collisions were identified from SRUC/NS[6] databases plus previous personal knowledge and web searches (Table 5.1). None were at wind farms with predicted White-tailed Eagle collisions, which is partly explained by the growth of the Scottish population since the wind farms were commissioned. In an FOI to Galileo Empower (dated 26/05/2026) NS reported 12 collisions by date and NHZ. Combining these data sets results in 15 unique collisions. Three of the collisions were at the Stronelairg wind farm but recent ornithology survey data from proposed developments immediately adjacent to Stronelairg did not identify significant White-tailed Eagle activity.

Table 5.1. Known White-tailed Eagle turbine collision victims 2014 - 2026

Year	Location	NS FOI
2014	Perthshire - A young White-tailed Eagle ('Red T') was killed at the Burnfoot Hill wind farm in February. 'Red T' was released in east Scotland in 2011 as part of the reintroduction. A post-mortem concluded that 'likely cause of death' was collision with a turbine.	No
2016	Mid May 2016 https://www.skye-birds.com/blog/2016/06/turbine-strike-on-white-tailed-eagle/ A bird found below Turbine 4 at the Edinbane wind farm. A post-mortem by SAC in Inverness confirmed the cause of death as a collision death. The bird was ringed as one of twins in North Uist.	Yes
2019	Highland April 2019 Stronelairg wind farm.	Yes
2020	Argyll & Bute Knapdale. There were no nearby turbines. It is unclear if this death was the result of a turbine collision.	Yes
2020	Eilean Siar, Isle of Lewis (Reid *pers comm*) a bird was injured at the Pentland Road wind farm and died from injuries several months later.	Yes
2021	Highland Stronelairg wind farm	Yes
2021	Argyll Cour wind farm	No

[6] https://www.nature.scot/doc/freedom-information-request-deaths-birds-prey-scotland-windfarms (FOI dated 8 December 2024).

2022	Highland Moy wind farm	Yes
2022	Highland Stronelairg wind farm	Yes
2022	From NS FOI July NHZ 10	Yes
2023	Highland Edinbane wind farm	Yes
2024	Highland – No further information	No
2025	March NHZ15	Yes
2025	May NHZ14	Yes
2026	Argyll, Cruach Mhor wind farm	Yes

5.3 Wind farm details

Eleven collisions are known at seven different wind farms; the other four known collisions lack sufficient information to attach them to a specific wind farm.

Burnfoot (Perthshire) - the 15x92 m diameter turbines became operational in 2010. No White-tailed Eagles were recorded during VP surveys. A single young bird from the East of Scotland releases (Section 6.4) was killed in 2014.

Cour (Kintyre) - the 10x92 m diameter turbines became operational in December 2016. No White-tailed Eagles were recorded during pre-construction VP surveys in 2007, 2010 or 2011. A single bird was killed in 202, with no further information was found about this collision.

Cruach Mhor (Kintyre) - the 35x52 m turbines became operational in early 2004. It is unlikely much, if any, White-tailed Eagle activity was recorded during pre-construction surveys which would have been at the turn of the century when there were less than 30 pairs in Scotland. Little additional information is known about the collision in spring 2026.

Moy (Highland) - the 20x100 m diameter turbines became operational in mid-2016. No additional information was found about birds seen during surveys or the collision in 2022 except that the dead bird tested positive for HPAI.

Pentland Road (Isle of Lewis) - the six 82 m diameter turbines became operational in 2013. It is probable that White-tailed Eagles were seen prior to construction. A single bird was injured in a collision in 2020.

Stronelairg (Highland) - the 66x115 m diameter turbines became operational in late 2018. Insufficient White-tailed Eagle activity was recorded during surveys to merit a collision analysis although it is known that one bird was recorded in 2014. Survey work for the adjacent Cloiche wind farm recorded 14 flights during 307 hours of surveying from 6 VPs in 2018 and 2019 suggesting there wasn't a lot of activity. Despite this there have been three collisions: 2019, 2021 and 2022.

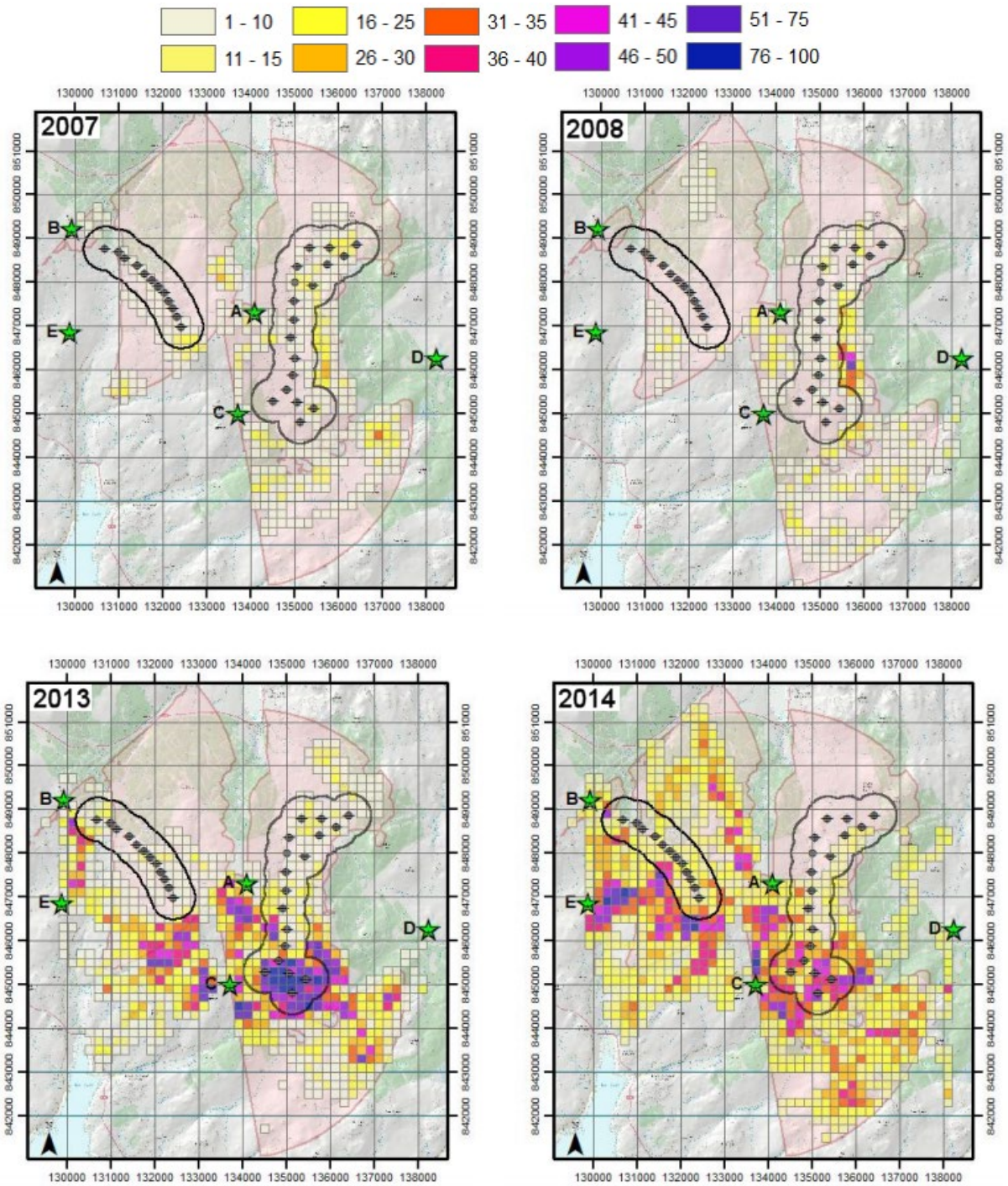
Edinbane (Isle of Skye) - the 18x71 m diameter turbines became operational in July 2010. Two birds are known to have died in collisions in 2016 and 2023.

5.4 Edinbane case study

There is more long-term information about White-tailed Eagle activity around the Edinbane, and adjacent Ben Aketil wind farms, than any other wind farm in Scotland. VP surveys were undertaken monthly from 2007 to 2014 (Fielding and Haworth, 2016) by two local eagle experts (Ken Crane and Kate Nellist). These surveys showed that there was considerable and increasing White-tailed Eagle flight activity in and around both wind farms (Fig. 5.1).

Fielding and Haworth (2016) also list a selection of the field observations of the White-tailed Eagles and the Edinbane turbines (Box 1) which mention a wind farm or turbine.

Figure 5.1. Habitat use by White-tailed Eagles recorded from three vantage points (A, B and C). Values are metres of flight (all altitudes) per 10 hours of observation rescaled to 0-100 where 100 is the maximum value over all years. The viewshed extent is shown as transparent pink shading. (Contains Ordnance Survey data © Crown copyright and database right 2020). Data are shown for 2007, 2008, 2013 & 2014 {redrawn from Fig. 8 in Fielding and Haworth, 2016).



BOX 1. Edited field note extracts from Table 5 in Fielding and Haworth (2016)

11/05/2011 09.14 Ad WE 10-100 gliding towards turbine 11 from east. Flew past turbine 12 at level of cockpit and continued slowly gliding <10 across rising ground heading SW
19/08/2011 13.12 Juv WE, no tags, gliding over forestry SE side Sron nan Aighean to forest east of Stone Geers, 13.24 reappeared flying 10-100 above windfarm road which bends between turbines 8 and 9, then flew along verge beside windfarm road as far as site hut, where it dropped <10 and flew between turbines 7 and 8, and <10 out over moor and landed within c120m of turbine 5.
28/10/2011 13.23 Ad WE 2 white tags, dropping and rising 10-100 between turbines 1 and 2. 13.32 Second Ad WE, also 2 white tags, hanging 10-100 into wind nearer to 1st turbine. Second bird dropped <10 as it flew downslope. First bird stayed 10-100 and drifted closer to tower, at about level of lowest blade tip (turning rapidly).
07/02/2012 10.51 Ad WE hanging into wind to E of tower of turbine 1, at level of lowest rotating blade tip.
12/09/2012 11.44-11.48 Ad WE no tags 10-100 slow glide into wind over Beinn a Chearcaill continued 10-100 between 4 stationary turbines and close over maintenance vans.
24/11/2012 11.36 WE drifted further E. 11.41 Set off flying through turbines, passing 10-100 on N side of turbine 11 to Cruachan Beinn a Chearcaill.
20/02/2013 12.04 Perched WE took off and flew <10 towards turbines, passing turbines 11 and 12 and flew <10 over windfarm road approx. where access road to turbine 13 joins it.
01/03/2013 13.33 young untagged WE 10-100 around SW side of Cruachan Glen Vic Askill. Drifting slowly N between turbines and hill. 13.34 It started to circle slowly up and drift over Beinn A Chearcaill, briefly swung W then back E over turbines >100. 13.38 Just above top of turbines it started flapping and gliding slowly N. It soon dropped 10-100 just N of turbines 13.39. 13.40 started to circle slowly up and drift back over turbines >100.
23/04/2013 11.14 WE (no tags and no feathers missing) circling up 10-100 over An Cleireach harassed by 2RN. 11.17 set off in a glide close to me and very close to and around the 5 south turbines. 11.19 it weaved between the turbines then started to circle up >100 between me and the turbines. 11.25 still >100 it had drifted just north of me. It then went in a very slow glide SW.
26/12/2013 4.07 WE took off and flew constantly flapping towards turbine 17 and flew past it on S side 10-100 below level of hub. Continued its flight passing turbines 16 and 15 in same way, appearing to fly close to them, also below hub height. With turbines facing S this meant bird was parallel to plane of rotating blades.
01/01/2014 10.32 WE 10-100 circling and hanging in strengthening wind on SE corner of CGVA until 10.37. It then went into a slow sweeping glide o/s between 2 working turbines at blade height.
04/02/2014 12.41 Young untagged WE flying 10-100 around east side of Ben Aketil in a slow glide east towards turbines. 12.45 Still 10-100 it swung south along line of turbines until 12.47 when it passed between 4th and 5th turbines from south and turned sharply east.
07/02/2014 11.08 SA WE 10-100 flying from Cruachan Beinn a Chearcaill, passed between 2 turbines and began rising >100.
01/09/2014 11.16 Ad WE flying 10-100 from direction of higher ground above AR and headed east towards turbine road. Passed 10-100 between turbines 6 & 7 from the south.

5.5 Working wind farm CRAs

5.5.1 Background

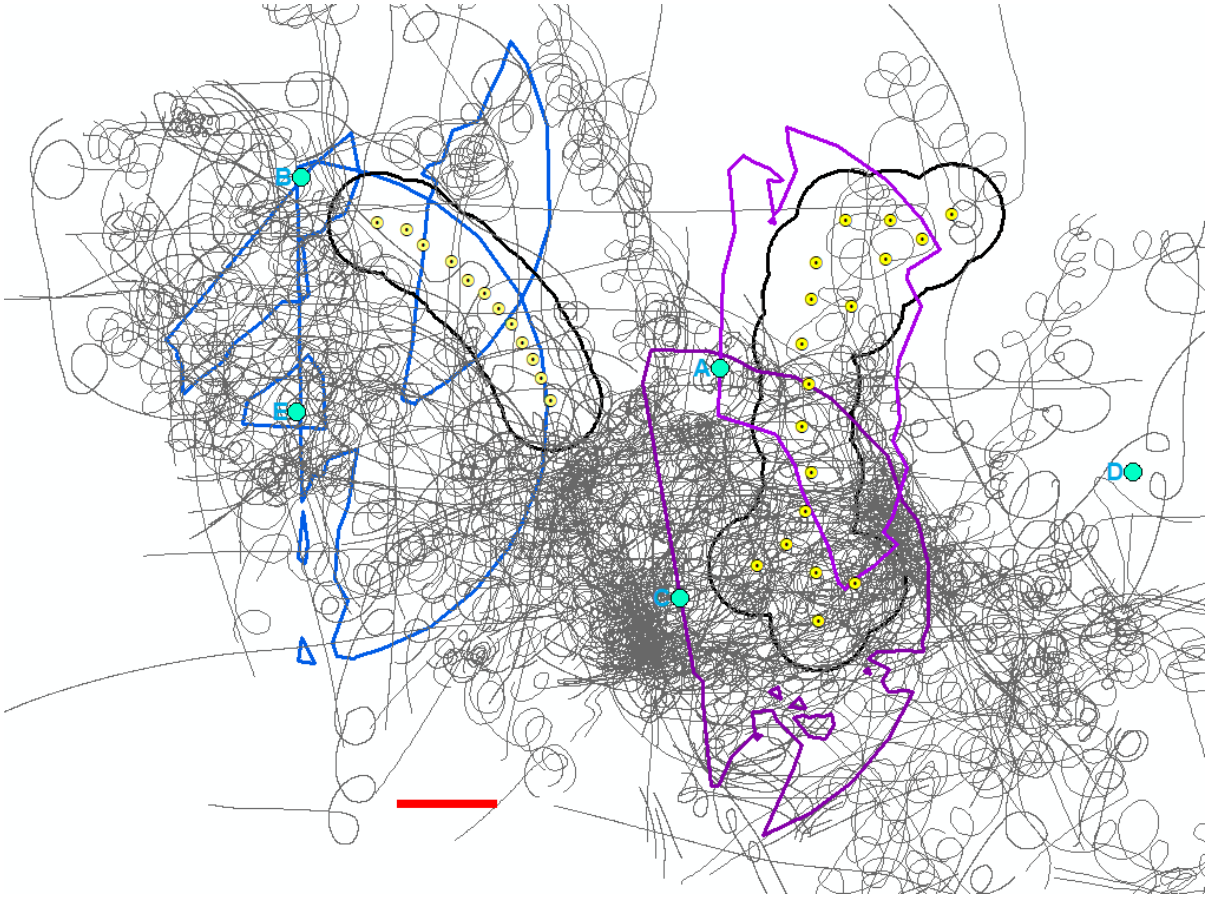
Using the survey data collected between 2007 and 2014 it is possible to estimate the number of collisions predicted at the two operational Skye wind farms (Edinbane and Ben Aketil) over this period. There are two important caveats. First, these data were collected with the aim of understanding how birds behaved once the turbines were constructed; although standard CRA procedures informed this approach and CRA was not envisioned at that time. Second, these wind farms were operational so some avoidance is expected and it must be assumed that calculations using alternative data, obtained had the wind farms not been there, would have

produced larger collision estimates. The collision estimates must, therefore, be treated as precautionary lower values compared with surveys had the turbines not been there.

VP data collection started on 16th January 2007 using vantage points A, B and C. VP D (not used in the CRA) was added in January 2008 to record habitat use associated with a possible White-tailed Eagle roost site. VP E was added in January 2010 to provide better coverage of the Ben Aketil wind farm. All surveys were completed by the local eagle experts, Ken Crane and Kate Nellist. When possible, flight activity was recorded beyond the viewshed's perimeter so that birds could be tracked on flights back into the wind farm. Only flights within the viewshed's perimeter and a 500 m turbine buffer were included in the CRA. Collisions can only occur when flights are within the Rotor Swept Volume (RSV) and flights were recorded in the three height bands: 1 below the RSV (<25 m); 2 within the RSV (25 – 105 m); and 3 (>105 m) above the RSV. As turbines were present it was easier for the surveyors to estimate the height band than in a site with no turbines.

Fig. 5.2 shows all White-tailed Eagle flights recorded at height 2 between 2007 and 2014. Also shown are the four VPs and viewsheds used in the CRA described below.

Figure 5.2 White-tailed Eagle flights at RSV recorded between January 2007 and December 2014. VPs and their viewsheds plus the turbines are shown. The red bar is 1 km.



The CRA reported below does not distinguish age classes but they are important when it comes to the PVA (Section 7). Sixty eight percent of White-tailed Eagles were aged and proportions were approximately equal for adults (48%) sub-adults (59%). Relative proportions varied greatly over the years from a low of 35% adults in 2008 to a maximum of 64% in 2009.

It is important to note that the original bird surveys took place between 2002 and 2005 when there was relatively little White-tailed Eagle activity in this area. At this time there were <30 pairs in Scotland. Consequently, comparisons between pre-construction and post-construction surveys are meaningless.

5.5.2 Edinbane wind farm

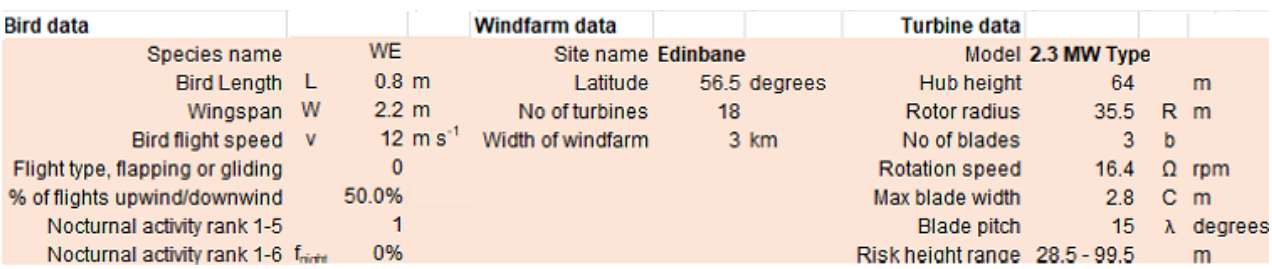
Preliminary construction began in early 2008, whilst main site works commenced during August 2008. Wind turbines started to arrive during late summer 2009 and construction was completed in June 2010. All turbine bases, for the original 13 turbines, had been completed by 20th June 2009, with the first turbine complete by 15th July 2009. Construction was slower than the adjacent Ben Aketil and six were complete, with four more under construction, by the 6th October 2009. By the date of the VP survey on the 28th November 2009 the original 13 were complete and construction had started on the five bases for the later extension. Work on all 18 Edinbane turbines was completed by June 2010. Therefore, all bird data collected from July 2010 were unaffected by construction activities, with the wind farm becoming operational in 2011.

The Edinbane CRA uses data from VPs A and C (Figs. 5.1 & 5.2). Flights were clipped to the viewshed and the turbine 500 m buffer. Flight lengths were converted to durations by assuming a flight speed of 12 m/s. The values used in the CRA, using the updated NS collision spreadsheet, are shown in Fig. 5.3. Table 5.2 summaries the results and Fig. 5.4 summaries the trend in the estimated number of collisions per year. Only flights at height 2, within the RSH, were used.

Table 5.2. VP hours by year, m of flight by year and duration (s) of flight by year. The lower row is the estimated number of collisions per year with 95% avoidance rate. The vertical bar separates the construction years from the operational years.

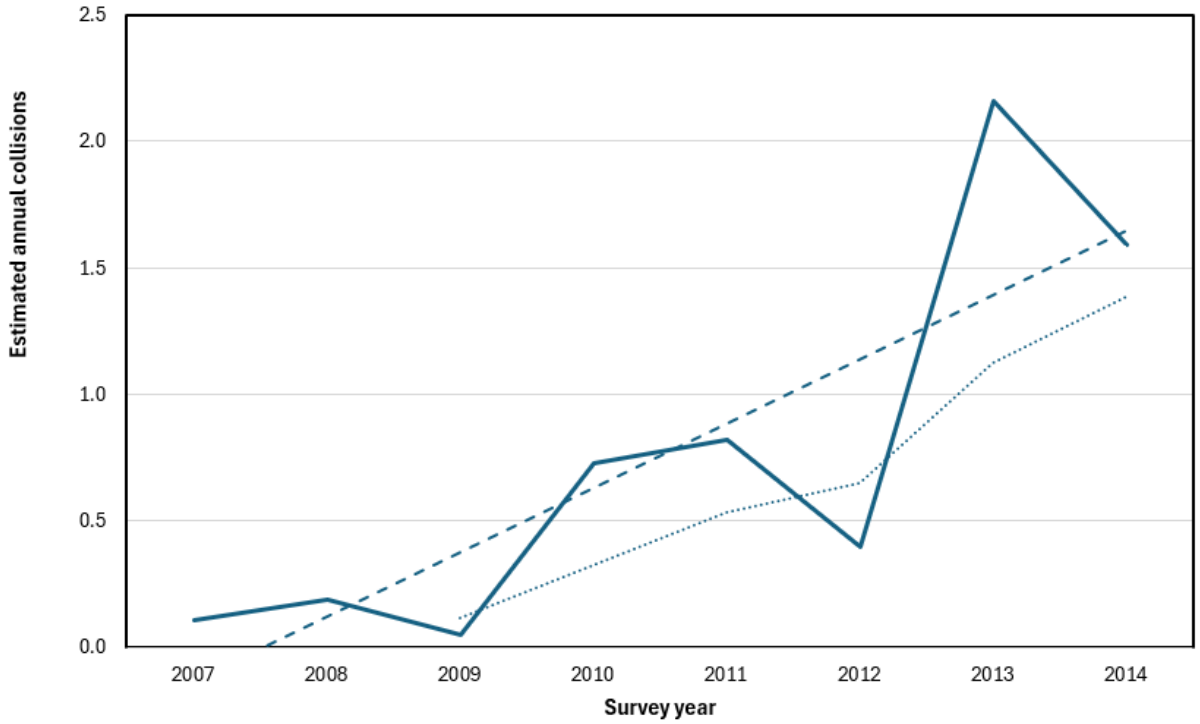
VP hours	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**Total**
A	106	110	110	112	98	112	108	108	108	863
C	102	111	109	108	113	108	108	108	108	867
VP m of flight										
A	763	3,316		1,869		3,227	6,738	4,136	3,342	20,049
C	2,755	3,581	1,537	1,9390	20,053	8,701	62,459	34,138	19,077	152,614
VP s of flight at 12m/s										
A	64	276	0	156	0	269	562	345	278	1,671
C	230	298	128	1,616	1,671	725	5,205	2,845	1,590	12,718
Collisions	**0.11**	**0.19**	**0.05**	**0.65**	**0.59**	**0.35**	**2.07**	**1.16**	**0.68**	

Figure 5.3 CRA values for the White-tailed Eagle and the wind farm.



Bird data				**Windfarm data**			**Turbine data**			
Species name		WE		Site name	**Edinbane**		Model	**2.3 MW Type**		
Bird Length	L	0.8	m	Latitude	56.5	degrees	Hub height	64		m
Wingspan	W	2.2	m	No of turbines	18		Rotor radius	35.5	R	m
Bird flight speed	v	12	m s^{-1}	Width of windfarm	3	km	No of blades	3	b	
Flight type, flapping or gliding		0					Rotation speed	16.4	Ω	rpm
% of flights upwind/downwind		50.0%					Max blade width	2.8	C	m
Nocturnal activity rank 1-5		1					Blade pitch	15	λ	degrees
Nocturnal activity rank 1-6	f_{night}	0%					Risk height range	28.5 - 99.5		m

Figure 5.4. Trend in the estimated number of annual collisions per year at Edinbane wind farm. The dashed line is the linear trend and the dotted line is the 3-year moving average. The vertical bar separates the construction years from the operational years.



Although there is considerable variation in the estimated number of collisions there is a clear increasing trend reflecting increases in the size of the White-tailed Eagle population. The 2007 SRMS report reported that "*2007 was an exciting year for Sea eagles in Western Scotland. Six new pairs were located, bringing the total number of occupied territories to 42. The new pairs were widely spaced, expanding the breeding range of the species to the north, south and east. Thirty-five pairs laid eggs and 31 broods hatched. Twenty-four pairs bred successfully fledging a record 34 young*". By 2014 the SRMS data indicated there were 96 pairs in Scotland with 20 pairs on Skye. In 2023 this had increased to 28 pairs on Skye and ~160 nationally. It is, therefore, not unreasonable to expect a continuing rise in the estimated number of collisions at the Edinbane wind farm which predicts ~ 24 collisions in the 12 years between 2014 and 2025. Two collisions are known (2016 and 2023). Even if it is assumed the number of recorded collisions is an underestimate it is clear that the collision estimates from the NS recommended CRA outputs vastly overestimate the number of potential collisions.

