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## Bhlaraidh Extension Wind Farm

### Appendix 6.3 Golden Eagle Population Modelling

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## 1 INTRODUCTION

Population modelling has been used to assess potential impacts for some Scottish wind farm projects where golden eagle has been identified as a sensitive receptor, and has commonly been based on the golden eagle population modelling (GEPM) methods used in Whitfield *et al.* (2006<sup>i</sup>; 2008<sup>ii</sup>); Fielding and Haworth (2010<sup>iii</sup>) and Haworth (2014<sup>iv</sup>). The GEPM procedure has been used for assessing the potential effects of the proposed Bhlaraidh Wind Farm Extension (the ‘Proposed Development’). The model uses a deterministic matrix formulation and can be used to explore how additional eagle mortality may affect predicted growth rates of the Natural Heritage Zone (NHZ) 7: Northern Highlands’ golden eagle population.

There are four key parameters in the model:

- Number of occupied ranges;
- Mean number of young fledged per pair per year;
- Annual survival rate of young birds; and
- Annual survival rate of adult, range-holding birds.

Estimates for the first two are available with a reasonably high degree of confidence at an NHZ 7 level. The latter two are more difficult to estimate at the level of individual NHZ populations and therefore the values for these have been informed by studies conducted on other populations, in combination with regional information, such as trends in the number of occupied ranges, which can be used to modify their values (Haworth, 2014<sup>iv</sup>).

Only the female half of the population is modelled. Therefore, calculated collision rates were halved, assuming a 1:1 sex ratio, equal activity and equal risk of collision.

Fielding and Haworth (2010<sup>iii</sup>) describe how alternative scenarios can be modelled to obtain predicted rates of population growth over a duration of 25 years, with or without a proposed wind farm and with varying rates of additional mortality on adults and/or sub-adults. The predicted population growth rate, the expected number of occupied territories after a period of 25 years and the time to reach a notional population target (e.g., the level associated with the wider concept of “Favourable Conservation Status” outlined below) can be reviewed whilst varying levels of additional mortality.

The parameter ranges considered in the GEPM for assessing the potential impacts of the Proposed Development and other wind farms cumulatively are outlined in turn in **Table 6.3.1** and detailed in the text below.

Table 6.3.1 Parameters used in the GEPM

Parameter	Golden Eagle Conservation Framework Report 2008	Values to be used in GEPM	Rationale			
Number of pairs within NHZ 7	45	49	Highland Raptor Study Group data estimated a minimum of 49 pairs within NHZ 7 in 2019; up from 45 pairs from the national census in 2003.			
Total number of ranges within NHZ 7	90	90	Highland Raptor Study Group did not provide an updated estimate of number of ranges in 2019, and so estimate from the national census in 2003 has been used in the GEPM.			
Favourable Conservation Status of NHZ 7: Occupancy	60	60	66% occupancy rate of total available ranges within NHZ 7.			
S1 – survival rate from fledging to age 4 (note this is not the annual rate but the product of 4 annual rates)	0.400	0.250 0.2725 0.300 0.350 0.400	0.2725 for ages 0-4 combined (annual survival of 0.7225 <sup>4</sup> ) is the value extrapolated from the model, based on the best fit of observed population growth from 2003 (45 pairs) to 2019 (49 pairs), using the predicted adult survival (0.9512) and mean productivity (0.462) rates for this period. 0.400 was used by Whitfield <i>et al.</i> (2008 <sup>ii</sup> ) and Haworth (2014 <sup>iv</sup> ). This equates to a 40% survival from fledging to adulthood (annual survival of 0.795 <sup>4</sup> ). This was considered to be the minimal sub-adult survival rate which would predict stability or expansion for any credible measure of productivity which has been identified.			
S2 – adult survival (note this is the annual rate)	0.9512	0.9512	0.9512 was used by Whitfield <i>et al.</i> (2006 <sup>i</sup> ; 2008 <sup>ii</sup> ) and Haworth (2014 <sup>iv</sup> ). This is a precautionary estimate which equates to a minimal adult survival rate (20 years of occupation) which predicts stability or expansion for any credible measure of productivity which has been identified. No NHZ-specific information is available.			
Mean fledging rate per pair within NHZ 7 (both sexes)	0.83 (2003 census) and 0.47 (mean 1982, 1992, 2003 censuses)	0.28	NHZ 7 productivity in 2003 national census. This was relatively low compared to other NHZs assessed in this year.			
		0.330	Mean productivity from 1982, 1992 and 2003 national censuses, as outlined in the Golden Eagle Conservation Framework. NHZ 7 mean productivity in 1982, 1992 and 2003 was 0.42, 0.29 and 0.28 respectively.			
		0.435	Mean of all available results for NHZ 7 population. From 1982, 1992, 2003, 2015-2019 monitoring.			
		0.462	Mean of all available results for NHZ 7 population in recent times. From 2003 and 2015-2019 monitoring.			
		0.498	From Highland Raptor Study Group data. Mean of 2015-2019 counts:			
			<b>Year</b>	<b>Territorial pairs monitored</b>	<b>Chicks</b>	<b>Chicks per monitored pair</b>
			2015	47	16	0.34
			2016	16	3	0.19
2017	27		17	0.63		
2018	27	23	0.85			
2019	25	12	0.48			

