Appendix 9.2: Collision Risk Modelling

2023

Loch Liath Wind Farm

Appendix 9.2: Collision Risk Modelling

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February 2023

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Report Quality Assurance Log

Date	Version	Created by	Checked by
18/11/2021	1.1	Blair Urquhart	Alex Ash
16/08/2022	1.2	Blair Urquhart	Alex Ash
21/02/2023	Issue	Blair Urquhart	

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Introduction

1.1. Birds that are not displaced by the proposed development would be potentially vulnerable to collision with the turbines. The level of collision with wind turbines is presumed to be dependent on the level of flight activity over the proposed development and the ability of birds to detect and manoeuvre around rotating turbine blades. Birds that collide with a turbine are likely to be killed or fatally injured. This may in turn affect the maintenance of bird populations.

1.2. Further studies in the field of bird-windfarm research are required to establish with certainty the extent to which birds can avoid collision with wind turbines, although an increasing body of evidence suggests that avoidance capacity is very high (Whitfield & Madders, 2006[1]; Urquhart & Whitfield, 2016[2]; SNH, 2018[3]). The indications from studies are that collisions are rare events (e.g., Fielding *et al*., 2021)[4] and occur mainly at sites where there are unusual concentrations of birds and turbines, or where the behaviour of the birds' concerned leads to high-risk situations (e.g., Gill *et al*., 1996[5]; Percival, 1998[6]; de Lucas *et al.,* 2007[7]). Examples include migration flyways, and where the food resource, and therefore level of bird activity, is exceptional.

Collision Risk Modelling

1.3. The Band collision risk model (CRM) (Band *et al*., 2007)[8] was used to estimate the potential number of bird collisions likely to occur at the proposed Loch Liath Wind Farm. The model requires input data based on species biometrics and flight characteristics, turbine specification and data on flights observed at the site.

1.4. NatureScot guidance on collision risk modelling was used (SNH, 2000[9]; Band *et al*., 2007[8]). This is a three-stage process, which involves:

1) An assessment of the probability of a collision, based on a bird flying through an operational turbine; and
2) An estimation of the number of birds passing through the swept zone of the turbine blades.

Multiplying stages 1 and 2 provides an estimate of collision risk with the turbines, assuming no avoidance action. After, the third stage is applied:

[1] Madders, M. & Whitfield, D.P. (2006). Upland raptors and the assessment of wind farm impacts. Ibis, 148, pp 43-56.
[2] Urquhart, B. & Whitfield, D.P. (2016). Derivation of an avoidance rate for red kite *Milvus milvus* suitable for onshore wind farm collision risk modelling Natural Research Information Note 7. Available at https://www.natural-research.org/ecological-research-charity/our-publications
[3] Scottish Natural Heritage (SNH). (2018). Avoidance Rates for the onshore SNH Wind Farm Collision Risk Model. SNH Information and Guidance Note. Scottish Natural Heritage, Battleby.
[4] Fielding, A.H., Anderson, D., Benn, S., Dennis, R., Geary, M., Weston, E. & Whitfield, D.P. (2021). Non-territorial GPS-tagged golden eagles *Aquila chrysaetos* a two Scottish wind farms: Avoidance influenced by preferred habitat distribution, wind speed and blade motion status. PLoS ONE 16(8): e0254159. https://doi.org/10.1371/journal.pone.0254159
[5] Gill, J.P., Townsley, M. & Mudge, G.P. (1996). Review of the impacts of wind farms and other aerial structures upon birds. SNH Review 21: 68pp.
[6] Percival, S.M. (1998). Birds and Turbines: managing potential planning issues. Proc. of the 20th BWEA Conference 1998: pp 345-350.
[7] de Lucas, M., Janss, G.F.E. & Ferrer, M. (eds). (2007). Birds and Wind Power: Risk Assessment and Mitigation. Quercus, Madrid.
[8] Band, W., Madders, M., & Whitfield, D.P. (2007). Developing field and analytical methods to assess avian collision risk at wind farms. In: de Lucas, M., Janss, G.F.E. & Ferrer, M. (Eds.) Birds and Wind Farms: Risk Assessment and Mitigation, pp. 259- 275. Quercus, Madrid.
[9] SNH. (2000). Windfarms and Birds: Calculating a theoretical collision risk assuming no avoiding action. SNH Information and Guidance Note. Scottish Natural Heritage, Battleby.

