CHAPTER 4

OCCURRENCE OF INTENSE BIRD MIGRATION EVENTS AT ROTOR HEIGHT IN BELGIAN OFFSHORE WIND FARMS AND CURTAILMENT AS POSSIBLE MITIGATION TO REDUCE COLLISION RISK

BRABANT Robin *, RUMES Bob & DEGRAER Steven

Royal Belgian Institute of Natural Sciences (RBINS), Operational Directorate Natural Environment (OD Nature), Aquatic and Terrestrial Ecology (ATECO), Marine Ecology and Management (MARECO), Vautierstraat 29, 1000 Brussels, Belgium.

* Corresponding author: robin.brabant@naturalsciences.be

Abstract

Songbirds are known to cross the North Sea in large numbers during autumn and spring migration. When flying at rotor height, these migrating birds are at risk of collision with turbine blades. This risk can increase when weather conditions deteriorate during these long migration flights over sea. Such deteriorating conditions can result in large numbers of possibly disoriented, weakened birds flying at rotor height and possibly to large numbers of bird collisions. An effective measure to reduce the number of collisions with wind turbines during intense migration events, is to temporarily idle turbines. Offshore wind farms in the Dutch Borssele area, adjacent to the Belgian wind farms, will need to idle turbines from 2023 onwards when the flux of birds exceeds 500 birds.km^{-1}.hour^{-1} at rotor height. Continuous bird radar surveys were performed in a Belgian offshore wind farm to record intense bird migration events. Such events, here defined by a bird flux higher than 500 birdtracks.km^{-1}.hour^{-1} at rotor height occurred 14 times during autumn 2019 (maximum of 995 birdtracks.km^{-1}.hour^{-1}) and did not occur in spring 2021 (maximum of 261 birdtracks.km^{-1}.hour^{-1}). All intense bird migration events occurred at night and comprised nocturnally migrating songbirds. Applying a collision risk model on the detected bird flux, a total estimated number of 761 songbird collisions would have been avoided if the turbines of all Belgian offshore wind farms would have been idled during the 14 hours in autumn 2019 when the bird flux exceeded 500 birdtracks.km^{-1}.hour^{-1} at rotor height. The uncertainty of the collision risk model results and the fact that we do not exactly know which species were registered by the radar does not allow to assess the significance of the number of songbird collisions with wind turbines in the Belgian part of the North Sea. It is however unlikely that this has a significant effect at population level. If this will still be the case for the cumulative effects of all planned wind farms in the (southern) North Sea is unknown.

1. Introduction

The southern North Sea is part of one of the main European migration flyways for large numbers of seabirds (Stienen *et al.* 2007) and non-marine birds (Buurma 1987; Alerstam 1990; Lensink *et al.* 2002; Bradarić *et al.* 2020; Manola *et al.* 2020). Estimates of the number of birds seasonally travelling through the southern North Sea vary from 85 million (Lensink *et al.* 2002) up to several hundreds of million (estimates of Helgoland mentioned in Hüppop *et al.* 2006), of which the vast majority are non-marine birds (Krijgsveld *et al.* 2011; Bradarić *et al.* 2020). During migration, birds fly at greater altitudes than when foraging or commuting between sites (Garthe & Hüppop 2004; Krijgsveld *et al.* 2011) and choose the altitude stratum in which their energy costs are lowest (Hüppop *et al.* 2006), ranging from sea-level up to 10 km. A general phenomenon is that birds fly high with tailwind and that they fly at a lower altitude with headwind (Alerstam 1990; Buurma 1987; Lensink *et al.* 2002).

Peaks of intense migration occur during good weather with favourable, supporting wind conditions (Bradarić *et al.* 2020). During these relatively long flights, birds can be overtaken by deteriorating weather conditions and will lower their flight altitude (Lensink *et al.* 2002). Such conditions result in large numbers of possibly disoriented, weakened birds flying at rotor height and possibly to large numbers of bird collisions. Lensink *et al.* (1999) reported three of these events in the period from 1978 until 1990, but concluded, based on limited data at sea, that these ‘falls’ occur at a yearly base in the southern North Sea.

The development of offshore wind farms (OWFs) in the North Sea might impact these migrating birds as they risk colliding with the turbines, resulting in an increased mortality rate. Fijn *et al.* (2015) reported on the magnitude of bird fluxes at rotor height during migration in the Dutch part of the North Sea. The majority of these fluxes consisted of gull species during the day and migrating songbirds at night. An effective measure to reduce the number of collisions with wind turbines during intense migration events, is to temporarily idle turbines (Cook *et al.* 2011; May 2017). This is, for example, foreseen as a mandatory condition for the exploitation of the wind farms in the Dutch Borssele area. When the flux of birds exceeds 500 birds.km^{-1}.hour^{-1} at rotor height, the number of rotations of the wind turbines must be reduced to less than one revolution per minute (rpm; Rijkswaterstaat 2019). This requires continuous monitoring of the intensity of bird migration by radar and has been estimated to result in approximately 30 hours of turbine downtime annually, i.e., 3 to 4 nights per year. The aim is to apply this measure from January 1st, 2023, onwards.