## 2 CONSERVATION STATUS OF NHZ 7: CENTRAL HIGHLANDS

Whitfield *et al.* (2008<sup>ii</sup>) devised three tests that should be applied to a golden eagle population to assess its conservation status. All three tests must be passed to achieve a favourable status.

1. Regionally, at least 66% of known territories should be occupied by pairs.
2. Demographic parameter values should allow the maintenance of a stable or expanding population. With limited information available on survival rates, an annual adult survival of 95.12% was adopted as the lower limit for a favourable conservation status classification. This equates to an expected 20 years of territory occupation by an adult. A minimum acceptable rate for sub-adult survival of 40% (across the first four years of life which equates to an annual survival rate of 79.5%) was used. Under these survival rates an average reproductive rate of about 0.28 fledglings per pair per year is the minimum required to maintain a stable population (i.e., a growth rate of 1). It follows, however, that if these parameter values varied regionally then lower rates in one parameter could be compensated for, to a degree, by higher rates in another parameter.
3. Compare the predicted population projections from the population model against the observed trends in the number of occupied territories from previous censuses. If the observed population trend failed to match predictions then the survival rates applied in the Level 2 test were probably too high (for example, if stability or increase was predicted but decline was observed). Under these circumstances it would be assumed that survival was below the lower limit for favourable status and the population would be deemed to have failed the Level 3 test.

The NHZ 7: Northern Highlands' golden eagle population was determined by Whitfield *et al.* (2008<sup>ii</sup>) to be in unfavourable conservation status.

The population failed the Level 1 test because, in 2003, only 45 ranges out of 90 known at that time were occupied, meaning that another 15 needed to be reoccupied for the NHZ to pass the Level 1 test.

For the Level 2 test, Whitfield *et al.* (2008<sup>ii</sup>) ran a population model for the NHZ with a starting population set at the 2003 level, and with a capped population set at the number of known territories. The output was the mean predicted number of occupied territories after 21- 30 years averaged over 100 simulated runs using randomly generated parameter values. NHZ 7 passed both Level 2 tests with observed fledging rates of 0.37 (mean for the 1982, 1992 and 2003 national surveys) and 0.28 for the 2003 national survey (i.e., at or above the minimum mean reproductive rate of 0.28).

The NHZ 7 population passed the Level 3 test, but it was noted that there was some uncertainty in this conclusion.

The main factors believed to be restricting growth of the NHZ 7 population were identified as over-grazing by red deer *Cervus elaphus*, persecution, recreation and afforestation.

As the level 1 test was failed, the NHZ 7 population was considered to be in Unfavourable Conservation Status in 2008.

## 3 GEPM INPUT PARAMETERS

### 3.1 Level 1 Test: Number of Currently Occupied Ranges

In Whitfield *et al.* (2008<sup>ii</sup>) a target of 66% occupation of known territories was prescribed before each NHZ population could be considered to be in favourable condition. For the NHZ 7 population, this would be 60 out of a possible 90 known territories. It is therefore considered that currently the Level 1 Favourable Conservation Status threshold remains unmet as most recent evidence in 2019 suggests that 49 territories are occupied.