3) An avoidance rate is applied (where known) to account for the fact that many species will take avoidance action.

1.5. The result of the model provides an estimate of the number of collisions that can be expected over a year or for the lifetime of the wind farm.

1.6. For the turbines proposed, the probability of a bird being struck by a turbine blade when passing through the rotor swept volume has been estimated, **assuming no avoidance** (see Appendix 1). However, it is widely accepted that birds are able to avoid turbine blades in a number of ways. Birds may exercise avoidance by detecting the wind farm or turbine and modifying their flight lines to avoid the structures (Macro avoidance). At close proximity, birds may see an oncoming blade and emergency avoidance action can be taken (Micro avoidance) (SNH, 2000)[9]. As such, an avoidance rate (SNH, 2018)[3] was applied to each model to estimate the collision risk for each species respectively.

Windfarm characteristics

1.7. The scheme has thirteen turbines and the flight risk volume (Vw), in these analyses, is based on a buffer constructed with a radius of 500 m (area = 528 ha), centred on the turbine locations with a height that was equal to the diameter of the turbine blades (155 m). The turbines used for the collision risk modelling were based on a hub height of 122.5 m, giving an overall tip height of 200 m[10]. Turbine specifications were obtained from the manufacturer[11] and are shown where relevant.

Viewsheds

1.8. Flight data were obtained from a total of four Vantage Points (VPs) that overlooked the 13-turbine layout. Viewsheds were estimated using a Digital Elevation Model (DEM) and a 20 m vertical offset above the ground surface (lowest point of rotor sweep at 45 m) (**Figure 1**). Other details of the viewshed calculation are given in **Table 1**.

Table 1. Vantage point survey effort and visible areas within the 500 m buffer drawn around the turbines.

VP No.	Visible area with 500m turbine buffer (ha)	Hours of observation between September and March (hrs)	Hours of observation between April and August (hrs)	Total hours of observation (hrs)
1	311.2	72.00	72.00	144.00
14	35.2	72.00	72.00	144.00
15	179.2	72.00	72.00	144.00
16	89.0	71.50	72.00	143.50

Flight activity within 500 m of turbines

1.9. A summary of flight activity recorded within 500 m of the proposed turbines is given in **Table 2**. All flights that passed within 500 m of the proposed turbines are shown in **Figure 2**.

Table 2. Summary of flight activity recorded within 500 m of the proposed turbines.

Species	Total flights	'At-risk' flights	No. individuals 'at-risk'	CRM undertaken
Dunlin	1	0	0	No
Golden eagle	17	16	16	**Yes**
Golden plover	5	2	7	No
Goose sp.	1	1	12	No
Greenshank	3	0	0	No
Greylag goose	1	1	10	No
Hen harrier	1	0	0	No
Merlin	1	1	1	No
Osprey	3	3	3	No
Pink-footed goose	3	3	175	No
Red kite	1	1	1	No
Red-throated diver	9	7	7	**Yes**

1.10. An 'at–risk' flight is one which passes into the 500 m turbine buffer with at least part of its flight at an altitude between 20 m and 200 m. Professional judgement was used as to whether a CRM was undertaken for each species, based on the Nature Conservation Importance of the species and the number of 'at-risk' flights or the number of individuals potentially 'at-risk'.

1.11. Details of 'at-risk' flights for consideration under a CRM are shown in **Table 3**. The total flight duration recorded during the vantage point watches was adjusted to give an estimate for the total expected over the period of occupancy by each species. The total potential flying time for each species was estimated from the sum of the day lengths of each day. Day length was estimated, for each day, using the method of Forsythe *et al*. (1995)[12] at latitude 57.3345° N.

[10] It should be noted that although three turbines have a tip height of 180 m, the rotor diameter remains the same (155 m). Therefore, as the proportion of airspace occupied by the rotors within the bands used to define 'risk height' (20-200m) remains the same for both tip heights then there is no difference in model outputs between the two turbine heights.

[11] https://www.vestas.com/en/products/turbines

[12] Forsythe, W.C., Rykiel, E.J., Stahl, R.S., Wu, H. & Schoolfield, R.M. (1995). A model comparison for day length as a function of latitude and day of year. Ecological Modelling. 80: 87 –95

Table 3. Flight durations recorded within VP viewsheds and clipped to 500 m survey buffer. Part, or all, of these flights at a height of 20 – 200 m agl places them at risk of a collision with the turbine blades (shaded columns).

