Fluxes of nocturnal bird migration through offshore wind farms Luchterduinen and Borssele

Summary of six years of bird radar data

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Preface

Rijkswaterstaat Zee en Delta (RWS) has commissioned Waardenburg Ecology to analyse radar data on nocturnal bird migration from Luchterduinen and Borssele Alpha to produce summarising tables of bird fluxes and energy production. The purpose of these tables is to aid in decision making regarding the threshold for defining migration peaks, which ultimately will be used for curtailment of offshore wind farms.

The authors thank everyone who has contributed to this report, especially Mainah Folkers (RWS) who carried out the data filtering and flux calculations of all radar data presented in this report. Also, we thank Winifred Roggekamp for delivering data of the bird migration model, weather data and wind turbine power curves. We thank our colleague Rob van Bemmelen for his valuable comments in a previous version of this report. Lastly, we thank Aylin Erkman and Jos de Visser from Rijkswaterstaat who coordinated the project.

Nederlandse samenvatting

Massale vogeltrek over de Noordzee vindt plaats gedurende de lente en de herfst. Deze trek is niet continu maar vertoont verschillend piekmomenten in flux. Op verzoek van Rijkswaterstaat zijn tabellen opgesteld die de nachtelijke flux van vogels door de windparken Luchterduinen en Borssele Alpha over de periode 2019-2024 samenvatten in verschillende flux klassen. Hierin is onder andere te zien hoeveel uren gedurende het seizoen pieken in vogeltrek plaatsvinden. Ook is te zien hoeveel procent van de gemeten vogeltrek tijdens deze momenten doortrekt. Deze tabellen kunnen bijdragen aan de besluitvorming van een nieuwe drempelwaarde voor stilstand voor kavelbesluiten van windparken op zee.

Contents

1 Introduction

To mitigate the effects of offshore wind farms on populations of migrating birds, curtailment of wind energy production is applied by temporarily and substantially decreasing the rotation speed of wind turbines. The decision to apply curtailment is made by the minister of Climate and Green Growth when expected bird migration is surpassing migration rates higher than 500 birds per hour per km at rotor height (25-300m), and if energy supply is not at risk. Bird migration rates are predicted using the bird migration prediction model developed by the University of Amsterdam (UvA) (Bradarić 2022). Validation of the model by the UvA and by Waardenburg Ecology showed that the threshold of 500 birds per hour per km is rarely exceeded in measurements by the radar at offshore wind farm Luchterduinen (Middelveld *et al.* 2024, Kraal *et al.* 2024). This leads to few, or no migration peaks being classified as such, which hampers the validation of the model and underestimates the actual number of migration peaks.

An important cause for the mismatch between the current high threshold and the low peaks predicted by the model is that the chosen threshold is based on measurements by a different radar system, collected at a different location. The threshold of 500 birds/km/h is based on the distribution of vertical radar measurements recorded at Offshore wind farm Egmond aan Zee (OWEZ) between June 2007 and May 2010 (Krijgsveld *et al.* 2015). The bird migration prediction model was developed based on data collected at Luchterduinen (LUD) using a horizontal radar system (Bradarić 2022). The vertical radar is known to detect more smaller objects compared to the horizontal radar, thus resulting in higher fluxes during nights of intense migration, as these usually consist mainly of passerines. The radars also differ in manufacturers. Each radar manufacturer uses their own algorithms to distinguish birds from other objects and clutter. This also results in potential differences between measured fluxes. Furthermore, locations and years might also differ in the amount of bird flux passing through. Van Bemmelen *et al.* (2022) showed that peak migration intensity does not always coincide between LUD and Borssele Alpha (BSA).

Due to differences in location and radar type it is not advisable to apply a threshold defined in one study onto measurements from another study. Therefore, a new threshold value is required. RWS has commissioned Waardenburg Ecology to analyse radar data on nocturnal bird migration from LUD and BSA to produce summarising tables of bird fluxes and energy production. The purpose of these tables is to aid in decision making regarding the threshold for defining migration peaks, which ultimately will be used for curtailment.

2 Methods

Radar data, both vertical and horizontal, as well as data on wind speed, were prepared and provided by RWS.

2.1 Radar data

Data on bird fluxes were collected by horizontal and vertical radars at Luchterduinen and Borssele Alpha (Figure 2.1). The radars at Luchterduinen have been operational since spring 2019, and at Borssele since autumn 2019. The installed bird radars are a so-called Robin 3D Fixed System, consisting of a horizontal Furuno magnetron-based S-band radar and a fixed vertical Furuno magnetron-based pulse X-band radar.

The radar data is filtered before calculating fluxes (also called mean traffic rates (MTR)). These filtering steps are required to distinguish between tracks of birds from noise (e.g. rain, waves, slow moving objects, reflection by turbines). Filtering and MTR calculation was carried out by RWS using methodology developed by the UvA for the horizontal radar (Bradarić 2022) and based on the methods of Leemans *et al*. (2024) for the vertical radar.

Fluxes can be calculated in different ways. Fluxes measured by horizontal radar is calculated based on a donut-shaped area from 1km to 2km distance of the radar. Fluxes for the vertical radar were based on tracks crossing a pre-defined line at 500m to 1000m on both sides of the radar, with an average height between 3m and 300m. For more information on the filtering and calculation of MTR we refer to Middelveld *et al.* (2024) for the horizontal radar and Leemans *et al*. (2024) for the vertical radar.

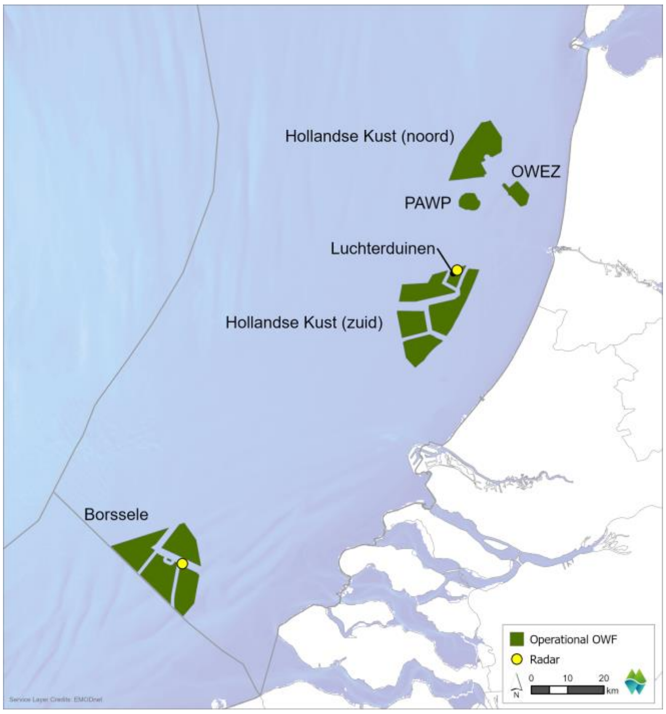

Figure 2.1 *The locations of operational offshore wind farms (OWF) in the Dutch part of the North Sea, and the locations of the bird radars at Luchterduinen and Borssele Alpha.*

2.2 Flux tables

In determining a new threshold value, a balanced decision is required between the number of collisions avoided and total power lost. Collisions avoided are related to the flux at rotor height through the wind farm. Power lost is determined by the wind speed during curtailment and the efficiency of the turbine to convert wind into energy. Peaks in nocturnal bird flux occur mostly during lower wind speeds (Bradarić *et al.* 2020). By identifying peaks in bird flux, it is possible to efficiently curtail wind turbines; thus maximising collisions avoided, and minimizing the loss of power.