The goal of this report is to assess the number of hours the flux of birds flying at rotor height exceeds 500 birds.km^{-1}.hour^{-1} in the Belgian OWFs and to assess the significance of curtailment in reducing collision risk.

2. Material and methods

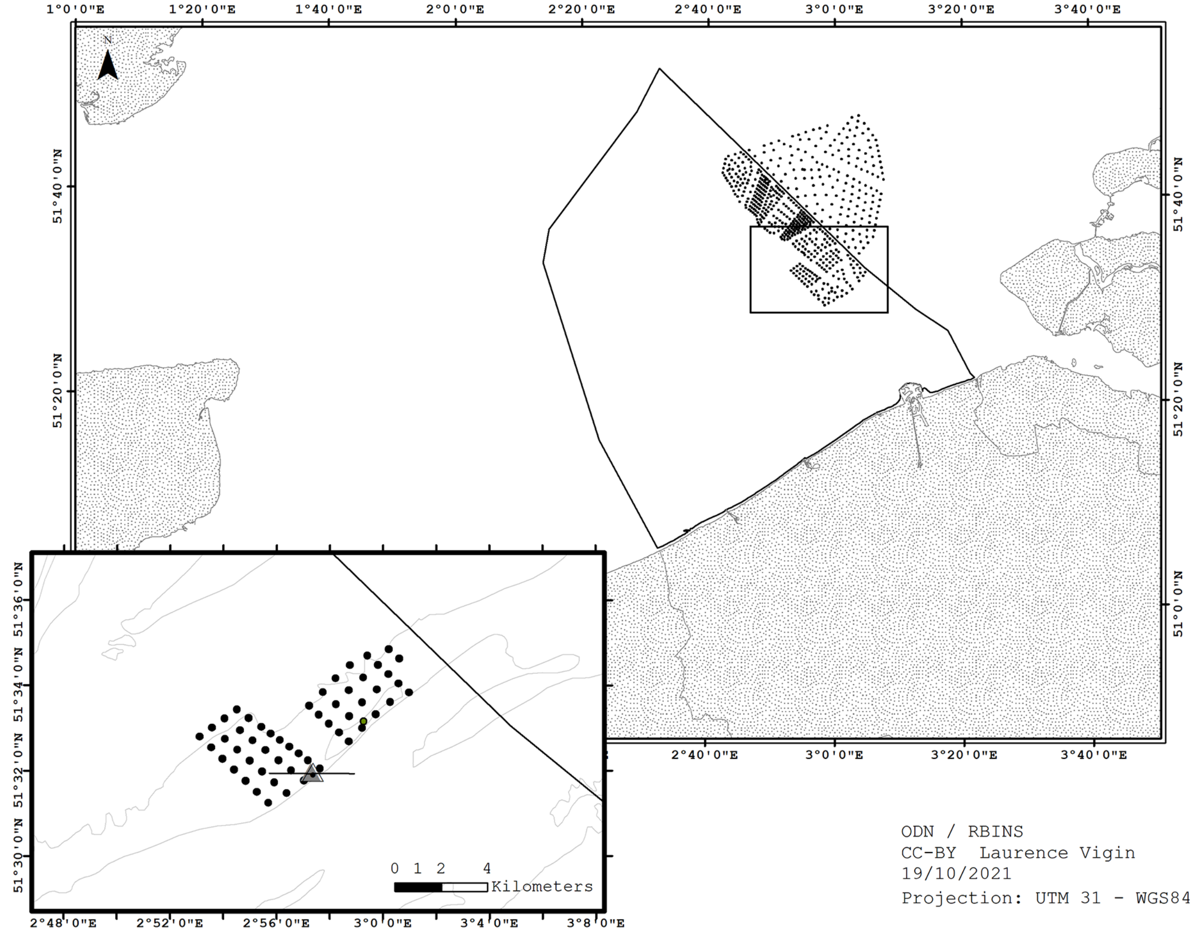
2.1. Research strategy

We used a vertically mounted bird radar with automated bird tracking software to assess the intensity of bird migration in the Belgian part of the North Sea (BPNS) during two migration seasons. We then assessed the frequency of occurrence of intense bird migration events at rotor height, here defined as a bird flux exceeding 500 birdtracks.km^{-1}.hour^{-1}. This is the threshold value used in the Dutch Borssele wind farms to idle the turbines. We finally estimated the number of collision victims that would have been avoided if the Belgian OWFs would have idled the turbines during these intense migration events with a collision risk model.