Species	Season	VP No.	No. of flights	No. of birds	Total flying time (sec)	Time in height category (sec)					
						<20m	20-50m	50-100m	100-150m	150-200m	>200 m
Golden eagle	Apr-Aug	1	2	2	284		138	107	39		
		14	1	1	42	29	13				
		15	1	1	6		6				
		16	2	2	67		12		31	24	
	Sep-Mar	1	8	8	485	70	118	139	158		
		15	2	2	181			125	24		31
		16	1	1	24	24					
Golden eagle Total			**17**	**17**	**1088**	**123**	**287**	**371**	**252**	**24**	**31**
Red-throated diver	Apr-Aug	1	2	2	41	17	24				
		15	2	3	108	30	78				
		16	4	5	126	76	19		31		
	Sep-Mar	1	1	1	86		54	32			
Red-throated diver Total			**9**	**11**	**361**	**123**	**175**	**32**	**31**		

Species-specific information

1.12. **Table 4** summarises the species-specific information used in the collision risk calculations. Collision probability was obtained using the SNH (2000)[9] model and details, for each species, are available in Appendix 1. Species length and wingspan have been derived using a mean of the figures presented within Snow & Perrins (1998)[13] and flight speeds were derived using Alerstam *et al.* (2007)[14] or Provan & Whitfield (2006)[15] as suggested by NatureScot (SNH, 2014)[16].

Table 4. Species-specific information used in the collision risk calculations.

Species	Bird length			Wingspan			Flight speed (ms^{-1})	Collision probability (%)	Total potential flying time (hrs)
	Min (cm)	Max (cm)	Average (m)	Min (cm)	Max (cm)	Average (m)			
Golden eagle	75	88	**0.82**	204	220	**2.12**	14	6.9	4,504
Red-throated diver	53	69	**0.61**	106	116	**1.11**	18	5.3	2,485

Results

1.13. **Table 5** summarises the results of collision risk modelling for each of the species.

Table 5. Collision risk modelling results

Species	Occupancy	Avoidance Rate (%)	Birds colliding per year
Golden eagle	All year	99.0	0.054
Red-throated diver	Breeding season	99.5	0.007

1.14. The annual collision risk for golden eagle is predicted to be 0.054 birds or one bird every 18.6 years.

1.15. The annual collision risk for red-throated diver is predicted to be 0.007 birds or one bird every 134.1 years.

13 Snow, D. W. & Perrins, C. M. (1998). The Birds of the Western Palearctic. Concise Edition. Oxford University Press.
14 Alerstam T., Rosén M., Bäckman J., Ericson P.G.P. & Hellgren O. (2007). Flight speeds among bird species: allometric and phylogenetic effects. PLoS Biol, **5**, 1656-1662
15 Provan, S. & Whitfield, D.P. (2006). Avian flight speeds and biometrics for use in collision risk modelling. Report to Scottish Natural Heritage from Natural Research (Projects) Ltd
16 SNH. (2014). Bird Speeds and Biometrics for Collision Risk Modelling. Scottish Natural Heritage, Inverness.

Detailed calculations

Golden eagle

WIND FARM PARAMETERS		
Size of windfarm envelope	528	ha
Number of turbines	13	
Rotor diameter	155	m
Hub height	122.5	m
Max. rotor depth in metres	4.2	m
Max. chord	4.00	m
Pitch	15.0	degrees
Rotation period	5.00	s
Turbine operation time	85	%

BIRD PARAMETERS		
Length	0.82	m
Wingspan	2.12	m
Flapping (0) or gliding (+1)	1	
Assumed flight speed	14	ms^-1
Number of hours birds potentially present	4504	hrs
Assumed avoidance rate	99	%

BAND USED TO DEFINE 'RISK HEIGHT'		
Max height	200	m
Min height	20	m

VP	Watch Data		Bird Flight Data	
	Area (ha)	Time (hrs)	Total (s)	'Risk height' (s)
1	311.2	144.0	769	699
14	35.2	144.0	42	13
15	179.2	144.0	186	155
16	89.0	143.5	91	67
Totals	614.6	575.5	1088	934

