TECHNICAL APPENDIX 7.4 – COLLISION RISK MODELLING

Red Kite CRM (Year 1, 2020-2021)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as October - July.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	77	15822.73	56961828	180	3.1600E-06
2	166.81	78	13011.18	46840248	1035	2.2096E-05
3	398.35	78	31071.30	111856680	1245	1.1130E-05
Total	770.65	233	179561.45	646421220	2460	3.6387E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 3.639E-5/3 = **1.213E-05**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 1.213E-5 **2.9259E-03**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **2.853E-03**

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Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for October - July and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 3646.145

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 3646.145 x 2.853E-3
No. of hours of bird occupancy = 10.402

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.63 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.63)
Vr = 598452.118 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 10.402 x 3600 x 598452.118/282244716
Bird occupancy in rotor swept volume = 79.397

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.63)/13
Bird transit time through the rotors = 0.3294 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 79.397/0.3294
No. of transits = 241.059

[2] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M. (1995) *A model comparison for daylength as a function of latitude and day of year*. Ecological Modelling, Vol 80, Issue 1, 87-95.

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.63 m
Wingspan	1.85 m
Bird speed	13 m/s
F:Gliding	0.63662

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.63/1.85
Bird aspect ratio (b) = 0.341

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	4.2441318	14.957971	1	0.00125	13.384678	1	0.00125	0.00125
0.075	0.575	1.4147106	5.5104211	0.423878544	0.003179089	3.9371284	0.302856032	0.00227142	0.0075
0.125	0.7015	0.8488264	4.1975771	0.322890548	0.004036132	2.2781601	0.175243083	0.002190539	0.0125
0.175	0.8601	0.6063045	3.8508924	0.296222491	0.005183894	1.4975202	0.11519386	0.002015893	0.0175
0.225	0.99435	0.4715702	3.6782505	0.282942346	0.006366203	0.9575487	0.07365759	0.001657296	0.0225
0.275	0.94665	0.3858302	3.12238	0.240183076	0.006605035	0.532193	0.040937926	0.001125793	0.0275
0.325	0.89895	0.3264717	2.9629664	0.227920495	0.007407416	0.7567056	0.058208125	0.001891764	0.0325
0.375	0.85125	0.2829421	2.6998953	0.207684254	0.00778816	0.8892619	0.06840476	0.002565178	0.0375
0.425	0.80355	0.2496548	2.4833686	0.191028351	0.008118705	0.9752737	0.075021056	0.003188395	0.0425
0.475	0.75585	0.2233754	2.298688	0.176822153	0.008399052	1.0294394	0.079187647	0.003761413	0.0475
0.525	0.70815	0.2021015	2.1367547	0.164365744	0.008629202	1.0608578	0.081604449	0.004284234	0.0525
0.575	0.66045	0.1845275	1.9916346	0.153202659	0.008809153	1.0754631	0.082727928	0.004756856	0.0575
0.625	0.61275	0.1697653	1.8592925	0.143022498	0.008938906	1.0772903	0.082868482	0.00517928	0.0625
0.675	0.56505	0.1571901	1.7368889	0.133606835	0.009018461	1.069179	0.082244539	0.005551506	0.0675
0.725	0.51735	0.1463494	1.6223675	0.124797497	0.009047819	1.0531855	0.08101427	0.005873535	0.0725
0.775	0.46965	0.1369075	1.5142027	0.116477132	0.009026978	1.0308354	0.079295029	0.006145365	0.0775
0.825	0.42195	0.1286101	1.4112388	0.108556834	0.008955939	1.0032844	0.077175719	0.006366997	0.0825
0.875	0.37425	0.1212609	1.3125843	0.100968022	0.008834702	0.971424	0.074724925	0.006538431	0.0875
0.925	0.32655	0.1147063	1.2175402	0.09365694	0.008663267	0.9359532	0.0719964	0.006659667	0.0925
0.975	0.27885	0.1088239	1.1255512	0.086580861	0.008441634	0.8974273	0.069032872	0.006730705	0.0975
Overall p(collision)			**Upwind**		**0.14669974**	**Downwind**		**0.08000427**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.14669974 + 0.08000427)/2
Average probability of collision = 0.113352

Annual collision risk for Red kite assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 241.059 x 0.113352
Annual collision risk = 27.324 birds

Corrected annual collision risk assuming avoidance

Red kite avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 27.324 x (1 - 0.98)
Annual collision risk, with avoidance = 0.546 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.465 birds

Calculate number of years per collision

Number of years per collision for Red kite = 1/corrected annual risk
Number of years per collision for Red kite = 1/0.465

Number of years per collision for Red kite = 2.1528

Red Kite (Year 2, 2021-2022)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as the whole year.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	86	17672.14	63619704	1905	2.9944E-05
2	166.81	84	14012.04	50443344	1885	3.7369E-05
3	398.35	92	36648.20	131933520	5840	4.4265E-05
Total	770.65	262	201910.30	726877080	9630	1.1158E-04

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 1.116E-4/3 = **3.719E-05**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 3.719E-5 **8.9721E-03**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **8.748E-03**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4481.135

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4481.135 x 8.748E-3
No. of hours of bird occupancy = 39.2

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.63 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.63)
Vr = 598452.118 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 39.2 x 3600 x 598452.118/282244716
Bird occupancy in rotor swept volume = 299.221

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.63)/13
Bird transit time through the rotors = 0.3294 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 299.221/0.3294
No. of transits = 908.471

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.63 m
Wingspan	1.85 m
Bird speed	13 m/s
F:Gliding	0.63662

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.63/1.85
Bird aspect ratio (b) = 0.341