2.2. Radar hardware

Radar is a valuable tool to obtain data on the intensity of bird movements and their flight altitudes. Radar observations greatly contribute to the understanding of bird migration because of the ability to register birds continuously at large spatial scale and at high altitudes (Eastwood 1967; Bruderer 1997a, 1997b; Gauthreaux & Belser 2003; Liechti *et al.* 2019; Nilsson *et al.* 2019). There are several advantages compared to visual observations as radar is not limited to lower altitudes, daylight or good visibility and does not suffer from observer bias. However, radar systems also have some limitations and the recorded data should be handled cautiously (Schmaljohann *et al.* 2008; Fijn *et al.* 2015). Radars are unable to distinguish species and do not always allow to differentiate between single birds and bird groups.

Bird flux and flight altitude data were collected by a vertically mounted 25 kW marine surveillance radar (JRC JMA-5320-7, X-band (9.41 ± 3.0 KHz), nominal beam angle: 20°, rotation speed: 24 rpm). The radar antenna rotates in the vertical pane and as such, scans a vertical 'radar screen' that registers all the targets moving through that screen. As this 'radar screen' is narrow, every registration can be an individual bird or a flock of birds passing through that area. The flux of birds is expressed as migration traffic rate (MTR), i.e., number of birds that pass across a one kilometer line during an hour (birds.km^{-1}.hr^{-1}; Schmaljohann *et al.* 2008). As the radar is not able to differentiate individual birds from a small flock of birds, the MTR for this type of radar is actually the number of bird groups. km^{-1}.hour^{-1} or a minimum estimate of the number of birds.km^{-1}.hour^{-1} (Fijn *et al.* 2015). Therefore the results are further presented as birdtracks km^{-1}.hour^{-1}.



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Projection: UTM 31 - WGS84

Figure 1. Map of the Belgian part of the North Sea (black polygon) with indication of the Belgian wind farms. The adjacent Borssele wind farms in the Dutch part of the North Sea are shown to the East of the Belgian wind farms. The location of the individual turbines (dots) and the radar location on the transformer platform (triangle) in the C-Power wind farm on the Thorntonbank are shown in the inset. The black line indicates the orientation of the vertical radar from East to West.

The radar antenna is installed on the offshore platform inside the C-Power wind farm on the Thorntonbank in the BPNS since 18 September 2019, after Brabant & Degraer (2017) concluded that the S-band antenna, previously used on the Thorntonbank, was not performing optimally, and had to be replaced by an X-band magnetron radar. Since then, the radar has been performing well and the data presented here are collected with that new vertically mounted antenna. The orientation of the radar is East to West (Fig. 1).

2.3. Bird tracking software and data post-processing

The radar operates continuously year-round and is remotely controlled. The system is operated by the Merlin software (DeTect Inc., Florida USA) which is specifically designed to track individual birds (DeTect Inc. 2010; Brabant *et al.* 2012). The Merlin software links consecutive registrations of a target, and thus registers the flight path of a moving target. Within the Merlin software the range of detection can be specified. This is the range of the radar beam that is being processed by the Merlin tracking software. In this study, the range is set at one nautical mile (nm, 1.852 km), which means an area of one nm on both sides of the radar position and an altitude up to 2 nm is being processed by the bird tracking software.