	Flight Activity Per Unit Time & Area		Weighted By Observation Effort	
VP	Observation effort (HaHr)	Flying time at 'risk height'	Weighting	Adjusted time at 'risk height'
1	44807.12	0.0000043	0.507	0.0000022
14	5069.88	0.0000007	0.057	0.0000000
15	25811.52	0.0000017	0.292	0.0000005
16	12775.00	0.0000015	0.144	0.0000002
Totals	88463.53	0.000002043	1.000	0.0000029

Mean activity hr^-1 in wind farm	
Risk height	0.15485%
Rotor height	0.13334%

MORTALITY ESTIMATE		
Flight risk volume (Vw)	818400000	m^3
Rotor radius^2	6006.25	m
Combined rotor swept area (Va)	245299	m^2
Vr = Va * (d + l)	1230177	m^3
Bird occupancy (n)	6.01	hrs / yr
Bird occupancy of rotor swept vol (b)	32.50	bird-secs
Bird transit time (t)	0.36	secs
No. of transits through rotors	91.38	per year
Estimated no. of collisions	5.39	per year
After allowing for avoidance	0.054	per year
i.e. equivalent to one bird every	**18.6**	**years**

Red-throated diver

WIND FARM PARAMETERS		
Size of windfarm envelope	528	ha
Number of turbines	13	
Rotor diameter	155	m
Hub height	122.5	m
Max. rotor depth in metres	4.2	m
Max. chord	4.00	m
Pitch	15.0	degrees
Rotation period	5.00	s
Turbine operation time	85	%

BIRD PARAMETERS		
Length	0.61	m
Wingspan	1.11	m
Flapping (0) or gliding (+1)	0	
Assumed flight speed	18	ms^-1
Number of hours birds potentially present	2485	hrs
Assumed avoidance rate	99.5	%

BAND USED TO DEFINE 'RISK HEIGHT'		
Max height	200	m
Min height	20	m

VP	Watch Data		Bird Flight Data	
	Area (ha)	Time (hrs)	Total (s)	'Risk height' (s)
1	311.2	72.0	127	110
14	35.2	72.0	0	0
15	179.2	72.0	108	78
16	89.0	72.0	126	50
Totals	614.6	288.0	361	238

VP	Flight Activity Per Unit Time & Area		Weighted By Observation Effort	
	Observation effort (HaHr)	Flying time at 'risk height'	Weighting	Adjusted time at 'risk height'
1	22403.56	0.0000014	0.506	0.0000007
14	2534.94	0.0000000	0.057	0.0000000
15	12905.76	0.0000017	0.292	0.0000005
16	6409.76	0.0000022	0.145	0.0000003
Totals	44254.02	0.000001302	1.000	0.0000015

Mean activity hr^-1 in wind farm	
Risk height	0.07888%
Rotor height	0.06792%

MORTALITY ESTIMATE		
Flight risk volume (Vw)	818400000	m^3
Rotor radius^2	6006.25	m
Combined rotor swept area (Va)	245299	m^2
Vr = Va * (d + l)	1179891	m^3
Bird occupancy (n)	1.69	hrs / yr
Bird occupancy of rotor swept vol (b)	8.76	bird-secs
Bird transit time (t)	0.27	secs
No. of transits through rotors	32.87	per year
Estimated no. of collisions	1.49	per year
After allowing for avoidance	0.007	per year
i.e. equivalent to one bird every	**134.1**	**years**

Appendix 1

Probability of collision - golden eagle

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.00	m
Pitch (degrees)	15.0	
BirdLength	0.82	m
Wingspan	2.12	m
F: Flapping (0) or gliding (+1)	1	
Bird speed	14	m/sec
RotorDiam	155	m
RotationPeriod	5.00	sec
integration interval	0.05	
Bird aspect ratioo: β	0.38	