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	4.2441318	14.957971	1	0.00125	13.384678	1	0.00125	0.00125
0.075	0.575	1.4147106	5.5104211	0.423878544	0.003179089	3.9371284	0.302856032	0.00227142	0.0075
0.125	0.7015	0.8488264	4.1975771	0.322890548	0.004036132	2.2781601	0.175243083	0.002190539	0.0125
0.175	0.8601	0.6063045	3.8508924	0.296222491	0.005183894	1.4975202	0.11519386	0.002015893	0.0175
0.225	0.99435	0.4715702	3.6782505	0.282942346	0.006366203	0.9575487	0.07365759	0.001657296	0.0225
0.275	0.94665	0.3858302	3.12238	0.240183076	0.006605035	0.532193	0.040937926	0.001125793	0.0275
0.325	0.89895	0.3264717	2.9629664	0.227920495	0.007407416	0.7567056	0.058208125	0.001891764	0.0325
0.375	0.85125	0.2829421	2.6998953	0.207684254	0.00778816	0.8892619	0.06840476	0.002565178	0.0375
0.425	0.80355	0.2496548	2.4833686	0.191028351	0.008118705	0.9752737	0.075021056	0.003188395	0.0425
0.475	0.75585	0.2233754	2.298688	0.176822153	0.008399052	1.0294394	0.079187647	0.003761413	0.0475
0.525	0.70815	0.2021015	2.1367547	0.164365744	0.008629202	1.0608578	0.081604449	0.004284234	0.0525
0.575	0.66045	0.1845275	1.9916346	0.153202659	0.008809153	1.0754631	0.082727928	0.004756856	0.0575
0.625	0.61275	0.1697653	1.8592925	0.143022498	0.008938906	1.0772903	0.082868482	0.00517928	0.0625
0.675	0.56505	0.1571901	1.7368889	0.133606835	0.009018461	1.069179	0.082244539	0.005551506	0.0675
0.725	0.51735	0.1463494	1.6223675	0.124797497	0.009047819	1.0531855	0.08101427	0.005873535	0.0725
0.775	0.46965	0.1369075	1.5142027	0.116477132	0.009026978	1.0308354	0.079295029	0.006145365	0.0775
0.825	0.42195	0.1286101	1.4112388	0.108556834	0.008955939	1.0032844	0.077175719	0.006366997	0.0825
0.875	0.37425	0.1212609	1.3125843	0.100968022	0.008834702	0.971424	0.074724925	0.006538431	0.0875
0.925	0.32655	0.1147063	1.2175402	0.09365694	0.008663267	0.9359532	0.0719964	0.006659667	0.0925
0.975	0.27885	0.1088239	1.1255512	0.086580861	0.008441634	0.8974273	0.069032872	0.006730705	0.0975
Overall p(collision)			**Upwind**		**0.14669974**	**Downwind**		**0.08000427**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.14669974 + 0.08000427)/2
Average probability of collision = 0.113352

Annual collision risk for Red kite assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 908.471 x 0.113352
Annual collision risk = 102.977 birds

Corrected annual collision risk assuming avoidance

Red kite avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 102.977 x (1 - 0.98)
Annual collision risk, with avoidance = 2.06 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 1.751 birds

Calculate number of years per collision

Number of years per collision for Red kite = 1/corrected annual risk
Number of years per collision for Red kite = 1/1.751

Number of years per collision for Red kite = 0.5712

Goshawk (Year 1, 2020-2021)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as October - July.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	77	15822.73	56961828	75	1.3167E-06
2	166.81	78	13011.18	46840248	45	9.6071E-07
3	398.35	78	31071.30	111856680	3170	2.8340E-05
Total	770.65	233	179561.45	646421220	3290	3.0617E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 3.062E-5/3 = **1.021E-05**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 1.021E-5 **2.4620E-03**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **2.400E-03**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for October - July and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 3646.145

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 3646.145 x 2.400E-3
No. of hours of bird occupancy = 8.752

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.56 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.56)
Vr = 588668.421 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 8.752 x 3600 x 588668.421/282244716
Bird occupancy in rotor swept volume = 65.716

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 16 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.56)/16
Bird transit time through the rotors = 0.2632 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 65.716/0.2632
No. of transits = 249.646

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.56 m
Wingspan	1.42 m
Bird speed	16 m/s
F:Gliding	0.63662

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.56/1.42
Bird aspect ratio (b) = 0.394