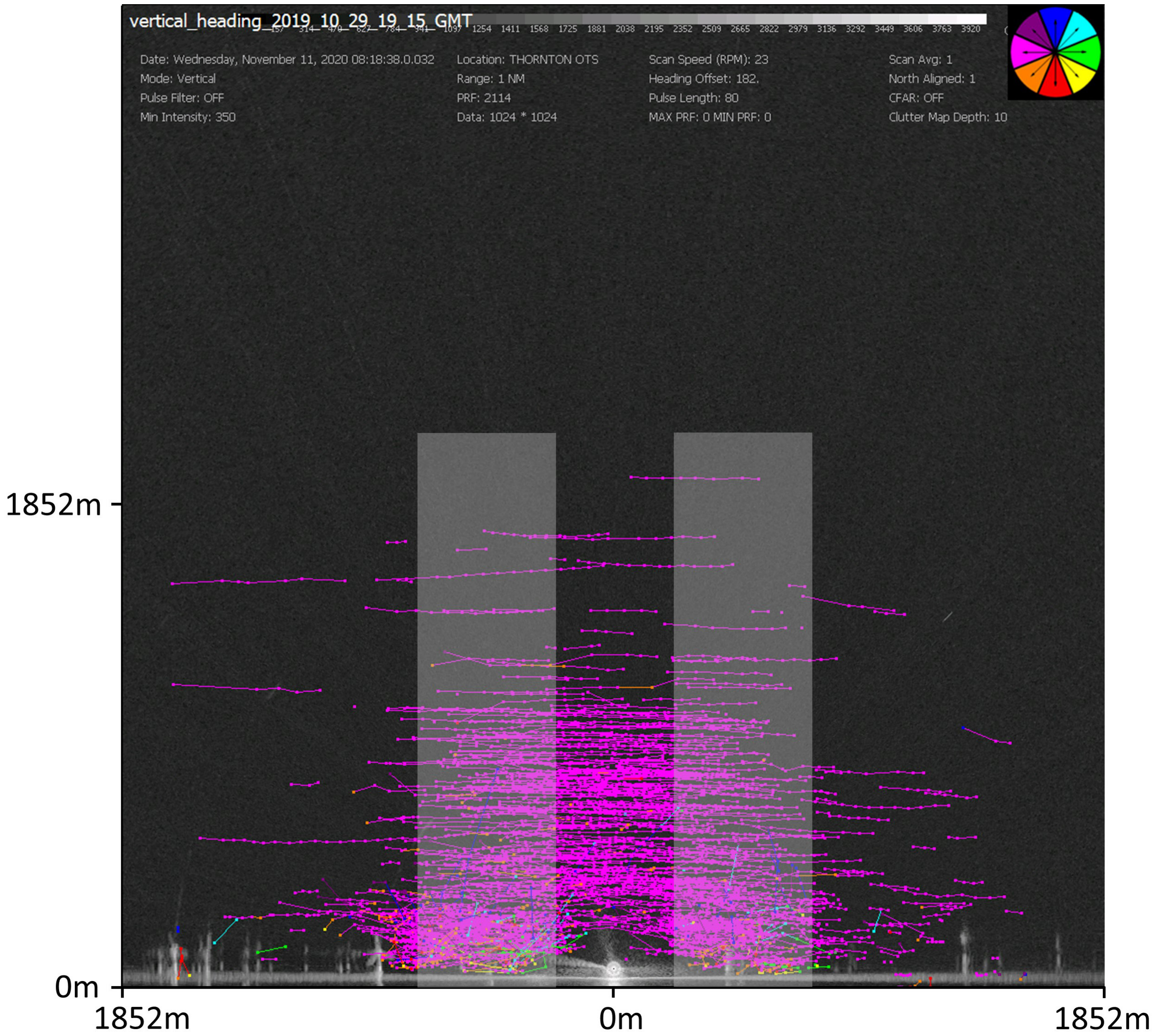
However, these processed data still contain some non-bird tracks coming from different sources (e.g., rain, wind turbines, side lobes). As we use the radar data to determine the flux of birds in the area, clutter has to be removed as accurately as possible. Precipitation was manually removed from the database by visually scanning visualisations of 15 minutes of data and removing rain events. Turbines were removed from the data based on their geographic position. All objects above 2000 m were also removed from the dataset.

The manual post-processing of the radar data to remove non-bird echoes (mainly rain events) from the data is not 100% effective, resulting in occasional noise present in the data at rotor height. After visually reviewing the complete dataset it could be concluded that this noise was never to that extent that it affects the number of hours where MTR exceeds 500 birdtracks.km^{-1}.hour^{-1}. In the near future, a filtering model will be developed to remove noise automatically based on radar echo characteristics, as was already effectively done for the S-band radar system (Brabant *et al.* 2016).

The MTR was calculated as the sum of the number of bird tracks per hour, registered in two columns of 500 m wide selected from the entire measurement volume (Fig. 2; at 150 to 650m distance from the radar, both to the east and west; following the approach of Fijn *et al.* 2015). In doing so, we avoided using the data close to the radar location, which is saturated with reflections of the radar platform, and further than 650 m from the radar to avoid detection loss at further distance from the radar (Fijn *et al.* 2015). Fijn *et al.* (2015) describe that for a magnetron radar, similar to the one used in this study, this detection loss starts at 900 m for smaller birds.

We calculated MTR values for every hour in these study periods per altitude layer of 50 m and also between 24 and 193 m, being the lowest point and highest point of turbine rotors in the Belgian OWFs, to determine the MTR at rotor height.

For this analysis, we used data from two migration seasons, i.e., autumn/winter 2019 (20 September until 15 December) and winter/spring 2021 (7 January until 15 May). The radar was continuously operational throughout both survey periods, autumn/winter 2019 and winter/spring 2021, except from 11 to 15 of April 2021 when the radar system was shut down because of high wind conditions. Data from 2020 were not continuous because of several technical issues and were therefore not used.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Date: Wednesday, November 11, 2020 08:18:38.0.032
Mode: Vertical
Pulse Filter: OFF
Min Intensity: 350

Location: THORNTON OTS
Range: 1 NM
PRF: 2114
Data: 1024 * 1024

Scan Speed (RPM): 23
Heading Offset: 182.
Pulse Length: 80
MAX PRF: 0 MIN PRF: 0

Scan Avg: 1
North Aligned: 1
CFAR: OFF
Clutter Map Depth: 10

Figure 2. Visualisation of 15 minutes of bird radar data from October 29th, 2019 19:15 until 19:30 UTC. Each bird track represents a single bird or a group of birds. The radar position is in the bottom centre of the image (0 m). The radar range (1852 m) is indicated to the East and West of the radar position. The color of the bird tracks represents the direction of flight within the radar beam (e.g., from West to East is purple). The gray columns, at 150 m to 650 m from the radar position and up to 2000 m, indicate the radar data which is used to determine the migration traffic rate (MTR, birds.km^{-1}.hr^{-1}).