To aid in this decision, flux tables were constructed where the seasonal migration is summarised per flux class, following Krijgsveld *et al.* (2015). For the horizontal radar, flux classes of 50 birds per km per hour were used. For the vertical radar, which in general detects more tracks, flux classes of 100 birds per km per hour were used. The tables also give an overview of total amount of hours during which the highest migration rates occur. By calculating the cumulative number of birds passing per flux class, we determined the percentage of total migration recorded by the radars for that season. This percentage also represents the percentage of fatalities that could be prevented, if turbines were to be shut down during hours with an MTR of at least that flux class and assuming that the number of collisions is proportional to the flux. The absolute number of collisions was not estimated as this requires assumptions on the local wind turbine specifics (such as number of turbines and size of the turbines) and the bird species involved, and hence these estimations come with substantial uncertainty. Power generated (kWh) per MW turbine was calculated using a general function based on mean wind speed per hour (m/s), which was provided by RWS. Similar to the percentage of fatalities prevented, the tables also indicate the cumulative percentage power lost if turbines were curtailed for hours with an MTR of at least that flux class. The percentage power lost was determined based on the hours with valid radar data. Therefore, this percentage does not necessarily represent the percentage energy lost per year.

Massive bird migration occurs in autumn and spring. We present nocturnal bird fluxes separately for both seasons. Migration patterns differ between these two seasons in total amount of migration, direction, departure location and responses to meteorological variables (e.g. in autumn easterly winds will bring more birds from Scandinavia in the direction of LUD and BSA, whereas in spring, western winds can support bird migrating from the UK to the Netherlands). Also, the importance of the seasons to survival of populations is different for the seasons, considering that in autumn, a large proportion of birds will be immatures, while in spring, virtually all individuals will be mature individuals. A collision avoided in spring is therefore more valuable to bird populations than a collision avoided in autumn since the bird has already survived half a year longer and is more likely to produce offspring.

Migration can occur in a broad front across the North Sea or peaked in certain areas of the North Sea. Also, distance to the coast may play a role in the intensity of migration. To investigate the effect of location, we present the results separately for both locations (LUD and BSA). For both locations, both vertical and horizontal radar data are available for most seasons. Horizontal and vertical radars operate slightly different (e.g. S-band vs X-band) which results in different detection sensitivity, and handle clutter in a different way. Therefore, the data of these radars are also presented separately.

Finally, we distinguished between the period within a season. To be able to compare with the data used for the bird migration prediction model of the UvA, we present data for the full season, but also for a shorter period that was used for training and developing the model (referred to as ‘short season’). For spring, the full season covers the period from 15th of February to the end of May; the short season covers the period 15th of February till the 30th of April. For autumn the full season starts at the 15th of August and ends the 30th of November; the short season starts the 1st of October and ends on the 30th of November.

Summarising, flux tables were created for the two radar locations (LUD and BSA), for two radars (horizontal radar (HR) and vertical radar (VR)), for the two migration seasons (Spring and Autumn) and for two lengths of each season (full season (3.5 months) and short season (only using the months as used for training the model)). Tables were constructed per year as well as for all years together. To illustrate the differences between years in the cumulative number of hours and the percentage of the total flux, the median, the extremes (minimum and maximum value) and the mean are included in the tables.

3 Results

In this report we present the availability of radar data, and the summarising tables over the available years (2019-2024). For the full results, we refer to a supplementary (separate), interactive document.

3.1 Data availability

It is important to be aware how many hours are included in the analysis to avoid any biases to certain years or months. Only nocturnal hours are included where the radar was operational, and the detection of birds was not significantly hampered by noise.

An overview of when the radar was functioning, is plotted per month for both horizontal radars (Figure 3.1). Several things stand out. First, compared to LUD, the horizontal radar of BSA collected relatively few data over the period of 2019 - 2022. The explanation for the high number of excluded hours at BSA is unclear. Possibly, a software update could be the reason behind this pattern. However, we do not have the data to verify this.

Secondly, more hours were excluded due to too much filtering by the radar in autumn compared to spring, for both radars. This loss of data can be significant. For example, for LUD in November 2023, more than 50% of the hours could not be used for analysing bird flux. The loss of data in autumn is very likely to be explained by more frequent periods of strong winds and by higher rainfall.

The functioning of the vertical radar was also explored over time (Figure 3.2). Both vertical radars had, compared with the horizontal radar, more problems with collecting suitable data. This resulted in high numbers of “Filter on”-hours. Especially the vertical radar in BSA showed a lot of filtered hours and few suitable hours. Also, it is noteworthy that these radars were not operational for most of 2024. In early spring 2024, there was an issue with a damaged radar. It was decided that all vertical radars would be shut down until the issue was resolved.