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	5.2235469	16.798348	1	0.00125	15.225056	0.951565988	0.001189457	0.00125
0.075	0.575	1.7411823	6.1238804	0.382742524	0.002870569	4.5505877	0.284411732	0.002133088	0.0075
0.125	0.7015	1.0447094	4.658792	0.291174502	0.003639681	2.739375	0.171210936	0.002140137	0.0125
0.175	0.8601	0.746221	4.2637415	0.266483845	0.004663467	1.9103693	0.119398083	0.002089466	0.0175
0.225	0.99435	0.5803941	4.0542696	0.253391847	0.005701317	1.3335677	0.083347982	0.00187533	0.0225
0.275	0.94665	0.4748679	3.4140681	0.213379254	0.005867929	0.8238811	0.05149257	0.001416046	0.0275
0.325	0.89895	0.4018113	2.9507724	0.184423277	0.005993757	0.4911004	0.030693773	0.000997548	0.0325
0.375	0.85125	0.3482365	2.8388145	0.177425909	0.006653472	0.6103426	0.038146415	0.001430491	0.0375
0.425	0.80355	0.3072675	2.5873795	0.161711219	0.006872727	0.7312628	0.045703924	0.001942417	0.0425
0.475	0.75585	0.2749235	2.3751397	0.148446234	0.007051196	0.8129877	0.050811729	0.002413557	0.0475
0.525	0.70815	0.2487403	2.1908966	0.136931039	0.00718888	0.8667159	0.054169743	0.002843912	0.0525
0.575	0.66045	0.2271107	2.0273467	0.126709166	0.007285777	0.899751	0.056234436	0.00323348	0.0575
0.625	0.61275	0.2089419	1.8795235	0.117470219	0.007341889	0.9170592	0.057316203	0.003582263	0.0625
0.675	0.56505	0.1934647	1.7439323	0.108995769	0.007357214	0.9221356	0.057633472	0.003890259	0.0675
0.725	0.51735	0.1801223	1.6180423	0.101127644	0.007331754	0.9175107	0.057344417	0.00415747	0.0725
0.775	0.46965	0.1685015	1.4999759	0.093748492	0.007265508	0.9050622	0.056566389	0.004383895	0.0775
0.825	0.42195	0.1582893	1.3883105	0.086769407	0.007158476	0.8862127	0.055388293	0.004569534	0.0825
0.875	0.37425	0.1492442	1.2819489	0.080121808	0.007010658	0.8620594	0.053878711	0.004714387	0.0875
0.925	0.32655	0.1411769	1.180031	0.073751939	0.006822054	0.8334624	0.052091399	0.004818454	0.0925
0.975	0.27885	0.1339371	1.0818732	0.067617074	0.006592665	0.8011054	0.050069085	0.004881736	0.0975
Overall p(collision)			**Upwind**		**0.12191899**	**Downwind**		**0.05870293**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.12191899 + 0.05870293)/2
Average probability of collision = 0.090311

Annual collision risk for Goshawk assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 249.646 x 0.090311
Annual collision risk = 22.546 birds

Corrected annual collision risk assuming avoidance

Goshawk avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 22.546 x (1 - 0.98)
Annual collision risk, with avoidance = 0.451 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.383 birds

Calculate number of years per collision

Number of years per collision for Goshawk = 1/corrected annual risk
Number of years per collision for Goshawk = 1/0.383

Number of years per collision for Goshawk = 2.6091

Goshawk (Year 2, 2021-2022)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as the whole year.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	86	17672.14	63619704	60	9.4310E-07
2	166.81	84	14012.04	50443344	320	6.3438E-06
3	398.35	92	36648.20	131933520	805	6.1016E-06
Total	770.65	262	201910.30	726877080	1185	1.3388E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 1.339E-5/3 = **4.463E-06**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 4.463E-6 **1.0766E-03**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **1.050E-03**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4481.135

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4481.135 x 1.050E-3
No. of hours of bird occupancy = 4.704

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.56 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.56)
Vr = 588668.421 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 4.704 x 3600 x 588668.421/282244716
Bird occupancy in rotor swept volume = 35.317

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 16 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.56)/16
Bird transit time through the rotors = 0.2632 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 35.317/0.2632
No. of transits = 134.165

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.56 m
Wingspan	1.42 m
Bird speed	16 m/s
F:Gliding	0.63662

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.56/1.42
Bird aspect ratio (b) = 0.394

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	5.2235469	16.798348	1	0.00125	15.225056	0.951565988	0.001189457	0.00125
0.075	0.575	1.7411823	6.1238804	0.382742524	0.002870569	4.5505877	0.284411732	0.002133088	0.0075
0.125	0.7015	1.0447094	4.658792	0.291174502	0.003639681	2.739375	0.171210936	0.002140137	0.0125
0.175	0.8601	0.746221	4.2637415	0.266483845	0.004663467	1.9103693	0.119398083	0.002089466	0.0175
0.225	0.99435	0.5803941	4.0542696	0.253391847	0.005701317	1.3335677	0.083347982	0.00187533	0.0225
0.275	0.94665	0.4748679	3.4140681	0.213379254	0.005867929	0.8238811	0.05149257	0.001416046	0.0275
0.325	0.89895	0.4018113	2.9507724	0.184423277	0.005993757	0.4911004	0.030693773	0.000997548	0.0325
0.375	0.85125	0.3482365	2.8388145	0.177425909	0.006653472	0.6103426	0.038146415	0.001430491	0.0375
0.425	0.80355	0.3072675	2.5873795	0.161711219	0.006872727	0.7312628	0.045703924	0.001942417	0.0425
0.475	0.75585	0.2749235	2.3751397	0.148446234	0.007051196	0.8129877	0.050811729	0.002413557	0.0475
0.525	0.70815	0.2487403	2.1908966	0.136931039	0.00718888	0.8667159	0.054169743	0.002843912	0.0525
0.575	0.66045	0.2271107	2.0273467	0.126709166	0.007285777	0.899751	0.056234436	0.00323348	0.0575
0.625	0.61275	0.2089419	1.8795235	0.117470219	0.007341889	0.9170592	0.057316203	0.003582263	0.0625
0.675	0.56505	0.1934647	1.7439323	0.108995769	0.007357214	0.9221356	0.057633472	0.003890259	0.0675
0.725	0.51735	0.1801223	1.6180423	0.101127644	0.007331754	0.9175107	0.057344417	0.00415747	0.0725
0.775	0.46965	0.1685015	1.4999759	0.093748492	0.007265508	0.9050622	0.056566389	0.004383895	0.0775
0.825	0.42195	0.1582893	1.3883105	0.086769407	0.007158476	0.8862127	0.055388293	0.004569534	0.0825
0.875	0.37425	0.1492442	1.2819489	0.080121808	0.007010658	0.8620594	0.053878711	0.004714387	0.0875
0.925	0.32655	0.1411769	1.180031	0.073751939	0.006822054	0.8334624	0.052091399	0.004818454	0.0925
0.975	0.27885	0.1339371	1.0818732	0.067617074	0.006592665	0.8011054	0.050069085	0.004881736	0.0975
Overall p(collision)			**Upwind**		**0.12191899**	**Downwind**		**0.05870293**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.12191899 + 0.05870293)/2
Average probability of collision = 0.090311