5.5.3 Ben Aketil wind farm

Two Ben Aketil turbines had been constructed by late September 2007, rising to five by the start of October and nine by later 2007. On the 3rd November 2007 all ten were complete with eight functioning. An additional two turbines were installed during spring 2010. As at the Edinbane wind farm, all bird data collected from July 2010 were unaffected by construction activities, with the wind farm becoming operational in 2011. There are no known White-tailed Eagle collisions at Ben Aketil.

Table 5.3 summaries the results and Fig. 5.5 summaries the trend in the estimated number of collisions per year. Flights were observed during 2007 – 2009 but none were within the RSV.

The annual collision rate trend is similar to that at Edinbane but the estimated number of collisions is lower reflecting the differences in flight density shown in Figs. 5.1 and 5.2.

Table 5.3. VP hours by year, m of flight by year and duration (s) of flight by year. The lower row is the estimated number of collisions per year with 95% avoidance rate. The vertical bar separates the construction years from the operational years.

VP hours	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
B	105	110	108	101	110	108	108	108
E				105	103	108	108	108
VP m of flight								
B				0	1,776	651	842	2,665
E				2,484	4,554	305	1,169	8,989
VP s of flight at 12m/s								
B				0	148	54	70	222
E				207	380	25	97	749
Collisions	**0**	**0**	**0**	**0.08**	**0.23**	**0.05**	**0.09**	**0.43**

Fig. 5.6 shows the combined number of estimated collisions at Ben Aketil and Edinbane. Again, it is important to stress that after July 2010 both wind farms were fully operational but there was sufficient activity to produce quite large collision estimates even after allowing for some avoidance. If the linear trend in Fig. 5.6 is extrapolated the estimated number of collisions in 2023 (last recorded collision) and 2030 would be 3.93 and 5.71 per year respectively. Whilst it is bad practice to extrapolate a trend line beyond the last value on the x axis that is what, in effect, happens in PVA collision sensitivity analyses (Section 7).

Figure 5.5. Trend in the estimated number of annual collisions per year at the Ben Aketil wind farm. The dashed line is the linear trend and the dotted line is the 3-year moving average. The vertical bar separates the construction years from the operational years.

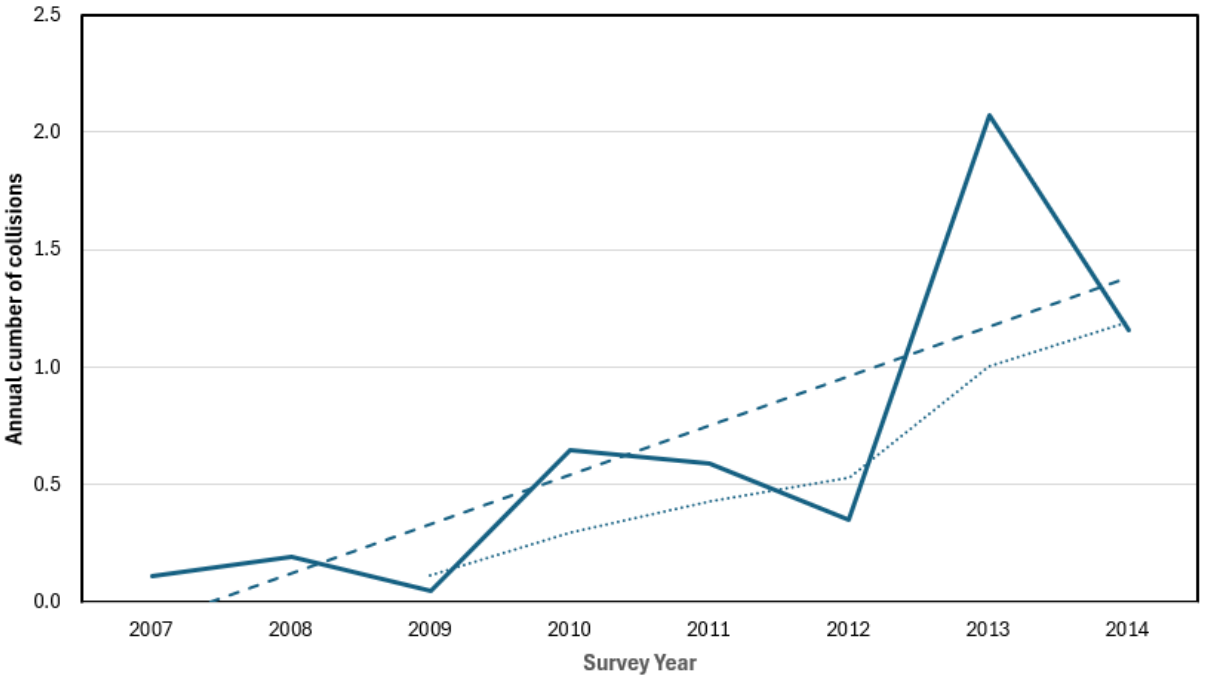
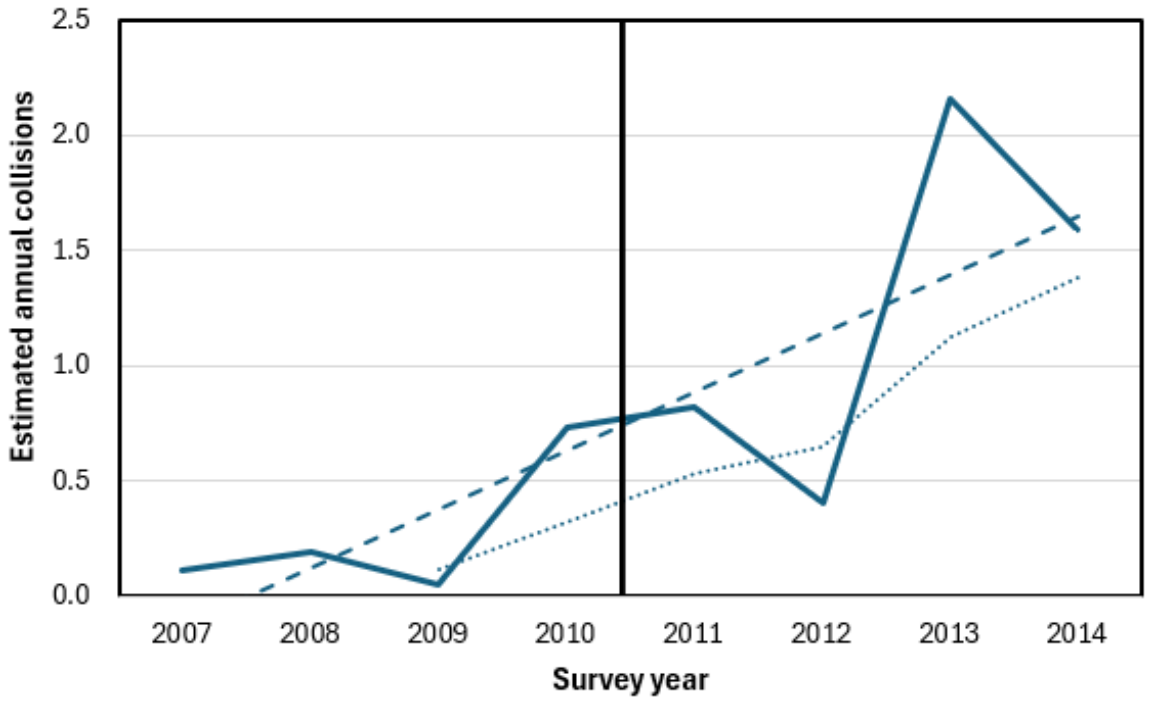


Figure 5.6. Trend in the estimated number of annual collisions per year at the Ben Aketil and Edinbane wind farms. The dashed line is the linear trend and the dotted line is the 3-year moving average. The vertical bar separates the construction years from the operational years.



5.6 Conclusions

The lack of meso-scale (intermediate scale) avoidance of the turbines at Edinbane and Ben Aketil is similar to observations in Europe, particularly at Smøla (Dahl *et al.*, 2012 & 2013, May *et al.*, 2010 & 2013) and in Germany (Krone and Treu, 2018). As only two collisions have been observed this must mean there has been micro-scale (fine scale) avoidance such that individuals may make last-minute adjustments to flight paths or altitude to avoid collisions. Data were not available in sufficient detail to investigate this further but as more tracking data become available it may be possible to better quantify the levels of avoidance at all scales, although macro-scale (broader scale) avoidance of entire wind farms seems unlikely for White-tailed Eagles.

Given the amount of activity within the wind farms and NatureScot's advised 95% avoidance rate, it is surprising there have not been more collisions there. After combining the CRA estimates from Ben Aketil and Edinbane, over the operational and surveyed period 2010 – 2014, the standard CRA approach suggests ~30 collisions should have occurred between 2014 and 2025 but only two collisions have been recorded. This is only 7% of predicted collision levels. Some collisions are likely to have gone undetected, or unreported, but a failure to report seems unlikely. Caryl *et al* (2016) concluded that for larger birds "incidental" searches as part of routine maintenance activities "are not too bad" on the likely precision of casualty estimates. Also, it is unlikely that the discrepancy is result of undetected collisions because the scale of predicted collisions would have impacted the Skye population.

The CRA for the proposed redesigned Ben Sca estimated an annual collision rate of 2.69 birds per year which is in line with the extrapolated estimates for Ben Aketil and Edinbane. Similarly, the estimated annual collision rate at Glen Ullinish II (2021 – 2023) was 3.33. Unless White-tailed

Eagles have now abandoned the Ben Aketil and Edinbane wind farms the question must be why have there been so few collisions there?

It is clear that the level of bird activity is a very poor predictor of the collision probability and using the current CRA tools leads to an over-estimate the number of collisions. In the case of White-tailed Eagles around the Ben Aketil and Edinbane wind farms, our analysis indicates that the realised collision level is only 7% of the CRA predictions calculated whilst the turbines were operational. This disparity is a result of problems with the CRA's assumptions which could be explained by a large underestimate of the collision avoidance rate for White-tailed Eagles in Scotland.

Footnote

The above analyses of CRAs relate to White-tailed Eagles but it is clear from of the significant disparities between the numbers of actual collisions and the numbers estimated in the cumulative totals from CRAs, *for all species,* that all cumulative collision estimates are excessive.

6. Scottish White-tailed Eagle and wind farm spatial and temporal trends

6.1 Summary

The section documents change in the number and spread of White-tailed Eagles and wind turbines across Scotland and attempts to understand how the two are linked.

Both have shown significant expansion but the rates differ within and between regions. Overall, there are now more than 200 pairs[7] of White-tailed Eagles with a possible continuing expansion to ~350 pairs by 2030. In addition to data from the raptor study groups there is indirect evidence for the scale and speed of the White-tailed Eagle's extraction such as the Sea Eagle Management Scheme. There was data from the citizen science programme eBird along with White-tailed Eagle observations from EIAs to demonstrate the change in this distribution over time.

Using mainland Argyll as a case study there is no evidence that the increasing number of turbines is restricting the White-tailed Eagle's expansion.

There was no evidence that the recent outbreak of HPAI has had a significant long-lasting impact on the Scottish White-tailed Eagle population.

The reintroduction of White-tailed Eagles into England may seem unrelated to wind power but removing birds from Scotland is equivalent to losses due to collisions. The proposal to remove birds noted that "*The removal of 12 young each summer from 2019-2023 would have a negligible effect on overall productivity… would pose no risk to the donor population given the current and expected rate of population increase*". This is significantly more birds than are removed from the population by wind farms on an annual basis.

The section also examines evidence for a delay between the end of bird surveys for a proposed wind farm and the date on which the wind farm becomes operational. If the population continues to expand at its recent historic rate the quality and value of these historic collision assessments become even less robust.

6.2 Spatial and numerical expansion and trends

Across Scotland, over the last 20+ years, both White-tailed Eagles and wind farms have experienced a period of spatial expansion and growth in numbers. Depending on the overlap between the increasing number of wind farms and the expanding White-tailed Eagle population there should be a corresponding rise in the number of collisions and, potentially, evidence for an impact on the Scottish White-tailed Eagle population. If wind farms are constructed where there are no White-tailed Eagles there will not be a problem; however, that seems an improbable scenario. This section examines:

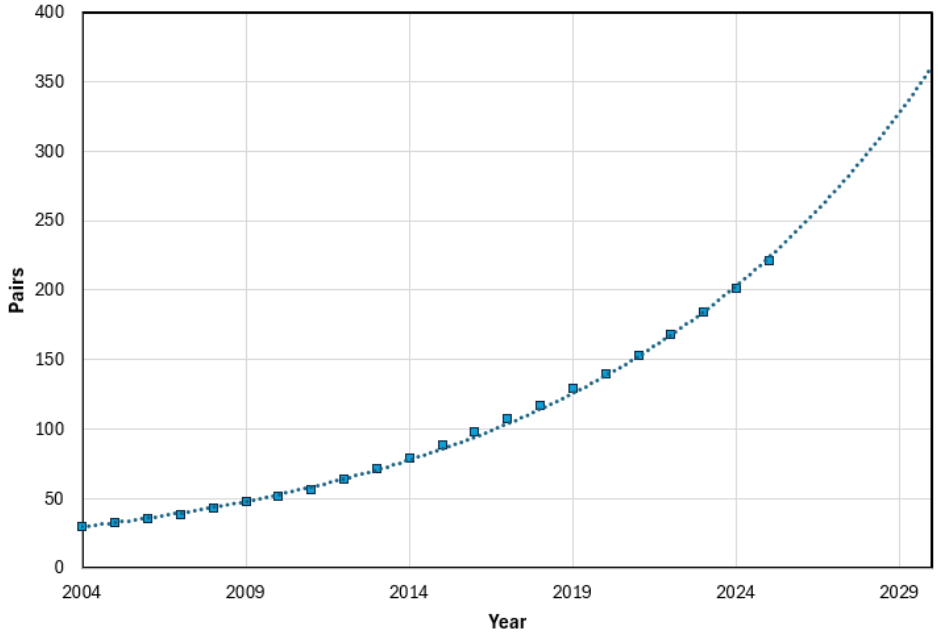
1. trends in the White-tailed Eagle population, regionally and nationally;
2. trends in wind energy developments; and
3. evidence for spatial overlap between the two.

[7] "Scotland now hosts around 200 breeding pairs of white-tailed eagles (also known as sea eagles), representing both a remarkable conservation success and a challenge for some farmers and crofters" https://www.nature.scot/scotlands-sea-eagles-balancing-conservation-and-farming Scotland's Sea Eagles: Balancing Conservation and Farming Jun 20, 2025 Season 2 Episode

6.2.1 White-tailed Eagle trends using SRMS and other data

The ways in which raptor data are summarised by year and region results in complications. There are two main spatial recording systems which cover the period of interest in this report; NS's Natural Heritage Zones (NHZ); and the SRMS RSG (Raptor Study Group) areas. Their boundaries differ and overlap making it impossible, in the absence of nest coordinates, to re-allocate nests between the two systems. For example, the Argyll RSG region includes all of NHZ 14 (Argyll West and Islands) except for Arran which is in the South Strathclyde RSG. The Argyll RSG also includes Mull (NHZ 4, Western Seaboard), a stronghold for White-tailed Eagles, plus Coll and Tiree which are in NHZ 3 (Western Isle) and some of the Argyll RSG land is in the Lochaber NHZ (NHZ 13).

Figure 6.1. National White-tailed Eagle population using data from Fig. 10 in Sansom et al (2016) for the period 2004-25 when the annual increase was 10%. The dashed line shows the expected number of pairs to 2030 using the same 10% annual growth rate.



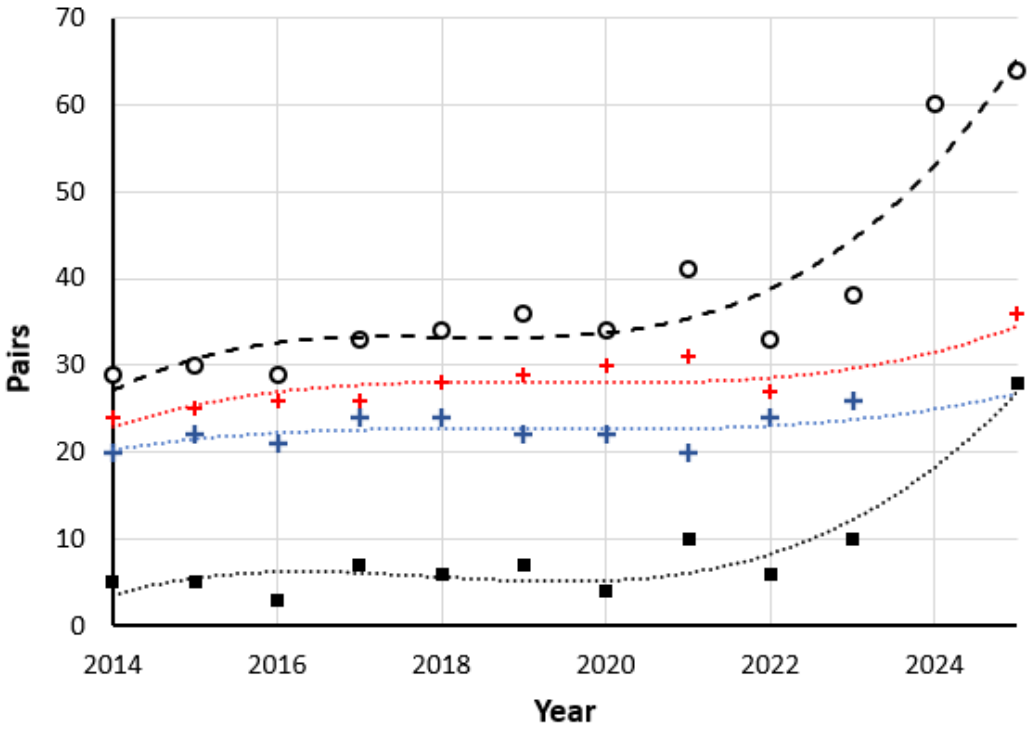
Nationally, it is relatively easy to track the expanding population, at least in terms of its size. Roos *et al*. (2015) examined trends in breeding numbers and productivity between 1983-2015 which showed that the population increased nationally and regionally showing both a steady growth in numbers combined with an expansion in the places they were seen and bred. Sansom *et al*. (2016) used these data to predict strong population growth and a spread across Scotland reaching >200 pairs by 2025. These are the data which NS states[8] are an accurate representation of the population's trajectory. Fig. 6.1 is reproduced using data in Figure 10 of Sansom *et al* (2016) extrapolated to 2030 when there predicted to be ~350 pairs which translates to ~1,400 individuals (adults, dispersers and floaters of all ages).

Wilson *et al* (2015) reported the number of pairs by NHZ in 2013 and, for White-tailed Eagles, the number of monitored breeding pairs was the highest since its 1975 reintroduction and they suggest that these 2013 numbers are close to being comprehensive. There were 82 territorial pairs across 11 NHZs but 65 pairs were in three NHZs: NHZ 3 Coll, Tiree & the Western Isles 23 pairs; NHZ 6 Western Seaboard 34 pairs; and NHZ 14 Argyll West & Islands 8 pairs.

[8] FOI 26/5/2026 NS ref SIR183820/A5855004

Argyll is an interesting case study as there has been considerable expansion in both the number of turbines and the number of White-tailed Eagles. In 2015 the Argyll RSG (ARSG) reported 29 pairs with nest sites, 25 pairs laid eggs plus one possible. Eighteen pairs were successful and fledged 22 chicks. Additional new "pairs" were located but none were known to have built nests. Scott Smith (ARSG, *pers* comm) said that the number of pairs was uncertain during the years with Covid restrictions but that there were 37 to 39 pairs in 2023 and 57 to 60 in 2024. These numbers are supported by a record in the minutes of a 2025 Forest & Raptors Joint Working Group meeting[9] where it was reported that there had been an increase in White-tailed Eagle territories in Argyll from the 37 reported two years previously to 64 known home ranges with most nesting in forestry and some taking over previous osprey nests. Fig. 6.2 shows the trends in White-tailed Eagle pairs in the ARSG region, using SRMS data, for the period 2014-25.

Figure 6.2 Trends in the number of White-tailed Eagle pairs, using SRMS data, for the period 2014-25 in the Argyll RSG region. Crosses are island pairs: red Argyll islands & blue Skye; The black squares are the Argyll mainland and the open circles are the ARSG data (mainland plus islands).



The data in Fig. 6.2 suggest that both Skye and the Argyll islands (mainly Mull) have reached something close to their carrying capacities as their populations have stopped expanding and are unlikely to undergo future significant increases. This is unsurprising as both were early population centres for the expanding population. In their Appendix 2, Sansom *et al.* (2016) report that "*...the predicted maximum number of breeding pairs would vary between around 28 (Skye) to 125 (Argyll excluding Mull...). As Mull was used as a baseline scenario, the predictions for Mull were close to the observed current population size.*". Further, in their Table A2-3 the predicted maximum number of pairs is 21 for Mull and 30 for Skye.

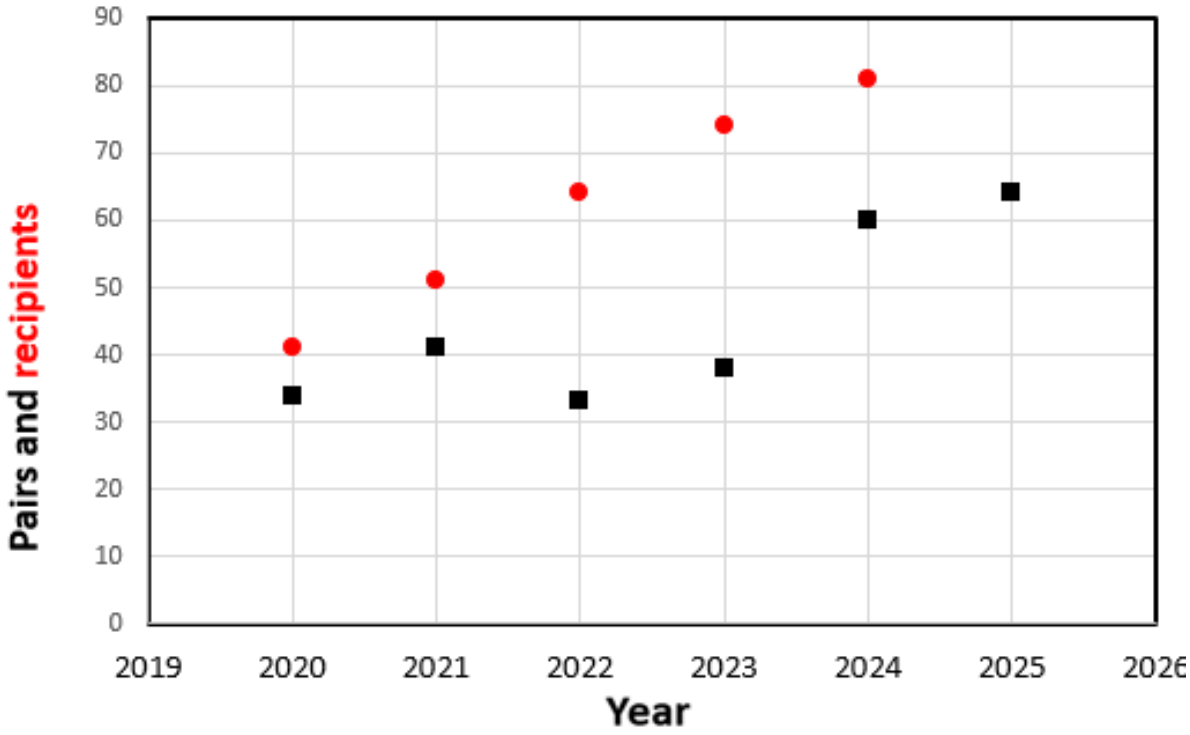
What is remarkable is the rapid increase in Argyll mainland eagle pairs since 2022 in a landscape with 284 operational turbines in 17 wind farms.

[9] Notes of the Raptors and Forestry Joint Working Group – Meeting Tuesday 9th December 2025

6.2.2 Other evidence

The Sea Eagle Management Scheme[10,11] (SEMS) provides strong additional supporting evidence for a rapid expansion nationally and in Argyll. The overall SEMS budget rose from £72,000 in 2015 to £970,000 in 2025. It is reasonable to assume that the payments and number of participants (affected farmers and crofters) are correlated with sea eagle abundance and this is shown in Argyll and Lochaber (Fig.6.3) where there have been simultaneous increases in the size of the sea eagle population and the number of participants in the SEMS.