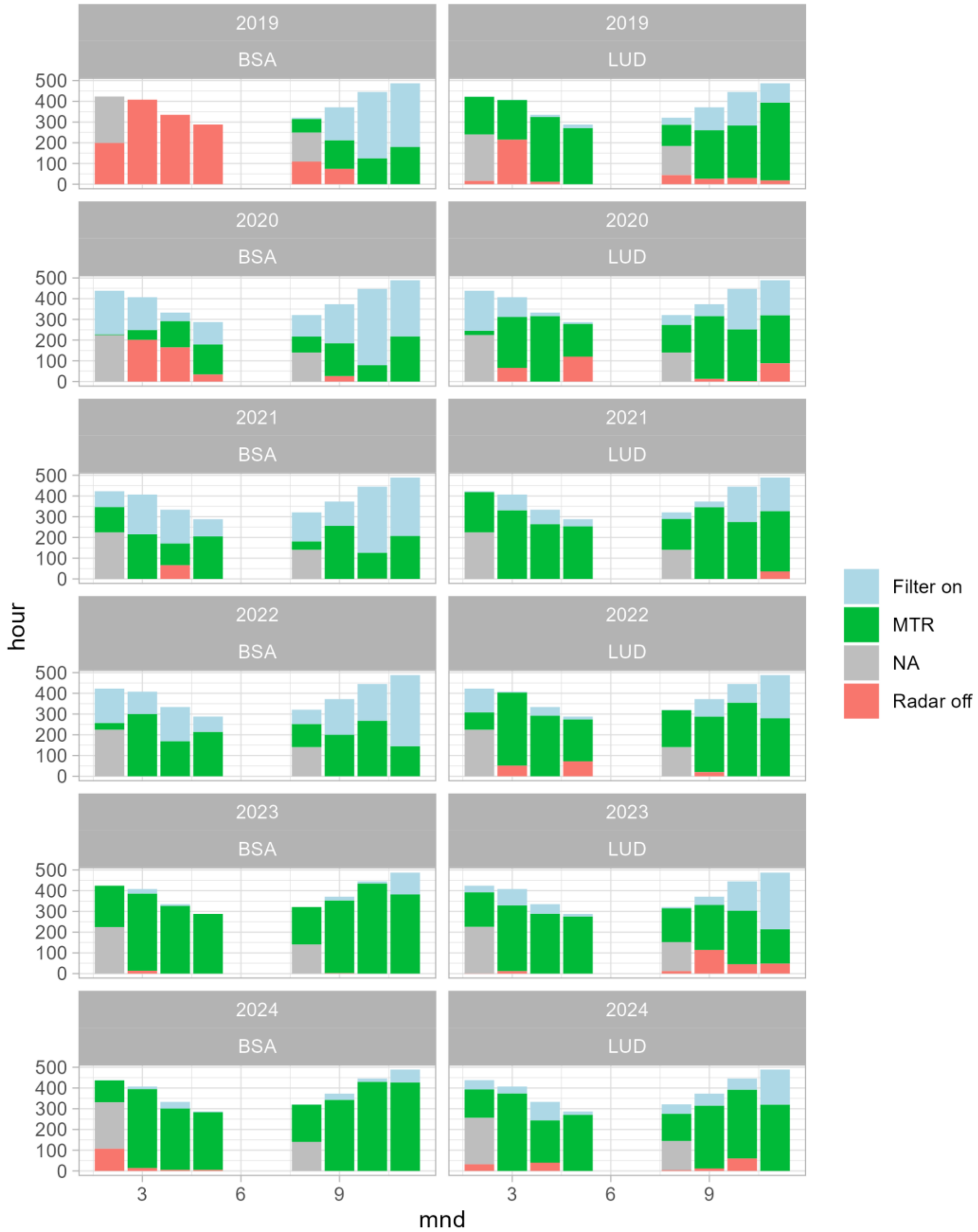

Figure 3.1 *Monthly radar functioning over time (2019-2024) for the* ***horizontal radars*** *at BSA (left) and LUD (right). All nighttime hours per season are classified. 'MTR' represents suitable data. 'Radar off' indicates the hours where the radar was not operational. 'Filter on' indicates the hours where too much filtering was applied (due to e.g. wave clutter or rain) resulting in incorrect MTRs. 'NA' represents the hours outside the scope of this study (nocturnal hours from 1 February to 15 February and from 1 August to 15 August).*

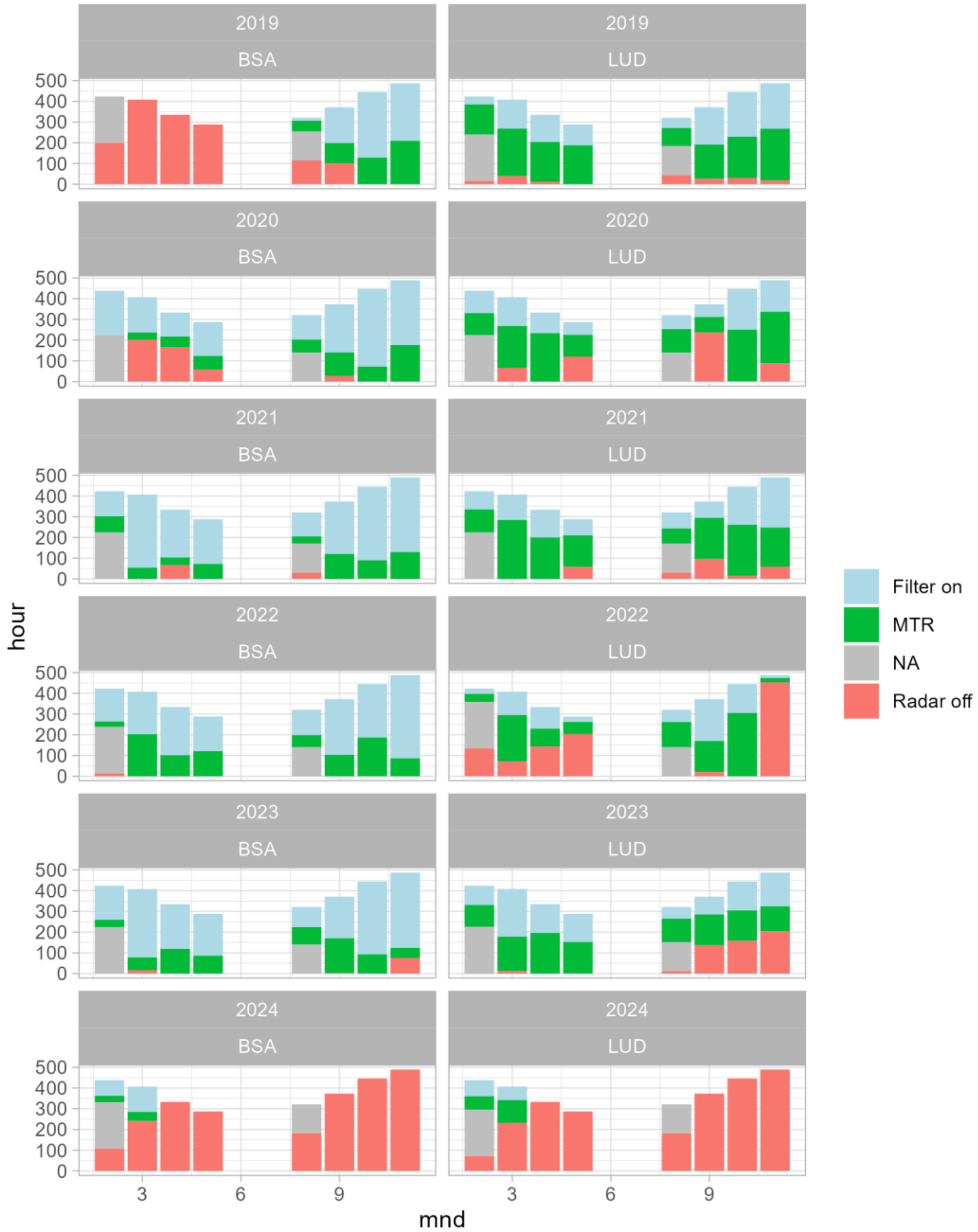

Figure 3.2 *Monthly radar functioning over time (2019-2024) for the* ***vertical radars*** *at BSA and LUD. Only nighttime hours were included. 'MTR' represents suitable data. 'Radar off' indicates the hours where the radar was not operational. 'Filter on' indicates the hours where too much filtering was applied (due to e.g. wave clutter or rain) resulting in incorrect MTRs. 'NA' represents the hours outside the scope of this research (nocturnal hours from 1 February to 15 February and from 1 August to 15 August).*

3.2 Flux tables

Here, we present the flux tables summarising flux as measured by the different radars over the years 2019-2024. In the box below, we provide an explanation of each column. The complete overview of flux tables including the tables per year, can be found in the supplementary document. An example of such a table for one year can be found in Appendix I to show how the different columns were calculated.