Annual collision risk for Goshawk assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 134.165 x 0.090311
Annual collision risk = 12.117 birds

Corrected annual collision risk assuming avoidance

Goshawk avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 12.117 x (1 - 0.98)
Annual collision risk, with avoidance = 0.242 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.206 birds

Calculate number of years per collision

Number of years per collision for Goshawk = 1/corrected annual risk
Number of years per collision for Goshawk = 1/0.206

Number of years per collision for Goshawk = 4.8548

Kestrel (Year 1, 2020-2021)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as October - July.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	77	15822.73	56961828	1695	2.9757E-05
2	166.81	78	13011.18	46840248	5415	1.1561E-04
3	398.35	78	31071.30	111856680	7305	6.5307E-05
Total	770.65	233	179561.45	646421220	14415	2.1067E-04

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 2.107E-4/3 = **7.022E-05**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 7.022E-5 **1.6940E-02**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **1.652E-02**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for October - July and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 3646.145

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 3646.145 x 1.652E-2
No. of hours of bird occupancy = 60.222

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.34 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.34)
Vr = 557919.658 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 60.222 x 3600 x 557919.658/282244716
Bird occupancy in rotor swept volume = 428.555

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 8 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.34)/8
Bird transit time through the rotors = 0.499 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 428.555/0.499
No. of transits = 858.875

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1) 1
No. of blades 3
Maximum chord 4 m
Pitch (degrees) 20
Rotor radius 58.5 m
Rotation Period 3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length 0.34 m
Wingspan 0.76 m
Bird speed 8 m/s
F:Flapping 1

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.34/0.76
Bird aspect ratio (b) = 0.447

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.6117734	8.4164018	1	0.00125	6.8431092	0.855388646	0.001069236	0.00125
0.075	0.575	0.8705911	3.3298982	0.41623727	0.00312178	1.7566055	0.219575688	0.001646818	0.0075
0.125	0.7015	0.5223547	2.7340312	0.341753895	0.004271924	0.8146141	0.101826764	0.001272835	0.0125
0.175	0.8601	0.3731105	2.7229219	0.340365238	0.005956392	0.3695497	0.046193712	0.00080839	0.0175
0.225	0.99435	0.290197	2.7849721	0.34812151	0.007832734	0.6157298	0.076966219	0.00173174	0.0225
0.275	0.94665	0.2374339	2.4799405	0.309992558	0.008524795	0.7902465	0.098780811	0.002716472	0.0275
0.325	0.89895	0.2009056	2.2486855	0.281085689	0.009135285	0.8909865	0.111373319	0.003619633	0.0325
0.375	0.85125	0.1741182	2.0616966	0.257712071	0.009664203	0.9474606	0.118432576	0.004441222	0.0375
0.425	0.80355	0.1536337	1.9033503	0.23791879	0.010111549	0.975292	0.121911496	0.005181239	0.0425
0.475	0.75585	0.1374618	1.7646017	0.220575215	0.010477323	0.9835257	0.12294071	0.005839684	0.0475
0.525	0.70815	0.1243702	1.6398514	0.20498143	0.010761525	0.9777611	0.122220135	0.006416557	0.0525
0.575	0.66045	0.1135554	1.5254477	0.190680967	0.010964156	0.9616499	0.120206237	0.006911859	0.0575
0.625	0.61275	0.1044709	1.4189074	0.177363429	0.011085214	0.9376753	0.117209413	0.007325588	0.0625
0.675	0.56505	0.0967323	1.3184831	0.164810389	0.011124701	0.9075847	0.113448093	0.007657746	0.0675
0.725	0.51735	0.0900612	1.2229094	0.152863674	0.011082616	0.8726436	0.109080447	0.007908332	0.0725
0.775	0.46965	0.0842508	1.1312475	0.141405932	0.01095896	0.8337906	0.104223829	0.008077347	0.0775
0.825	0.42195	0.0791446	1.0427861	0.130348257	0.010753731	0.7917371	0.098967142	0.008164789	0.0825
0.875	0.37425	0.0746221	0.9569765	0.119622068	0.010466931	0.7470318	0.093378971	0.00817066	0.0875
0.925	0.32655	0.0705885	0.8733889	0.109173609	0.010098559	0.7001046	0.087513069	0.008094959	0.0925
0.975	0.27885	0.0669685	0.7916812	0.098960153	0.009648615	0.6512973	0.081412164	0.007937686	0.0975
Overall p(collision)			**Upwind**		**0.17729099**	**Downwind**		**0.10499279**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.17729099 + 0.10499279)/2
Average probability of collision = 0.141142

Annual collision risk for Kestrel assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 858.875 x 0.141142
Annual collision risk = 121.223 birds

Corrected annual collision risk assuming avoidance

Kestrel avoidance rate = 0.95

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 121.223 x (1 - 0.95)
Annual collision risk, with avoidance = 6.061 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 5.152 birds

Calculate number of years per collision

Number of years per collision for Kestrel = 1/corrected annual risk
Number of years per collision for Kestrel = 1/5.152

Number of years per collision for Kestrel = 0.1941

Kestrel (Year 2, 2021-2022)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as the whole year.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	86	17672.14	63619704	10293	1.6179E-04
2	166.81	84	14012.04	50443344	7843	1.5548E-04
3	398.35	92	36648.20	131933520	6235	4.7259E-05
Total	770.65	262	201910.30	726877080	24371	3.6453E-04