Calculation of alpha and p(collision) as a function of radius

r/R radius	c/C chord	α alpha	Upwind: collide length	Upwind: p(collision)	Upwind: y(x)	Downwind: collide length	Downwind: p(collision)	Downwind: y(x)
0				1.00	0.000		1.00	0.000
0.05	0.575	2.90	10.94	0.47	0.047	9.75	0.41	0.041
0.1	0.622	1.45	6.08	0.26	0.052	4.79	0.20	0.041
0.15	0.781	0.97	5.02	0.21	0.064	3.41	0.14	0.043
0.2	0.939	0.72	4.58	0.19	0.078	2.63	0.11	0.045
0.25	0.971	0.58	3.96	0.17	0.084	1.95	0.08	0.041
0.3	0.923	0.48	3.33	0.14	0.085	1.42	0.06	0.036
0.35	0.875	0.41	2.86	0.12	0.085	1.05	0.04	0.031
0.4	0.827	0.36	2.83	0.12	0.096	1.12	0.05	0.038
0.45	0.780	0.32	2.59	0.11	0.099	0.98	0.04	0.037
0.5	0.732	0.29	2.39	0.10	0.102	0.88	0.04	0.037
0.55	0.684	0.26	2.22	0.09	0.104	0.83	0.04	0.039
0.6	0.637	0.24	2.07	0.09	0.106	0.88	0.04	0.045
0.65	0.589	0.22	1.93	0.08	0.107	0.92	0.04	0.051
0.7	0.541	0.21	1.81	0.08	0.108	0.94	0.04	0.056
0.75	0.494	0.19	1.69	0.07	0.108	0.96	0.04	0.061
0.8	0.446	0.18	1.59	0.07	0.108	0.96	0.04	0.066
0.85	0.398	0.17	1.49	0.06	0.108	0.97	0.04	0.070
0.9	0.350	0.16	1.40	0.06	0.107	0.96	0.04	0.074
0.95	0.303	0.15	1.31	0.06	0.106	0.95	0.04	0.077
1	0.255	0.14	1.22	0.05	0.104	0.94	0.04	0.080

Overall p(collision) = Upwind 9.0% Downwind 4.8%

Average 6.9%

Probability of collision – red-throated diver

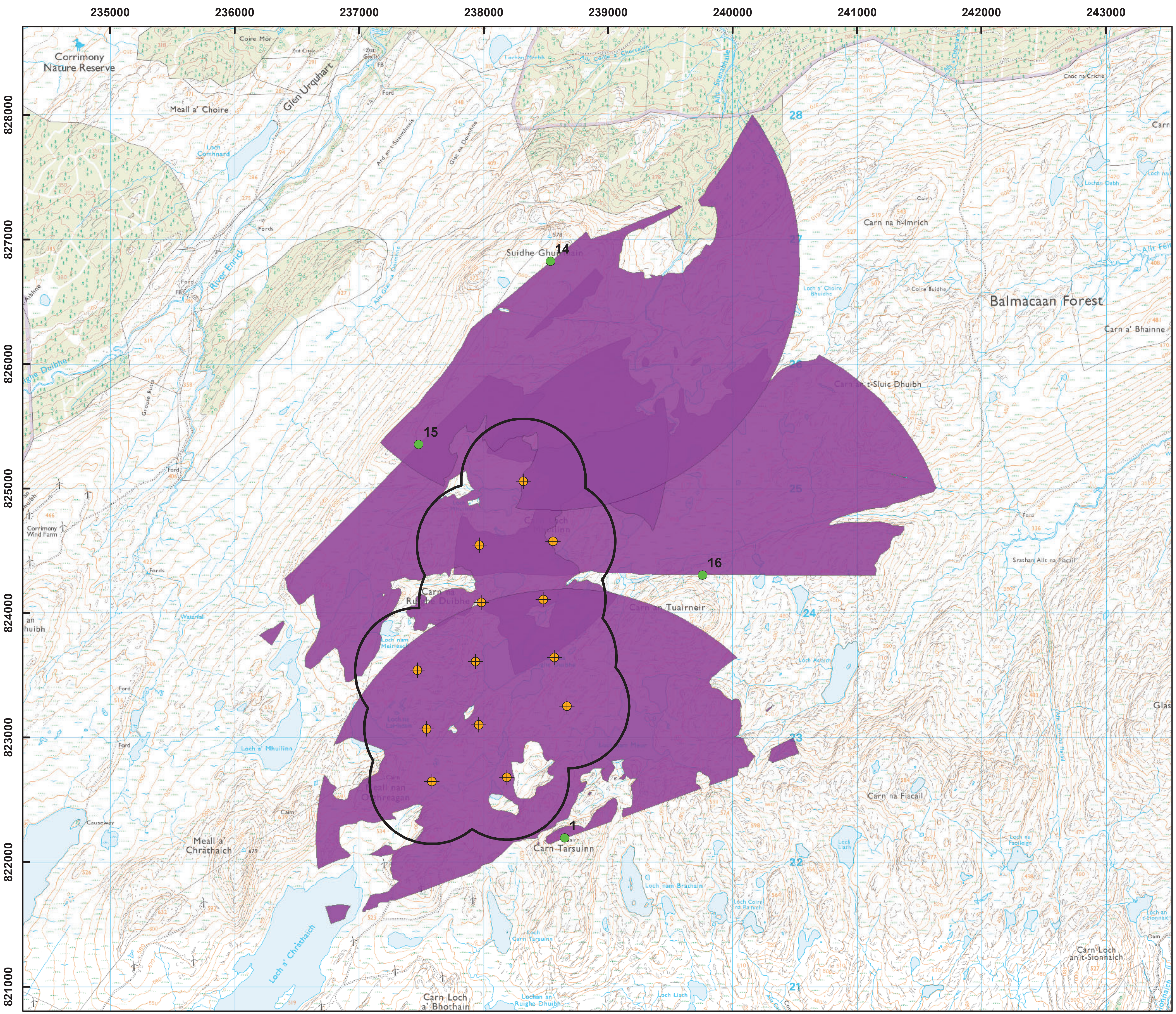
K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.00	m
Pitch (degrees)	15.0	
BirdLength	0.61	m
Wingspan	1.11	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	18	m/sec
RotorDiam	155	m
RotationPeriod	5.00	sec
integration interval	0.05	
Bird aspect ratioo: β	0.55	