Box: explanation table columns

Flux class: the range of flux as measured by the radar, also known as mean traffic rate (n birds/km/h). A square bracket indicates that the value itself is included, a round bracket indicates that all values until that value are included.
N unique years: the number of years that this flux level was recorded.
Sum n hours: the number of hours that a certain flux class occurred for that season.
% time: the percentage of the total number of hours with radar data that a certain flux class occurred.
Cum. n hours: the cumulative number of hours of the total number of hours with radar data that a certain flux class and higher occurred.
Cum. n hours (%): the percentage of the total number of hours with radar data that a certain flux class or higher occurred. This column also represents the cumulative percentage of idle time, when assuming that turbines were shut down during hours of this flux level or higher.
Sum MTR (birds/km): the total summed flux for a certain flux class measured during the season over all years. Sum MTR forms an intermediate step in calculating the cumulative MTR. It indicates the classes during which most birds were detected.
Cum. MTR (%): the percentage of cumulative flux compared to the total flux measured for all available hours for that specific season and location. Since flux is assumed to be linearly related to collisions, this column also represents the cumulative percentage of collisions avoided, if turbines were shut down during hours of this flux level or higher.
Mean wind speed (m/s): the mean wind speed during all available hours of a certain flux class.
Sum power (kWh/MW): the potential power generated per mega Watt wind turbine is calculated per hour. This column represents the summed power per flux class for hours with radar data available.
Cum. power (%): the percentage of cumulative power compared to the total power for that season and location – for hours with available radar data.

All / min. / max. / median for the columns cum. n hours and cum. MTR (%):
Seasonal migration can be quite different in the total amount of migration, in the peakedness of migration (sometimes uniform, sometimes large peaks), and also in the detections of migration (some years with good weather circumstances when radar functioned very good, and some years where many hours were filtered from the analysis). Due to these differences, some years might be overrepresented in all years table. Therefore, columns with the median, minimum and maximum of the different years were added to show differences between years.

Table 3.1 Bird flux summarised for the horizontal radar at LUD during spring across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[1100,1150]	1	1	0.02	1	0	0	1	0.2	0.02	1115	0.9	0	0	5	0.8	4.66	96	0
[1000,1050)	1	1	0.02	2	0	0	1	0.3	0.04	1031	1.7	0	0	5.3	1.7	8.51	481	0
[950,1000)	1	1	0.02	3	0	0	2	0.5	0.05	955	2.4	0	0	9.3	2.4	6.28	258	0
[900,950)	3	5	0.09	8	0	0.5	5	1.3	0.14	4545	5.9	0	1.2	21.5	5.7	5.8	1051	0.1
[850,900)	1	1	0.02	9	0	0.5	6	1.5	0.16	887	6.6	0	1.2	25.4	6.3	4.27	57	0.1
[800,850)	3	4	0.07	13	0	1	7	2.2	0.23	3341	9.2	0	2.4	29.1	8.8	7.05	1339	0.1
[750,800)	3	3	0.05	16	0	2	7	2.7	0.28	2341	11	0	6	29.1	10.7	6.55	856	0.2
[700,750)	2	5	0.09	21	0	3.5	7	3.5	0.37	3646	13.8	0	10.1	29.1	12.6	6.5	1400	0.2
[650,700)	1	2	0.04	23	0	3.5	9	3.8	0.4	1361	14.8	0	11.9	29.1	13.2	6.18	496	0.2
[600,650)	1	1	0.02	24	0	4	9	4	0.42	604	15.3	0	13.9	29.1	13.9	4.37	67	0.2
[550,600)	2	4	0.07	28	0	4.5	12	4.7	0.49	2351	17.1	0	16.3	29.5	15.2	7	1320	0.3
[500,550)	3	3	0.05	31	0	5	13	5.2	0.54	1546	18.3	0	18.7	29.5	16.5	6.09	717	0.3
[450,500)	3	8	0.14	39	0	6	18	6.5	0.68	3893	21.3	0	24.2	31.7	19	6.5	2242	0.4
[400,450)	5	9	0.16	48	0	7.5	22	8	0.84	3784	24.2	0	28	36.4	21.7	5.44	1700	0.4
[350,400)	4	10	0.18	58	1	8	27	9.7	1.02	3717	27.1	2.3	28.7	41.5	24.2	7.54	3842	0.6
[300,350)	3	9	0.16	67	2	8	32	11.2	1.17	2831	29.3	4.1	29	45.8	25.9	6.12	2197	0.7
[250,300)	5	14	0.25	81	2	10	40	13.5	1.42	3853	32.3	4.1	32.3	51.9	28.5	5.34	2616	0.8
[200,250)	6	33	0.58	114	7	15	47	19	2	7272	37.9	10.4	38.9	56.1	34.3	6.2	8668	1.1
[150,200)	6	48	0.84	162	17	22	54	27	2.84	8293	44.3	24.5	41.8	59.7	41.2	7.08	16459	1.7
[100,150)	6	94	1.65	256	24	40	76	42.7	4.48	11589	53.2	37.2	48.8	67.3	50.6	5.77	22312	2.6
[50,100)	6	272	4.77	528	62	84.5	145	88	9.25	19020	67.9	55.8	63.3	80.4	65.6	5.72	62200	4.9
[0,50)	6	5180	90.75	5708	741	971.5	1049	951.3	100	41554	100	100	100	100	100	8.61	2524954	100

Table 3.2 Bird flux summarised for the horizontal radar at LUD during autumn across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[1000,1050)	1	1	0.02	1	0	0	1	0.2	0.02	1039	0.5	0	0	4.3	0.7	0.28	0	0
[900,950)	1	1	0.02	2	0	0	1	0.3	0.03	927	1	0	0	4.3	1	4.18	48	0
[850,900)	2	2	0.03	4	0	0.5	2	0.7	0.07	1760	1.9	0	1.5	4.3	1.8	4.14	88	0
[800,850)	1	1	0.02	5	0	1	2	0.8	0.08	824	2.3	0	3	4.3	2.4	1.2	0	0
[750,800)	5	7	0.12	12	0	2	4	2	0.2	5439	5.1	0	5.8	7.5	5.3	3.82	647	0
[700,750)	4	7	0.12	19	0	3	7	3.2	0.32	5101	7.7	0	9.6	11.8	7.8	3.66	537	0.1
[650,700)	3	4	0.07	23	0	3	9	3.8	0.39	2758	9.1	0	9.7	14.7	9.1	4.72	654	0.1
[600,650)	3	9	0.15	32	0	5	14	5.3	0.54	5578	11.9	0	12.4	21.3	11.7	3.56	651	0.1
[550,600)	5	12	0.2	44	1	5.5	19	7.3	0.74	6929	15.4	1.4	13.7	27.6	15	4.49	1586	0.2
[500,550)	6	13	0.22	57	5	7.5	21	9.5	0.96	6787	18.9	6.5	17.4	29.9	18.4	3.94	1243	0.2
[450,500)	6	23	0.39	80	8	11.5	24	13.3	1.35	10883	24.4	13.4	24.2	32.9	24.2	3.44	1150	0.3
[400,450)	5	18	0.3	98	8	15.5	28	16.3	1.66	7625	28.2	19.7	28	36.5	27.8	4.47	2356	0.4
[350,400)	6	23	0.39	121	11	18	34	20.2	2.04	8563	32.6	25.8	31.3	41.3	31.9	3.97	2225	0.5
[300,350)	6	29	0.49	150	13	22.5	40	25	2.53	9442	37.4	28.6	35.5	45.4	36.7	3.9	2450	0.6
[250,300)	6	41	0.69	191	19	30.5	48	31.8	3.23	11333	43.1	35.4	38.9	53.3	42.5	4.44	4395	0.8
[200,250)	6	49	0.83	240	25	39.5	57	40	4.06	10965	48.7	40.9	45.3	61.7	48.3	4.23	4871	1.1
[150,200)	6	73	1.23	313	37	48.5	73	52.2	5.29	12440	55	46.5	51.9	67.5	54.6	4.56	10173	1.5
[100,150)	6	145	2.45	458	56	67.5	107	76.3	7.74	17686	64	56.7	62.1	73.7	63.6	4.56	18644	2.4
[50,100)	6	442	7.47	900	109	135	210	150	15.21	30942	79.7	75.1	78.5	86.3	79.3	4.8	64882	5.4
[0,50)	6	5018	84.79	5918	804	1014	1087	986.3	100	39982	100	100	100	100	100	7.69	2046003	100