Figure 6.3. Number of sea eagle pairs in the ARSG region (SRMS date) and the number of participants in the SEMS scheme (Argyll and Lochaber). Source of SEMS data https://www.nature.scot/doc/freedom-information-request-sea-eagle-compensation-scheme



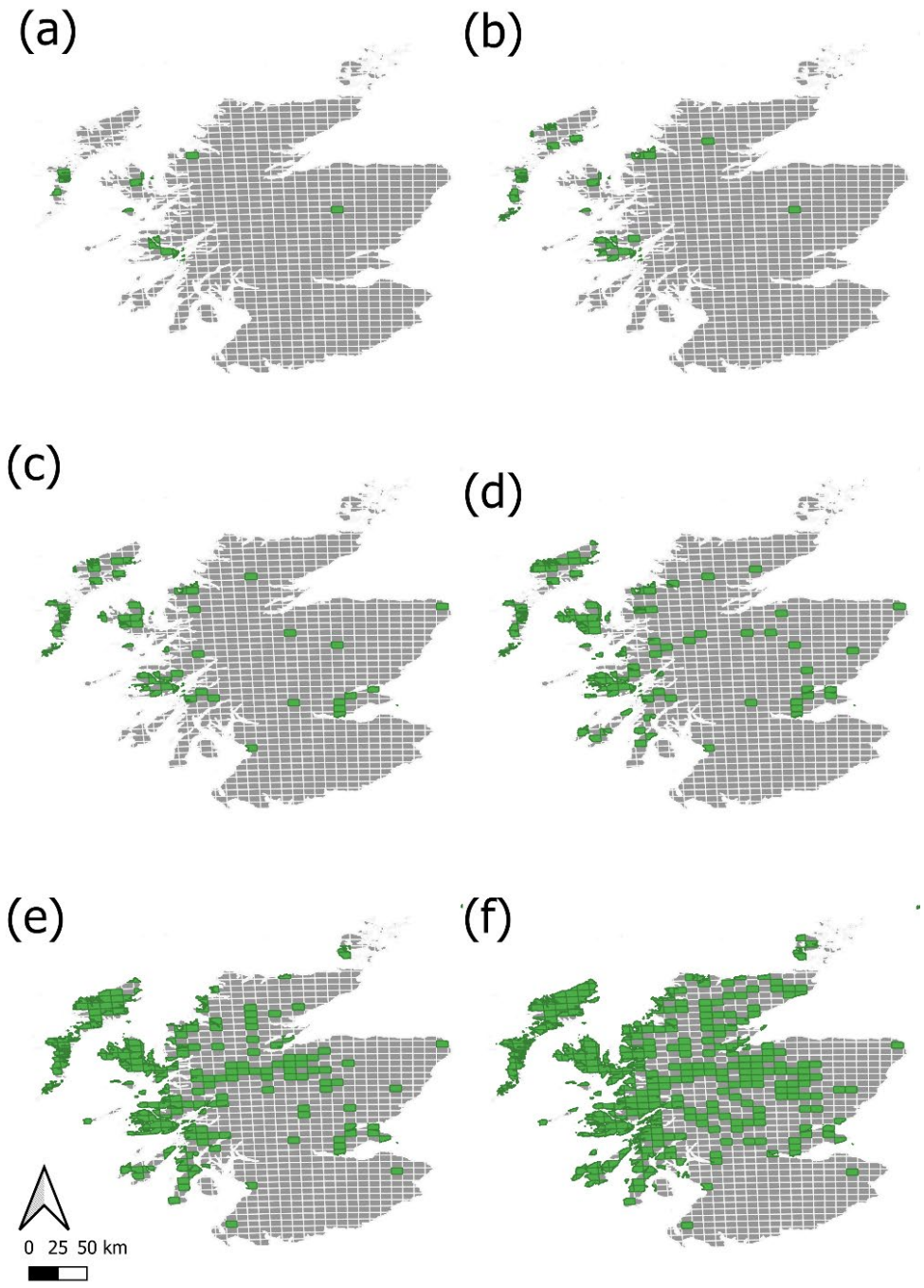
6.2.3 Spatial Expansion

White-tailed eagles have not only increased in terms of population size but also in terms of their spatial distribution. We used data from the citizen science programme eBird (Sullivan *et al*. 2009), downloaded from the Global Biodiversity Information Facility (GBIF.org 2026), along with White-tailed Eagle observations from EIAs to demonstrate the change in this distribution over time (Fig 6.4). In the 1990s, White-tailed Eagles were restricted to just a few locations, mostly on the west coast. However, by the early 2000, they were present across a wider area on the Inner Hebrides and a larger number of mainland locations. The expansion in their distribution on the mainland which continued to increase in the late 2010s and early 2020s.

Figure 6.4. Change in the distribution of White-tailed Eagles in Scotland based on records from eBird and EIAs showing the distribution (green area) in (a) the 1990s, (b) 2001 – 2005, (c) 2006 – 2010, (d) 2011 -2015, (e) 2016 – 2020 and (f) 2021 – 2025.

---

[10] https://www.nature.scot/doc/freedom-information-request-sea-eagle-compensation-scheme
[11] https://web.archive.org/web/20240305081059/https://www.nature.scot/doc/white-tailed-eagle-action-plan-review-2020



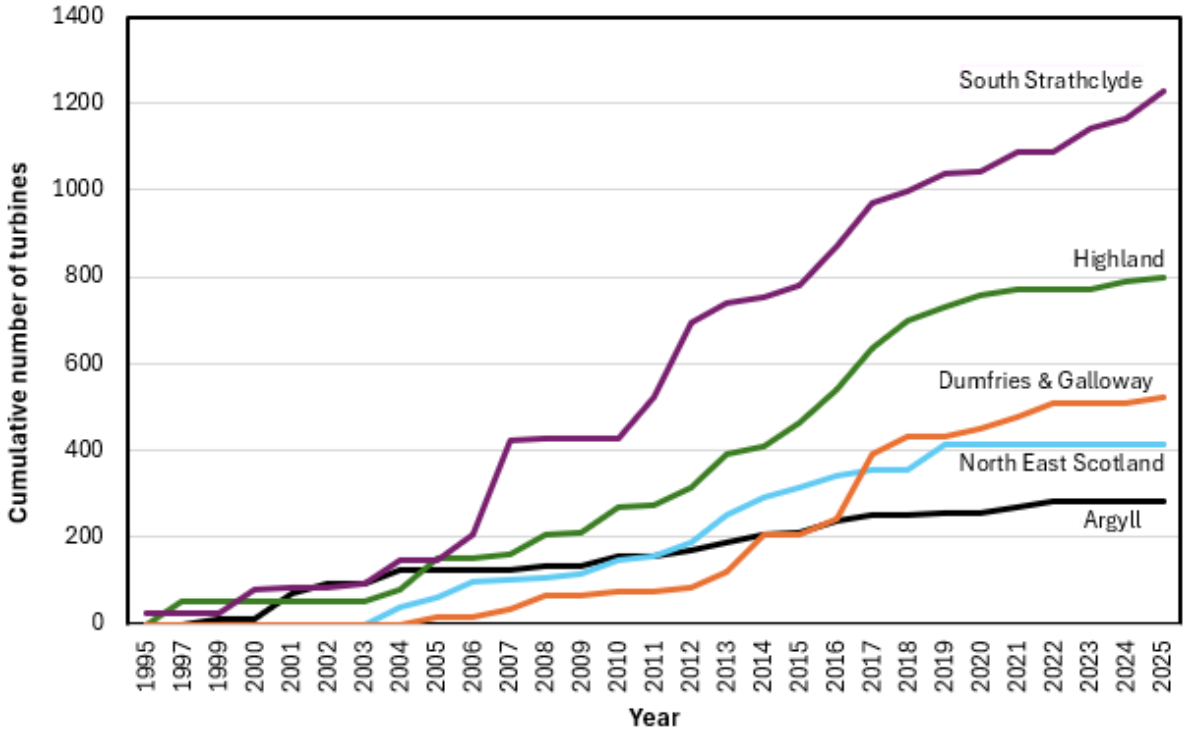
6.3 Distribution in relation to wind farms

6.3.1 Distribution and time line for wind farms in Scotland.

Information has been collected (by AF) over a number of years from a variety sources including national wind farm databases and planning websites to keep track of all wind farms in Scotland with more than two turbines. Information recorded for each wind farm includes: date power generation started, number of turbines and their locations, chord width, turbine diameter, tip height and power output. Fig. 6.5 tracks the cumulative growth in the number of operational turbines in five SRSG regions. Whilst numbers have continued to grow in some regions, particularly in the south of Scotland, growth has stalled in other regions such as Argyll and North

East Scotland. However, there are consented and schemes in planning which, if constructed would result in increases in Argyll and North East Scotland.

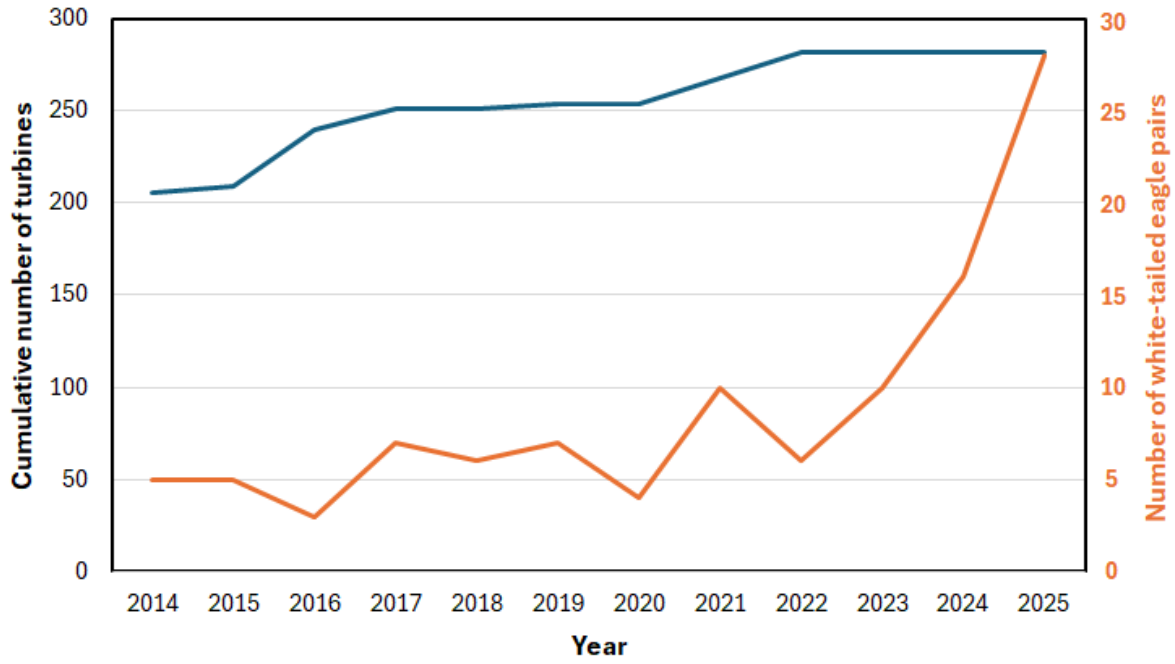
Figure 6.5. Growth in the number of operational turbines in five SRSG regions.



We know from Fig. 6.2 that the Argyll White-tailed Eagle population has experienced a significant increase since 2022, a period when there have been no new operational wind farms in the Argyll SRSG region. We also know that in 2014-15 there were only five mainland ARSG regional pairs and in 2025 there were 28 pairs, a ~500% increase during a time in which the number of turbines increased from 209 to 284, a 35% increase. Fig. 6.5 shows the trend in the numbers of turbines and the number of White-tailed Eagle pairs in the mainland part of the Argyll SRG region. The Argyll islands are excluded as they have no significant wind farms.

There is no evidence that the increasing number of turbines on the Argyll mainland is restricting the White-tailed Eagle's expansion.

Figure 6.5. Growth in the number of operational turbines (blue line) and White-tailed Eagle pairs (orange line) in the mainland part of the Argyll SRG region.



6.3.2 Spatial and temporal overlap of wind farms and White-tailed Eagles from EIA data

The information in Section 6.3.1 is spatially relatively coarse. Finer detail can be found in the many wind farm EIAs. EIAs were searched for information on the number of White-tailed Eagle flights recorded during wind farm VP surveys[12]. Because there was inconsistency in what information was publicly available an index was created which required three pieces of information which were extracted from 154 EIAs (Table 6.1).

1. VP survey hours;
2. VP survey dates (minimum start and end dates);
3. Number of White-tailed Eagle records.

The index was the number of records per VP survey hour, plus the year of the first record. It is not a density estimate as it takes no account of the area surveyed. Surveyed areas were often missing or ambiguous. The survey years covered the period 2002 – 2024 and of the 154 EIAs, 68 recorded no White-tailed Eagle activity.

Some of the 154 schemes have been refused or withdrawn whilst others are in planning waiting for a decision or approved but not yet constructed. The VP surveys were undertaken at time when the White-tailed Eagle population was quite different. For example, Lewis and Harris had three pairs in 2003, 31 in 2019 and 42 in 2023. A 2004 survey would record considerably less activity than a 2016 survey as shown in the Edinbane example (Section 5.4.2).

Some sites have multiple records because there have been several schemes in effectively the same location, as they were surveyed at different times, they were kept separate. Table 6.1 is a breakdown of records by region.

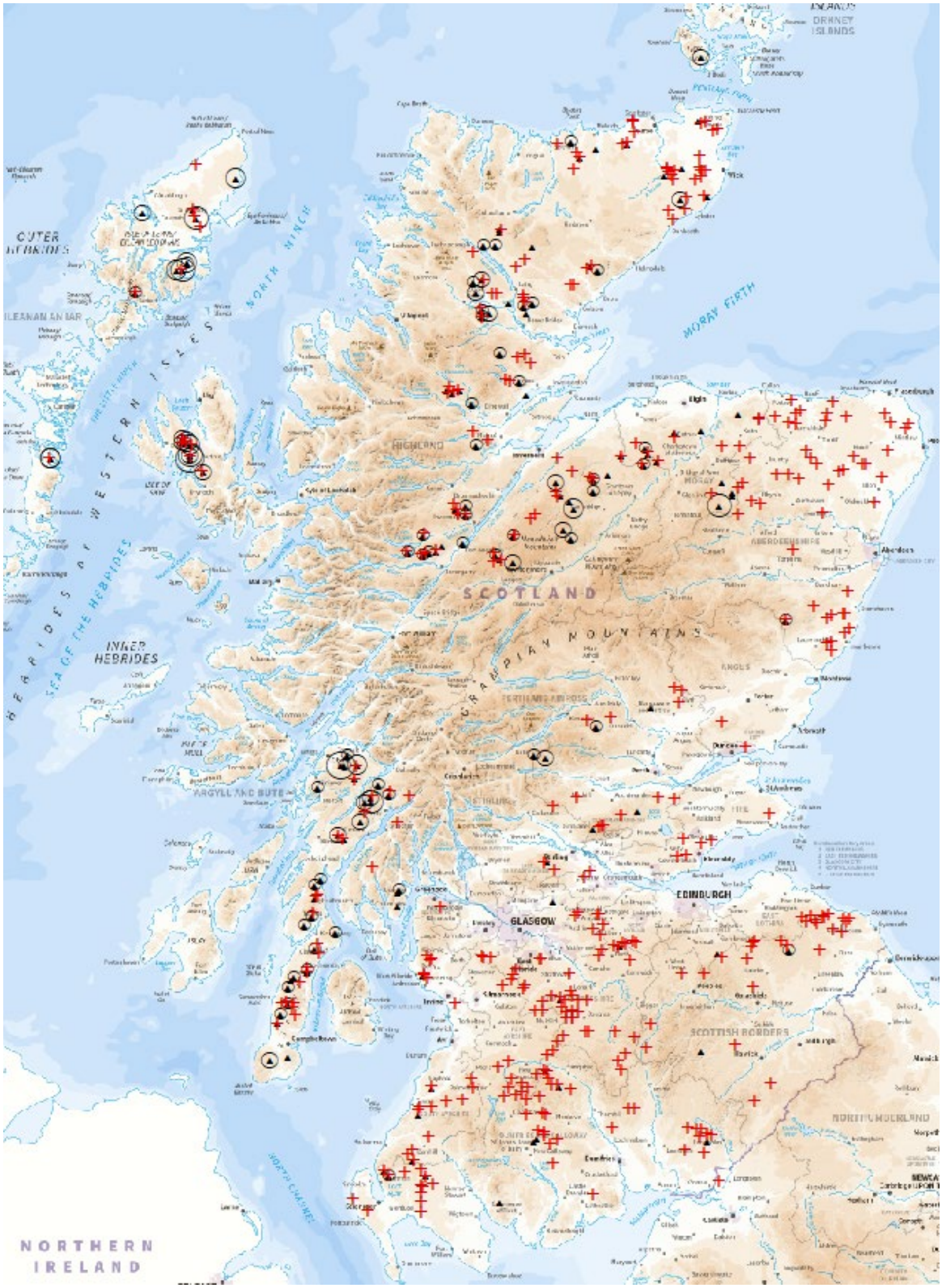
[12] To avoid confusion, the 114 wind farms in Appendix 1 contained all of the details needed to recreate the collision probability calculations whilst the 154 EIAs referred to here had the information needed for section 6.3.2 but not all had the detail presented in Appendix 1.

Table 6.1. Number of sites with White-tailed Eagle record data by NHZ, SRSG region and NS region. Also shown are the numbers of consented and operational wind farms by region. Mean is the mean number of White-tailed Eagle records per 1,000 hours of VP survey.

Region	Sites	Consented	Operational	All	Mean
NHZ					
Argyll West and Islands	35	5	19	24	49
Border Hills	4	3	25	28	1
Breadalbane and East Argyll	3	0	3	3	18
Cairngorm Massif	2	0	1	1	42
Central Highlands	22	5	13	18	12
Eastern Lowlands	2	1	36	37	0
Moray Firth	1	0	1	1	0
North Caithness and Orkney	2	3	9	12	31
North East Coastal Plain	0	0	30	30	0
North East Glens	5	2	15	17	0
Northern Highlands	21	8	14	22	6
The Peatlands of Caithness & Sutherland	22	10	23	33	13
West Central Belt	6	3	51	54	0
Western Isles	12	1	6	7	141
Western Seaboard	9	1	5	6	204
Western Southern Uplands & Inner Solway	11	21	42	63	0
Wigtown Machairs and Outer Solway	0	0	3	3	0
SRSG region					
Argyll	35	5	19	24	49
Central	2	0	10	10	8
Dumfries & Galloway	8	12	32	44	1
Eileanan an Iar	10	1	5	6	123
Highland	71	27	61	88	33
Lothian & Borders	4	5	30	35	1
North East Scotland	11	2	56	58	8
Orkney Islands	1	0	0	0	62
South Strathclyde	8	11	65	76	0
Tayside	5	0	17	17	8
Uists	2	0	1	1	222
NS Region					
East Highlands	16	2	73	75	8
Hebrides	21	2	11	13	168
North Highlands	62	26	56	82	11
Orkney	1	0	0	0	62
Southern Uplands	20	28	127	155	0
West Highlands	37	5	29	34	47

The higher levels of the activity index were, as expected, in those regions known to have more pairs of White-tailed Eagles. Fig. 6.6 shows the distribution of wind farms and the locations of those with a White-tailed Eagle record index. The spread of the White-tailed Eagle records broadly follows the distribution of wind farms except for the North East coastal plain and the south of Scotland. These gaps reflect a lack of suitable EIAs in the public domain.

Figure 6.6. Distribution of operational and consented wind farms (red +) and locations with White-tailed Eagle records (lone black triangles indicate sites with suitable information but no White-tailed Eagle flights (i.e. no evidence of White-tailed Eagles during surveys), the size of the black circle around a triangle indicates the relative size of the eagle index). Contains Ordnance Survey data © Crown copyright and database right 2020.



Currently, in the south of Scotland there are many wind farm proposals and operational wind farms but there is, to date, little recorded White-tailed eagle activity. It will be surprising if White-tailed Eagle activity does not increase around these wind farms. Given the size and density of wind farms in the south of Scotland it will be surprising if the growth of the White-tailed Eagle population in that region is not matched with an increasing number of collisions, *none of which will have been predicted in their EIAs.* However, had White-tailed Eagle activity been higher during the surveys it is also true that the predicted collision levels would have been very likely to overestimate the level of mortality whilst failing to account for the population's expansion between the end of the bird surveys and the start of energy generation.

6.4 The Irish and English reintroductions

The Scottish population began from a reintroduction project bringing birds from Norway. The first unsuccessful attempts were on Fair Isle. The main project started with a release of 75 young on the Rhum National Nature Reserve between 1975 - 1985, with the first successful breeding in 1985 on Mull. The initial stages progressed slowly but by 2000 there were 22 breeding pairs which then began to increase quite rapidly at around ~10% per year (see Sansom *et al.* (2016)). A second, East Coast, release phase ran between 2007 – 2012 with 85 released on the east coast; the first of these bred successfully in 2013 in Fife marking the first successful breeding attempt by White-tailed Eagles breeding in East Scotland for nearly 200 years.

A reintroduction programme into Ireland comprised the release of ~250 birds, also sourced from Norway between 2007 and 2025. No birds were removed from Scotland for the Irish reintroduction, so it is likely, via immigration, that this reintroduction has a net positive impact on the Scottish population.

The first phase of the Irish White-tailed Eagle reintroduction released 100 chicks in the Killarney National Park in south-west (2007 and 2012). They dispersed widely throughout Ireland and bred for the first time in 2012 on Lough Derg. In 2020 there was a small breeding population of eight to ten pairs across five Irish counties. Following a review (Fielding, 2019) of the progress of the Irish reintroduction a second phase was considered appropriate as during the early years of the Irish reintroduction, illegal killing was a significant cause of mortality although there was some optimism that the rate of persecution and unintentional poisoning had declined. Fielding (2019) recommended that an additional release of 25 birds (5 per year over 5 years) was likely to be beneficial for the Irish White-tailed Eagle population. Additional releases started in 2020, ending in 2025; one of which became the first to breed in Northern Island in more than 150 years. They are now widely dispersed across Ireland[13] with a hotspot of records on Rathlin Island which is only ~25 km from the Mull of Kintyre. There are thought to be ~150 individuals with 17 known pairs.

It might be thought that the Irish reintroduction was not relevant to the Scottish population but movements from Ireland to Scotland have been reported. One of the pairs breeding near the Beinn Ghlas wind farm in Argyll was released into Ireland and the Mid Moile wind farm (Dumfries) EIA report has detailed accounts of the movements of a male satellite-tracked immature White-tailed Eagle recorded during a VP survey in November 2019. He was released in Connemara in 2018 and the tracking data showed that after being present in the Loch Ryan area, he moved to the Rhins of Galloway, roosting on the cliffs near the Mull of Galloway. He spent much on the

[13] National Biodiversity Data Centre, Ireland, White-tailed Eagle (Haliaeetus albicilla), accessed 07 June 2026, https://maps.biodiversityireland.ie/Species/10139

winter on the Isle of Man before returning to the West Galloway area in January 2020 but he returned, briefly, to the Mid Moile area in March 2020. These movements clearly show that the Irish Sea is not a barrier to White-tailed Eagle movements between Ireland and Scotland.

An English reintroduction started in 2019 and is ongoing, with a second release location planned in 2026. Forty White-tailed Eagles were removed from Scotland[14] between 2019 and 2025 for the Isle of Wight White-tailed Eagle project. It has not been possible to establish how many were removed each year but from the available information it appears that 13 were released between 2019 and 2022, less than expected as a result of Covid and Avian Influenza. However, this means that 32 must have been released between 2023 and 2025. In addition, starting in 2026[15] it has been agreed "*to release up to 20 young eagles from this additional location (Exmoor National Park) over the course of three years*". These extra birds from Scotland appear to be additional to continuing releases on the Isle of Wight.

NS seem to have accepted the view (p20) in the Roy Dennis Wildlife Foundation and Forestry England (2019) report that "*The removal of 12 young each summer from 2019-2023 would have a negligible effect on overall productivity… would pose no risk to the donor population given the current and expected rate of population increase*". This is significantly more birds than are removed from the population by wind farms on an annual basis and if NS is worried about the potential future impact of planning stage wind farm projects, we have already demonstrated the CRA tool is inaccurate and leads to significant collision over-estimation.

The birds released in England appear to be exploring widely and it is possible that one or more will settle in Scotland. Currently, they appear to be suffering from a relatively large number of persecution events which may get worse as they spread more widely. In contrast to the Irish reintroduction, birds for the English reintroduction have come from Scotland. Although some may return to Scotland, there must be a net overall negative impact on the Scottish population, at least in the medium term. However, it should be noted that the opinion expressed in the Roy Dennis Wildlife Foundation and Forestry England (2019) report is it would result in "*a negligible effect on overall productivity… would pose no risk to the donor population given the current and expected rate of population increase*"

6.5 Avian Influenza

There were concerns that the outbreak of Avian Influenza (HPAI) could have a significant impact on raptors, particularly the White-tailed Eagle as it is known prey on wildfowl. Wilson *et al.* (2025) reviewed the evidence by comparing 2022 SRMS breeding data with equivalent data from previous years. There was evidence for reductions in productivity that were greatest in areas where breeding pairs had access to coastal and marine habitats. However, it wasn't possible to rule out other factors, such as weather, as causes for the poor breeding performance in 2022.

Wilson *et al* (2026) is an update to the previous work which examined 2023 breeding season data and apparent impacts of HPAI were weaker for 2023 than in 2022. There was evidence that breeding success of White-tailed Eagle across most of Scotland appeared much improved in 2023 but with a continuing impact in some areas. Unusually, the White-tailed Eagle Inland study observed increased breeding success in 2022 but experienced a decline in 2023.

[14] https://www.forestryengland.uk/nature-wildlife/white-tailed-eagle-reintroduction-project accessed 07 June

[15] https://roydennis.org/additional-releases-of-white-tailed-eagle-to-take-place-this-summer-in-exmoor-national-park/

Overall, there is little evidence for a large and continuing impact of HPAI on the Scottish White-tailed Eagle population so its role in any reductions in the population's rate of spread are likely to be small.

6.6 Cumulative Collisions – Scale and Significance of White-tailed Eagle collisions

Assessing the impact of cumulative collision risk is not easy and this is recognised by NS so it is important to understand the criteria used by NS to evaluate the size and significance of cumulative collision risks.