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 3.645E-4/3 = **1.215E-04**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 1.215E-4 **2.9312E-02**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **2.858E-02**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4481.135

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4481.135 x 2.858E-2
No. of hours of bird occupancy = 128.069

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.34 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.34)
Vr = 557919.658 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 128.069 x 3600 x 557919.658/282244716
Bird occupancy in rotor swept volume = 911.365

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 8 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.34)/8
Bird transit time through the rotors = 0.499 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 911.365/0.499
No. of transits = 1826.483

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1) 1
No. of blades 3
Maximum chord 4 m
Pitch (degrees) 20
Rotor radius 58.5 m
Rotation Period 3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length 0.34 m
Wingspan 0.76 m
Bird speed 8 m/s
F:Flapping 1

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.34/0.76
Bird aspect ratio (b) = 0.447

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.6117734	8.4164018	1	0.00125	6.8431092	0.855388646	0.001069236	0.00125
0.075	0.575	0.8705911	3.3298982	0.41623727	0.00312178	1.7566055	0.219575688	0.001646818	0.0075
0.125	0.7015	0.5223547	2.7340312	0.341753895	0.004271924	0.8146141	0.101826764	0.001272835	0.0125
0.175	0.8601	0.3731105	2.7229219	0.340365238	0.005956392	0.3695497	0.046193712	0.00080839	0.0175
0.225	0.99435	0.290197	2.7849721	0.34812151	0.007832734	0.6157298	0.076966219	0.00173174	0.0225
0.275	0.94665	0.2374339	2.4799405	0.309992558	0.008524795	0.7902465	0.098780811	0.002716472	0.0275
0.325	0.89895	0.2009056	2.2486855	0.281085689	0.009135285	0.8909865	0.111373319	0.003619633	0.0325
0.375	0.85125	0.1741182	2.0616966	0.257712071	0.009664203	0.9474606	0.118432576	0.004441222	0.0375
0.425	0.80355	0.1536337	1.9033503	0.23791879	0.010111549	0.975292	0.121911496	0.005181239	0.0425
0.475	0.75585	0.1374618	1.7646017	0.220575215	0.010477323	0.9835257	0.12294071	0.005839684	0.0475
0.525	0.70815	0.1243702	1.6398514	0.20498143	0.010761525	0.9777611	0.122220135	0.006416557	0.0525
0.575	0.66045	0.1135554	1.5254477	0.190680967	0.010964156	0.9616499	0.120206237	0.006911859	0.0575
0.625	0.61275	0.1044709	1.4189074	0.177363429	0.011085214	0.9376753	0.117209413	0.007325588	0.0625
0.675	0.56505	0.0967323	1.3184831	0.164810389	0.011124701	0.9075847	0.113448093	0.007657746	0.0675
0.725	0.51735	0.0900612	1.2229094	0.152863674	0.011082616	0.8726436	0.109080447	0.007908332	0.0725
0.775	0.46965	0.0842508	1.1312475	0.141405932	0.01095896	0.8337906	0.104223829	0.008077347	0.0775
0.825	0.42195	0.0791446	1.0427861	0.130348257	0.010753731	0.7917371	0.098967142	0.008164789	0.0825
0.875	0.37425	0.0746221	0.9569765	0.119622068	0.010466931	0.7470318	0.093378971	0.00817066	0.0875
0.925	0.32655	0.0705885	0.8733889	0.109173609	0.010098559	0.7001046	0.087513069	0.008094959	0.0925
0.975	0.27885	0.0669685	0.7916812	0.098960153	0.009648615	0.6512973	0.081412164	0.007937686	0.0975
Overall p(collision)			**Upwind**		**0.17729099**	**Downwind**		**0.10499279**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.17729099 + 0.10499279)/2
Average probability of collision = 0.141142

Annual collision risk for Kestrel assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 1826.483 x 0.141142
Annual collision risk = 257.793 birds

Corrected annual collision risk assuming avoidance

Kestrel avoidance rate = 0.95

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 257.793 x (1 - 0.95)
Annual collision risk, with avoidance = 12.89 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 10.956 birds

Calculate number of years per collision

Number of years per collision for Kestrel = 1/corrected annual risk
Number of years per collision for Kestrel = 1/10.956

Number of years per collision for Kestrel = 0.0913

Hobby (Year 1, 2020)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - October.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	42	8630.58	31070088	0	0.0000E+00
2	166.81	42	7006.02	25221672	450	1.7842E-05
3	398.35	42	16730.70	60230520	120	1.9923E-06
Total	770.65	126	97101.90	349566840	570	1.9834E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 1.983E-5/3 = **6.611E-06**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 6.611E-6 **1.5949E-03**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **1.555E-03**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - October and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2229.574

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2229.574 x 1.555E-3
No. of hours of bird occupancy = 3.467

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.33 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.33)
Vr = 556521.987 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 3.467 x 3600 x 556521.987/282244716
Bird occupancy in rotor swept volume = 24.61

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 8 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.33)/8
Bird transit time through the rotors = 0.4977 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 24.61/0.4977
No. of transits = 49.445

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.33 m
Wingspan	0.87 m
Bird speed	8 m/s
F:Gliding	0.63662

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.33/0.87
Bird aspect ratio (b) = 0.379