Table 3.3 Bird flux summarised for the horizontal radar at BSA during spring across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[850,900)	1	1	0.03	1	0	0	1	0.2	0.03	865	1.1	0	0	2.9	0.6	4.62	92	0
[800,850)	1	2	0.05	3	0	0	3	0.6	0.08	1654	3.1	0	0	8.5	1.7	5.21	301	0
[650,700)	1	1	0.03	4	0	0	3	0.8	0.1	656	4	0	0	8.5	2.2	2.76	0	0
[600,650)	1	2	0.05	6	0	0	5	1.2	0.15	1267	5.5	0	0	12.8	3.1	4.28	124	0
[550,600)	2	4	0.1	10	0	0	6	2	0.25	2322	8.4	0	0	14.8	4.9	5.33	651	0.1
[500,550)	1	2	0.05	12	0	0	8	2.4	0.3	1033	9.7	0	0	18.3	5.6	3.62	64	0.1
[450,500)	2	2	0.05	14	0	1	8	2.8	0.36	912	10.8	0	4.2	18.3	6.8	3.94	122	0.1
[400,450)	2	2	0.05	16	0	1	8	3.2	0.41	829	11.9	0	6.1	18.3	8.4	2.84	17	0.1
[350,400)	2	4	0.1	20	0	1	11	4	0.51	1493	13.7	0	6.1	22.2	9.5	6.16	987	0.1
[300,350)	4	10	0.25	30	2	3	12	6	0.76	3213	17.7	6.9	11.2	22.2	14.5	6.58	3081	0.3
[250,300)	5	17	0.43	47	4	6	19	9.4	1.19	4596	23.5	11.6	20.3	29.7	20.8	5.68	3639	0.5
[200,250)	4	22	0.56	69	4	11	29	13.8	1.75	4939	29.6	18.7	25.7	37.3	26.4	4.92	3948	0.7
[150,200)	5	43	1.09	112	8	16	41	22.4	2.85	7693	39.2	29.1	35.8	44.5	36.5	4.8	7137	1.1
[100,150)	5	77	1.96	189	11	24	76	37.8	4.8	9398	50.9	34.8	42.5	58.9	46.2	5.6	17438	2.1
[50,100)	5	172	4.37	361	23	45	154	72.2	9.17	12328	66.3	47.8	55.1	77.9	59.8	5.23	31533	3.9
[0,50)	5	3574	90.83	3935	323	716	1187	787	100	27088	100	100	100	100	100	8.4	1685643	100

Table 3.4 Bird flux summarised for the horizontal radar at BSA during autumn across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[1050,1100)	1	1	0.02	1	0	0	1	0.2	0.02	1071	0.5	0	0	1.7	0.3	1.03	0	0
[950,1000)	1	1	0.02	2	0	0	2	0.3	0.04	988	0.9	0	0	3.2	0.5	1.23	0	0
[900,950)	3	5	0.1	7	0	1	3	1.2	0.14	4614	3	0	2.1	6.4	2.6	3.95	591	0
[850,900)	1	1	0.02	8	0	1	4	1.3	0.16	853	3.4	0	2.1	6.4	2.8	2.77	0	0
[800,850)	3	4	0.08	12	0	1.5	5	2	0.23	3297	4.9	0	3.6	9.3	4.1	3.31	42	0
[750,800)	3	5	0.1	17	0	2	7	2.8	0.33	3859	6.6	0	5.7	11.7	5.5	3.55	308	0
[700,750)	5	11	0.21	28	0	4	10	4.7	0.55	7919	10.1	0	9.5	15.1	8.7	4.72	1623	0.1
[650,700)	5	10	0.2	38	0	6	13	6.3	0.74	6703	13.2	0	13.8	18.2	11.4	3.91	958	0.2
[600,650)	5	17	0.33	55	0	9	17	9.2	1.07	10543	17.9	0	18.1	23	15.9	3.91	1383	0.3
[550,600)	4	12	0.23	67	0	11	22	11.2	1.31	6881	21	0	21.4	24.6	18.3	4.37	1522	0.4
[500,550)	5	16	0.31	83	0	13	28	13.8	1.62	8436	24.8	0	24.6	30.1	21.7	4.32	1817	0.5
[450,500)	5	22	0.43	105	0	18	35	17.5	2.05	10392	29.4	0	30.7	35.1	25.9	4.69	2944	0.6
[400,450)	6	26	0.51	131	1	20	48	21.8	2.56	10981	34.3	3	35	43.3	30.1	4.94	4189	0.8
[350,400)	6	33	0.64	164	3	23	68	27.3	3.2	12429	39.9	8.3	38.1	55.2	34.8	4.79	4737	1.1
[300,350)	6	39	0.76	203	6	29.5	83	33.8	3.96	12710	45.6	15.3	41.7	62.9	40.2	5.16	7004	1.5
[250,300)	6	48	0.94	251	7	36	99	41.8	4.9	13112	51.5	17.2	47.9	69.8	45.6	4.47	6267	1.9
[200,250)	6	54	1.05	305	8	44	117	50.8	5.95	11875	56.8	18.7	53.3	76	50.4	5	9402	2.4
[150,200)	6	101	1.97	406	16	61.5	146	67.7	7.92	17756	64.8	28.8	61.1	84.1	58.6	4.5	12911	3.1
[100,150)	6	150	2.93	556	33	93.5	174	92.7	10.85	18223	73	43.7	68.3	89.4	67.8	4.71	21430	4.3
[50,100)	6	349	6.81	905	60	163	224	150.8	17.66	24643	84	56.8	81.2	95.2	79.8	4.7	48660	7
[0,50)	6	4220	82.34	5125	509	677	1380	854.2	100	35642	100	100	100	100	100	7.62	1678317	100