### 3.2 Level 2 Test: Survival Rates

Survival rates specific to the NHZ 7 population are unknown and so precautionary values for S1 (sub-adult) and S2 (adult) survival rates were used in the model, taken from the following sources:

- **S2 survival: 0.9512** was used in Whitfield *et al.* (2008<sup>ii</sup>) for various NHZs. This was defined as the lowest rate for attaining favourable conservation status used in Whitfield *et al.* (2006<sup>i</sup>).
- **S1 survival:** a four-year survival rate of **0.2725** for survival from ages 0-4 (equating to annual survival of 0.7225) was derived using the model to match the observed increased population growth from 2003 to 2019, with conservative adult survival (0.9512) and the long-term mean observed productivity rates this period (0.435). This is lower than the national mean survival rate of 0.400 used in the Golden Eagle Conservation Framework model, which was defined as the lowest rate for attaining favourable conservation status used in Whitfield *et al.* (2006<sup>i</sup>), in combination with the S2 survival rate above.

To simulate carrying capacity in the GEPM a cap of 90 was placed on the number of pairs. Once this population size is achieved in the model the growth rate becomes 1 (i.e., stable), whereafter, all excess individuals would have to be recruited to neighbouring NHZ populations to breed. Consequently, the rates of growth refer to the period of growth prior to this limit being attained. These were calculated as the average of the annual rates, but omitted the first 3 annual values as these reflect starting conditions in the model and not the stable growth rate (Caswell 2001<sup>v</sup>).

### 3.3 Level 2 Test: Mean Fledging Rate

The mean fledging rate of 0.498 was based on values provided in the most recent five years of monitoring within NHZ 7 (2015 to 2019), as per **Table 6.3.1**.

## 4 RESULTS OF THE GEPM

### 4.1 Baseline Scenario

With the more recent data now available, an updated evaluation of the current conservation status of the NHZ 7 population can be made, within the context of the three tests described above.

1. Occupancy: based on results of the most recent census, a minimum of 49 out of a possible 90 territories are likely to be currently occupied within NHZ 7, resulting in an occupancy rate of 54%, thereby failing to meet the minimum 66% occupancy rate: **Unfavourable Conservation Status**.
2. The mean productivity per pair is currently around 0.498 (0.249 females per pair), based on 2015 to 2019 results. Using the precautionary survival rates (S1 = 0.2725; s2 = 0.9512) population growth would be

around 1.012 (1.2%) per year (**Table 6.3.1**), leading to 60 territories being occupied by year 23, and 61.8 territories occupied in year 25: **Favourable Conservation Status**.

- The predicted growth rates correspond to the gradual growth between the 2003 and 2015 censuses, and the recent further population estimate provided by the Highland Raptor Study Group (e.g., an increase in the NHZ 7 population from 45 pairs in 2003, to 47 pairs in 2015 and 49 pairs in 2019): **Favourable Conservation Status**.

This means that despite productivity and survival appearing to reach favourable levels, limiting factors on the territory occupancy rates (previously identified as grazing, persecution recreation and afforestation by Whitfield *et al.* 2008<sup>ii</sup>) appear to still be keeping the NHZ 7 population in **Unfavourable Conservation Status**.

**Table 6.3.1 Growth rate predictions of NHZ 7 golden eagle population under baseline scenario (excluding any effects associated with the Proposed Development).**

		Mean fledging rate				
		0.280	0.330	0.435	0.462	0.498
S1 survival rate	0.250	0.986	0.992	1.002	1.005	1.008
	0.2725	0.989	0.995	1.006	1.009	1.012
	0.300	0.992	0.999	1.010	1.013	1.017
	0.350	0.998	1.005	1.018	1.021	1.026
	0.400	1.004	1.011	1.026	1.029	1.030

Growth rates above 1.00 indicate population increase, rates below 1.00 indicate decline. A rate of 1.05 for example, indicates 5% annual growth. Note that these growth rates only apply until the population attains the carrying capacity (90 pairs).

#### 4.2 With Additional Mortality due to Predicted Collisions at the Proposed Development

The collision model mean annual mortality prediction of 0.180 birds per year due to the Proposed Development was included in the GEPM as an additional source of mortality to the NHZ 7 population (note this was halved to account for female only collisions). Using the mean fledging rate of 0.498, and a precautionary S1 survival rate of 0.2725, the population growth rate declined slightly from 1.2% to 1.1%, and there was an extension to the period taken for the 66% favourable occupancy rate (60 pairs) to be attained from 23 to 26 years.