6.6.1 NS's response to the Reporter's questions regarding White-tailed Eagle at Ben Aketil wind farm

The following comments are from NS's response to the Reporter's questions[16] regarding White-tailed Eagle at Ben Aketil wind farm (letter dated 5th March 2026). The response also makes several mentions of the Balmeanach wind farm. Although the questions and answers refer to two specific wind farms the principles are more general.

Question - What developments have been factored into the cumulative national collision risk calculated by NatureScot? Specifically, does the cumulative total include only consented and operational development, or does it also include any development for which there is a live application whose individual collision risk has been reported to NatureScot?

NS response - The cumulative total of modelled collision risk …includes operational, consented and at application proposals at the time of our responses. ***The level of risk is fluid as proposals are approved, refused, amended or withdrawn*** *(our bold).*

Question - … does a development adding significantly to a growing cumulative collision risk imply that any increment by any development to the cumulative collision risk at a national level would be a significant cumulative effect (in the meaning of the law on environmental impact assessment)?

NS response - this does not mean that any collision risk is significant. For example, a proposal may have a very low to negligible risk .. so would not add significantly to overall risks. …We consider the WTE collision risk quoted for both Ben Aketil and Balmeanach Wind Farms to be ***'significant' in this context; they are predicting relatively high collision risk*** *(our bold), which will clearly add to cumulative risks.*

NS is likely to seek mitigation, amendment or potentially object to, in order to minimise the growing cumulative impact risk, if the predicted impact is judged to be significant. As ***cumulative risk is incremental, managing these higher risk proposals down seeks to ensure that impacts on the WTE population are not at a level that undermine its continued expansion and recovery of its former range, the key conservation aims post reintroduction*** (our bold).

Question - If Ben Aketil became operational would it have a significant cumulative impact …on account of the increment it would add to the cumulative national collision risk?

NS response - It is ***difficult to predict what the actual collision risk would be for any wind farm by the time it becomes operational*** *because there are so many variables. As such the*

[16] NatureScot (2026), *Advice Regarding White-Tailed eagles for inquiry Section 36 wind fam – Ben Aketil*, ECU Case Reference: WIN-270-22

impact of Ben Aketil is already factored into future cumulative risk assessment, ***the risk is higher now for future proposals*** *(our bold).*

Question - For Balmeanach, NatureScot recommends a package of monitoring, research and mitigation... These additional measures have not been recommended for Ben Aketil ... Does NatureScot wish to update its advice for Ben Aketil in this regard?

NS response - No, we do not wish to update our advice. The comments we provided in our Ben Aketil response were appropriate based on the information provided and the cumulative position at the time we responded. Since we responded to Ben Aketil multiple proposals within the distribution of WTE have been submitted which predict high collision impacts of close to, or more than, 1+ bird/yr. It is these applications and the growing national cumulative risk that have prompted us to recommend further mitigation measures to reduce collision risk for more recent applications such as Balmeanach.

6.6.2 Problems created by delays between bird surveys and wind farms becoming operational

In addition to the short comings of the collision assessment process set out in Sections 2 - 5 there are problems with the implicit and explicit assumptions in the NS replies to the Reporter set out in section 6.6.1. The message from these exchanges is that cumulative risk is not well defined and is at least partly subjective. The two main problems with the NS approach, which NS partly acknowledges, are.

1. The NS cumulative total of modelled collision risk includes operational, consented and at application proposals at the time of their responses. Inevitably this results in an over-estimate.
2. It is difficult to predict what the actual collision risk would be for any wind farm by the time it becomes operational.

These two problems can be rephrased as two questions.

1. How many of the "consented and at application proposals" will become operational?
2. What is the time interval between a wind farm ending its bird surveys and its operation and how does this affect the expected number of collisions if the White-tailed Eagle population is expanding?

The answer to the first question, on which proposals are included, is clearly important as it has a direct impact on the cumulative total.

The second question is important when the White-tailed Eagle population has been growing at annual rate of ~10% per year as the collision landscape will change over time. The question would be largely irrelevant for a stable population.

NS has provided various assessments of wind farm collision mortalities which, when summed, produce a cumulative total of the predicted annual number of collisions. NS correctly recognise that not all of the developments included in these cumulative assessments will be constructed.

At various times NS has indicated these cumulative sums are very close to a threshold, above which additional collisions would result in a significant impact on Scotland's White-tailed Eagle population trajectory.

Fig. 10 in Sansom *et al* (2016) is a predicted trajectory for the Scottish population assuming no extra mortality. NS, in a FOI (26/5/26 NS ref SIR183820/A5855004) response to Galileo Empower, state that "***the predictions of growth to 2025 in the 2016 report are quite accurate***" (our emphasis). In this modelled scenario the population expands at a mean annual rate of ~10%. NS

recognise that predictions beyond 2025 to 2040 may be less reliable. Despite the NS acceptance of the Sansom *et al* (2016) predictions, there have been discrepancies between the Samson modelling and national totals from the SRMS data. Between 2013 and 2018 there were more pairs in the SRMS data compared with predicted trajectory, with a maximum discrepancy in 2015 when there were 122 pairs in the SRMS data and 89 on the predicted trajectory. However, since the arrival of Covid restrictions the number of pairs in the SRMS data has been less than those on the predicted trajectory. Given the acknowledged surveying problems during that period (Scott Smith, *pers comm*) it is appropriate to rely on the predicted Sansom values which NS consider to be accurate.

Given the NS concern relating to the population impacts of cumulative wind farm collision, it is interesting to consider that 45 White-tailed Eagles have been removed from Scotland[17] between 2019 and 2025 for the Isle of Wight White-tailed Eagle project (Section 6.4). It is unclear if NS accepted the opinion (Roy Dennis Wildlife Foundation and Forestry England (2019) p21) that "*the removal of 'excess' young may actually be beneficial to the Scottish population by reducing intraspecific competition in the most densely populated areas*."

There were 13 known turbine White-tailed Eagle collisions (Table 5.1) between 2019 and 2025, which combined with the 45 translocations, is a loss of a minimum of 58 birds from the Scottish population during this period. Despite this, the NS view is that "*the predictions of growth to 2025 in the 2016 report are quite accurate*", which would imply that the loss of almost 10 birds per year (57 birds between 2019 & 2025) had no impact on the Scottish population's trajectory. It is difficult to square this judgement with a view that a significant collision threshold is imminent. Simply stated, the White-tailed Eagle population has continued to grow on the 'no extra mortality' Sansom modelling scenario despite the removal of up to 10 birds per annum, over two thirds of which are translocations under NS control. The model must therefore underestimate population growth.

It is also interesting to consider the impact of a rapidly expanding population on the estimated number of collisions. It is rational to assume that as the population expands there will be more collisions. Indeed, Sansom *et al* (2016, p26) suggest that "*a more realistic modelling approach is to assume that the annual mortality is related to the overall population size*". There is some empirical evidence to support this view given that most recorded collisions have occurred at wind farms which did not predict collisions, largely because the bird surveys used to inform their CRAs took place when the population was much smaller.

Fig. 6.7 uses collision data from 48 wind farm[18] CRAs to plot the cumulative number of annual collisions (blue dots and lines). Fig. 6.7 also shows the predicted, and apparently accurate, trajectory of the Scottish population (solid black line) from Sansom *et al*. (2016). The cumulative number of predicted collisions broadly tracks the growth of the population. This indicates predicted collision rates are increasing as birds become more frequently encountered during wind farm ornithology surveys. As wind farms and White-tailed Eagles are not spread evenly across the Scottish landscape it is important not to overstate the robustness of this relationship.

---

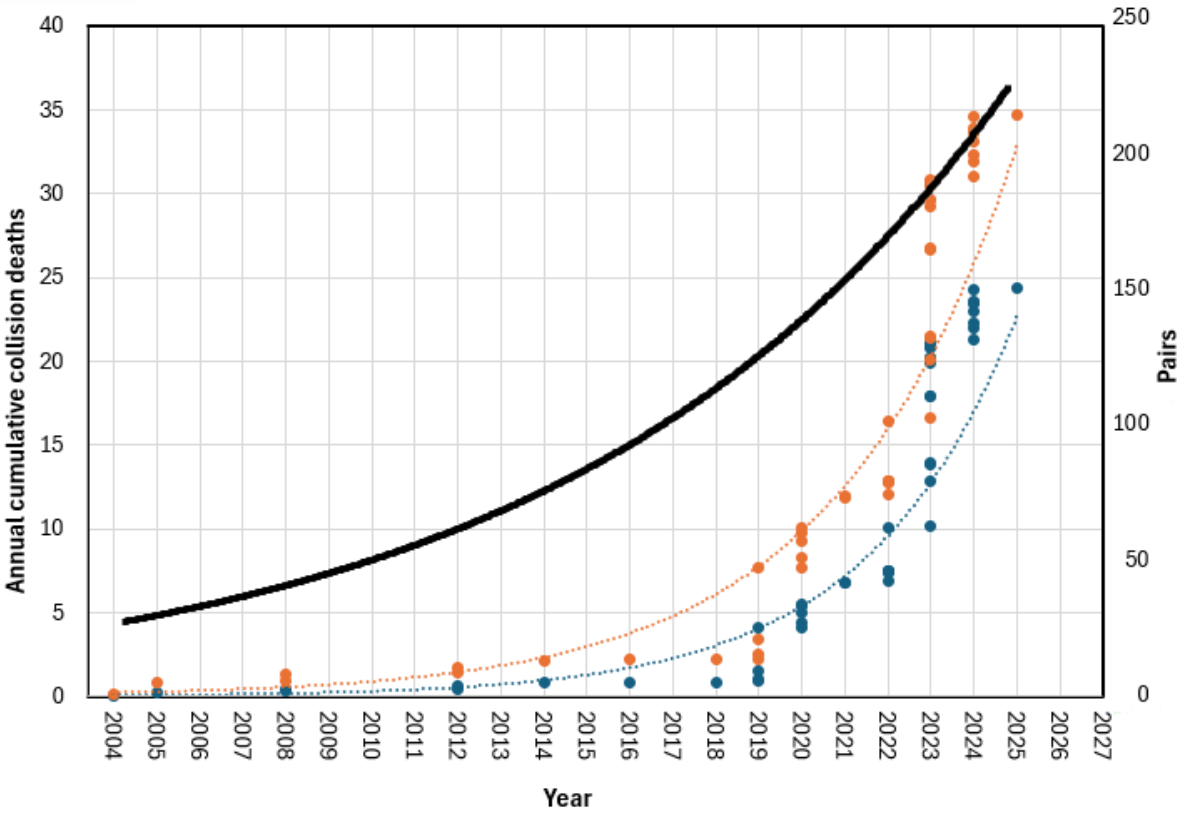
[17] https://www.forestryengland.uk/nature-wildlife/white-tailed-eagle-reintroduction-project

[18] 2004 Feriosbhal; 2005 Pairc; 2008 Edinbane, Loch Carnan (Lochdar Hill); 2012 Glen Lonan, Glen Ullinish I, 2014 Blarghour; 2016 Clachaig; 2018 High Constellation; 2019 Breackerie, Cloice, Stornoway Consented, Uisenis; 2020 Armadale, Bhlaraidh Extension, Corriegarth II, Glasvaar, Hoy; 2021 An Carr Dubh, Ourack; 2022 Acheilidh ,Beinn Ghlas Repower, Ben Aketil Repowered, Eredine, Ladyfield, Tomchrasky; 2023 Allt an Tuir, Ben Sca Repowering, Clune, Cnoc Buidhe, Dorenell Extension, Dunside Borders, Glen Ullinish II, Glentarken, Highland, Killean, Meall Dearg, Shinness; 2024 Ballach, Beinneum II, Coille Linne, Corr Chnoc, Glen Lednock, High Brenfield, Inveroykel, Lynemore; 2025 Allt Domhain.

Using the last bird survey date (not the date of planning submission or determination) reported in wind farm CRAs, and an assumed annual population growth rate of 10%, collision estimates can be adjusted to take account of more birds (orange dots and line).

In Fig. 6.7 the unadjusted 2025 total is 24.3 birds per year whilst the adjusted total is 34.7 which is almost 43 % larger and above any of the previously suggested NS thresholds. This analysis has been completed on a combination of operational, consented and in planning projects to demonstrate the impact a rising population has on CRA outputs. Nevertheless, the analysis applies to all operational wind farms in Scotland that now share territories with the White-tailed Eagle. If project CRAs were updated at all these operational schemes, national predicted collision would rise significantly above the current NS 'concern threshold' of ~21-22 birds per annum. However, as we have already established, predicted collisions, even allowing for population growth, significantly overestimates real collision. This discrepancy can be investigated further by trying to answer the second question which is important when the White-tailed Eagle population has been growing at annual rate of ~10% per year. Using data from the Sansom *et al* (2016) report, the population increased from ~100 pairs in 2016 to ~220 pairs in 2025. So, if there is a theoretical gap of 10 years from the end of bird surveys to a wind farm becoming operational, the population could have more than doubled. Clearly, if predicted collisions were being realised on the ground, this finding would change the level of any cumulative significance.

Figure 6.7. Unadjusted (blue dots and line) annual cumulative collisions from 48 CRAs and adjusted for a 10% annual growth rate in the Scottish population (orange dots and lines). The x axis is the last year of bird survey data. Also shown, based on Fig. 10 in Sansom et al (2016) is the growth in the Scottish White-tailed Eagle population (thick black line, scale on right side).



The time between bird surveys ending and energy production starting is not easy to assess and it has been almost impossible to find real data. The timescale is largely dependent on the planning process but even more on grid connectivity. The UK Government via the Onshore Wind Energy Task Force has recognised this[19] and it suggests that ~6 years (since the end of bird surveys) is common but ~10 years still happens for complex schemes.

In NS's reply to the Reporter about the Ben Aketil wind farm proposal a list of wind farms used for the cumulative assessment was attached (Table 6.2). Planning websites and developer web sites were searched (between 4/6/26 & 6/6/26) for information on bird survey dates, planning permission (submission and decision dates) and any actual or possible operational start dates. [Note some planning details have been updated from the NS table following decisions which post-dated the NS letter].

Only three of the 53 developments had an end date for bird surveys and an operational start date with a mean interval of 8.8 years. All three began operating in 2015 or earlier. There were 10 developments with planning approval in which the developer gave a probable start year for operation; the mean time from the end of bird surveys to beginning operations was 11.6 years.

Planning start and decision date were available for 16 developments with a mean interval of 2.4 years. Dates for the end of bird surveys and planning start dates were available for 39 developments and the mean interval was 1.9 years. This suggests that the mean period from ending bird surveys to receiving a planning decision was ~4.3 years. Subsequent to receiving planning there will be pre-construction activities and construction itself. It is also normal to require planning permission for a grid connection plus a date when the development can be connected to the grid.

Table 6.2. Status of 52 wind farms listed as part of the cumulative assessment for the Ben Aketil wind fam in a NS letter to DEPA (date 5/3/26) "Advice regarding White-tailed Eagles for inquiry Section 36 wind farm - Ben Aketil wind farm, Isle of Skye". Four columns have been added to the original table: date bird surveys ended; planning start and decision dates; and an operational date. If only a month and year were available the day is the 15th.

NHZ	Wind farm	Collision Risk	Surveys End	Planning Start	Planning Decision	Operational
Operational						
3	Beinn Greidaig	0.000			15/06/09	17/07/15
3	Lochdar Hill (Uist)	0.039	23/03/08			18/02/13
3	Monan (North Harris)	0.085	12/06/06		12/06/08	19/03/15
3	Pentland Road	0.030	15/06/02			28/03/13
7	Beinneun Extension	0.000				16/02/17
7	Bhlaraidh	0.000				15/09/17
14	Beinn an Tuirc Phase 3	0.000				15/10/21
14	Carraig Gheal	0.000				31/08/13
Approved						
2	Orkney Community	0.224	15/03/20	15/10/20	15/12/21	
3	Druim Leathann repowering	0.117	30/08/13			by 2030
3	Stornoway	0.289	15/08/19		15/01/22	2031

[19] https://www.gov.uk/government/groups/onshore-wind-industry-taskforce

NHZ	Wind farm	Collision Risk	Surveys End	Start	Planning Decision	Operational
3	Uisenis	2.530	13/03/19	22/08/23	18/09/25	2030
7	Bhlaraidh Extension	0.050	04/07/20	16/08/21	30/08/22	
7	Bunloinn	0.000	15/08/21	30/03/22	02/04/24	
7	Kirkan	0.000	15/08/18	14/03/19	25/07/23	
7	Tomchrasky	0.014	14/02/22	21/11/22	06/05/25	
12	Glendye	0.340	15/06/16	02/10/18	27/10/23	2030
14	A'Chruach (Phase 2)	0.000				
14	Airigh	0.000	30/08/16	01/07/17	20/03/20	
14	Clachaig Glen 2	0.052	21/07/16	17/03/23	08/11/24	2028
14	Glasvaar	0.138	15/08/22	15/07/22	20/12/24	
14	High Constellation	0.013	15/08/18	28/05/19	26/06/20	2028
14	Ladyfield	0.017	24/11/21	18/12/23	02/05/25	pre-2030
Application						
5	Acheilidh Wind Farm	0.036	24/08/22	15/05/24		
5	Shinness	0.161	20/03/23	15/04/24		
6	Balmeanach	0.944		15/05/25		
6	Beinn Mheadhonach	0.220	15/03/22	15/11/23		
6	Ben Aketil Repowering	0.512	15/12/22	09/06/23		
6	Ben Sca Redesign	2.687	15/12/23	15/05/25		
6	Glen Ullinish II	1.939	15/03/23	31/07/23		
7	Ballach	0.160	22/08/24	06/08/25		
10	Cloiche	0.140	14/08/16	28/04/20	30/11/23	2027-28
10	Clune	0.970	19/12/23	03/03/25		
10	Corriegarth 2	0.311	08/01/21	20/12/23		
10	Highland	0.005	16/06/23	15/04/25		
10	Lynemore	0.603	10/08/24	01/05/25		
10	Ourack	0.070	26/07/16	18/10/22	25/03/25	
11	Dorenell Extension	4.000	15/03/24	08/08/25		
14	Allt Domhain	0.037	05/03/25	18/07/25		
14	An Carr Dubh	1.228	26/08/21	12/04/23		
14	Beinn Ghlas repowering	0.246	15/08/22	21/07/25		
14	Blarghour S36c	0.103	15/09/14	10/10/19	29/10/21	
14	Breackerie	0.031	15/08/19	30/10/23		
14	Cnoc Buidhe	0.109	15/08/23	10/04/25		
14	Corr Chnoc	0.643	27/05/24	08/01/25		
14	Eredine	0.109	22/04/20	20/11/24		
14	High Brenfield	0.045	15/03/24	10/06/25		
14	Killean	0.575	15/03/24	15/08/24		
15	Glen Lednock	0.488	15/07/24	11/06/25		
15	Glentarken	0.304	26/07/23	21/01/25		
15	Meall Dearg	0.190	09/08/23	11/08/25		
Refused						
14	Earraghail	0.000	10/11/21	22/02/22	14/02/25	

Combining all of this information it appears that the UK Government's assessment of a common interval of ~6 years, between ending bird surveys and becoming operational, is optimistic and its recognition that complex schemes can have an interval approaching 10 years is more appropriate. The eight operational wind farms in Table 6.2 have bird survey dates which will be, on average, around 15 years old in 2027 whilst 14 of the approved wind farms have a date for the end of bird surveys between 2013 and 2022.

Given the rate at which the Scottish White-tailed Eagle population has expanded it is unhelpful to view the NS national cumulative collision total with a high degree of certainty. This point underscores the previous findings that the level of predicted turbine collision in Scotland overestimates White-tailed Eagle deaths, the overestimate becomes even larger if the cumulative modelling was to account for population growth.

7. White-tailed Eagle Population Viability Analysis (PVA)

7.1 Summary

In section 1 we explained how an assessment of a potential threat to the future of Scotland's White-tailed Eagle population as a result of collisions with wind turbines was predicated on combining the results from two separate analyses.

The first set of analyses, concerned with quantifying the magnitude of the impact, are covered in Sections 2 – 5. It was shown that current approaches significantly over-estimate the scale of the impact in terms of how many birds will be killed.

This section is concerned with the second set of analyses which model the population trajectory of the Scottish White-tailed Eagle and identify what level of additional mortality the population can sustain. Consequently, the aim of this section is to understand how a PVA can be used to investigate the evidence for a possible significant impact of collision mortality on the future of Scotland's White-tailed Eagle population. The section begins by explaining what a PVA is and what assumptions must be made prior to its use.

Concepts such as allowable take, density dependence and counterfactual modelling are covered before published information is used to develop a PVA. We include this information to provide a context for assessing a PVA. Our PVAs investigate how different levels of collision mortality affect the predicted future trajectory for the Scottish White-tailed Eagle population.

The PVA results strongly suggest the observed growth in the Scottish White-tailed Eagle population should not have occurred if White-tailed Eagles had been lost in accordance with the calculated collision risk from EIAs. Indeed, if the Sansom *et al.* (2016) figures accurately represent the current status of the population, as accepted by NS, this can only have occurred if the number of collisions has been very much smaller than originally calculated in the EIAs, even after increasing the estimates to account for the White-tailed Eagle's expansion. Accounting for population growth and geographical expansion (Edinbane Scenario) wind farm CRM predictions resulted in a predicted population size of 156 pairs in 2025, equivalent to an approximate 4% annual collision rate. Real population numbers demonstrate the excess mortality rate is significantly under 1%, even after accounting for the large number of birds taken for the English reintroduction.

These PVA models suggest that collisions with wind turbines must, so far, be rare and have had a limited impact on population growth over the last twenty years. More accurate assessments of risk, which recognise the many limitations of the current method described in this report, are needed in order to assess the viability of the Scottish White-tailed eagle population into the future as the current estimates of collision risk, even after taking the previously ignored elevated risk due to the spatial expansion of the population into account, cannot be reconciled with the observed population growth.

7.2 Population Viability Analysis.

A PVA uses models of population growth to estimate the probability that a population will go extinct within a given timeframe to derive a result such as "*given current circumstances the probability of the extinction of White-tailed Eagles over the next 25 years is x%.*" (Possingham *et al.,* 2013). Current circumstances would usually be taken to mean with and without additional collision mortality.

A population model is a mathematical abstraction of how the size of a population (e.g. number of breeding pairs) is expected to change over time. At its simplest, if the number of immigrants and births is greater than the number emigrants and deaths the population will increase, at a rate determined by the size of the difference. Simpler models ignore immigration and emigration so the change in population size is a function of the birth (productivity) and death (survival) rates. Although there are examples of birds from Ireland entering the Scottish population the numbers are not large; ignoring immigration and emigration is unlikely to bias a model.

If something happens to change productivity and/or survival the trajectory of the population changes. For example, a change in climate could increase or decrease both depending on the nature of the change. Generally, in wind farm related scenarios the only assumed change is a decrease in annual survival resulting for collisions with wind turbines. Consequently, it is assumed there is no other changes to productivity or survival (e.g. should persecution increase), other than normal annual fluctuations.

7.3 Using PVAs to understand the impact of additional mortality.

NS has a duty to protect wildlife in Scotland and part of that duty involves understanding how developments, such as wind farms, may affect wildlife. Although there will be exceptions, the most likely impacts from human activities will be negative and the role of NS becomes one of quantifying the magnitude of the impacts and understanding whether if they are likely to be biologically significant. Neither of those is simple and caution is needed if important decisions are made on the basis of a single rule system, particularly when the costs of either decision error are large and there are known limitations with the rule system.

Instead of relying on a single assessment method to determine the significance of an impact it is better to look for a consensus across a range of methods that use, as far as possible, different assumptions and place different weights on available information. If these methods, with their different assumptions, errors, precision and biases, predict the same outcome for the impact there is more confidence about the final conclusion and recommendation. If the methods predict different outcomes a judgement on the most probable outcome is needed. Such judgements should be informed by the majority predicted outcome (if more than two assessment methods are employed), the disparity in the predictions, the methodological assumptions and the biology of the species in question (e.g. how long does it live, what is its age at first reproduction?).

Understanding whether a particular development is likely to have a biologically significant impact requires the use of a PVA and a definition of what is the desired/acceptable future population trajectory, i.e. what level of impact is acceptable? In an expanding population, such as the Scottish White-tailed Eagle, a numerical limit is inappropriate as its magnitude, as a percentage of the population changes over time. The process of deciding if a single development is likely to have biologically significant impact is complicated because developments never happen in isolation. There will be similar developments on different time lines combined with unconnected factors which may also be having impacts; for example, persecution, afforestation, removal of birds for a reintroduction and climate change. The assessment must, therefore, be cumulative across *all* potentially negative impacts.

There have been attempts to introduce existing approaches into assessing the impacts of offshore wind farms on birds. For example, the US has a concept of allowable take which is similar to the ideas around sustainable harvests in, for example, commercial fisheries. Zimmerman *et al* (2022), in a study of the bald eagle, noted that a key assumption underlying

sustainable take is that density-dependent responses can offset the removal of individuals to maintain population viability. Unfortunately, as discussed in Section 7.4, the mechanism and strength of density dependence is difficult to detect in field data although it is an inevitable biological phenomenon once a population becomes too large with respect to available resources.

Other approaches such as ABC (Acceptable Biological Change) and PBR (Potential Biological Removal) have been suggested for assessing the amount of additional mortality that can be accommodated whilst allowing a population to remain within 'acceptable' limits. Neither approach was developed with advice on planning decisions as a primary role but they have been considered for offshore wind farms. Both ABC and PBR provide qualitative and imprecise measures of acceptable biological change and they become more reliable as more of the underlying assumptions are met but it is rare that the assumptions are met, but the same is true for any assessment procedure.