2.4. Collision risk modelling

Collision risk model (CRM) allows to estimate the number of bird collisions at sea, where carcass searches are impossible. CRM uses the technical wind farm and turbine specifications, bird-related variables and bird densities to calculate the collision risk per species. The calculations were carried out with the basic collision risk model of Band (2012). The extended CRM of Band (2012) could not be used, because that extension requires detailed information on species-specific flight height distribution throughout the rotor height, which is lacking in our dataset.

As the radar detections are not species-specific, it is not possible to do species-specific CRM estimates. We however know that the highest bird migration peaks occur at night-time (Brabant *et al.* 2017; Nilsson *et al.* 2019) and are mainly terrestrial birds (Alerstam 1990; Krijgsveld *et al.* 2011).

Table 1. Average dimensions of thrushes, used as bird related input data for the collision risk model.

Species	Body_Length (m)[1]	Wingspan (m)[1]	Flight_Speed (m/s)[2]	Nocturnal_ Activity (% of diurnal activity)	Flight	Proportion in Flight
Thrushes *Turdus* sp.	0.24	0.36	12.4	1	flapping	1

[1] Cramp (1977–1985); [2]Alerstam *et al.* (2007).

Table 2. Average wind farm and turbine related input data of the Belgian offshore wind farms used for bird collision risk modelling.

N of turbines	Width (km)	Latitude (°)	tidal offset (m)	turbine model (MW)	n of blades	rotor radius (m)	air gap (m)	max blade width (m)	rotor speed (rpm)	Pitch (°)
399	35	51.6	4.3	6.9	3	73	26.9	5.0	12.11	5.5

Therefore, we used average sizes of thrushes, a species group that is known to migrate in huge numbers at night, for the bird-related input data in the CRM (Table 1).

We calculated the number of expected collisions when the MTR at rotor height exceeded 500 birdtracks.km^{-1}.hour^{-1} for the nine Belgian OWFs in the area. For simplicity we used average wind turbine dimensions for the Belgian OWFs (Table 2). More details on input variables used in the BPNS can be found in Brabant & Vanermen (2020). Rotor speed and pitch were taken from Gyimesi *et al.* (2018). Information on turbine activity per month were taken from Masden (2015).

The CRM also includes a micro-avoidance rate, accounting for last-minute avoidance actions of birds. The avoidance rate is a very important factor in CRM and has a large impact on the outcome. It has proven difficult to quantify and is likely to vary in response to a wide range of environmental and ecological factors, as well as the configuration of the wind farm. Based on the available evidence, it is widely accepted that total avoidance levels amongst birds are likely to be high (Chamberlain *et al.* 2006; Krijgsveld *et al.* 2011; Everaert 2014), commonly higher than 98% and for many seabirds above 99% (Cook *et al.* 2012), also at night (Welcker *et al.* 2017). Most probably, this rate is species-specific and may also depend on weather conditions. Based on the available evidence, it is widely accepted that total avoidance levels amongst birds are likely to be high (Chamberlain *et al.* 2006; Krijgsveld *et al.* 2011; Everaert, 2014), commonly higher than 98% and for many seabirds above 99% (Cook *et al.* 2012), also at night (Welcker *et al.* 2017). Most probably, this rate is species-specific and may also depend on weather conditions. As the radar data are not species-specific, we applied the general micro-avoidance value of 97.6% determined by Krijgsveld *et al.* (2011), based on their extensive radar research in a comparable offshore environment. This rate was also used by Poot *et al.* (2011) to estimate songbird collisions in Dutch OWFs.

Calculations and graphs were made in R version 3.2.2. (R Core Team 2015), making use of the packages ggplot2 (Wickham 2016), cowplot (Wilke 2016), reshape2 (Wickham 2007) and plyr (Wickham 2011).

3. Results

The highest migration intensity was observed in the month October 2019 (Fig. 2 and Fig. 3, upper panel), with a maximum of 17511 tracks/day on October 29th. In spring

2021, the maximum number of tracks in one day was 4870 on March 20th (Fig. 3, lower panel).

Both in autumn 2019 and spring 2021, the number of bird tracks decreased with altitude (Fig. 4). 11.9% of all bird tracks recorded in autumn 2019 were detected in the lowest 50 m. In Spring 2021, this is even 22.7%. The percentage of bird tracks detected at rotor height (24-193 m) is similar in both study periods, being 41.4% in autumn 2019 and 38.2% in spring 2021.