**Table 6.3.2 Growth rate predictions of NHZ 7 golden eagle population with a mean annual collision rate of 0.180 associated with the Proposed Development.**

		Mean fledging rate				
		0.280	0.330	0.435	0.462	0.498
S1 survival rate	0.250	0.984	0.990	1.000	1.003	1.007
	0.2725	0.987	0.993	1.004	1.007	1.011
	0.300	0.991	0.997	1.009	1.012	1.016
	0.350	0.996	1.003	1.017	1.020	1.024
	0.400	1.002	1.010	1.024	1.028	1.030

This demonstrates that the NHZ 7 golden eagle population would be expected to continue to expand despite the additional mortality predicted to be associated with collisions with turbines at the Proposed Development.

#### 4.3 With NHZ 7 Cumulative Annual Collision Rate

A worst-case cumulative annual collision rate for all other installed, constructed, consented or application stage wind farm projects, including the Proposed Development, within NHZ 7 was estimated to be 0.547 collisions per year (assuming all collisions are attributable to NHZ 7 adult birds) for both sexes (i.e., 0.273 females).

Using this value, the annual population growth rate was reduced from 1.2% to 0.8% based on an S1 survival rate of 0.2725 (**Table 6.3.3**). At this rate of growth, the 66% occupancy rate would be achieved after year 25, probably after around 30 years.

**Table 6.3.3 Growth rate predictions of NHZ 7 golden eagle population with a mean annual cumulative collision rate of 0.547 associated with all NHZ 7 projects.**

		Mean fledging rate				
		0.280	0.330	0.435	0.462	0.498
S1 survival rate	0.250	0.980	0.986	0.997	1.000	1.003
	0.2725	0.983	0.989	1.001	1.004	1.008
	0.300	0.987	0.993	1.006	1.009	1.013
	0.350	0.993	1.000	1.014	1.018	1.022
	0.400	0.999	1.007	1.022	1.026	1.030

The model predicts continued growth in the majority of modelled scenarios, with the exception of the most precautionary fledging and S1 survival rates. This suggests that the NHZ 7 golden eagle population is likely to continue to increase, despite the additional mortality predicted to be associated with collisions with turbines at the Proposed Development and other projects within NHZ 7.

## 5 SUMMARY AND CONCLUSIONS

Based on the gradual increase in number of occupied territories between 2003 and 2019, but ongoing low occupancy rates, the NHZ 7 golden eagle population is currently considered to be in unfavourable conservation status. Modelling of the potential effects of collisions on the population suggest that:

- Under a baseline scenario (zero collisions) growth would continue slowly, and the 66% occupancy rate would be met around 23 years from now.
- With additional mortality due to predicted collisions with turbines at the Proposed Development (0.180 per year) is taken into consideration, population growth would decline slightly from 1.2% to 1.1%. This would delay the 66% occupancy rate being reached by around three years.
- With cumulative collision mortality from the Proposed Development and all other wind farm projects within NHZ 7 (0.547 per year), population growth would still occur under most combinations of demographic rates, albeit with an increase in duration for 66% occupancy rate to be attained, at around year 30.

- With continued gradual growth predicted, despite additional mortality associated with collisions due to the Proposed Development and other projects, it is predicted that occupancy rates would increase, and Favourable Conservation Status would still be attained over the long-term, and there would be no significant effects on the NHZ 7 population as a result of additional mortality associated with collisions.

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<sup>i</sup> Whitfield, D. P., Fielding, A. H., McLeod, D. R. A., Haworth, P. F. & Watson, J. 2006. A conservation framework for the golden eagle in Scotland: refining condition targets and assessment of constraint influences. *Biological Conservation*, 130(4), 465-480.

<sup>ii</sup> Whitfield, D P, Fielding, A H, McLeod, D R A and Haworth, P F (2008). A conservation framework for golden eagles: implications for their conservation and management in Scotland. Scottish Natural Heritage.

<sup>iii</sup> Fielding, A. and Haworth, P. (2010). Golden eagles and wind farms: A report created under an SNH Call-of-Contract Arrangement. Haworth Conservation.

<sup>iv</sup> Haworth, P. (2014). The Dunmaglass Wind Farm Regional Eagle Conservation Management Plan. Haworth Conservation.

<sup>v</sup> Caswell, H. (2001) *Matrix Population Models*. Sinauer Associates, Inc., Sunderland, MA.