Calculation of alpha and p(collision) as a function of radius

r/R radius	c/C chord	α alpha	Upwind: collide length	Upwind: p(collision)	Upwind: y(x)	Downwind: collide length	Downwind: p(collision)	Downwind: y(x)
0				1.00	0.000		1.00	0.000
0.05	0.575	3.71	12.94	0.43	0.043	11.75	0.39	0.039
0.1	0.622	1.85	7.16	0.24	0.048	5.87	0.20	0.039
0.15	0.781	1.24	5.91	0.20	0.059	4.29	0.14	0.043
0.2	0.939	0.93	5.36	0.18	0.071	3.42	0.11	0.045
0.25	0.971	0.74	4.61	0.15	0.077	2.60	0.09	0.043
0.3	0.923	0.62	3.84	0.13	0.077	1.93	0.06	0.039
0.35	0.875	0.53	3.31	0.11	0.077	1.49	0.05	0.035
0.4	0.827	0.46	2.95	0.10	0.078	1.23	0.04	0.033
0.45	0.780	0.41	2.66	0.09	0.080	1.04	0.03	0.031
0.5	0.732	0.37	2.42	0.08	0.080	0.90	0.03	0.030
0.55	0.684	0.34	2.21	0.07	0.081	0.79	0.03	0.029
0.6	0.637	0.31	2.03	0.07	0.081	0.71	0.02	0.028
0.65	0.589	0.29	1.87	0.06	0.081	0.65	0.02	0.028
0.7	0.541	0.26	1.72	0.06	0.080	0.62	0.02	0.029
0.75	0.494	0.25	1.59	0.05	0.079	0.65	0.02	0.032
0.8	0.446	0.23	1.47	0.05	0.078	0.67	0.02	0.036
0.85	0.398	0.22	1.36	0.05	0.077	0.69	0.02	0.039
0.9	0.350	0.21	1.25	0.04	0.075	0.69	0.02	0.042
0.95	0.303	0.20	1.15	0.04	0.073	0.70	0.02	0.044
1	0.255	0.19	1.06	0.04	0.070	0.69	0.02	0.046