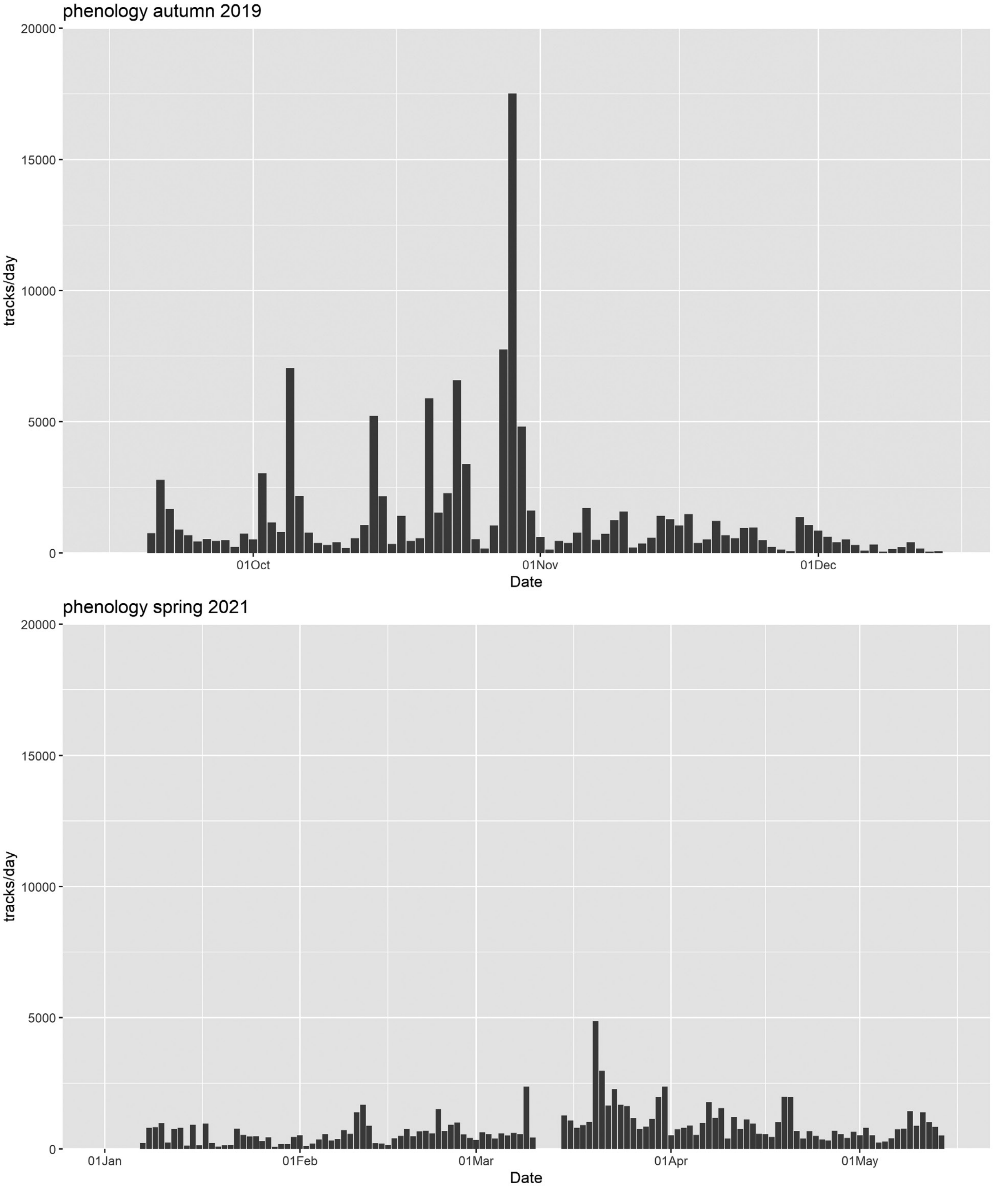

Figure 3. Number of bird tracks per day, recorded by the radar, for autumn 2019 (upper panel) and spring 2021 (lower panel).

During the entire study period, the MTR at rotor height exceeded 500 birdtracks.km^{-1}.hour^{-1} during 14 hours. These all occurred in October 2019 after sunset. The highest registered MTR at rotor height was 995 birdtracks.km^{-1}.hour^{-1} on October 14th between 22:00 and 23:00 CET. In the first half of 2021, the MTR at rotor height was never higher than 500 birdtracks.km^{-1}.hour^{-1} (Fig. 5). The highest recorded flux during that period was 261 birdtracks.km^{-1}.hour^{-1}.

During the 14 hours in autumn 2019 when the MTR exceeded the threshold value of 500 birdtracks.km^{-1}.hour^{-1}, a total estimated number of 761 collisions would have been avoided if the turbines of the Belgian OWFs had been idled.