In effect both methods, but particularly ABC, are wrappers around population models that provide a, hopefully, consistent interpretation of the outputs from population models. The absence of a clear framework for cumulative assessments is a problem for birds and wind farms in Scotland.

Timescale of impact is important for both methods. In addition to the duration of a post-construction assessment period, the interval between the impact period and identification of the demographic rates is relevant. It would not be unusual for the interval between the median age of the demographic rates and the assessment date to be greater than the assessment interval. As shown in section 6.6.2 this is a big problem when combining predicted impacts on an expanding population such as the White-tailed Eagle.

ABC has its origins in climate change studies, at least with respect to the use of consistent terminology for describing uncertainty about risk (Mastrandrea *et al*., 2010). ABC has adopted these definitions of uncertainty (Table 7.1) but the terminology was developed to describe the uncertainty about climate change scenarios rather than biological change *per se*. Nonetheless, it would be helpful to have consistency in what the terms mean, particularly when it comes to assessing the significance of development impacts on birds.

Table 7.1. Mastrandrea et al. *(2010) uncertainty classes*

Term	**Probability (P)**
Virtually certain	>0.991
Extremely likely	0.951-0.990
Very likely	0.901-0.950
Likely	0.668-0.900
About as likely as not	0.333-0.667
Unlikely	0.101-0.332
Very unlikely	0.051-0.100
Extremely unlikely	0.011-0.050
Exceptionally unlikely	<0.01

PBR has a different origin but it has similarities with cumulative wind farm collision mortality approaches. PBR is defined by the United State National Oceanic and Atmospheric Administration as "*the maximum number of animals, not including natural mortalities, that may*

be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." This can be rephrased as how many White-tailed Eagles can be killed by wind farms in Scotland whilst still allowing the White-tailed Eagle population to remain in a favourable condition?

The allowable number (the maximum cumulative collision impact in the context of this report) is derived from three elements: minimum population estimate of the stock; one-half the maximum theoretical or estimated net productivity rate of the stock at a small population size and a recovery factor of between 0.1 and 1.0. PBR was originally developed for situations in which an estimated population trajectory is much longer than the life time of any wind farm. Importantly, and reflecting its origins in fisheries, the PBR calculation assumes that the main impact is on adult survival. PBR has been used in at least one wind farm assessment when Bellebaum *et al*. (2013) used it to determine if the level of red kite mortality was approaching the PBR-identified mortality threshold across all of the wind farms in the German federal state of Brandenburg.

7.4 A note on density dependence and counterfactual models

What is density dependence?

Density dependence is a complex and natural population regulation mechanism which relies on feedback between the current population size and the resources (e.g. food and nest sites) available to that population. In populations of large raptor species, density dependence can take the form of changes to survival and/or productivity (e.g. Houston & Schmutz, 1995; Carrete *et al*., 2006; Ferrer *et al*. 2006; Kruger, 2007). **The interpretation of the effects of additional mortality are very different for populations with and without density dependence effects.**

Recently established or small populations can have high productivity while the number of pairs is well below the habitat's carrying capacity. However, as a population expands there are likely to be food shortages and behavioural interactions, particularly with non-breeding ("floaters") which result in density-dependent processes, primarily reducing breeding success but also survival. For example, Bretagnolle *et al* (2008) investigated density dependence in the growth rate and fecundity of a recovering osprey population in Corsica over a 31 period. This is analogous to the recovering Scottish White-tailed Eagle population albeit on a different spatial and temporal scale. They showed that density dependence in the population growth rate during the stable period was related to reductions in productivity, coinciding with an increase in the number of non-breeders and more interactions with conspecific floaters, suggesting that behavioural interference influenced hatching success. Bretagnolle *et al* (2008) also noted that adult survival can be negatively related to population density which would be an important factor for population regulation, especially for a long-lived bird like the osprey.

Density dependence is unlikely to be operating on all of the Scottish White-tailed Eagle population as the national population is currently expanding rapidly. However, it may be operating locally in areas with the longest histories of White-tailed Eagle occupation such as the islands of Mull and Skye.

Density dependence can be seen in an S-shaped logistic growth curve, where population growth slows as the number of pairs approaches a habitat's carrying capacity. The slowing growth rate is assumed to be a consequence of changes to productivity and survival rates resulting from increased competition for resources. In the absence of such limitations the population should experience continuing exponential growth which results in clearly unrealistically large population sizes.

The major challenge for a PVA which aims to simulate a population showing density dependence is the size of the carrying capacity. Density dependence processes become more severe as a population approaches the carrying capacity. This can be illustrated in a simple model in which the population growth rate (change in N over time t) is given by $dN/dt = rN(1-N/K)$, where r is the intrinsic growth rate, and K is the carrying capacity.

As N approaches K the term $(1-N/K)$ approaches zero and N/K approaches 1, decreasing the overall growth rate. [If N = 100 and K = 100 $(1-N/K)$ = (1-100/100 or 1 – 1) and rN is multiplied by 0 meaning that the rate of change, dN/dt, is 0].

It is not simple to derive a value for K without empirical data but a value can be derived (see Box 7.1 which uses a method promoted by NS). Such values of K should not be over-interpreted as they are unlikely to be accurate.

Box 7.1. NS derivation of a value for K

r is the population's intrinsic growth rate derived from a model's assumed productivity and survival rate (i.e. the proportional annual change).

$r_{observed} = r_{max} . (1-N/K)$ where:

- r_{max} = 0.1;
- $r_{observed}$ = 0.075 (e.g. an observed NHZ population growth rate)
- N = 40 (the current NHZ population size in pairs)
- K = carrying capacity (unknown)

K can be found by solving the equation $r_{observed} = r_{max} . (1-N/K)$ when only K is unknown.

- $0.075 = 0.1 \times (1 - 40/K)$
- $0.75 = 1 - 40/K$
- $40/K = 0.25$
- K = ~160 pairs

It should be noted that K = 160 pairs may represent an optimistic estimate of the carrying capacity as it depends on many assumptions.

Density dependence assumes some feedback between K and the N, the current population size. As in Box 7.1 this is usually expressed as a ratio of K/N. As a population expands K/N becomes smaller. For example, if K is 100 and N is 50 then K/N is 2 but if N is 120 then K/N is 0.833. Once K/N drops below 1 (N>K) the K/N ratio can be used to reduce survival and productivity rates by this amount. For example, if productivity was 1 it would be 0.833 when K = 100 and N = 120.

The consequence of this feedback is that in a density dependent model the population becomes incapable of demonstrating sustained growth once the population exceeds K. Additional collision mortality has the effect of decreasing N which in turn reduces the density dependent reduction in the productivity and survival, allowing the population grow faster than it would have done without the additional wind farm mortality. If the population is below K, the effects of the additional mortality is more significant.

What is a counterfactual model?

A counterfactual model has its origins in economics and medicine and it estimates what would have happened in an alternate, hypothetical reality where interventions or conditions were different. For example, what would have happened to a person if they had not started taking a

hypertension drug? In other words, it tries to answer "what if" questions. The scenario without additional collision mortality is a hypothetical or counterfactual scenario.

Modelled population sizes with no density dependence, over significant time periods, could never be accepted as realistic. Combining an absence of density dependence with a counterfactual approach replaces a plausible model in which a precautionary carrying capacity is assumed, with a comparison of two modelled trajectories that have no basis in reality. Even if the counterfactual approach is accepted the end point is a subjective assessment of what is a significant impact (in percentage terms)? The longer the models run the more unrealistic the density dependence-free scenario becomes and the larger the impact becomes as the gap widens between a null model, with no collisions, and a model which assumes added collision mortality.

There is no guidance, based on any objective scientific criteria, on how or when two population trajectories should be compared. It is an approach which, in the face of even tiny mortality, always results in a divergence of the model trajectories and, if run long enough, the difference must inevitably become large. So, at what point are the models stopped and how different do they have to be at that point to be significant? This is an entirely subjective approach biased towards arriving at an inevitable objection based on an untenable large theoretical impact.

7.5 A PVA for White-tailed Eagle in Scotland

7.5.1 Model Structure

Here we use a Lefkovitch matrix (Fig 7.1; Caswell 2001) as the basis for a White-tailed Eagle PVA in Scotland. The model is written in the R programming language (See Appendix 2).

The NS FOI response[20] confirms that the trajectory presented in Sansom *et al.* (2016) adequately represents the observed increase in the Scottish White-tailed Eagle population so we use this as the basis for the demographic parameters required to construct the matrix.

The model consists of four stages, fledglings in their first year (s0) followed by four sub-adult age classes (s1-s4) and an adult stage (adult) which can be represented in a 6x6 matrix (Fig. 7.1). Transition of individuals between the fledgling and each sub-adult age class reflects their survival from year to year as does the transition between the final sub-adult stage and adulthood. For example, how many birds fledged in August 2025 are still alive in August 2026? The adult stage is the final class, and mortality here represents annual survival of adults.

All survival parameters were taken from Sansom *et al* (2016). Fledgling survival is 87.4%, as is survival from s2 to s3 and s3 to s4. Survival from s3 into s4 is lower at 85.5%. Both survival from s4 into the adult stage and annual adult survival is 96.1%. Fecundity was set at 0.385 female chicks per breeding female. This value was the national mean from SRMS data 2004 – 2023. For all parameters, values were sampled in each year of each simulation from uniform distributions ranging from 10% higher and lower than the parameter value. This stochastic variation represents changing environmental conditions which can affect both productivity and survival in any given year.

[20] NatureScot FOI response (ref: SIR183820/A5855004) dated 26 May 2026

Figure 7.1. A Lefkovitch matrix representing the Scottish White-tailed Eagle population. Birds reach maturity after five years and only mature adults breed.

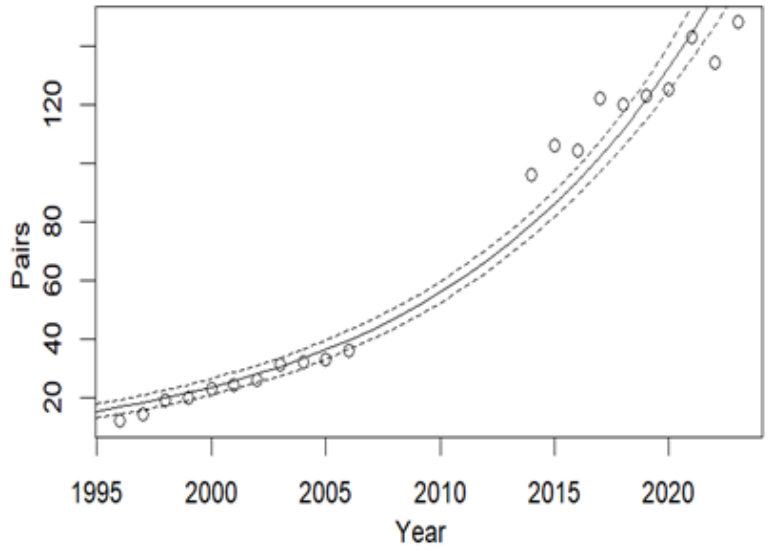
s0	s1	s2	s3	S4	adult
0.000	0.000	0.000	0.000	0.000	**0.385**
0.874	0.000	0.000	0.000	0.000	0.000
0.000	**0.874**	0.000	0.000	0.000	0.000
0.000	0.000	**0.874**	0.000	0.000	0.000
0.000	0.000	0.000	**0.855**	0.000	0.000
0.000	0.000	0.000	0.000	**0.961**	**0.961**

We present a national model here as White-tailed Eagles are unlikely to be sufficiently reproductively isolated to be considered as separate populations (Whitfield *et al*., 2009).

7.5.2 PVA results with no added collision mortality

Population growth in the Scottish White-tailed Eagle population has been sustained and there is no indication from the current rate of growth (Fig. 7.2) and changes in productivity (Fig .7.3) that the population is nearing its carrying capacity (Bårdsen *et al*. 2026; Heuck *et al*. 2017). Therefore, density dependence was included in the model but the carrying capacity was set to be a relatively high value of 1,200 pairs, so that density dependent effects would not be realised unless the simulated population grew well above its current level.

Figure 7.2. Pairs of White-tailed Eagle known to occupy territories between 1996 & 2023 from SRMG annual reports. Fitted line represents a Generalised Linear Model with Poisson errors, fitted to the data showing a significant positive effect of Year on the number of pairs (β = 0.09, p < 0.001) with 95% confidence intervals.



We used the same starting population of 30 breeding pairs as used by Sansom *et al*. (2016) for 2004. Individuals were allocated to the other stage classes based on the stable age structure of the population matrix (s0 = 9.90, s1 = 8.10, s2 = 6.90, s3 = 6.60, s4 = 6.45 adults = 30).

The demographic parameters used in this model, even with stochastic variation, result in strong population growth (λ = 1.095, 9.5% annual rate of increase in the number of pairs). We simulated 1,000 White-tailed Eagle populations and ran each simulation for 21 years, comparing the resulting population change with the values predicted by Sansom *et al*. (2016) and observed data from SRMG reports (Fig 7.4). All of the simulated populations showed strong, positive growth and

the mean population growth was well matched to the Sansom et *al*. (2016) predictions which NS considers to be a very accurate representation of the actual growth of the Scottish population. The shape of this growth also represents the trend in SRMG monitored pairs, although this number is likely to be smaller than the actual population as not all pairs are monitored in recent years.

Figure 7.3. Fledged chicks per pair of White-tailed Eagle monitored from SRMG data between 1996 & 2023 annual reports. Fitted line represents a linear model fitted to the data showing a significant positive effect of Year on the number of chicks fledged per monitored pair (β = 0.008, p = 0.016) with 95% confidence intervals.

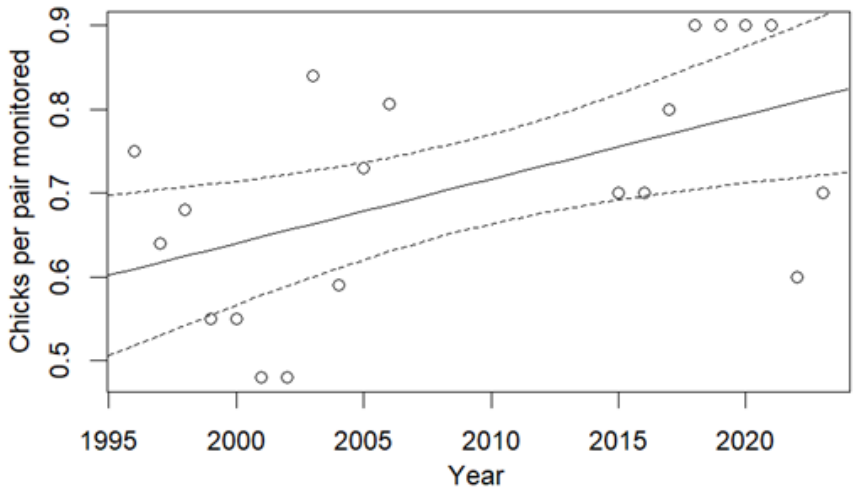
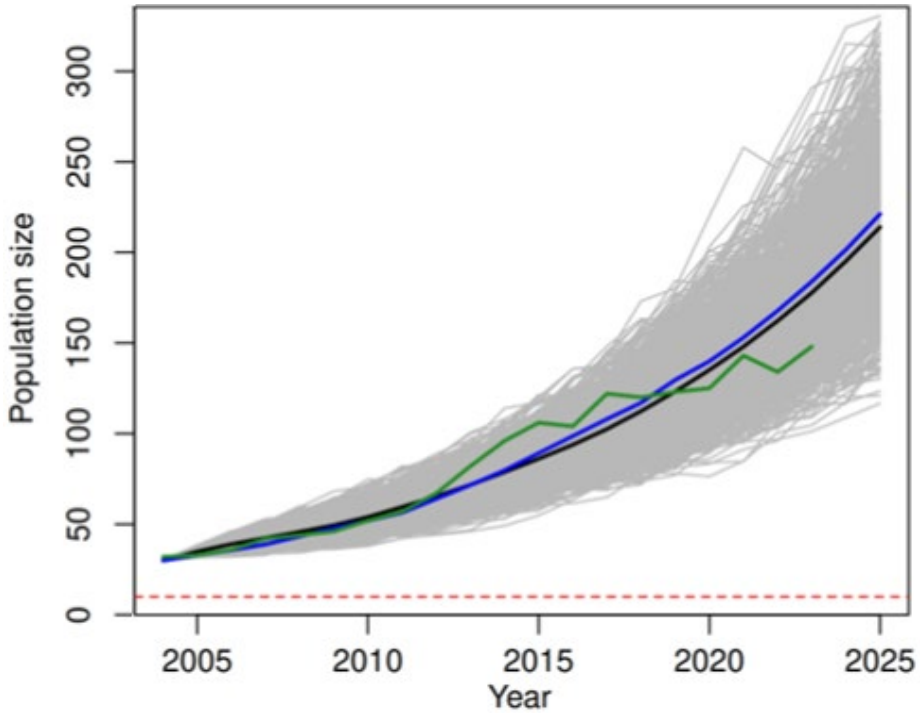


Figure 7.4. Projected population growth from a Population Viability Analysis for White-tailed Eagle in Scotland. Grey lines represent 1000 stochastic simulations with the mean population trajectory represented by the black line. Also represented are the predicted population size from the Sansom et al. (2016) model (blue line) and the number of pairs monitored by SRMG (green line), both starting in 2004. The dashed red line represents a quasi-extinction threshold of ten breeding pairs. The probability of extinction over the 21 years of simulation using this PVA was 0.



7.5.3 Incorporating collision mortality into the PVA

Using the model described in Sections 7.5.1 & 7.5.2 we developed models in which eagles were removed from the population in line with the collision risk estimates from windfarms which were operational between 2004 and 2025. Of the 48 windfarm CRAs assessed in Section 6, only two predicted any collision risk during this time, Edinbane (Skye, operational 2010; estimate 0.15) and Loch Carnan (South Uist, operational 2013; estimate 0.039). The effect of additional collisions on the population will be larger if breeding adults are lost but studies have shown no clear age-pattern in windfarm collisions for White-tailed Eagle (Heuck *et al.,* 2020). We therefore applied 50% of the predicted losses to adult birds and 50% to earlier age classes in each year.

Cumulative losses per year, due to predicted collisions, were based on two estimates (equivalent to the orange and blue lines in Fig. 6.7): first, the originally calculated collision risk which takes no account of population growth since the assessment was completed (Fig. 6.7 blue line). The second uses an annually updated collision estimate which incorporates additional collision mortality of 10% per year due to the long-term increase in the White-tailed Eagle population since the assessment was undertaken (orange line in Fig. 6.7). Additionally, we calculated collision risk based on the proportional increase in the Scottish population since the collision risk estimate was produced. Between 2011 – 2012 the Edinbane risk estimate was multiplied by the proportional population change since 2010 and between 2014 – 2025 the collision risk calculated for Edinbane in 2013 plus the collision risk for Loch Carnan were multiplied by the population increase since 2013. Collision risk was converted to a percentage mortality in each year by dividing the estimate of birds killed by collisions by the population size for that year predicted by Sansom *et al.* (2016).

Along with these collision-risk based models, we ran more general models using percentage estimates of mortality in line with the estimates presented in Fig. 6.7. These were 1, 3, 5, 8 and 12% of the population.

All models with increased collision losses (Fig. 7.5) produced mean trajectories (black line) slightly below those predicted by Sansom *et al*. (2016) (blue line in Fig. 7.5) but the very low

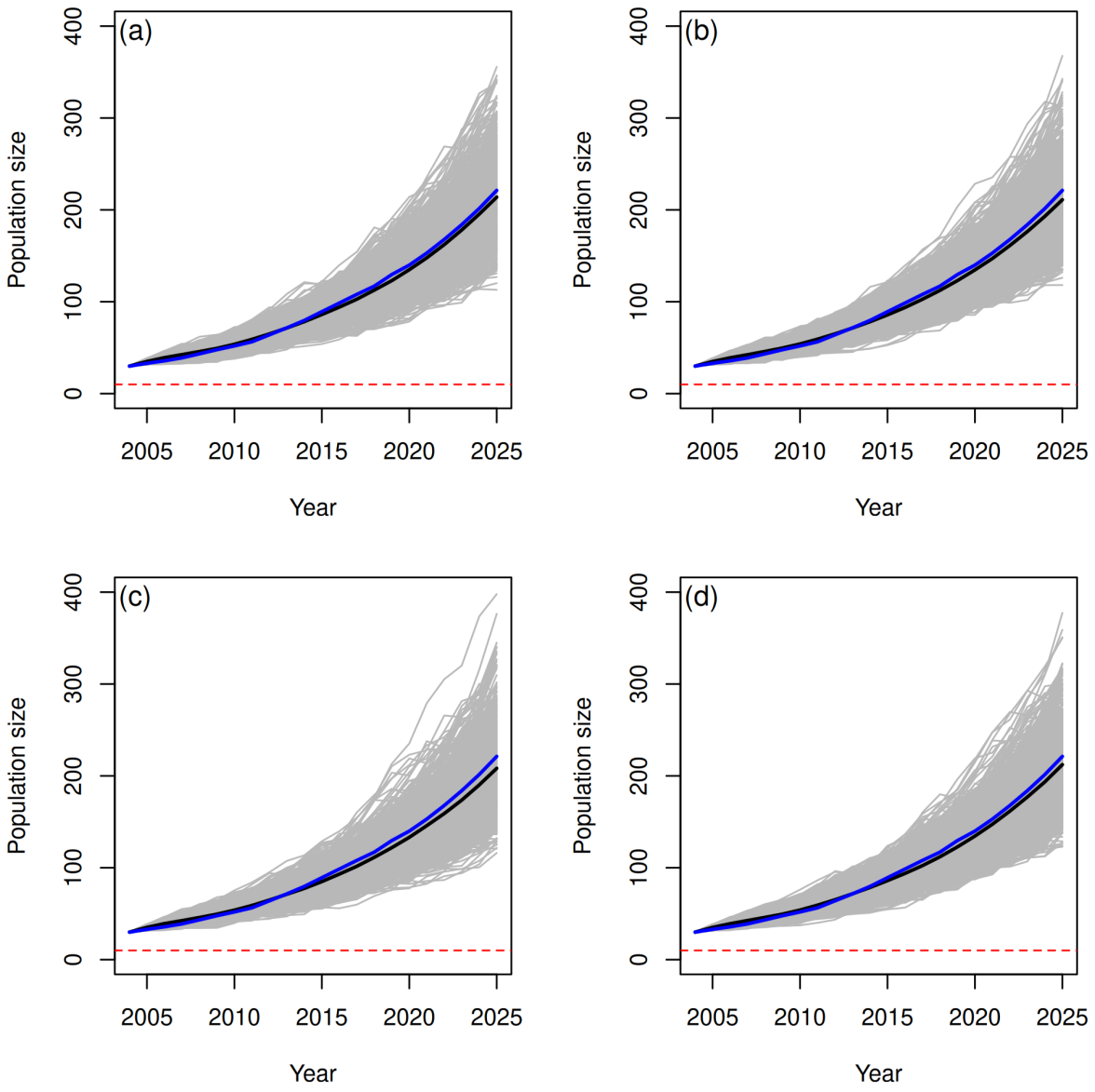
estimated collisions resulted in predicted populations (grey lines in Fig. 7.5) both above and below the population projected by Sansom *et al*. (2016) indicating that these values were possible under this scenario.

As the FOI from NS acknowledges, the figures predicted by Sansom *et al*. (2016) are considered to be an accurate representation of the growth and current status of the Scottish population. As such, the results in Figure 7.5 suggest that the estimates of collision risk between 2004 and 2025 could not have been substantially higher than those used in our PVA models.