Table 3.5 Bird flux summarised for the vertical radar at LUD during spring across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[1800,1900)	1	1	0.03	1	0	0	1	0.2	0.03	1880	1	0	0	14	2.3	6.62	292	0
[1400,1500)	1	1	0.03	2	0	0	1	0.3	0.06	1458	1.7	0	0	14	3	6.16	246	0
[1200,1300)	1	1	0.03	3	0	0.5	1	0.5	0.09	1219	2.3	0	1.4	14	3.5	8.52	482	0.1
[1100,1200)	1	1	0.03	4	0	1	1	0.7	0.12	1190	3	0	3.1	14	4	8.87	517	0.1
[900,1000)	1	1	0.03	5	0	1	1	0.8	0.15	934	3.4	0	3.1	14	4.4	9.36	566	0.1
[800,900)	2	2	0.06	7	0	1	2	1.2	0.21	1644	4.3	0	4.3	14	5.2	6.03	467	0.2
[700,800)	1	1	0.03	8	0	1.5	2	1.3	0.24	767	4.7	0	5.2	14	5.5	8.68	498	0.2
[600,700)	2	10	0.3	18	0	1.5	8	3	0.54	6479	8	0	9.8	14	8.2	6.45	2751	0.4
[500,600)	5	10	0.3	28	1	3.5	10	4.7	0.83	5440	10.8	2.3	12.5	19.5	10.8	6.76	3063	0.6
[400,500)	5	13	0.39	41	1	6.5	13	6.8	1.22	5869	13.8	4.3	13.8	22	13.3	7	4461	0.9
[300,400)	6	36	1.07	77	3	13	22	12.8	2.29	12259	20.1	11	17.8	29.7	19.5	7.41	13092	1.8
[200,300)	6	86	2.56	163	11	29	41	27.2	4.85	20868	30.8	18.7	30.5	42.7	30.3	7.7	33360	4
[100,200)	6	320	9.52	483	35	89.5	112	80.5	14.37	44246	53.6	38.6	54.8	67.5	53	8.34	140904	13.4
[0,100)	6	2879	85.63	3362	176	636	755	560.3	100	90403	100	100	100	100	100	8.47	1297567	100

Table 3.6 Bird flux summarised for the vertical radar at LUD during autumn across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[2300,2400)	1	1	0.03	1	0	0	1	0.2	0.03	2356	0.8	0	0	3.7	0.7	8.9	520	0
[2100,2200)	1	1	0.03	2	0	0	1	0.4	0.06	2156	1.6	0	0	4	1.5	10.99	729	0.1
[2000,2100)	2	2	0.06	4	0	0	2	0.8	0.12	4141	3.1	0	0	7.8	2.9	8.55	970	0.2
[1900,2000)	1	2	0.06	6	0	2	2	1.2	0.19	3887	4.5	0	7	7.8	4.3	11.7	1601	0.3
[1700,1800)	1	2	0.06	8	0	2	4	1.6	0.25	3514	5.8	0	7	12.4	5.4	9.04	1067	0.3
[1600,1700)	1	1	0.03	9	0	2	4	1.8	0.28	1616	6.4	0	7	12.4	6	4.89	119	0.3
[1500,1600)	1	2	0.06	11	0	2	6	2.2	0.34	3050	7.5	0	7	17.2	7	9.78	1217	0.4
[1400,1500)	1	1	0.03	12	0	2	6	2.4	0.37	1450	8	0	7	17.2	7.5	6.16	246	0.5
[1300,1400)	3	3	0.09	15	0	3	7	3	0.46	4019	9.4	0	9.4	19.3	8.9	9.4	1709	0.6
[1200,1300)	4	5	0.15	20	1	4	9	4	0.62	6219	11.7	2.3	11.6	23.2	11.1	7.4	1851	0.7
[1100,1200)	1	1	0.03	21	1	4	10	4.2	0.65	1169	12.1	2.3	11.6	25.1	11.5	9.21	551	0.8
[1000,1100)	3	5	0.15	26	1	4	11	5.2	0.81	5243	14	2.3	11.6	26.8	13.4	6.69	1497	0.8
[900,1000)	5	8	0.25	34	2	7	13	6.8	1.05	7579	16.7	4.1	16.7	29.8	16.1	6.9	2631	1
[800,900)	4	7	0.22	41	3	7	16	8.2	1.27	5895	18.9	5.8	18.1	33.8	18.2	8.12	3234	1.3
[700,800)	5	17	0.53	58	7	11	18	11.6	1.8	12623	23.4	11.5	20.8	36.1	22.8	5.62	4212	1.6
[600,700)	5	21	0.65	79	11	14	25	15.8	2.45	13601	28.3	16.4	26.3	43.1	27.7	6.54	6485	2
[500,600)	5	25	0.77	104	16	21	28	20.8	3.22	13755	33.3	21.8	32.8	45.6	32.8	7.22	9283	2.7
[400,500)	5	22	0.68	126	19	23	36	25.2	3.91	10058	36.9	24.6	37	51.3	36.3	7.95	9320	3.3
[300,400)	5	36	1.12	162	24	32	41	32.4	5.02	12535	41.4	28.1	42.7	53.9	40.9	5.54	8309	3.9
[200,300)	5	90	2.79	252	41	49	60	50.4	7.81	21873	49.3	36	49.4	61	48.8	7.87	36521	6.5
[100,200)	5	315	9.76	567	96	106	136	113.4	17.58	42334	64.6	52.3	63.5	75.2	64.1	7.69	126145	15.4
[0,100)	5	2659	82.42	3226	530	687	707	645.2	100	98235	100	100	100	100	100	8.35	1196205	100

Table 3.7 Bird flux summarised for the vertical radar at BSA during spring across all years (2019-2024) for the full season.

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[1700,1800)	1	1	0.08	1	0	0	1	0.2	0.08	1753	1.6	0	0	6.6	1.3	8.94	524	0.1
[1500,1600)	1	1	0.08	2	0	0	2	0.4	0.16	1547	3.1	0	0	12.3	2.5	6.28	258	0.2
[1400,1500)	2	2	0.16	4	0	0	3	0.8	0.32	2866	5.7	0	0	17.6	4.7	10.61	1382	0.5
[900,1000)	1	1	0.08	5	0	0	4	1	0.41	930	6.6	0	0	21.1	5.4	5.71	201	0.6
[800,900)	1	4	0.32	9	0	1	4	1.8	0.73	3365	9.7	0	6.1	21.1	7.1	4.02	217	0.6
[700,800)	2	2	0.16	11	0	1	5	2.2	0.89	1558	11.1	0	7.9	21.1	9.1	9.08	1075	0.9
[600,700)	4	6	0.49	17	1	2	8	3.4	1.38	3806	14.7	7.9	8.7	23.5	12.8	9.27	3170	1.6
[500,600)	4	6	0.49	23	1	3	9	4.6	1.87	3270	17.7	8.7	16.4	27.7	16.6	6.77	2021	2.1
[400,500)	3	8	0.65	31	1	5	14	6.2	2.52	3416	20.9	8.7	19.2	29.2	18.6	4.99	1117	2.4
[300,400)	4	17	1.38	48	1	8	22	9.6	3.9	6132	26.5	8.7	28.9	33.4	24	6.7	5403	3.7
[200,300)	5	57	4.63	105	3	22	37	21	8.52	13728	39.3	14.9	38.2	50.1	37	7.17	20742	8.7
[100,200)	5	200	16.23	305	12	73	113	61	24.76	27809	65	32.9	64.4	76.7	61.8	6.75	67400	24.9
[0,100)	5	927	75.24	1232	76	244	452	246.4	100	37736	100	100	100	100	100	6.95	312541	100