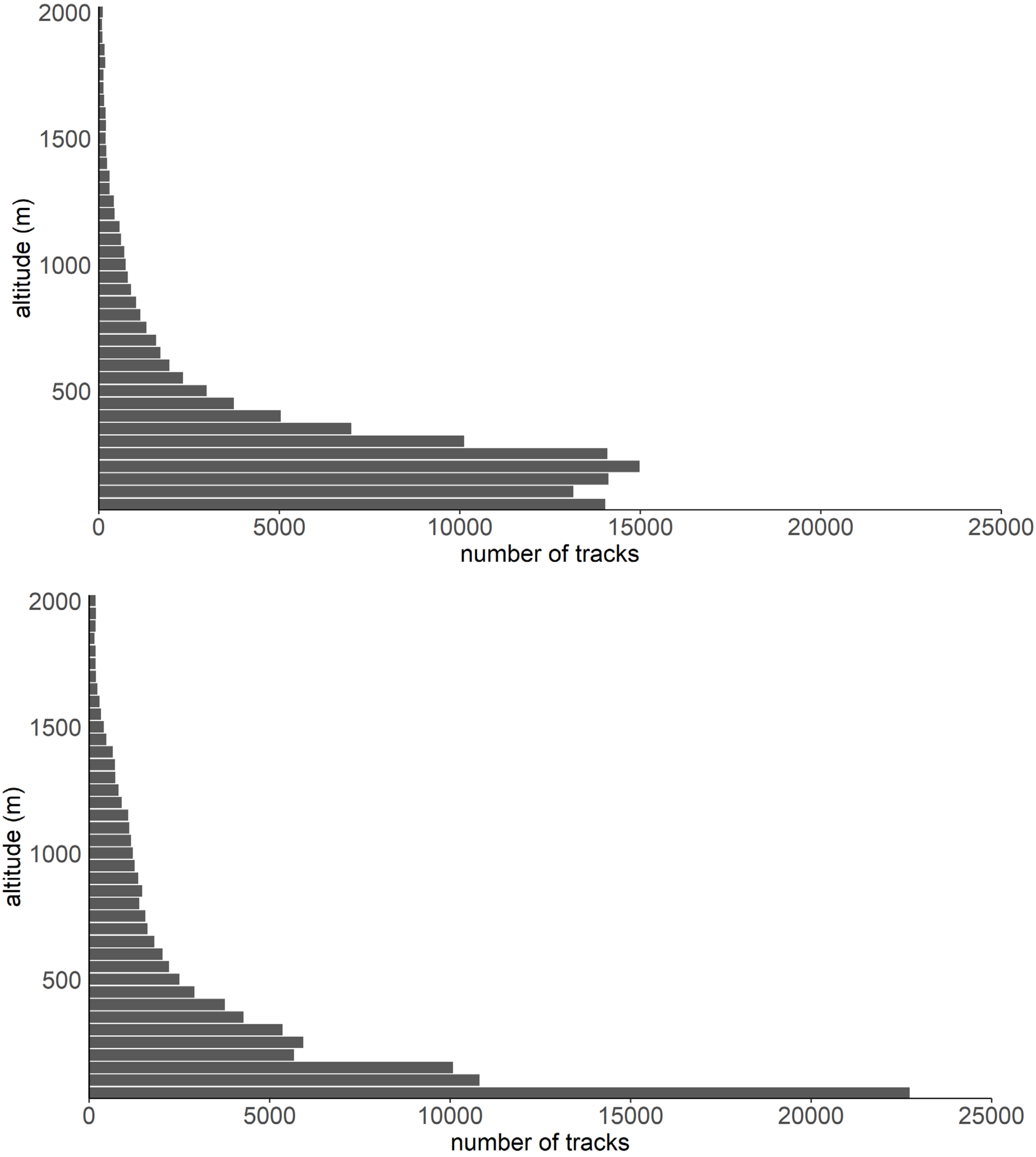

Figure 4. Total number of bird tracks per 50 m altitude layer for autumn 2019 (upper panel) and spring 2021 (lower panel).