By way of demonstration, taking the operational schemes only from Fig. 6.8, collision risk was calculated from 2005 to 2025 at Loch Carnan and Edinbane respectively (for uncorrected and corrected population levels). Loch Carnan and Edinbane were the only operational wind farms with a predicted White-tailed Eagle collision risk. When these values were applied into the model, they produced outputs of 210 and 209 pairs in 2025, both marginally lower than the Sansom *et al* zero-collision trajectory (see scenarios b and c of Fig. 7.5). Applying an increase in the estimated collisions due to the increasing size of the population in each year, resulted in a similar estimate (Fig. 7.5d). However, these collision risk estimates are based on EIAs at only two windfarms where White-tailed Eagles were present in significant enough numbers during EIAs. The population has changed not only numerically, but also spatially since then and a much larger area is likely to be affected (see section 7.5.5 & 7.5.6)

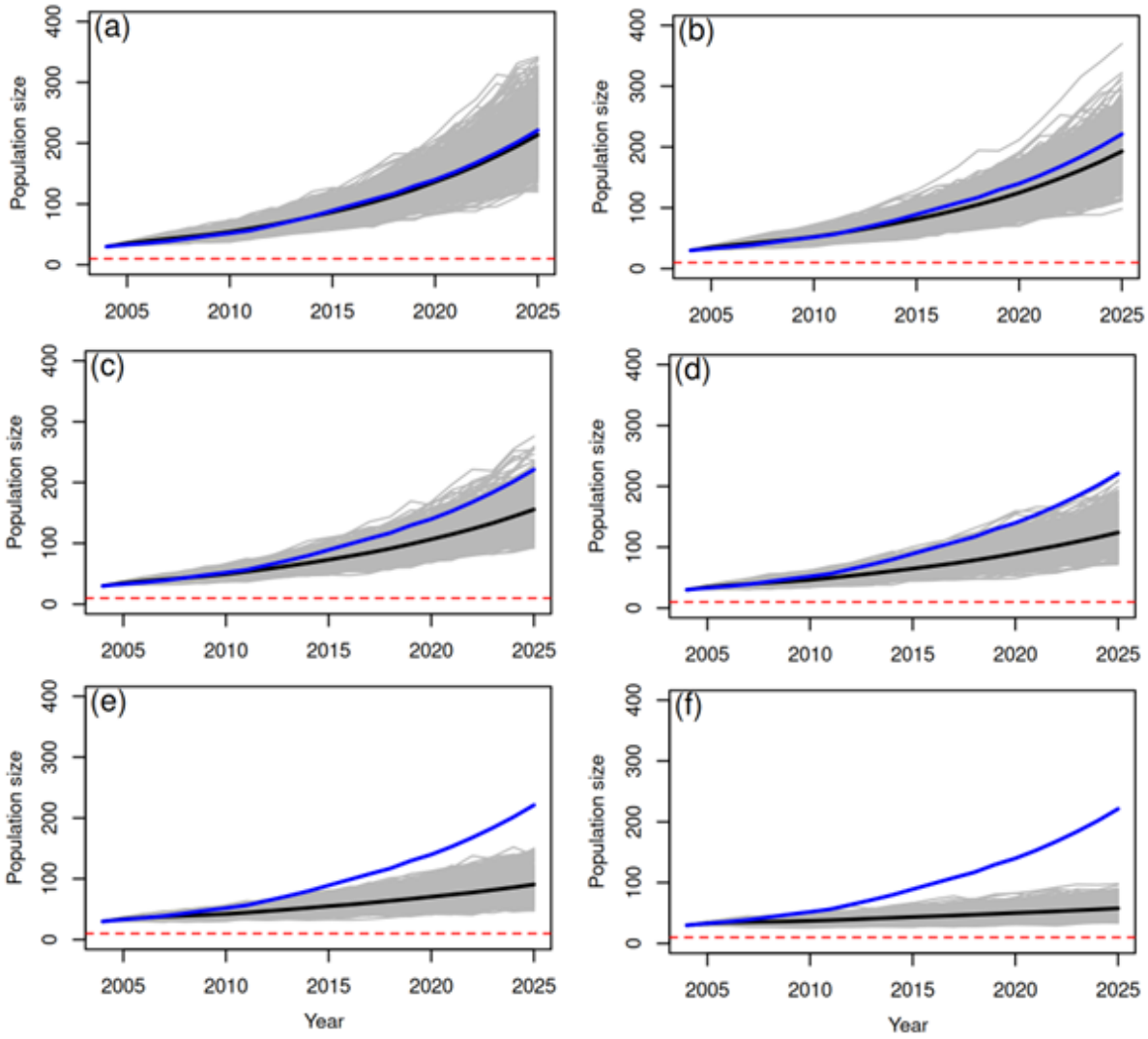
It should also be noted that the 2025 population has also experienced a significant loss of young birds to the English reintroduction which must mean that the effect of additional wind farm mortality is even lower than the very small effect apparent in Fig. 7.5.

Figure 7.5. Projected population growth from a PVA for White-tailed Eagle in Scotland. Grey lines represent 1,000 stochastic simulations with the mean population trajectory represented by the black line. Also represented is the predicted population size from the Sansom et al. (2016) model (blue line) starting in 2004. The four plots (a) no additional deaths, (b) deaths from collisions based on the cumulative collision risk for operational windfarms in each year between 2004 and 2025, (c) deaths from collisions based on the corrected cumulative collision risk from operational windfarms between 2004 and 2025, (d) deaths from collisions based on a proportional increase in collision risk based on the proportional change in population size each year. Note: operational wind farms in these plots refers only to the Edinbane and Loch Carnan wind farms.



Using a range of percentage mortality estimates, corresponding to the range in Fig. 6.7, resulted in populations all falling below the Sansom *et al.* (2016) projection, (Fig. 7.6). Even with 1% mortality (up to 11 birds per annum, based on a total population of approximately 1,100 birds in 2025) the projected population was only 20 pairs lower in 2025 than the Sansom *et al*. (2016) projection with no mortality (Figs. 7.6 a & b). Increasing mortality percentage rates (Figs. 7.6 c – f) resulted in smaller populations albeit still with a mean final population size of 58 pairs with 12% mortality (up to 132 birds per annum, based on a total population of approximately 1,100 birds in 2025). As the Scottish White-tailed Eagle population has increased, it is clear that estimates of collision risk produced when entered planning are not representative of the current White-tailed Eagle population in that area. This is most clearly seen in the known collisions (Table 5.1) and the assessed impacts at those wind farms. The estimated collision risk, based on the current approach, should be higher with a consequential greater impact on the Scottish population resulting in population impacts similar to those presented in Figs. 7.5 b-f. **As this apparent increase in risk is not supported by the PVA model results it is clear that current CRA models overestimate collision risk.**

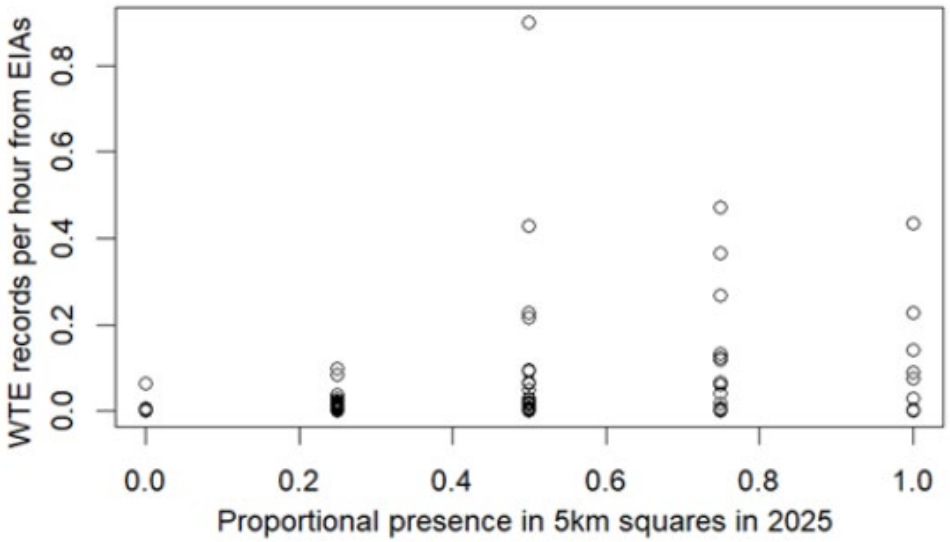
Figure 7.6. Projected population growth from a PVA for White-tailed Eagle in Scotland. Grey lines represent 1,000 stochastic simulations with the mean population trajectory represented by the black line. Also represented is the predicted population size from the Sansom et al. (2016) model (blue line) starting in 2004. The six plots are (a) no additional deaths, (b) 1% annual mortality from collisions (c) 3% annual mortality from collisions, (d) 5% annual mortality from collisions, (e) 8% annual mortality from collisions and (f) 12% annual mortality from collisions.



7.5.4 Spatial expansion

We used a 10 km^2 grid to understand the changing distribution of White-tailed Eagles in Scotland (see Fig. 6.4). Within these 10km^2 squares, we used data from EIAs and the citizen science platform eBird to estimate the proportion of the four 5 km^2 within them where White-tailed Eagles have been recorded (proportional presence). We then explored the correlation between this proportional presence value and the number of eagle flights recorded by EIAs, after correcting for time surveying, using a Spearman's rank correlation. This showed a significant, positive correlation between eagle activity and proportional presence ($r_s = 0.62$, $n = 154$, $p < 0.001$; Fig. 7.7). At least 41 currently operational windfarms have a higher value for proportional presence than when they first began producing power. Around half of these had no White-tailed Eagle records in the 10km^2 (proportional presence of 0) around them when they were originally assessed but now have White-tailed Eagles present with two sites now recording White-tailed Eagles in every 5 km^2 square (proportional presence of 1).

Figure 7.7. Proportional presence in 5km² of each 10km² where windfarm EIAs have been conducted against the observed White-tailed Eagle records per hour form the EIA surveys.

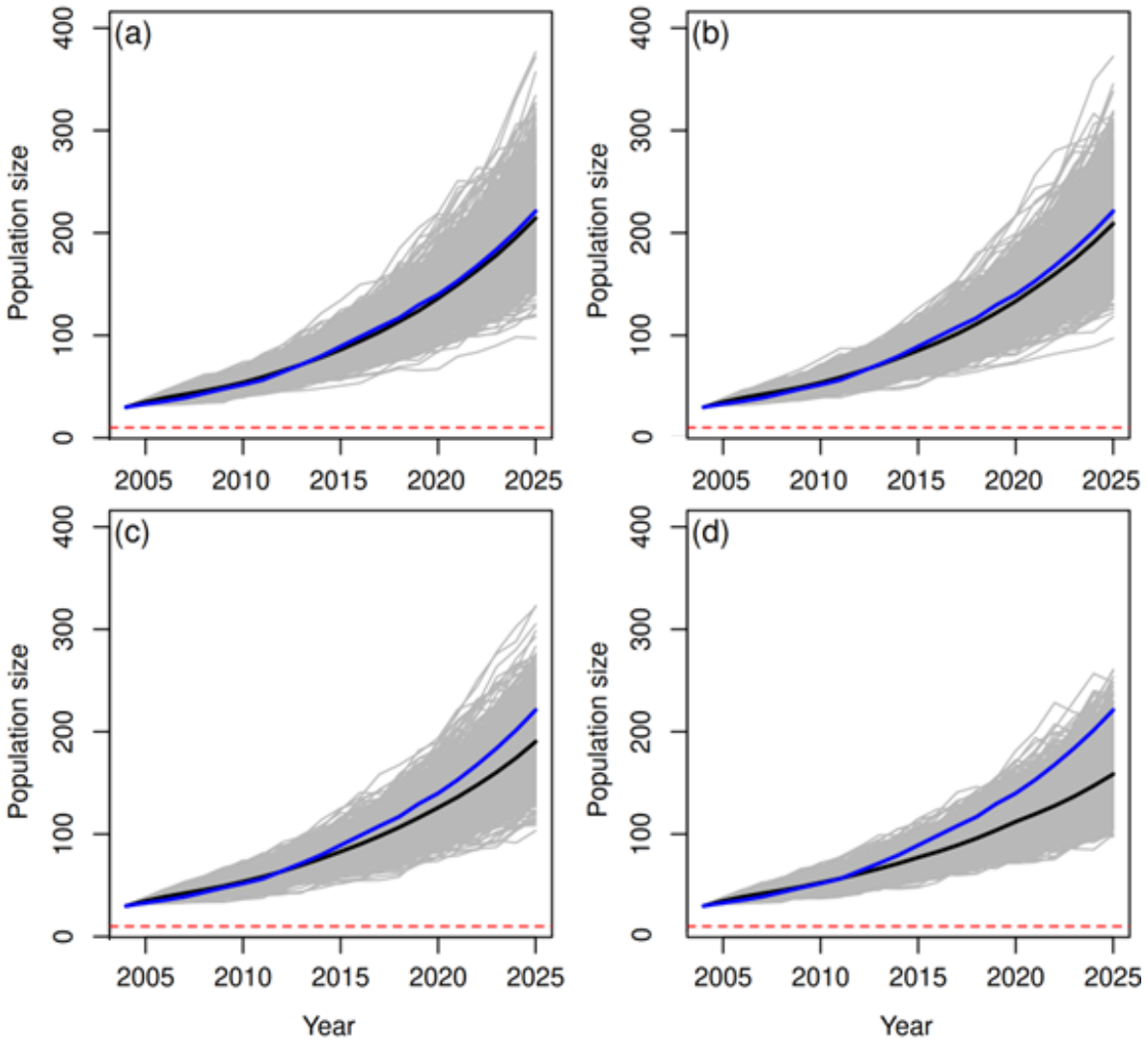


7.5.5 Collision risk accounting for spatial expansion

In order to understand the potential impact of a spatially expanding White-tailed Eagle population we used estimates of collision risk from the Edinbane and Loch Carnan EIAs to calculate a potential collision risk for each five-year period from 2005 – 2025. Using the correlation above (Section 7.5.4), we calculated an estimate of collision risk related to the proportion of 5 km squares with White-tailed Eagle activity around all operational windfarms, including those with no predicted collision risk, in each five-year period. Edinbane had White-tailed Eagle activity in half of the 5 km squares making up the 10 km square in the windfarm location and a collision risk of 0.15 per year in 2010. Therefore, for the Edinbane scenario, for each 5km square with eagle activity around an operational windfarm we assumed an annual collision risk of 0.075 (0.15/2). Loch Carnan had one 5 km square with White-tailed Eagle activity in 2013 and an annual collision risk of 0.039. Therefore, for the Loch Carnan scenario, for each 5km square with eagle activity around an operational windfarm we assumed a collision risk of 0.039.

Both of the scenarios representing increased collision risk due to spatial expansion of the White-tailed eagle population resulted in substantially lower predicted mean final population sizes than both the Sansom et al. (2016) projection with no additional mortality (Figure 7.8a) and the PVA based on EIA collision risks of the two operational windfarms with collision risk values for White-tailed Eagle (Figure 7.8b). The Loch Carnan scenario, which had a lower risk per 5 km of presence, resulted in a mean of 189 pairs (Figure 7.8c) and the Edinbane scenario resulted in a mean final population of 156 pairs (Figure 7.8d). Both of these scenarios represent relatively low apparent collision risk compared to other EIAs represented in Fig. 6.7, suggesting that both of these scenarios are a conservative estimate of the collision risk using current methods. Despite the conservate outcomes, both estimates are equivalent to a loss of between 2-4% of the population per annum which we know to be false, the real apparent collision rate being significantly under 1% based on the analysis in Figure 7.6. **Therefore, given the final predicted populations represented in Figure 7.8 are much lower than the current population size for White-tailed Eagle, we can rule out real collision at these levels, adding support to the idea that collision risk estimated based on current methods is likely to be an overestimate.**

Figure 7.8. Projected population growth from a PVA for White-tailed Eagle in Scotland. Grey lines represent 1,000 stochastic simulations with the mean population trajectory represented by the black line. Also represented is the predicted population size from the Sansom et al. (2016) model (blue line) starting in 2004. The four plots show (a) no additional deaths, (b) deaths from collisions based on the cumulative collision risk for operational windfarms with collision risk estimates in each year between 2004 and 2025, (c) deaths from collisions based on applying the collision risk estimate from Loch Carnan proportionally to all operational windfarms, not just Loch Carnan and Edinbane, based on the presence of White-tailed Eagles in each five year period and (d) deaths from collisions based on applying the collision risk estimate from Edinbane proportionally to all operational windfarms based on the presence of White-tailed Eagles in each five year period.



7.6 PVA Conclusions

The PVA results strongly suggest the observed growth in the Scottish White-tailed Eagle population should not have occurred if White-tailed Eagles had been lost in accordance with the calculated collision risk from EIAs. Indeed, if the Sansom *et al.* (2016) figures accurately represent the current status of the population, as accepted by NS, this can only have occurred if the number of collisions has been very much smaller than originally calculated in the EIAs, even after increasing the estimates to account for the White-tailed

Eagle's expansion. Accounting for population growth and geographical expansion (Edinbane Scenario) wind farm CRM predictions resulted in a predicted population size of 156 pairs in 2025, equivalent to an approximate 4% annual collision rate. Real population numbers demonstrate the excess mortality rate is significantly under 1%, even after accounting for the large number of birds taken for the English reintroduction.

These PVA models suggest that collisions with wind turbines must be rare and have had a limited impact on population growth over the last twenty years. More accurate assessments of risk, which recognise the many limitations of the current method described in this report, are needed in order to assess the viability of the Scottish White-tailed eagle population into the future as the current estimates of collision risk, even after taking the previously ignored elevated risk due to the spatial expansion of the population into account, cannot be reconciled with the observed population growth.

8. Conclusions and recommendations

8.1 Assessment framework

As outlined in Section 1, NS is concerned about the potential threat to the future of Scotland's White-tailed Eagle population as a result of collisions with wind turbines. The NS concern is predicated on combining the results from two independent analyses.

1. **CRA** (Sections 2 – 5 of this report) estimates the number of collisions, both cumulatively and at individual wind farms.
2. **PVA** (Sections 6 and 7 of this report) models the Scottish White-tailed Eagle population trajectory and what level of additional mortality the population can sustain.

In Section 1 (Table 1.1, repeated below as Table 8.1) the conclusions from the CRA and PVA are combined in a decision error matrix. NS confirmed the population trajectory in Sansom *et al.* (2016) was accurate, at least up to 2025, and our explorations of a PVA support that opinion. This suggests that the middle row in Table 8.1 is correct and the focus is now on the accuracy of the CRA estimates. Our clear conclusion is that the current CRA method, and published CRA results, significantly overestimate the collision risk. This means that the real population growth rate, as accepted by NS, is only possible if collision risk has not been significant.

Table 8.1 Decision error risk matrix

		CRA-Turbine collision estimates		
		Under-estimate	**Accurate**	**Over-estimate**
PVA-Population model growth trajectory	**Under-estimate**	Potentially accurate	Over-estimates risk	Over-estimates risk
	Correct	Under-estimates risk	Accurate	Over-estimates risk
	Over-estimate	Under-estimates risk	Under-estimates risk	Potentially accurate

There is a potential argument that the CRAs for almost all operational wind farms show there was no risk from them and thus it is unsurprising that population growth rate has not experienced a significant reduction. However, that argument is based on false premises.

1. Almost all known collisions have occurred at wind farms where no collisions were predicted.
2. Historic CRA estimates fail to take account of the expansion in the White-tailed Eagle population since the wind farm became operational and the significant expansion in the White-tailed Eagle population between the end of bird surveys, on which the CRA estimate is based, and the start of wind farm operations. In the context of an expanding population, almost all CRA estimates should be larger once a wind farm is constructed. Presumably this is part of the explanation for collisions at wind farms where there were no predicted collisions.
3. The NS cumulative total excludes the significant known losses to the English reintroduction.

The conclusion from point 2 is that the impact of predicted wind farm collisions should be even larger than currently recorded. However, as no population impact has been observed, the

number of predicted collisions has to be a significant overestimate, particularly given the export of birds to England. Table 8.2 lists the problems we have identified but it also suggests some possible solutions.

Table 8.2 Summary of problems and possible solutions.

CRA problem identified in the report	**Possible solution**
Empirical data demonstrates that the current way of estimating bird density is compromised and does not take account of how birds use the landscape.	A solution to this problem requires a different approach to estimating bird density, presumably taking account of habitat heterogeneity within the viewsheds and within the proposed wind farm footprint. However, this requires estimating density at smaller scales than the viewshed which would provide less freedom for later turbine positioning. It may be possible to investigate a grid approach (e.g. density per grid cell) rather than a global density within a viewshed.
A disproportionate survey effort during periods of the day or year when birds are most active overestimates collision outputs and *vice versa*. We have seen it suggested in NS responses to CRAs that an under-representation of early morning and late afternoon VP surveys under-estimates the collision risk. The opposite appears to be true and a disproportionate survey effort during periods of the day when birds are most active over-estimates collision outputs.	The empirical evidence from many CRAs is that White-tailed Eagle activity has marked annual and diurnal patterns. Hopefully, the annual patterns would be identified in VP surveys but the proportion of the day surveyed changes significantly across the year and it is unclear how this impacts the density estimate. There are considerable amounts of satellite tracking data with much more available in the near future. Movement patterns obtained from these data could be used to refine surveys (the same applies to Golden Eagle).
Data were extracted from 114 CRAs; of which 48 estimated a White-tailed Eagle collision probability. There was great inconsistency in the bird and turbine metrics used, even for apparently very similar turbines. In many cases rotation speed was too fast, sometimes faster than the turbine specifications. Overall, these CRAs entered values into the collision model which inflated the collision probability. There was also confusion between operational time and operational capacity.	Reduce the freedom consultants have in how the CRA parameters are selected. The risk is an increased bias while the reward is increased precision. An equation was developed in this report, based on the work of Saint-Drenan *et al* (2020), to estimate a realistic mean turbine rpm. NS should provide advice on operational time and operational capacity and how this affects the mean turbine rotation speed. A prescribed flight speed could be estimated from satellite tracking data. The work needed to produce the estimate could be undertaken by the recently established sea eagle research group.

Most consultants appear to err on the side of precautionary values, often exceeding what is feasible, resulting in a tendency to overestimate the number of collisions.	
Using field data from operational wind farms, it is clear the current CRA tools lead to a large over-estimate of the number of collisions. In the case of White-tailed Eagles at two Skye wind farms, our analysis indicate that the real collision level is only 7% of the CRA predictions calculated whilst the turbines were operational. The recorded collision rates at Edinbane and Ben Aketil are similar to observations in Europe. Given the amount of activity within the wind farms, combined with the behaviour of the White-tailed Eagles, it is surprising there have not been more collisions on Skye. After combining the CRA estimates from Ben Aketil and Edinbane, over the operational and surveyed period 2010 – 2014, the standard CRA approach suggests ~30 collisions should have occurred between 2014 and 2025 but only two collisions have been recorded. It is unlikely that the discrepancy is result of undetected collisions, not least because that scale of collisions should have had a clear impact on the Skye population. It is also unlikely that the discrepancy is a consequence of a population collapse as the CRA for the proposed redesigned Ben Sca, positioned between the Ben Aketil and Edinbane turbines, estimated an annual collision rate of 2.69 birds per year which is in line with the extrapolated estimates for Ben Aketil and Edinbane. Similarly, the estimated annual collision rate at Glen Ullinish II (2021 – 2023) was 3.33. Unless White-tailed Eagles have now abandoned the Ben Aketil and	In addition to the problems with the CRA method described above, the 95% collision avoidance estimate appears far too conservative and produces an unjustified inflation in the predicted number of collisions. It would be wise if NS could revisit this now that much more data are available. One problem is that collision avoidance estimates appear to be relative between species so changes to one inevitably result in comparisons with other species. For example, it is reasonable to assume that White-tailed Eagles are more prone to collisions than Golden Eagles who have a 99% recommended avoidance rate. This implies a relative risk which is five times larger for White-tailed Eagles than Golden Eagles. Recent peer-reviewed research using satellite tracking (see below for latest publication) suggests that Golden Eagles largely avoid wind farms and the 99% avoidance rate is also conservative. If the Golden Eagle avoidance rate was, for example, 99.9%, there may be more willingness to reconsider the White-tailed Eagle collision avoidance rate. If the relative risk remains at five the appropriate White-tailed Eagle collision avoidance would be 99.5%. If Golden Eagle collision avoidance was increased to 99.9% while the White-tailed Eagle rate remained at 95% the relative risk would then be an unrealistic 50. A simple, pragmatic solution to reduce the error of CRA predictions for the White-tailed Eagle would be to increase the avoidance rate to 97.5% or 98%. Even at these rates this report indicates that predicted collision for the species would still be overestimated so the adjusted rate would still be conservative. If it were subsequently demonstrated that Golden Eagle avoidance is greater than 99%, rates for White-tailed Eagles could be raised even further given their relative risks. Fielding, A.H., Anderson, D., Benn, S., Taylor, J., Tingay, R., Weston, E.D. and Whitfield, D.P. 2024. Approach Distances of Scottish Golden

Edinbane wind farms the question must be why have there been so few collisions there?	Eagles *Aquila chrysaetos* to Wind Turbines according to Blade Motion Status, Wind Speed, and Preferred Habitat. *Diversity*, 16(1), 71; https://doi.org/10.3390/d16010071
There have been significant expansions in the number and spread of White-tailed Eagles and wind turbines across Scotland but at rates which differ within and between regions. Overall, there are now more than 200 pairs of White-tailed Eagles with a possible continuing expansion to ~350 pairs by 2030. Analysis of the spatial expansion and distribution of White-tailed Eagles across Scotland revealed no evidence that wind farms are a factor constraining their spread. In addition to data from the raptor study groups there is indirect evidence for the scale and speed of the White-tailed Eagle's expansion such as the Sea Eagle Management Scheme. Data from the citizen science programme eBird along with White-tailed Eagle observations from EIAs was used to demonstrate the change in this distribution over time. There was no evidence that the recent outbreak of HPAI has had a significant long-lasting impact on the Scottish White-tailed Eagle population. The reintroduction of White-tailed Eagles into England may seem unrelated to wind power but removing birds from Scotland is equivalent to a loss due to a collision. The proposal to remove birds noted that "*The removal of 12 young each summer from 2019-2023 would have a negligible effect on overall productivity… would pose no risk to the donor population given the current and expected rate of population increase*". This is significantly more birds than are removed from the	Wind farm deaths should not be considered in isolation, all non-natural deaths (including exports to England) should be combined in a cumulative assessment. NS accepted the view that the removal of 12 juveniles from Scotland (translocations to England) from 2019-2023 would not have a negative effect on overall population productivity. This is far in excess of any annual mortality caused by wind farms. Data in wind farm bird surveys are a very significant resource which is currently vastly underused. They could provide data on how a species is distributed and expanding (or contracting). The resources needed to process all of the current and future data manually are probably prohibitive but given recent advances in AI methods it may be possible to use historic and future data more effectively than we have in this report. Such information would provide great insight into how wind farms and other environmental changes affect all important species. Perhaps the work could be undertaken as part of PhD programme? The approach to assessing the potential cumulative impact needs to be amended. First the cumulative total includes wind farms in planning which may never get built or will change significantly between the original proposal and construction. As such, only operational wind farms should be used in cumulative assessments. However, that is not the current approach. In a 05 March 2026 NS response to the DPEA it states "*The attached spreadsheet was used to assess the Balmeanach and Ben Sca applications*…." Only seven of the 54 listed wind farms were operational and their cumulative annual collision mortality was 0.069 (15 years to kill one bird). It is telling that none of the wind farms with known White-tailed Eagle collisions are in the NS cumulative list. There are 14 approved (not yet constructed) wind farms with a cumulative annual mortality of 3.77. The remaining 17 are in planning with a cumulative total of 17 per year. If approved, and construction

population by wind farms on an annual basis and NS agreed to their removal. The delay between the end of bird surveys for a proposed wind farm and the date on which the wind farm becomes operational is such that the White-tailed Eagle population has significantly increased.	goes ahead, it will be many years before they become operational so this cumulative collision estimate cannot be considered reliable for what, by then, will then be an extremely inaccurate population size. Delays between bird surveys and wind farm operation become very significant when a population is expanding or contracting at a significant annual rate. The cumulative total needs to be more pragmatic, not least by recognising the impact of the time delays in both historic assessments and future times to operation. But this recommendation cannot be actioned in isolation. Account must be taken of the significant overestimates produced by CRAs using current approaches.