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.6117734	7.8780088	0.984751096	0.001230939	6.3047161	0.788089514	0.000985112	0.00125
0.075	0.575	0.8705911	3.1504338	0.393804226	0.002953532	1.5771411	0.197142644	0.00147857	0.0075
0.125	0.7015	0.5223547	2.6263525	0.328294069	0.004103676	0.7069355	0.088366938	0.001104587	0.0125
0.175	0.8601	0.3731105	2.7129219	0.339115238	0.005934517	0.3595497	0.044943712	0.000786515	0.0175
0.225	0.99435	0.290197	2.7749721	0.34687151	0.007804609	0.6057298	0.075716219	0.001703615	0.0225
0.275	0.94665	0.2374339	2.4699405	0.308742558	0.00849042	0.7802465	0.097530811	0.002682097	0.0275
0.325	0.89895	0.2009056	2.2386855	0.279835689	0.00909466	0.8809865	0.110123319	0.003579008	0.0325
0.375	0.85125	0.1741182	2.0516966	0.256462071	0.009617328	0.9374606	0.117182576	0.004394347	0.0375
0.425	0.80355	0.1536337	1.8933503	0.23666879	0.010058424	0.965292	0.120661496	0.005128114	0.0425
0.475	0.75585	0.1374618	1.7546017	0.219325215	0.010417948	0.9735257	0.12169071	0.005780309	0.0475
0.525	0.70815	0.1243702	1.6298514	0.20373143	0.0106959	0.9677611	0.120970135	0.006350932	0.0525
0.575	0.66045	0.1135554	1.5154477	0.189430967	0.010892281	0.9516499	0.118956237	0.006839984	0.0575
0.625	0.61275	0.1044709	1.4089074	0.176113429	0.011007089	0.9276753	0.115959413	0.007247463	0.0625
0.675	0.56505	0.0967323	1.3084831	0.163560389	0.011040326	0.8975847	0.112198093	0.007573371	0.0675
0.725	0.51735	0.0900612	1.2129094	0.151613674	0.010991991	0.8626436	0.107830447	0.007817707	0.0725
0.775	0.46965	0.0842508	1.1212475	0.140155932	0.010862085	0.8237906	0.102973829	0.007980472	0.0775
0.825	0.42195	0.0791446	1.0327861	0.129098257	0.010650606	0.7817371	0.097717142	0.008061664	0.0825
0.875	0.37425	0.0746221	0.9469765	0.118372068	0.010357556	0.7370318	0.092128971	0.008061285	0.0875
0.925	0.32655	0.0705885	0.8633889	0.107923609	0.009982934	0.6901046	0.086263069	0.007979334	0.0925
0.975	0.27885	0.0669685	0.7816812	0.097710153	0.00952674	0.6412973	0.080162164	0.007815811	0.0975
Overall p(collision)			**Upwind**		**0.17571356**	**Downwind**		**0.1033503**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.17571356 + 0.1033503)/2
Average probability of collision = 0.139532

Annual collision risk for Hobby assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 49.445 x 0.139532
Annual collision risk = 6.899 birds

Corrected annual collision risk assuming avoidance

Hobby avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 6.899 x (1 - 0.98)
Annual collision risk, with avoidance = 0.138 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.117 birds

Calculate number of years per collision

Number of years per collision for Hobby = 1/corrected annual risk
Number of years per collision for Hobby = 1/0.117

Number of years per collision for Hobby = 8.5262

Hobby (Year 2, 2021-2022)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - October.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	56	11507.44	41426784	225	5.4313E-06
2	166.81	51	8507.31	30626316	45	1.4693E-06
3	398.35	56	22307.60	80307360	75	9.3391E-07
Total	770.65	163	125615.95	452217420	345	7.8345E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 7.835E-6/3 = **2.612E-06**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 2.612E-6 **6.2999E-04**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **6.142E-04**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - October and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 3064.564

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 3064.564 x 6.142E-4
No. of hours of bird occupancy = 1.882

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.33 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.33)
Vr = 556521.987 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 1.882 x 3600 x 556521.987/282244716
Bird occupancy in rotor swept volume = 13.362

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 8 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.33)/8
Bird transit time through the rotors = 0.4977 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 13.362/0.4977
No. of transits = 26.846

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.33 m
Wingspan	0.87 m
Bird speed	8 m/s
F:Gliding	0.63662

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.33/0.87
Bird aspect ratio (b) = 0.379

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.6117734	7.8780088	0.984751096	0.001230939	6.3047161	0.788089514	0.000985112	0.00125
0.075	0.575	0.8705911	3.1504338	0.393804226	0.002953532	1.5771411	0.197142644	0.00147857	0.0075
0.125	0.7015	0.5223547	2.6263525	0.328294069	0.004103676	0.7069355	0.088366938	0.001104587	0.0125
0.175	0.8601	0.3731105	2.7129219	0.339115238	0.005934517	0.3595497	0.044943712	0.000786515	0.0175
0.225	0.99435	0.290197	2.7749721	0.34687151	0.007804609	0.6057298	0.075716219	0.001703615	0.0225
0.275	0.94665	0.2374339	2.4699405	0.308742558	0.00849042	0.7802465	0.097530811	0.002682097	0.0275
0.325	0.89895	0.2009056	2.2386855	0.279835689	0.00909466	0.8809865	0.110123319	0.003579008	0.0325
0.375	0.85125	0.1741182	2.0516966	0.256462071	0.009617328	0.9374606	0.117182576	0.004394347	0.0375
0.425	0.80355	0.1536337	1.8933503	0.23666879	0.010058424	0.965292	0.120661496	0.005128114	0.0425
0.475	0.75585	0.1374618	1.7546017	0.219325215	0.010417948	0.9735257	0.12169071	0.005780309	0.0475
0.525	0.70815	0.1243702	1.6298514	0.20373143	0.0106959	0.9677611	0.120970135	0.006350932	0.0525
0.575	0.66045	0.1135554	1.5154477	0.189430967	0.010892281	0.9516499	0.118956237	0.006839984	0.0575
0.625	0.61275	0.1044709	1.4089074	0.176113429	0.011007089	0.9276753	0.115959413	0.007247463	0.0625
0.675	0.56505	0.0967323	1.3084831	0.163560389	0.011040326	0.8975847	0.112198093	0.007573371	0.0675
0.725	0.51735	0.0900612	1.2129094	0.151613674	0.010991991	0.8626436	0.107830447	0.007817707	0.0725
0.775	0.46965	0.0842508	1.1212475	0.140155932	0.010862085	0.8237906	0.102973829	0.007980472	0.0775
0.825	0.42195	0.0791446	1.0327861	0.129098257	0.010650606	0.7817371	0.097717142	0.008061664	0.0825
0.875	0.37425	0.0746221	0.9469765	0.118372068	0.010357556	0.7370318	0.092128971	0.008061285	0.0875
0.925	0.32655	0.0705885	0.8633889	0.107923609	0.009982934	0.6901046	0.086263069	0.007979334	0.0925
0.975	0.27885	0.0669685	0.7816812	0.097710153	0.00952674	0.6412973	0.080162164	0.007815811	0.0975
Overall p(collision)			**Upwind**		**0.17571356**	**Downwind**		**0.1033503**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.17571356 + 0.1033503)/2
Average probability of collision = 0.139532