Table 3.8 *Bird flux summarised for the vertical radar at BSA during autumn across all years (2019-2024) for the full season.*

flux class (n birds/hr /km)	n unique years	sum n hours	% time	cum. n hours					cum. n hours (%)	sum MTR	cum. MTR (%)					mean wind speed (m/s)	sum power (kWh/ MW)	cum. power (%)
				all	min.	med.	max.	mean			all	min.	med.	max.	mean			
[3100,3200]	1	2	0.09	2	0	0	2	0.4	0.09	6315	1.8	0	0	6.1	1.2	7.71	801	0.1
[2900,3000)	1	1	0.05	3	0	0	2	0.6	0.14	2931	2.6	0	0	6.1	1.9	12.87	917	0.3
[2600,2700)	1	1	0.05	4	0	0	3	0.8	0.19	2623	3.4	0	0	8.6	2.4	9.21	551	0.4
[2500,2600)	1	2	0.09	6	0	1	3	1.2	0.28	5158	4.8	0	3.5	9.3	4.3	8.74	1007	0.5
[2400,2500)	1	2	0.09	8	0	2	3	1.6	0.38	4863	6.2	0	8.6	9.3	5.4	10.28	1288	0.7
[2200,2300)	3	4	0.19	12	0	3	4	2.4	0.57	9030	8.8	0	9.3	13.4	7.9	8.74	2017	1
[2100,2200)	2	2	0.09	14	0	3	5	2.8	0.66	4349	10	0	9.3	17.4	9.1	8.04	869	1.2
[2000,2100)	2	2	0.09	16	0	3	6	3.2	0.75	4108	11.1	0	9.3	17.4	10.1	8.1	879	1.3
[1900,2000)	2	3	0.14	19	0	3	8	3.8	0.89	5842	12.8	0	9.3	20.9	11.5	7.46	1129	1.5
[1800,1900)	2	2	0.09	21	0	4	9	4.2	0.99	3714	13.8	0	11.5	20.9	12.4	8.88	1037	1.7
[1600,1700)	2	2	0.09	23	0	4	10	4.6	1.08	3277	14.8	0	11.5	21.9	13.1	11.6	1559	1.9
[1500,1600)	2	2	0.09	25	0	5	11	5	1.18	3098	15.7	0	13.2	23.3	13.8	6.46	551	2
[1400,1500)	3	4	0.19	29	0	5	12	5.8	1.37	5711	17.3	0	16.6	24.7	15.1	7.9	1686	2.3
[1300,1400)	1	2	0.09	31	0	5	14	6.2	1.46	2700	18	0	16.6	27.3	15.6	7.9	839	2.4
[1200,1300)	2	5	0.24	36	0	7	16	7.2	1.7	6191	19.8	0	18.4	29.7	17.1	7.2	1822	2.7
[1100,1200)	4	7	0.33	43	0	9	17	8.6	2.03	8278	22.1	0	23	30.8	19.3	7.95	3127	3.2
[1000,1100)	4	9	0.42	52	0	12	18	10.4	2.45	9396	24.8	0	25.7	31.9	21.8	10.7	5930	4.1
[900,1000)	3	6	0.28	58	0	14	20	11.6	2.73	5732	26.4	0	27.1	33.6	23.4	6.74	2050	4.4
[800,900)	4	12	0.57	70	1	17	23	14	3.3	10345	29.3	2.4	30.6	36.1	26.1	6.55	3291	5
[700,800)	5	21	0.99	91	7	19	28	18.2	4.29	15494	33.7	14.5	33	39.6	31.2	5.35	4239	5.6
[600,700)	5	25	1.18	116	11	23	35	23.2	5.46	16218	38.3	21.8	36	44	35.9	6.51	7291	6.8
[500,600)	5	28	1.32	144	15	26	44	28.8	6.78	15361	42.7	29.1	38.3	49.3	40.3	6.69	8506	8.1
[400,500)	5	58	2.73	202	19	36	70	40.4	9.51	25718	49.9	39.4	44.4	59.8	47.5	6.58	17711	10.9
[300,400)	5	77	3.63	279	28	52	99	55.8	13.14	26711	57.5	44.9	51.9	69.3	54.8	6.91	26213	15.1
[200,300)	5	158	7.44	437	51	85	144	87.4	20.58	38395	68.4	55.3	62.6	80	65.8	6.47	47678	22.6
[100,200)	5	346	16.3	783	79	180	204	156.6	36.88	48946	82.2	70.5	80.4	88.5	80.1	6.86	117909	41.2
[0,100)	5	1340	63.12	2123	375	427	488	424.6	100	62875	100	100	100	100	100	6.27	372097	100

4 Discussion

The goal of this research was to construct tables summarising bird flux to aid in deciding on a new threshold value to define nocturnal bird migration peaks. While the construction of tables is quite straightforward, some considerations have to be taken into account when using or interpreting them.

Due to their ability to detect bird movements on a relatively large scale and during day and night, radars are a suitable tool to study nocturnal bird migration. Yet, radars are not perfect observers of bird migration. They cannot identify bird species, and, moreover, other moving objects, or even rain or waves can be classified as bird tracks. To prevent non-bird tracks from entering the database, filtering is applied. We showed that filtering results in a significant number of hours excluded. If missing data would be random across conditions and time, the remaining data would still give an unbiased view of the occurrence of peak migration. However, data is often missing for specific, non-random, reasons, in particular during periods with strong wind and/or high precipitation. It is often assumed that filtering predominantly occurs when the circumstances for bird migration are suboptimal, for example during periods of strong winds, which often coincide with high waves or rain. Numerous studies have shown that migrating birds often select nights with weak to medium tailwinds and no precipitation (e.g. McLaren *et al.* 2012, Bradarić *et al.* 2020). These studies used, for example, tracking devices or radars on land, which are not limited to favourable weather circumstances like the horizontal bird radars at Luchterduinen and Borssele Alpha that were used in our study. This suggest that the hours with the highest fluxes are included in the current dataset. However, validating this is impossible as the radars may not have been operational during all migration peaks, and peak migration may also occur under suboptimal local conditions (Leemans *et al.* 2024), for example when weather conditions deteriorate between departure and arrival. From the flux tables of the horizontal radar, it seems that higher fluxes often coincide with on average relatively low wind speeds. This thus might be biased since high fluxes are much more likely to be detected during these circumstances.

Another consideration is that the filtering of radar data is not flawless. To efficiently process the huge quantities of radar data that are being collected, the data is currently filtered according to a set of thresholds. These thresholds are determined for both horizontal radars separately as the amount of radar filtering may differ between radar systems depending on local circumstances that may generate noise (like the presence of nearby wind turbines). As a response to noise, which could also be waves or rain, the radars automatically start filtering this noise, which also decreases to detectability of birds. The horizontal radar suffers most from wave clutter at close distances to the radar, and hence filtering is most strong in this region. As wave height increases, the filtering at larger distances also becomes stronger, which often results in a circle around the radar where it is not able to detect birds any longer. The radius of this circle depends on the wave height. The post-filtering applied on the dataset should filter out all hours in which radar filtering took place between 1 km and 2 km distance (*i.e.* the area where MTR is calculated). However, we know from previous projects that with the current filtering thresholds there may be hours remaining in the dataset with (very) low MTRs (due to radar filtering), while the actual flight activity was likely higher. This was validated based on horizontal radar data at larger distances from the radar, or with vertical radar. This suggests that the current filtering thresholds are not strict enough.