9. References

Alerstam, T., Rosén, M., Bäckman, J., Ericson, P.G. & Hellgren, O. 2007. Flight speeds among bird species: allometric and phylogenetic effects. *PLoS Biol*.

Band, B., Madders, M. & Withfield, D.P. 2007. Developing field and analytical methods to assess avian collision risk at wind farms. In: de Lucas Castellanos, M.: *Birds and Wind Farms - Risk Assessment and Mitigation*, Madrid.

Bårdsen, B.J., Hansen, E. & Bustnes, J.O. 2026. From the brink of extinction to regulation: northern Europe's white-tailed eagles now face density dependence and climate constraints after rapid population growth. *Oikos*, p.e11974.

Bellebaum, J., Korner-Nievergelt, F., Dürr, T. & Mammen, U. 2013. Wind turbine fatalities approach a level of concern in a raptor population. *Journal for Nature Conservation*, 21, 394–400.

Bretagnolle, V., Mougeot, F. & Thibault, J.C. 2008. Density dependence in a recovering osprey population: demographic and behavioural processes. *Journal of Animal Ecology*, pp.998-1007.

Brown, L.H. and Amadon, D. 1968. *Eagles, hawks and falcons of the world*. *Volume 1*. Hamlyn Publishing Group.

Bruderer, B. and Bolt, A. 2001. Flight characteristics of birds: 1. Radar measurements of speeds, *Ibis*, 143. 178 – 204.

Carrete, M., Donazar, J.A. & Margalida, A. 2006. Density dependent productivity depression in Pyrenean bearded vultures: Implications for conservation. *Ecological Applications* 16: 1674–16.

Caryl, F., Vallejo, G., Tidhar, D. & Robinson, C. 2016. *Precision and bias of bird fatality estimates from two contrasting carcass detection strategies*. SWBSG Commissioned report number 1605. 75pp.

Caswell, H. 2001. *Matrix Population Models: Construction, Analysis and Interpretation*, 2nd Edition, Sinauer, Sunderland.

Dahl, E.L., Bevanger, K., Nygård, T., Røskaft, E. & Stokke, B. 2012. Reduced breeding success in White-tailed Eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. *Biological Conservation* 145:79–85.

Dahl, E.L., May, R., Hoel, P.L., Bevanger, K., Pedersen, H.C., Røskaft, E. & Stokke, B.G. 2013. White-tailed eagles (Haliaeetus albicilla) at the Smøla wind-power plant, Central Norway, lack behavioral flight responses to wind turbines. *Wildlife Society Bulletin*, *37*(1), pp.66-74.

De Lucas, M., Janss, G.F., Whitfield, D.P. & Ferrer, M. 2008. Collision fatality of raptors in wind farms does not depend on raptor abundance. *Journal of Applied Ecology*, 45(6), 1695-1703.

Douglas, D.J., Follestad, A., Langston, R.H. & Pearce-Higgins, J.W. 2012. Modelled sensitivity of avian collision rate at wind turbines varies with number of hours of flight activity input data. *Ibis*, 154(4), 858-861.

Ferguson-Lees, J. and Christie, D. A. 2001. *Raptors of the World*. Illustrated by Kim Franklin, David Mead, and Philip Burton. Houghton Mifflin. ISBN 978-0-618-12762-7.

Ferrer, M., de Lucas, M., Janss, G.F., Casado, E., Munoz, A.R., Bechard, M.J. & Calabuig, C.P. 2012. Weak relationship between risk assessment studies and recorded mortality in wind farms. *Journal of Applied Ecology*, *49*(1), 38-46.

Ferrer, M., Newton, I. & Casado, E. 2006. How to test different density-dependent fecundity hypotheses in an increasing or stable population. *Journal of Animal Ecology*. 75: 111–117.

Fielding, A.H. 2019. *An investigation into a possible second phase of releases of White-tailed Eagles into Ireland*. Report for the Golden Eagle Trust.

Fielding, A.H. and Haworth, P.F. 2015. Final report on the eight year monitoring programme (2007-2014) for the Edinbane wind farm on the Isle of Skye. Haworth Conservation Ltd.

Fielding, A.H., Anderson, D., Benn, S., Taylor, J., Tingay, R., Weston, E.D. & Whitfield, D.P. 2024. Approach Distances of Scottish Golden Eagles *Aquila chrysaetos* to Wind Turbines according to Blade Motion Status, Wind Speed, and Preferred Habitat. *Diversity*, 16(1), 71; https://doi.org/10.3390/d16010071.

García-Macía, J., Chirino, M., Morlanes, V., Torralvo, C., Sánchez, M., Morandini, V. & Ferrer, M. (in review). Highlighting the relevance of fine-scale collision risk in wind farms: a pre-operational study in southern Spain- Available at SSRN 7065031

Grünkorn, T., J. Blew, T. Coppack, O. Krüger, G. Nehls, A. Potiek, M. Reichenbach, J. von rönn, H. Timmermann & Weitekamp, S. 2016. *Prognosis and assessment of bird collision risks at wind turbines in northern Germany (PROGRESS)*. Final report commissioned by the Federal Ministry for Economic affairs and Energy in the framework of the 6. Energy research programme of the federal government. Reference number FKZ 0325300A-D.

Heuck, C., Herrmann, C., Schabo, D.G., Brandl, R. & Albrecht, J. 2017. Density-dependent effects on reproductive performance in a recovering population of white-tailed eagles *Haliaeetus albicilla*. *Ibis,* 159: 297–310.

Heuck, C., Herrmann, C., Wendt, J., Krone, O., Brandl, R. & Albrecht, J. 2020. Sex-but not age-biased wind turbine collision mortality in the White-tailed Eagle *Haliaeetus albicilla*. *Journal of ornithology*, 161(3), pp.753-757.

Houston, C. and Schmutz, J. 1995. Declining reproduction among Swainson's Hawks in prairie *Canada*. *J. Raptor Res*. 29: 198–201.

Krone, O. and Treu, G. 2018. Movement Patterns of White-Tailed Sea Eagles Near Wind Turbines. *The Journal of Wildlife Management*, 82: 1367-1375.

Krüger, O. 2007. Long-term demographic analysis in goshawk *Accipiter gentilis*: the role of density-dependence and stochasticity. *Oecologia* 152, 459–471.

López-Peinado, A., Egea-Casas, O. & López-López, P. 2024. Golden eagle movements: habitat use in a Mediterranean environment. pp 163-172 in: Rodriguez, J.B. & Ellis, D.H. (eds) *The Golden Eagle Around the World A Monograph on a Holarctic Raptor* Hancock House Publishers, Surry, BC, Canada.

Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.-K., Yohe, G.W. & Zwiers, F.W. 2010. *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change (IPCC)*. Available at http://www.ipcc.ch.

May, R., Nygård, T., Dahl, E. L. & Bevanger, K. 2013. Habitat utilization in White-tailed Eagles (Haliaeetus albicilla) and the displacement impact of the Smøla wind-power plant. *Wildlife Society Bulletin,* 37:75–83.

May, R.F., Lund, P.A., Langston, R., Dahl, E.L., Bevanger, K.M., Reitan, O., Nygård, T., Pedersen, H.C., Stokke, B.G. & Røskaft, E. 2010. Collision risk in White-tailed Eagles. Modelling collision risk using vantage point observations in Smøla wind-power plant. *NINA rapport*.

National Geographic Field Guide to the Birds of North America (4th ed.). Washington, D.C.: National Geographic. 2002.

Possingham, H.P., McCarthy, M.A. & Lindenmayer, D.B. 2013. Population Viability Analysis, pp410 - 423 In Levin, S.A. (ed) *Volume 4, Encyclopedia of Biodiversity*, Third Edition, Academic Press.

Provan, S. and Whitfield, D.P. 2006. *Avian Flight Speeds and Biometrics for Use in Collision Risk Modelling*. Unpublished Report to Scottish Natural Heritage.

Roos, S., Dobson, A., Noble, D., Haworth, P., Fielding, A., Carrington-Cotton, A., Etheridge, B. & Wernham, C. 2015. *Raptors in Scotland – a methodology for developing trends and indicators*. Scottish Natural Heritage Commissioned Report No. 542.

Roy Dennis Wildlife Foundation and Forestry England. 2019. *The feasibility of reintroducing White-tailed Eagles Haliaeetus albicilla to the Isle of Wight and the Solent*.

Saint-Drenan, Y.M., Besseau, R., Jansen, M., Staffell, I., Troccoli, A., Dubus, L., Schmidt, J., Gruber, K., Simões, S.G. & Heier, S. 2020. A parametric model for wind turbine power curves incorporating environmental conditions. *Renewable Energy*, *157*, pp.754-768.

Sansom, A., Evans, R. & Roos, S. 2016. *Population and future range modelling of reintroduced Scottish White-tailed Eagles* (Haliaeetus albicilla). Scottish Natural Heritage Commissioned Report No. 898.

Whitfield, D.P., Douse, A., Evans, R.J., Grant, J., Love, J., McLeod, D.R., Reid, R. & Wilson, J.D. 2009. Natal and breeding dispersal in a reintroduced population of White-tailed Eagles *Haliaeetus albicilla*. *Bird Study*, *56*(2), pp.177-186.

Willgohs, J. F. 1961. *The White-tailed Eagle* Haliaëtus albicilla albicilla *(Linné) in Norway*. Norwegian Universities Press.

Wilson, M.W., Austin, G.E., Gillings, S. & Wernham, C.V. 2015. *Natural Heritage Zone Bird Population Estimates*. SWBSG Commissioned report number SWBSG_1504. pp72.

Wilson, M.W., Beckmann, B.C. and Wernham, C.V. 2025. Reduced breeding success consistent with effects of high pathogenicity avian influenza (HPAI) on raptors in Scotland in 2022. *Bird Study*, *72*(1), pp.51-60.

Wilson, M.W., Beckmann, B.C., Challis, A. & Wernham, C.V. 2026. *An analysis of Scottish Raptor Monitoring Scheme data to improve understanding of the impact of Avian Influenza in 2023 on raptors and raptor populations in Scotland*. NatureScot Research Report 1367

Zimmerman, G.S., Millsap, B.A., Abadi, F., Gedir, J.V., Kendall, W.L. & Sauer, J.R. 2022. Estimating allowable take for an increasing bald eagle population in the United States. *The Journal of Wildlife Management*.

Appendix 1 Wind farms used in Section 4 (Band Collision Model)

SRSG Scottish Raptor Study Group Region; Wind farm Name; Number of Turbines; Blade pitch°; Rotation – seconds to complete one rotation; Diameter – turbine blade diameter (m); and Chord – turbine chord width used in the Band model.

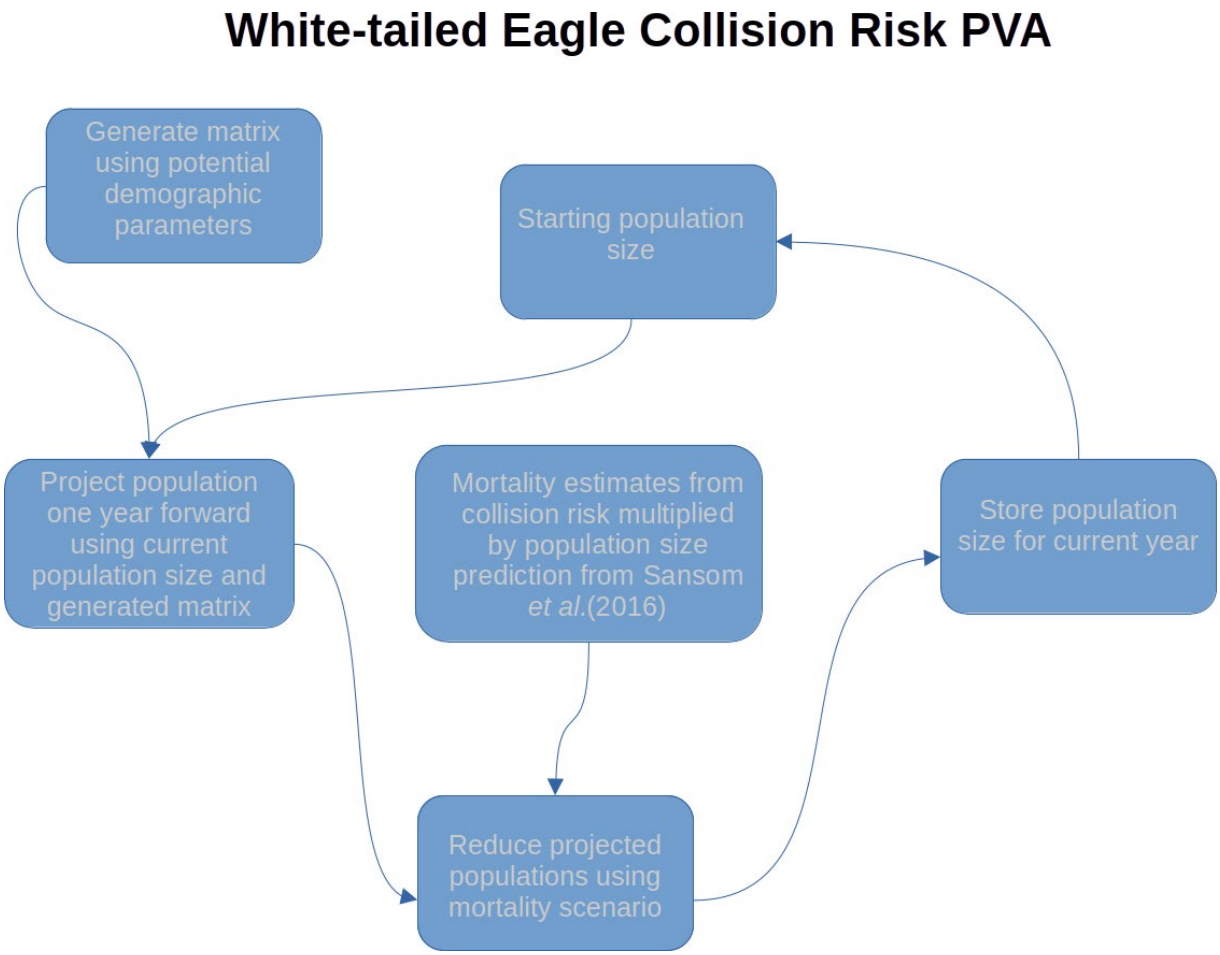
Rotation speed notes: [A] mean of the minimum and maximum values specified; [B] fastest speed specified

SRSG	Name	Turbines	Pitch	Rotation	Diameter	Chord
North East Scotland	Kildrummy	8	30	3.00	68	2.10
Highland	Edinbane	18	5	2.80	71	2.80
Highland	Tom nan Clach		20	2.90	71	4.23
Argyll	Dalbui	14	15	3.00	80	3.00
Eileanan an Iar	Loch Carnan	3	15	3.60	80	3.50
Argyll	Glen Lonan	6	15	4.69	82	3.50
Highland	Kyllachy	20	28	4.69	82	3.28
Highland	Glen Ullinish I	14	15	4.70	82	3.20
Highland	Burn of Whilk	9	15	3.16	90	3.80
Eileanan an Iar	Beinn Mhor	133	5	3.27	90	3.50
South Strathclyde	Auchrobert	12	12	3.50	90	3.50
Tayside	Dulater Hill (refused)	17	5	4.71	90	2.41
South Strathclyde	Assel Valley (Dalfask)	17	15	3.30[B]	91	3.50
Dumfries & Galloway	Glen App	14	12	3.25	93	3.50
Argyll	Cour	10	15	4.50	93	3.50
Dumfries & Galloway	Airies Farm	14	12	4.50	93	3.60
Eileanan an Iar	Tolstadh	14	15	5.00	93	3.50
Argyll	Killean (refused)	17	15	4.00	100	3.50
Highland	Stathy Wood	18	15	4.00	101	3.25
Argyll	Clachaig	14	15	5.00	101	3.50
Dumfries & Galloway	Lochhill	8	15	5.00	103	3.50
Highland	Millenium South Extension		15	4.00	104	3.25
Highland	Gordonbush Extension	16	16	3.40	105	4.00
Dumfries & Galloway	Sandy Knowe	6	15	4.00	112	4.20
South Strathclyde	Kirkhill	8	15	5.00	112	4.00
South Strathclyde	Chirmorie	22	15	5.00	115	3.80
Argyll	Blarghour	17	6	6.60[A]	115	
Highland	Creag Riabhach	3	6	4.20	116	3.10
Highland	Kintradwell (refused)	15	15	3.40	117	4.00
Argyll	Tangy IV (5 turbines assessed)	16	15	3.43	117	4.00
Highland	Cairn Duhie	16	15	3.43	117	4.00
North East Scotland	Glendye	26	15	4.11	117	4.00
Argyll	Airigh	14	15	4.80	117	4.50
South Strathclyde	Lethens	22	13	5.00	117	4.00
Argyll	Tangy IV (5 turbines assessed)	16	15	4.38	120	3.80
Argyll	Sheirdrim (refused)	19	15	5.20	120	3.80
Argyll	Tangy IV (5 turbines assessed)	16	15	3.75	126	4.00
Argyll	Tangy IV (5 turbines assessed)	16	15	4.96	127	4.75
Argyll	Tangy IV (5 turbines assessed)	16	15	4.80	130	4.20

SRSG	Name	Turbines	Pitch	Rotation	Diameter	Chord
Highland	Hollandmey	10	15	4.70	132	3.20
Highland	Kirkton (refused)	11	15	4.00	133	3.70
South Strathclyde	Knockkippen	12	5	4.30	133	4.50
Highland	Corriegarth 2	16	15	4.80	133	4.00
Highland	Armdale (withdrawn)	12	6	5.26	133	3.94
Highland	Garvary		6	6.86	133	4.20
Highland	Cloiche	36	5	3.40[B]	136	4.10
Highland	Tormsdale	12	5	3.40	136	4.10
Lothian & Borders	Cloich Forest	12	5	3.40	136	4.10
Central	Abhainn Dubh	13	15	4.00	136	4.10
South Strathclyde	Breezy Hill	20	6	4.29	136	4.10
Argyll	Ladyfield	13	15	4.40	136	4.10
Highland	Blairbair	8	15	4.80	136	4.10
South Strathclyde	Greenburn	16	5	4.90	136	4.10
Highland	Tom na Clach Extension 2021	7		5.90	136	4.10
Argyll	Glasvaar	11	6	6.12	136	4.20
Tayside	Windburn	13	6	4.29	138	4.30
North East Scotland	Clashindarroch II	14	5	5.70	140	4.01
Highland	Kirkan	17	15	6.43	142	4.00
South Strathclyde	Bankend Rig III	9	25	6.44	145	4.50
Highland	Golticlay Extension	6	15	5.60	149	4.15
Highland	Lethen (refused)	17	6	4.20	150	4.20
South Strathclyde	Arecleoch Extension	13	6	4.60	150	4.20
Argyll	Narachan (refused)	17	15	5.00	150	4.00
Dumfries & Galloway	Cloud Hill	11	15	5.50	150	4.20
Dumfries & Galloway	Callisterhall	7	6	6.00	150	4.20
Highland	Tomchrasky	14		8.54	150	4.20
Lothian & Bordersl	Heathland	14	6	5.26	153	4.00
Highland	Loch Liath	13	15	5.00	155	4.00
Highland	Millennium East	8	15	5.40	155	4.50
Highland	Shinness	16	15	5.40	155	4.50
Highland	Acheilidh	12	15	5.45	155	4.30
Argyll	Eredine	17	15	6.32	155	4.20
Argyll	Cnoc Buidhe	14	15	6.40	155	4.50
Central	Earlsburn	11	6	6.40	155	4.50
Highland	Ourack	18	6	6.40	155	4.50
Argyll	An Carr Dubh	13	15	6.43	155	5.40
Argyll	Earraghial (refused)	13	15	6.43	155	4.00
Highland	Ben Aketil (Repower)	9	15	6.43	155	5.40
Highland	Dell	9	15	6.43	155	5.40
North East Scotland	Craig Watch	11	15	6.43	155	4.42
Central	Earlsburn	14	6	6.44	155	4.50
Argyll	Rowan	13	6	8.54	155	4.50
Highland	Strath Oykel	11	8	8.54	155	4.50
Highland	Bhlaraidh Extension	18	15	6.18	158	4.00

SRSG	Name	Turbines	Pitch	Rotation	Diameter	Chord
Highland	Inveroykel	20	15	4.60	160	3.70
Highland	Kyllachy (New 2025)	11	15	6.25	160	4.20
Highland	Ceislein	11	15	7.15	160	4.20
Highland	Clune	18	15	4.00	162	4.60
Highland	Balnespick	9	6	4.96	162	4.30
Highland	Culachy (refused)	8	15	4.96	162	4.30
Highland	Watten (withdrawn)	7	15	4.96	162	4.30
Tayside	Glentarken	12	15	4.96	162	4.30
Highland	Carn Fearna	9	15	5.70	162	5.40
Argyll	Allt Domhain (Arnicle)	9	10	6.00	162	5.00
Dumfries & Galloway	Hopsrig	13	15	6.19	162	4.50
Dumfries & Galloway	Loganhead	9	15	6.19	162	4.50
Lothian & Borders	Newlands Hill	12	15	6.43	162	5.40
Highland	Lynemore	14	15	7.20	162	4.10
Argyll	High Brenfield	10	6	7.41	162	4.30
Highland	Glen Ullinish II	47	15	7.50	162	4.30
Argyll	Corr Chnoc	12	15	7.89	162	4.20
North East Scotland	Dornell Extension	67	15	7.97	162	4.20
Highland	Chleansaid	16	15	5.70	163	5.40
Highland	Creachan 2 options	13	15	5.95	163	4.15
Highland	Allt an Tuir	9	15	7.30	163	4.80
Highland	Ballach	20	15	7.32	163	4.30
Tayside	Meall Dearg	21	15	7.32	163	4.30
Highland	Highland	19	6	7.45	163	4.15
North East Scotland	Clashindarroch	22	20	3.00	170	4.00
North East Scotland	Clashindarroch Extension	22	20	3.00	170	4.00
Highland	Aultmore	16	6	6.50	170	4.50
Highland	Creachan	13	15	6.51	170	4.50
Lothian & Bordersl	Dunside Borders	15	15	4.96	172	4.20
Highland	Beinneum 2	19	10	5.50	172	4.50