Overall p(collision) = Upwind 7.1% Downwind 3.5%

Average 5.3%



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Key

- Flight activity survey area
- Turbine locations
- Vantage Points
- Viewsheds

Date produced: 07/09/2022
Source: NRP LTD

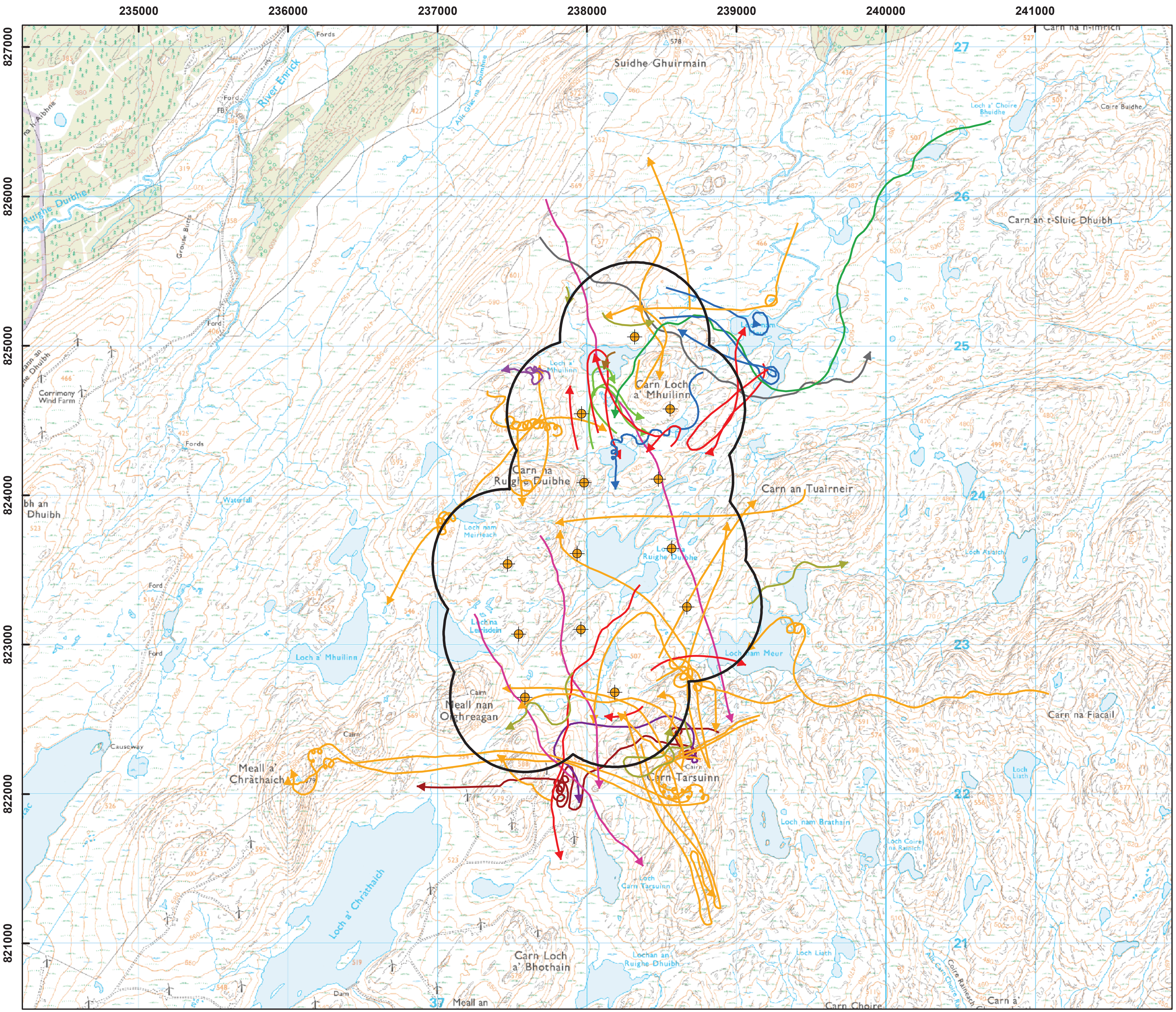
N

0 0.25 0.5 1 km

Technical Appendix: Collision Risk Modelling

Figure 1. Vantage Points and viewsheds used in collision risk modelling

Loch Liath



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Key

Flight activity survey area

Turbine locations

Flight lines

- Dunlin
- Golden eagle
- Golden plover
- Greenshank
- Greylag goose
- Hen harrier
- Merlin
- Osprey
- Pink-footed goose
- Red kite
- Red-throated diver
- Goose sp.

Date produced: 08/09/2022
Source: NRP LTD

N

0 0.25 0.5 1 km

Technical Appendix: Collision Risk Modelling

Figure 2. All flights that passed through 500m turbine buffer

Loch Liath