Annual collision risk for Hobby assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 26.846 x 0.139532
Annual collision risk = 3.746 birds

Corrected annual collision risk assuming avoidance

Hobby avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 3.746 x (1 - 0.98)
Annual collision risk, with avoidance = 0.075 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.064 birds

Calculate number of years per collision

Number of years per collision for Hobby = 1/corrected annual risk
Number of years per collision for Hobby = 1/0.064

Number of years per collision for Hobby = 15.7034

Peregrine (Year 1, 2020-2021)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as October - July.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	77	15822.73	56961828	225	3.9500E-06
2	166.81	78	13011.18	46840248	1005	2.1456E-05
3	398.35	78	31071.30	111856680	1320	1.1801E-05
Total	770.65	233	179561.45	646421220	2550	3.7207E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 3.721E-5/3 = **1.240E-05**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 1.240E-5 **2.9919E-03**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **2.917E-03**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for October - July and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 3646.145

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 3646.145 x 2.917E-3
No. of hours of bird occupancy = 10.636

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.42 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.42)
Vr = 569101.027 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 10.636 x 3600 x 569101.027/282244716
Bird occupancy in rotor swept volume = 77.205

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 16 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.42)/16
Bird transit time through the rotors = 0.2545 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 77.205/0.2545
No. of transits = 303.376

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.42 m
Wingspan	1.02 m
Bird speed	16 m/s
F:Flapping	1

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.42/1.02
Bird aspect ratio (b) = 0.412

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	5.2235469	17.40428	1	0.00125	15.830987	0.989436678	0.001236796	0.00125
0.075	0.575	1.7411823	6.3258574	0.395366087	0.002965246	4.7525647	0.297035296	0.002227765	0.0075
0.125	0.7015	1.0447094	4.7799782	0.29874864	0.003734358	2.8605612	0.178785074	0.002234813	0.0125
0.175	0.8601	0.746221	4.3503031	0.271893944	0.004758144	1.9969309	0.124808181	0.002184143	0.0175
0.225	0.99435	0.5803941	4.1215952	0.257599702	0.005795993	1.4008934	0.087555837	0.001970006	0.0225
0.275	0.94665	0.4748679	3.4691527	0.216822044	0.005962606	0.8789658	0.05493536	0.001510722	0.0275
0.325	0.89895	0.4018113	3.007535	0.187970937	0.006109055	0.5478629	0.034241433	0.001112847	0.0325
0.375	0.85125	0.3482365	2.6988145	0.168675909	0.006325347	0.4703426	0.029396415	0.001102366	0.0375
0.425	0.80355	0.3072675	2.4473795	0.152961219	0.006500852	0.5912628	0.036953924	0.001570542	0.0425
0.475	0.75585	0.2749235	2.2351397	0.139696234	0.006635571	0.6729877	0.042061729	0.001997932	0.0475
0.525	0.70815	0.2487403	2.0508966	0.128181039	0.006729505	0.7267159	0.045419743	0.002384537	0.0525
0.575	0.66045	0.2271107	1.8873467	0.117959166	0.006782652	0.759751	0.047484436	0.002730355	0.0575
0.625	0.61275	0.2089419	1.7395235	0.108720219	0.006795014	0.7770592	0.048566203	0.003035388	0.0625
0.675	0.56505	0.1934647	1.6039323	0.100245769	0.006766589	0.7821356	0.048883472	0.003299634	0.0675
0.725	0.51735	0.1801223	1.4780423	0.092377644	0.006697379	0.7775107	0.048594417	0.003523095	0.0725
0.775	0.46965	0.1685015	1.3599759	0.084998492	0.006587383	0.7650622	0.047816389	0.00370577	0.0775
0.825	0.42195	0.1582893	1.2483105	0.078019407	0.006436601	0.7462127	0.046638293	0.003847659	0.0825
0.875	0.37425	0.1492442	1.1419489	0.071371808	0.006245033	0.7220594	0.045128711	0.003948762	0.0875
0.925	0.32655	0.1411769	1.040031	0.065001939	0.006012679	0.6934624	0.043341399	0.004009079	0.0925
0.975	0.27885	0.1339371	0.9418732	0.058867074	0.00573954	0.6611054	0.041319085	0.004028611	0.0975
Overall p(collision)			**Upwind**		**0.11482955**	**Downwind**		**0.05166082**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.11482955 + 0.05166082)/2
Average probability of collision = 0.083245