Appendix 2 R code used in the PVA




```
## Scottish White-tailed Eagle PVA
#model population trajectory using a % age class mortality factor
library(popbio)

## Function to plot results
pva.plot <- function(pop, start.year, end.year, ext.thresh=10, ylim=c(0,max(pop + 7))){
  quasi.ext <- (length(which(apply(pop, 2, min) < ext.thresh))/ncol(pop))*100
  plot(pop[,1] ~ c(start.year:end.year), type="l", lwd=1, lty=1, xlab='Year',
       ylab="Population size", ylim=ylim, col="grey72")
  for (i in 1:ncol(pop)){
        lines(pop[,i] ~ c(start.year:end.year), type="l", lwd=1, lty=1, col="grey72")
    }
    ## Plot mean pop
    lines(apply(pop, 1, mean)~ c(start.year:end.year), lwd=2, lty=1, col="black")
    abline(ext.thresh, 0, col='red', lty=2) ## Minimum population
}

#Density Dependence
#density dependent reduction in parameter value
#in the equation x the ratio of pop size to carrying capacity
#based on y= 0.97/(1 + 0.03*0.0004^(-x))  or y=a/(1+bc^-x)
dd.ratio<-
c(0.995,0.985,0.975,0.955,0.935,0.900,0.840,0.750,0.650,0.580,0.530,0.490,0.470,0.460) # for
x=0.8 to x=1.45
dd.adj<-function(param,pop,pop.max,DD){
#curve is arbitrary showing reduction in parameter with pop size ratio but with min of 0.05 of
param value
```

```
  ifelse(DD,x<-round((pop/pop.max)/0.05)*0.05,x<-0)
# If no DD set x to 0 so that param remains unchanged by density otherwise round to 0.05
  if(x<0.8) y<-1
  if(x>1.45) y<-0.45
  if(x>0.75 && x<1.5){
    indx<-(x-0.75)/0.05
    y<-dd.ratio[indx]}
  return(param*y)
}

#Sansom, A., Evans, R. & Roos, S. 2016. Population and future range modelling of
#reintroduced Scottish White-tailed Eagles (Haliaeetus albicilla). Scottish Natural Heritage
#Commissioned Report No. 898
#s1,s2,s3,s4 & v are survival rates, f is number fledged per pair. Figs are from Table 8
Samsom et al 2016, figs after # are from Evans et al 2009

####### SETTING UP THE MODEL PARAMETERS
s1<-0.874      #0.819
s2<-0.874      #0.821
s3<-0.874      #0.857
s4<-0.855      #0.951
v <-0.961      #0.966
f <-0.385 #Mean from SRMG Data 2004 - 2023
params<-c(s1,s2,s3,s4,v,f)

n0.prop <- c(0.330, 0.270, 0.230, 0.220, 0.215, 1.000)
## Calculate proportion of different life stages relative to adult life stage based on current
data(200 pairs)
n0 <- n0.prop*30 #Scottish population in 2004 from Sansom et al. 2016
## Initial carrying capacity
car.cap<-1200  # National carrying capacity, above that productivity declines. See notes in my
Extra GU model, cc increased so that DD comes in later – more akin to having no DD

p.Imm<-0.5 #proportion birds killed that are 'young'
p.Ad <-1 - p.Imm
Dens.Dep<-TRUE #is density dependence operating?

###############
#function to add noise to parameters with cap
r.scale.min<-0.9
r.scale.max<-1.1
params.r<-function(p.list){
  p.list[1]<-runif(1, min=p.list[1]*r.scale.min, max=p.list[1]*r.scale.max)
  p.list[2]<-runif(1, min=p.list[2]*r.scale.min, max=p.list[2]*r.scale.max)
  p.list[3]<-runif(1, min=p.list[3]*r.scale.min, max=p.list[3]*r.scale.max)
  p.list[4]<-runif(1, min=p.list[4]*r.scale.min, max=p.list[4]*r.scale.max)
  p.list[5]<-runif(1, min=p.list[5]*r.scale.min, max=p.list[5]*r.scale.max)
  p.list[6]<-runif(1, min=p.list[6]*r.scale.min, max=p.list[6]*r.scale.max)
  return(p.list)
}

wte<-matrix(c(
  0,  0,  0,  0,  0,  f,
  s1, 0,  0,  0,  0,  0,
  0,  s2, 0,  0,  0,  0,
  0,  0,  s3, 0,  0,  0,
  0,  0,  0,  s4, 0,  0,
  0,  0,  0,  0,  v,  v
), nrow=6, byrow=TRUE)

### Baseline model and operational collision risk estimates
WTE.res.list <- vector(mode="list", length=8)
offset=0 #for results column
nsims <- 1000
simyears<-21
### Operational mortality estimates
collision.mortality <- read.csv('../Operational_Collision_Risk_Estimates.csv')
kill.vect <- data.frame('none'=0,
               'Estimate'=collision.mortality$ES.Op.Prop,
               'Corrected.Estimate'=collision.mortality$Es.Corr.Op.Prop)
p0<-pop.projection(wte,n0, simyears+1) # deterministic and no mortality
```

```
for(k.pct in 1:ncol(kill.vect)){
  mortality=kill.vect[,k.pct] #% mortality (note double for both sexes)
  reduce=1-mortality
  ## Create matrices to store parameters for each year of each simulation
  #store for results all simulations - growth rate
  pop.sims.r<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store for results all simulations - population size
  pop.sims.ad.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store for results all simulations - sub-adult deaths
  pop.sims.sa.killed<-matrix(nrow=simyears,ncol=nsims)
  #store for results all simulations - sub-adult deaths
  pop.sims.ad.killed<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.r[1,]<-0
  pop.sims.n[1,]<-sum(n0)
  pop.sims.ad.n[1,] <- n0[6]
  for(j in 1:nsims){
    n<-n0
    #run a single simulation for x years
    for(i in 1:simyears){
      s.params<-params.r(params)      #generate some random values within limits
      #if DD is opertating adjust the parameter values as appropriate
      s1.ran<-dd.adj(s.params[1],pop.sims.n[i,j],car.cap,Dens.Dep)
      s2.ran<-dd.adj(s.params[2],pop.sims.n[i,j],car.cap,Dens.Dep)
      s3.ran<-dd.adj(s.params[3],pop.sims.n[i,j],car.cap,Dens.Dep)
      s4.ran<-dd.adj(s.params[4],pop.sims.n[i,j],car.cap,Dens.Dep)
      v.ran<-dd.adj(s.params[5],pop.sims.n[i,j],car.cap,Dens.Dep)
      f.ran<-dd.adj(s.params[6],pop.sims.n[i,j],car.cap,Dens.Dep)
      #create the new Leslie matrix
      wte<-matrix(c(0,0,0,0,0,f.ran,s1.ran,0,0,0,0,0,0,s2.ran,0,0,0,0,0,0,s3.ran,0,0,0,
0,0,0,s4.ran,0,0, 0,0,0,0,0,v.ran,v.ran), nrow=6, byrow=TRUE)
      #run forwards 1 year and get the numbers per age class
      p<-pop.projection(wte,n, 2)
      n<-p$stage.vectors[,2]
      #reduce the number of pairs by the additional mortality rate
      n.sa<-n[-6]      #lose adults
      sub.ads<-sum(n.sa)      #number of SAs
      n.sa.p<-n.sa/sub.ads    #proportions in each age class
      n.sa.killed<-sub.ads*(p.Imm*mortality[i])      # find number of SA killed
      n.sa.kill.age<-n.sa.killed * n.sa.p            # split up the deaths by age class
      n[1:5]<-n.sa-n.sa.kill.age                     #SAs after mortality
      n.ad.killed<- n[6]*(p.Ad*mortality[i]) #adults killed
      n[6]<-n[6]- n.ad.killed
      #store the results
      pop.r<- p$lambda  #current growth rate
      pop.sims.r[i,j]<-pop.r
      pop.sims.n[i+1,j]<-sum(n)
      pop.sims.ad.n[i+1,j]<- n[6]
      pop.sims.sa.killed[i,j]<- n.sa.killed
      pop.sims.ad.killed[i,j]<- n.ad.killed
    }
    # Store results for each 'number killed' setting
    iter.res <- list(sims.r=pop.sims.r, sims.n=pop.sims.n, sims.ad.n=pop.sims.ad.n,
kill.sa=pop.sims.sa.killed, kill.ad=pop.sims.ad.killed)
  }
  ## Add to overall results as list within list - all lists have the same format
  WTE.res.list[[offset+1]] <- iter.res
  offset<-offset+1
}
names(WTE.res.list) <- paste('kill', names(kill.vect), sep='.')


## Changing Mortality as population changes
offset=0 #for results column
nsims <- 1000
simyears<-21
WTE.res.list.change <- vector(mode="list", length=2)
kill.vect.change <- data.frame('none'=0, 'Estimate'=collision.mortality$Operational_Estimates)
p0<-pop.projection(wte,n0, simyears+1) # deterministic and no mortality
for(k.pct in 1:ncol(kill.vect.change)){
  mortality=kill.vect.change[,k.pct] #% collision risk from operational windfarms
```

```
  ## Create matrices to store parameters for each year of each simulation
  #store for results all simulations - growth rate
  pop.sims.r<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store for results all simulations - population size
  pop.sims.ad.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store for results all simulations - sub-adult deaths
  pop.sims.sa.killed<-matrix(nrow=simyears,ncol=nsims)
  #store for results all simulations - adult deaths
  pop.sims.ad.killed<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.r[1,]<-0
  pop.sims.n[1,]<-sum(n0)
  pop.sims.ad.n[1,] <- n0[6]
  for(j in 1:nsims){
    n<-n0
    #run a single simulation for x years
    for(i in 1:simyears){
      s.params<-params.r(params)      #generate some random values within limits
      #if DD is opertating adjust the parameter values as appropriate
      s1.ran<-dd.adj(s.params[1],pop.sims.n[i,j],car.cap,Dens.Dep)
      s2.ran<-dd.adj(s.params[2],pop.sims.n[i,j],car.cap,Dens.Dep)
      s3.ran<-dd.adj(s.params[3],pop.sims.n[i,j],car.cap,Dens.Dep)
      s4.ran<-dd.adj(s.params[4],pop.sims.n[i,j],car.cap,Dens.Dep)
      v.ran<-dd.adj(s.params[5],pop.sims.n[i,j],car.cap,Dens.Dep)
      f.ran<-dd.adj(s.params[6],pop.sims.n[i,j],car.cap,Dens.Dep)
      #create the new Leslie matrix
      wte<-matrix(c(0,0,0,0,0,f.ran, s1.ran,0,0,0,0,0, 0,s2.ran,0,0,0,0,
                    0,0,s3.ran,0,0,0,0,0,0,s4.ran,0,0,0,0,0,0,v.ran,v.ran),nrow=6, byrow=TRUE)
      #run forwards 1 year and get the numbers per age class
      p<-pop.projection(wte,n, 2)
      n<-p$stage.vectors[,2]
      if(i < 8){
        mortality.ann <- mortality[i]/n[6]
      }
      if(i >= 8 & i < 10){
        pop.change <- n[6]/pop.sims.ad.n[7,j]
        #Change in population since 2007 when Edinbane became operational
        mortality.ann <- (mortality[i-1] * pop.change)/n[6]
        mortality[i] <- mortality.ann
      }
      if(i == 10){
        mortality.ann <- (mortality[i-1] + 0.039)/n[6]
        ### Additional mortality as Loch Carnan (Lochdar Hill) becomes operational
        mortality[i] <- mortality.ann
      }
      if(i > 10){
        pop.change <- n[6]/pop.sims.ad.n[10,j]
        #Change in population since 2010 when Loch Carnan (Lochdar Hill) became operational
        mortality.ann <- (mortality[i-1] * pop.change)/n[6]
        mortality[i] <- mortality.ann
      }
      #reduce the number of immatures and pairs by the additional mortality rate
      n.sa<-n[-6]             #lose adults
      sub.ads<-sum(n.sa)      #number of SAs
      n.sa.p<-n.sa/sub.ads                      # proportions in each age class
      n.sa.killed<-sub.ads*(p.Imm*mortality.ann)     # find number of SA killed
      n.sa.kill.age<-n.sa.killed * n.sa.p            # split up the deaths by age class
      n[1:5]<-n.sa-n.sa.kill.age                     # SAs after mortality
      n.ad.killed<- n[6]*(p.Ad*mortality.ann)        # adults killed
      n[6]<-n[6]- n.ad.killed
      #store the results
      pop.r<- p$lambda  #current growth rate
      pop.sims.r[i,j]<-pop.r
      pop.sims.n[i+1,j]<-sum(n)
      pop.sims.ad.n[i+1,j]<- n[6]
      pop.sims.sa.killed[i,j]<- n.sa.killed
      pop.sims.ad.killed[i,j]<- n.ad.killed
    }
    # Store results for each 'number killed' setting
    iter.res.change <- list(sims.r=pop.sims.r, sims.n=pop.sims.n, sims.ad.n=pop.sims.ad.n,
kill.sa=pop.sims.sa.killed, kill.ad=pop.sims.ad.killed)
```

```
  }
  ## Add to overall results as list within list - all lists have the same format
  WTE.res.list.change[[offset+1]] <- iter.res.change
  offset<-offset+1
}
names(WTE.res.list.change) <- paste('kill', names(kill.vect.change), sep='.')


# Scottish pairs
WTE.scot.sansom <- read.csv('../WTE_pop_sansom.csv')

Years.sim <- 2004:2025
png('WTE_PVA_Collisions_Plots_v2_OPERATIONAL.png', height=2000, width=2000, res=300)
layout(matrix(c(1, 2, 3, 4), ncol=2, byrow=TRUE))
par(mar=c(5, 5, 1, 1))
pva.plot(WTE.res.list[['kill.none']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0,400))
# No birds killed
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population - Sansom
mtext('(a)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list[['kill.Estimate']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0,400))
# Cumulative Collision Risk Estimates
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(b)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list[['kill.Corrected.Estimate']][['sims.ad.n']], start.year=2004,
end.year=2025, ylim=c(0, 400))
# Cumulative Collision risk estimates corrected for time - overall change
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(c)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.change[['kill.Estimate']][['sims.ad.n']], start.year=2004,
end.year=2025, ylim=c(0, 400))
# Cumulative Collision risk estimates corrected for time year on year
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(d)', 3, line=-1.2, adj=0.01)
dev.off()

## Exporing percentage changes in mortality
offset=0 #for results column
nsims <- 1000
simyears<-21
WTE.res.list.pc <- vector(mode="list", length=6)
kill.vect.pc <- data.frame('none'=0,
                           'One'=0.01,
                           'Three'=0.03,
                           'Five'=0.05,
                           'Eight'=0.08,
                           'Twelve'=0.12)
p0<-pop.projection(wte,n0, simyears+1) # deterministic and no mortality
for(k.pct in 1:ncol(kill.vect.pc)){
  mortality=kill.vect.pc[,k.pct]       #% collision risk from operational windfarms
  reduce=1-mortality
  ## Create matrices to store parameters for each year of each simulation
  #store for results all simulations - growth rate
  pop.sims.r<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store for results all simulations - population size
  pop.sims.ad.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store for results all simulations - sub-adult deaths
  pop.sims.sa.killed<-matrix(nrow=simyears,ncol=nsims)
  #store for results all simulations - adult deaths
  pop.sims.ad.killed<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.r[1,]<-0
  pop.sims.n[1,]<-sum(n0)
  pop.sims.ad.n[1,] <- n0[6]
  for(j in 1:nsims){
    n<-n0
```

```
    #run a single simulation for x years
    for(i in 1:simyears){
      s.params<-params.r(params)      #generate some random values within limits
      #if DD is opertating adjust the parameter values as appropriate
      s1.ran<-dd.adj(s.params[1],pop.sims.n[i,j],car.cap,Dens.Dep)
      s2.ran<-dd.adj(s.params[2],pop.sims.n[i,j],car.cap,Dens.Dep)
      s3.ran<-dd.adj(s.params[3],pop.sims.n[i,j],car.cap,Dens.Dep)
      s4.ran<-dd.adj(s.params[4],pop.sims.n[i,j],car.cap,Dens.Dep)
      v.ran<-dd.adj(s.params[5],pop.sims.n[i,j],car.cap,Dens.Dep)
      f.ran<-dd.adj(s.params[6],pop.sims.n[i,j],car.cap,Dens.Dep)
      #create the new Leslie matrix
      wte<-matrix(c(0,0,0,0,0,f.ran, s1.ran,0,0,0,0,0, 0,s2.ran,0,0,0,0,
                    0,0,s3.ran,0,0,0, 0,0,0,s4.ran,0,0, 0,0,0,0,v.ran,v.ran), nrow=6,
byrow=TRUE)
      #run forwards 1 year and get the numbers per age class
      p<-pop.projection(wte,n, 2)
      n<-p$stage.vectors[,2]
      #reduce the number of pairs by the additional mortality rate
      n.sa<-n[-6]                     #lose adults
      sub.ads<-sum(n.sa)                      #number of SAs
      n.sa.p<-n.sa/sub.ads            #proportions in each age class
      n.sa.killed<-sub.ads*(p.Imm*mortality)         # find number of SA killed
      n.sa.kill.age<-n.sa.killed * n.sa.p            # split up the deaths by age class
      n[1:5]<-n.sa-n.sa.kill.age                     # SAs after mortality
      n.ad.killed<- n[6]*(p.Ad*mortality)            # adults killed
      n[6]<-n[6]- n.ad.killed
      #store the results
      pop.r<- p$lambda  #current growth rate
      pop.sims.r[i,j]<-pop.r
      pop.sims.n[i+1,j]<-sum(n)
      pop.sims.ad.n[i+1,j]<- n[6]
      pop.sims.sa.killed[i,j]<- n.sa.killed
      pop.sims.ad.killed[i,j]<- n.ad.killed
    }
    # Store results for each 'number killed' setting
    iter.res.pc <- list(sims.r=pop.sims.r, sims.n=pop.sims.n, sims.ad.n=pop.sims.ad.n,
kill.sa=pop.sims.sa.killed, kill.ad=pop.sims.ad.killed)
  }
  ## Add to overall results as list within list - all lists have the same format
  WTE.res.list.pc[[offset+1]] <- iter.res.pc
  offset<-offset+1
}
names(WTE.res.list.pc) <- paste('kill', names(kill.vect.pc), sep='.')

WTE.scot.sansom <- read.csv('../WTE_pop_sansom.csv')

Years.sim <- 2004:2025
png('WTE_PVA_Collisions_Plots_v2_OPERATIONAL_PERCENTAGE.png', height=2000, width=2000,
res=300)
layout(matrix(c(1, 2, 3, 4,5, 6), ncol=2, byrow=TRUE))
par(mar=c(5, 5, 1, 1))
pva.plot(WTE.res.list.pc[['kill.none']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0,400))
# No birds killed
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population - Sansom
mtext('(a)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.pc[['kill.One']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0,400))
# 1% Mortality
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(b)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.pc[['kill.Three']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0, 400))
# 3% Mortality
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(c)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.pc[['kill.Five']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0, 400))
```

```
# 5% Mortality
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(d)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.pc[['kill.Eight']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0, 400))
# 8% Mortality
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(e)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.pc[['kill.Twelve']][['sims.ad.n']], start.year=2004, end.year=2025,
ylim=c(0, 400))
# 12% Mortality
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(f)', 3, line=-1.2, adj=0.01)
dev.off()

## Exploring increased mortality due to spatial spread of WTE
offset=0 #for results column
nsims <- 1000
simyears<-21
WTE.res.list.spat<- vector(mode="list", length=4)
kill.vect.spatial <- data.frame('none'=0,
          'Estimate'=collision.mortality$ES.Op.Prop,
          'Estimate.LC'=collision.mortality$Change.Op.Prop.LC,
          'Estimate.ED'=collision.mortality$Change.Op.Prop.ED)
p0<-pop.projection(wte,n0, simyears+1) # deterministic and no mortality
for(k.pct in 1:ncol(kill.vect.spatial)){
  mortality=kill.vect.spatial[,k.pct] #% collision risk from operational windfarms
  reduce=1-mortality
  ## Create matrices to store parameters for each year of each simulation
  #store results all simulations - growth rate
  pop.sims.r<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store results all simulations - population size
  pop.sims.ad.n<-matrix(nrow=simyears+1,ncol=nsims)
  #store results all simulations - sub-adult deaths
  pop.sims.sa.killed<-matrix(nrow=simyears,ncol=nsims)
  #store results all simulations - sub-adult deaths
  pop.sims.ad.killed<-matrix(nrow=simyears,ncol=nsims)
  pop.sims.r[1,]<-0
  pop.sims.n[1,]<-sum(n0)
  pop.sims.ad.n[1,] <- n0[6]
  for(j in 1:nsims){
    n<-n0
    #run a single simulation for x years
    for(i in 1:simyears){
      s.params<-params.r(params)      #generate some random values within limits
      #if DD is opertating adjust the parameter values as appropriate
      s1.ran<-dd.adj(s.params[1],pop.sims.n[i,j],car.cap,Dens.Dep)
      s2.ran<-dd.adj(s.params[2],pop.sims.n[i,j],car.cap,Dens.Dep)
      s3.ran<-dd.adj(s.params[3],pop.sims.n[i,j],car.cap,Dens.Dep)
      s4.ran<-dd.adj(s.params[4],pop.sims.n[i,j],car.cap,Dens.Dep)
      v.ran<-dd.adj(s.params[5],pop.sims.n[i,j],car.cap,Dens.Dep)
      f.ran<-dd.adj(s.params[6],pop.sims.n[i,j],car.cap,Dens.Dep)
      #create the new Leslie matrix
      wte<-matrix(c(0,0,0,0,0,f.ran, s1.ran,0,0,0,0,0, 0,s2.ran,0,0,0,0,
                    0,0,s3.ran,0,0,0,0,0,0,s4.ran,0,0,0,0,0,0,v.ran,v.ran),nrow=6, byrow=TRUE)
      #run forwards 1 year and get the numbers per age class
      p<-pop.projection(wte,n, 2)
      n<-p$stage.vectors[,2]
      #reduce the number of pairs by the additional mortality rate
      n.sa<-n[-6]             #lose adults
      sub.ads<-sum(n.sa)              #number of SAs
      n.sa.p<-n.sa/sub.ads    #proportions in each age class
      n.sa.killed<-sub.ads*(p.Imm*mortality[i])      # find number of SA killed
      n.sa.kill.age<-n.sa.killed * n.sa.p            # split up the deaths by age class
      n[1:5]<-n.sa-n.sa.kill.age                     # SAs after mortality
      n.ad.killed<- n[6]*(p.Ad*mortality[i]) # adults killed
      n[6]<-n[6]- n.ad.killed
```

```
      #store the results
      pop.r<- p$lambda  #current growth rate
      pop.sims.r[i,j]<-pop.r
      pop.sims.n[i+1,j]<-sum(n)
      pop.sims.ad.n[i+1,j]<- n[6]
      pop.sims.sa.killed[i,j]<- n.sa.killed
      pop.sims.ad.killed[i,j]<- n.ad.killed
    }
    # Store results for each 'number killed' setting
    iter.res.spat<- list(sims.r=pop.sims.r, sims.n=pop.sims.n, sims.ad.n=pop.sims.ad.n,
kill.sa=pop.sims.sa.killed, kill.ad=pop.sims.ad.killed)
  }
  ## Add to overall results as list within list - all lists have the same format
  WTE.res.list.spat[[offset+1]] <- iter.res.spat
  offset<-offset+1
}
names(WTE.res.list.spat) <- paste('kill', names(kill.vect.spatial), sep='.')

png('WTE_PVA_Collisions_Plots_v2_OPERATIONAL_SPATIAL.png', height=2000, width=2000, res=300)
layout(matrix(c(1, 2, 3, 4), ncol=2, byrow=TRUE))
par(mar=c(5, 5, 1, 1))
pva.plot(WTE.res.list.spat[['kill.none']][['sims.ad.n']],start.year=2004,end.year=2025,ylim=c(
0,400))
# No birds killed
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population - Sansom
mtext('(a)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.spat[['kill.Estimate']][['sims.ad.n']],start.year=2004,end.year=2025,yli
m=c(0,400))
# Cumulative Collision Risk Estimates
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(b)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.spat[['kill.Estimate.LC']][['sims.ad.n']],start.year=2004,end.year=2025,
ylim=c(0, 400))
# Cumulative Collision risk estimates including all operational windfarms with WTE activity
based on level at Loch Carnan
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(c)', 3, line=-1.2, adj=0.01)
pva.plot(WTE.res.list.spat[['kill.Estimate.ED']][['sims.ad.n']],start.year=2004,end.year=2025,
ylim=c(0, 400))
# Cumulative Collision risk estimates including all operational windfarms with WTE activity
based on level at Edinbane
lines(pairs ~ Years.sim, type='l', data=WTE.scot.sansom, col='blue', lwd=2)
# Actual population
mtext('(d)', 3, line=-1.2, adj=0.01)
dev.off()
```

Data Files used in R Code

Operational_Collision_Risk_Estimates.csv

Year	Operational_Estimates	Corrected.Operational.Estimates	Change.Estimate.LC	Change.Estimate.ED	WTE.pop	ES.Op.Prop	Es.Corr.Op.Prop	Change.Op.Prop.LC	Change.Op.Prop.ED
2004	0.0000	0.0000	0.0000	0.000	29.9	0.00000000	0.00000000	0.00000000	0.00000000
2005	0.0000	0.0000	0.1545	0.375	33.0	0.00000000	0.00000000	0.00468182	0.01136364
2006	0.0000	0.0000	0.1545	0.375	35.7	0.00000000	0.00000000	0.00432773	0.01050420
2007	0.0000	0.0000	0.1545	0.375	38.9	0.00000000	0.00000000	0.00397172	0.00964010
2008	0.0000	0.0000	0.1545	0.375	43.3	0.00000000	0.00000000	0.00356813	0.00866051
2009	0.0000	0.0000	0.1545	0.375	47.8	0.00000000	0.00000000	0.00323222	0.00784519
2010	0.1500	0.1500	0.8034	1.950	51.9	0.00289017	0.00289017	0.01547977	0.03757225
2011	0.1500	0.1950	0.8034	1.950	56.4	0.00265957	0.00345745	0.01424468	0.03457447
2012	0.1500	0.2100	0.8034	1.950	64.0	0.00234375	0.00328125	0.01255313	0.03046875
2013	0.1890	0.2640	0.8034	1.950	71.6	0.00263966	0.00368715	0.01122067	0.02723464
2014	0.1890	0.3024	0.8034	1.950	79.7	0.00237139	0.00379423	0.01008030	0.02446675
2015	0.1890	0.3213	1.3905	3.375	89.2	0.00211883	0.00360202	0.01558857	0.03783632
2016	0.1890	0.3402	1.3905	3.375	98.6	0.00191684	0.00345030	0.01410243	0.03422921
2017	0.1890	0.3591	1.3905	3.375	108.0	0.00175000	0.00332500	0.01287500	0.03125000
2018	0.1890	0.3780	1.3905	3.375	117.0	0.00161538	0.00323077	0.01188462	0.02884615
2019	0.1890	0.3969	1.3905	3.375	129.6	0.00145833	0.00306250	0.01072917	0.02604167
2020	0.1890	0.4158	3.1827	7.725	139.9	0.00135096	0.00297212	0.02274982	0.05521801
2021	0.1890	0.4347	3.1827	7.725	153.0	0.00123529	0.00284118	0.02080196	0.05049020
2022	0.1890	0.4536	3.1827	7.725	167.8	0.00112634	0.00270322	0.01896722	0.04603695
2023	0.1890	0.4725	3.1827	7.725	183.9	0.00102773	0.00256933	0.01730669	0.04200653
2024	0.1890	0.4914	3.1827	7.725	201.5	0.00093797	0.00243871	0.01579504	0.03833747
2025	0.1890	0.5103	3.1827	7.725	221.2	0.00085443	0.00230696	0.01438834	0.03492315

WTE_pop_sansom.csv

year	pairs
2004	29.9
2005	33.0
2006	35.7
2007	38.9
2008	43.3
2009	47.8
2010	51.9
2011	56.4
2012	64.0
2013	71.6
2014	79.7
2015	89.2
2016	98.6
2017	108.0
2018	117.0
2019	129.6
2020	139.9
2021	153.0
2022	167.8
2023	183.9
2024	201.5
2025	221.2