As a result, the number of hours within the lowest flux category [0,50) is most likely overrepresented in the data. The effect of this overrepresentation on the flux tables is unknown as it depends on what the actual fluxes were during these hours. For example, a few of these hours could in theory be peak migration hours, which would affect the cumulative number of hours in the highest classes. If the actual fluxes in most of these hours were indeed higher, it could also mean that the cumulative MTR percentage of peak hours will be lower. In other words, the cumulative percentage of birds that migrate during peak hours, and hence the percentage of birds that will be saved when deciding on a certain threshold, may possibly be lower than what is presented in the tables. But again, this depends on what the actual fluxes were during these hours. Additionally, the cumulative MTR percentage in each flux class represents only a percentage of the fluxes detected by the radar, and as such it is also strongly biased through other hours that are missing in the dataset. These factors of uncertainty should be considered when interpreting the cumulative MTR percentages that are presented in the flux tables.

Setting a filtering threshold that is not strict enough may also result in a higher probability that some clutter remains in the dataset. The automatic radar filtering increases in response to, for example, increasing waves or rain showers. This implies that there is a certain delay in which the filtering is applied. Therefore, especially when circumstances quickly change, clutter may still enter the database due to this delay in the radar filtering. To address this issue, filtering steps on some track characteristics (straightness, displacement over time and airspeed) are already taken to remove remaining clutter tracks. A potentially promising method to further improve this filtering could be using machine learning to identify clutter tracks. For example, automatic classification of wave clutter using machine learning for a Max 3D radar yields already very promising results. Similar methods could be applied to the offshore radar systems, like that in LUD and BSA. However, to develop sufficiently accurate models, it is necessary to collect many data on true positive bird tracks, as well as on tracks from noise. As offshore field visits are often challenging to arrange and bird numbers are generally lower than on land, it may require substantial effort to collect enough data to feed into these models. In the current study, manual inspection of the radar images during a sample of hours with the highest MTRs revealed hardly any false positive peaks caused by clutter, which means that any remaining clutter in the dataset will not likely influence the conclusions of this study.

The above-mentioned issues reveal that it is very important to further improve the methods for the filtering of radar data. However, note that simply applying stricter filtering thresholds may not necessarily lead to more desired outcomes, as migration peaks may also be filtered out when setting stricter filtering thresholds.

We recommend when comparing flux tables, to compare only between different years of the same season and the same location. As mentioned before, the amount of radar filtering may differ between radar systems depending on local circumstances that may generate noise (like the presence of nearby wind turbines). Comparing absolute fluxes between locations may therefore be biased, as, for example, one radar system may systematically record higher fluxes than the other. Furthermore, the total number of birds migrating in spring is generally lower than in autumn, as a proportion of birds died in winter. Also, the importance of the seasons to survival of populations is different for the seasons, considering that in autumn, a large proportion of birds will be immatures, while in spring, virtually all individuals will be mature individuals. A collision avoided in spring is therefore more valuable to bird populations than a collision avoided in autumn since the bird has already survived half a year longer and is more likely to produce offspring. This could be an argument for deciding on different thresholds for spring and for autumn. However, this may also be a trade-off with the total number of birds saved.

A possible solution to deal with differences in the absolute fluxes measured between different locations and different seasons, but also between different years (in some years migration is much more peaked in a few nights, while in other years migration is more spread out), is to define a curtailment 'threshold' as a certain maximum number of curtailment hours in spring and in autumn. Then still, curtailment is only applied when both the bird migration model and the expert team predict a migration peak. The tables in this report provide the minimum, median and maximum cumulative number of peak hours and cumulative MTR percentage over the different years. These different estimates show the variation in the peakedness of migration between different years. To be on the safe side, it is advisable - from an ecological point of view - to base the definition of a migration peak for the bird migration model (*i.e.* the trigger value) on the minimum or perhaps median values. Setting this trigger value to high may lead to false negative predictions that could have been avoided. The expert team predictions are able to filter out false positive predictions.

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Appendix I

Explanation of how a flux table for one season is constructed

As an example of a flux table for one season, the summarised results of the bird flux measured by the horizontal radar at Luchterduinen during spring 2023 are shown Table I.1. Only nightly hours when the radar was functional were included. In total, 1,049 hours with suitable flux data were collected this season. All suitable hours were classified in flux classes per 50 birds/km/h. Only flux classes with data are shown. The column “sum n hours” indicates how often a flux class occurred during this period. “% time” indicates the percentage of the total number of hours that a certain flux class occurred. For example, the flux class [800,850) was measured during only two hours. These two hours represent approximately 0.19 % of the time (= 2/1,049 *100). The column “cum. n hours” indicates the cumulative number of hours of the total number of hours that a certain flux class *and higher* occurred. For example, a flux class of [800,850) or higher was measured for 4 hours. This is 0.38 % of the total number of hours with suitable data (= 4/1,049 *100). The total number of birds measured per flux class is denoted under “sum MTR”. For example, for flux class [800,850), in total 1,691 bird tracks were recorded. The cumulative number of bird tracks measured per flux class is denoted under “cum MTR”. For example, for flux class [800,850) *and higher*, in total 3,641 tracks were measured (=1,691 + 919 + 1,031). Since in this year all flux, as measured by the radar, occurred during three massive peaks, the cumulative MTR of 3,641 represents 18.77 % of the total flux measured. The wind speed was measured during all hours. Per hour, the mean windspeed is used to calculate the potential power generated. For example, during the two hours of flux class [800,850), 834 kWh would be generated per MW turbine. For the 4 hours of flux class [800,850) and higher this represents 0.36 % of the total power generated during the hours included for this season (= (481+440+834) / (total power) * 100).

For the full results with all tables, we refer to a supplementary (separate), interactive document.

Table I.1 *Bird flux summarised for the horizontal radar at Luchterduinen (LUD) during spring 2023 (for the full season; 15 February – 31 May).*

flux class (birds/km/h)	sum n hours	% time	cum. n hours (%)	sum MTR	cum. MTR	cum. MTR (%)	mean wind speed (m/s)	sum power (kWh/MW)	cum. power (%)
[1000,1050)	1	0.1	0.1	1,031	1,031	5.32	8.51	481	0.1
[900,950)	1	0.1	0.19	919	1,950	10.05	8.1	440	0.19
[800,850)	2	0.19	0.38	1,691	3,641	18.77	7.87	834	0.36
[750,800)	1	0.1	0.48	779	4,420	22.79	7.59	389	0.44
[700,750)	1	0.1	0.57	718	5,138	26.49	9.03	533	0.54
[550,600)	1	0.1	0.67	590	5,728	29.53	7.23	353	0.62
[400,450)	1	0.1	0.76	423	6,151	31.72	7.8	410	0.7
[350,400)	1	0.1	0.86	393	6,544	33.74	10.1	640	0.83
[250,300)	2	0.19	1.05	577	7,121	36.72	7.48	756	0.98
[200,250)	5	0.48	1.53	1,176	8,297	42.78	8.04	2,168	1.42
[150,200)	1	0.1	1.62	163	8,460	43.62	9.73	603	1.54
[100,150)	7	0.67	2.29	841	9,301	47.96	6.48	2,072	1.97
[50,100)	40	3.81	6.1	2,696	11,997	61.86	5.74	8,486	3.69
[0,50)	985	93.9	100	7,397	19,394	100	8.54	474,425	100