Annual collision risk for Peregrine assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 303.376 x 0.083245
Annual collision risk = 25.255 birds

Corrected annual collision risk assuming avoidance

Peregrine avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 25.255 x (1 - 0.98)
Annual collision risk, with avoidance = 0.505 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.429 birds

Calculate number of years per collision

Number of years per collision for Peregrine = 1/corrected annual risk
Number of years per collision for Peregrine = 1/0.429

Number of years per collision for Peregrine = 2.3292

Peregrine (Year 2, 2021-2022)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as the whole year.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
1	205.49	86	17672.14	63619704	150	2.3578E-06
2	166.81	84	14012.04	50443344	345	6.8394E-06
3	398.35	92	36648.20	131933520	15	1.1369E-07
Total	770.65	262	201910.30	726877080	510	9.3108E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall windfarm area

Mean bird activity =Total bird activity/number of VPs
Mean bird activity = 9.311E-6/3 = **3.104E-06**

Overall area covered by VPs (excluding overlap) = 241.2348 ha
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 241.2348 x 3.104E-6 **7.4870E-04**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 91.4 m Observed height band max = 150 m
Rotor radius = 58.5 m Observed height band min = 30 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 149.9 m
Rotor min height = 32.9 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (149.9 - 32.9)/(150 - 30)
Proportion of actual height band = 0.975

Corrected bird activity = **7.300E-04**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4481.135

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4481.135 x 7.300E-4
No. of hours of bird occupancy = 3.271

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 241.2348 x 10000 x 58.5 x 2
Vw = 282244716 m3

Calculate the combined rotor swept volume

Number of turbines = 13
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.42 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 13 x Pi x 58.5 x 58.5 x (3.652 + 0.42)
Vr = 569101.027 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)
Bird occupancy in rotor swept volume = 3.271 x 3600 x 569101.027/282244716
Bird occupancy in rotor swept volume = 23.745

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 16 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.42)/16
Bird transit time through the rotors = 0.2545 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 23.745/0.2545
No. of transits = 93.306

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1
No. of blades	3
Maximum chord	4 m
Pitch (degrees)	20
Rotor radius	58.5 m
Rotation Period	3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.42 m
Wingspan	1.02 m
Bird speed	16 m/s
F:Flapping	1

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.42/1.02
Bird aspect ratio (b) = 0.412

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	5.2235469	17.40428	1	0.00125	15.830987	0.989436678	0.001236796	0.00125
0.075	0.575	1.7411823	6.3258574	0.395366087	0.002965246	4.7525647	0.297035296	0.002227765	0.0075
0.125	0.7015	1.0447094	4.7799782	0.29874864	0.003734358	2.8605612	0.178785074	0.002234813	0.0125
0.175	0.8601	0.746221	4.3503031	0.271893944	0.004758144	1.9969309	0.124808181	0.002184143	0.0175
0.225	0.99435	0.5803941	4.1215952	0.257599702	0.005795993	1.4008934	0.087555837	0.001970006	0.0225
0.275	0.94665	0.4748679	3.4691527	0.216822044	0.005962606	0.8789658	0.05493536	0.001510722	0.0275
0.325	0.89895	0.4018113	3.007535	0.187970937	0.006109055	0.5478629	0.034241433	0.001112847	0.0325
0.375	0.85125	0.3482365	2.6988145	0.168675909	0.006325347	0.4703426	0.029396415	0.001102366	0.0375
0.425	0.80355	0.3072675	2.4473795	0.152961219	0.006500852	0.5912628	0.036953924	0.001570542	0.0425
0.475	0.75585	0.2749235	2.2351397	0.139696234	0.006635571	0.6729877	0.042061729	0.001997932	0.0475
0.525	0.70815	0.2487403	2.0508966	0.128181039	0.006729505	0.7267159	0.045419743	0.002384537	0.0525
0.575	0.66045	0.2271107	1.8873467	0.117959166	0.006782652	0.759751	0.047484436	0.002730355	0.0575
0.625	0.61275	0.2089419	1.7395235	0.108720219	0.006795014	0.7770592	0.048566203	0.003035388	0.0625
0.675	0.56505	0.1934647	1.6039323	0.100245769	0.006766589	0.7821356	0.048883472	0.003299634	0.0675
0.725	0.51735	0.1801223	1.4780423	0.092377644	0.006697379	0.7775107	0.048594417	0.003523095	0.0725
0.775	0.46965	0.1685015	1.3599759	0.084998492	0.006587383	0.7650622	0.047816389	0.00370577	0.0775
0.825	0.42195	0.1582893	1.2483105	0.078019407	0.006436601	0.7462127	0.046638293	0.003847659	0.0825
0.875	0.37425	0.1492442	1.1419489	0.071371808	0.006245033	0.7220594	0.045128711	0.003948762	0.0875
0.925	0.32655	0.1411769	1.040031	0.065001939	0.006012679	0.6934624	0.043341399	0.004009079	0.0925
0.975	0.27885	0.1339371	0.9418732	0.058867074	0.00573954	0.6611054	0.041319085	0.004028611	0.0975
Overall p(collision)			**Upwind**		**0.11482955**	**Downwind**		**0.05166082**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.11482955 + 0.05166082)/2
Average probability of collision = 0.083245

Annual collision risk for Peregrine assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 93.306 x 0.083245
Annual collision risk = 7.767 birds

Corrected annual collision risk assuming avoidance

Peregrine avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 7.767 x (1 - 0.98)
Annual collision risk, with avoidance = 0.155 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.132 birds

Calculate number of years per collision

Number of years per collision for Peregrine = 1/corrected annual risk
Number of years per collision for Peregrine = 1/0.132

Number of years per collision for Peregrine = 7.5733