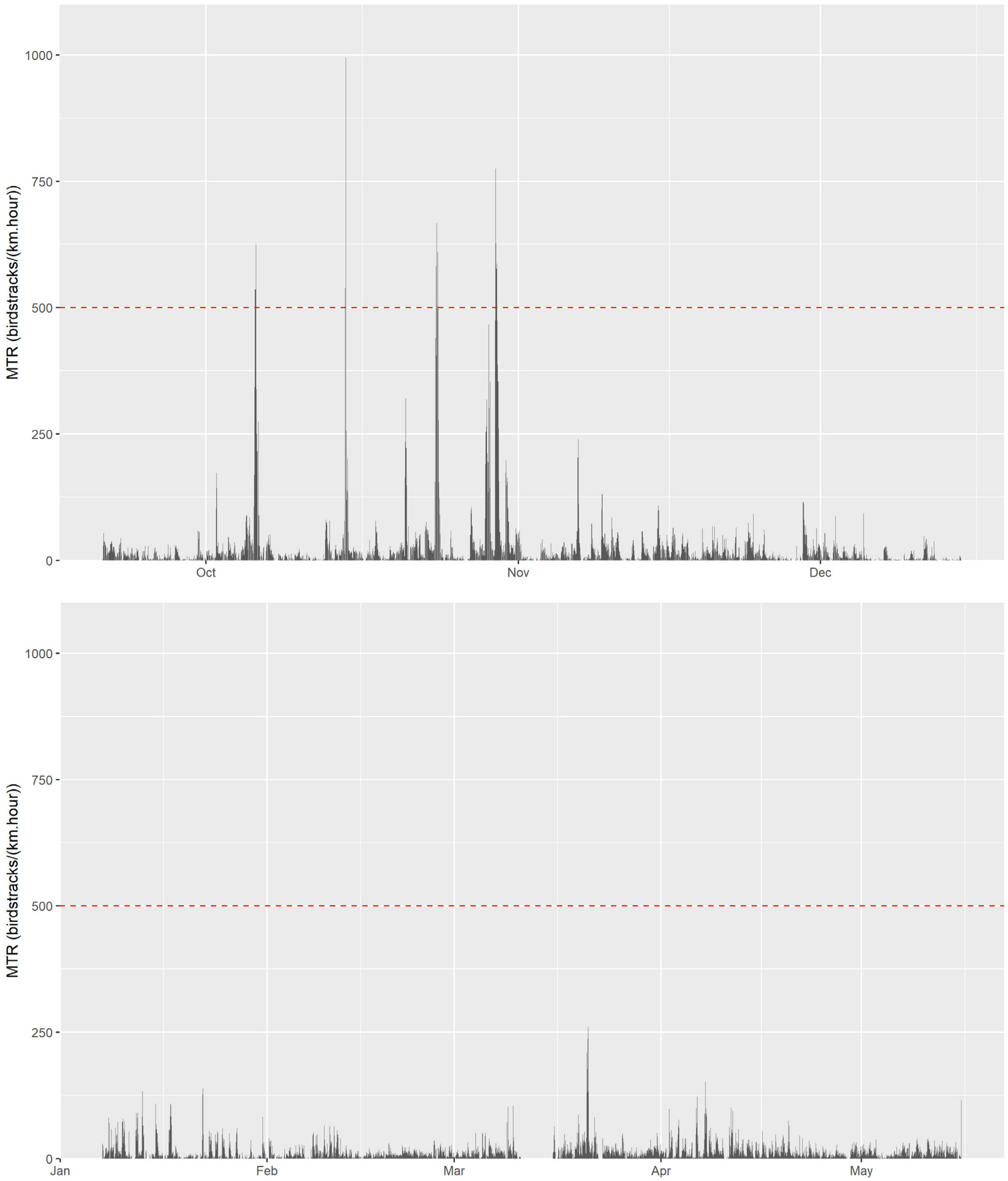

Figure 5. MTR (birdtracks.km^{-1}.hour^{-1}) at rotor height (24–193 m) for autumn 2019 (upper panel) and spring 2021 (lower panel). The dashed red line indicates the threshold for curtailing the turbines in the Dutch Borssele wind farm area, being 500 birdtracks.km^{-1}.

4. Discussion

The highest bird fluxes were logically registered during the main bird migration months, being September, October, March and April. Although we have no data from our site during the summer months, we know from previous radar studies (Brabant *et al.* 2017) and radar studies in the adjacent Dutch part of the North Sea (Krijgsveld *et al.* 2011) that the bird flux in summer is lower than in migration seasons. We can therefore assume that the MTR threshold value of 500 birdtracks.km^{-1}.hour^{-1}would not have been exceeded during summer months. The number of hours during the study period during which the threshold was surpassed is rather low (14 hours) and about half of the Dutch estimate of 30 hours per year, based on the results of Krijgsveld *et al.* (2011). All these events occurred at night and most likely are nocturnal passerine migration events. Especially Blackbird *Turdus merula*, Song Thrush *Turdus philomelos*, Redwing *Turdus iliacus* and Robin *Erithacus rubecula* migrate in high numbers at night (Krijgsveld *et al.* 2011; Fijn *et al.* 2015). These are most likely birds that winter in the UK and mainly originate from Scandinavia and NE-Europe (Bourne 1980; Buurma 1987; Alerstam 1990; Lensink *et al.* 2002; Leopold *et al.* 2014; Nilsson *et al*. 2019). The intense migration events in our dataset coincide with departures of large numbers of birds towards the UK, seen on bird- and meteorological radars from coastal sites in Belgium and the Netherlands (pers. comm. Hans van Gasteren). Although, part of our radar detections can also be birds crossing the North Sea directly from Scandinavia, which is also a known migration route for passerines (Buurma 1987; Lensink *et al*. 2002).

A high portion of the detected birds flew at rotor height, being 41.4% in autumn 2019 and 38.2% in spring 2021, and as such, were at risk of collision with the turbine rotors. An estimated number of 682 collisions could have been avoided in autumn 2019, if turbines in the Belgian OWFs would have been idled during peaks of intense bird migration. These CRM results are based on several assumptions (e.g., avoidance rate, flight speed) and should therefore be handled with care and be considered as an estimate of the order of magnitude of the expected number of collisions. Also, the radar cannot reliably differentiate individual birds from small bird flocks (Fijn *et al*. 2015), meaning that the MTR values used as input for the CRM bird density data are underestimating the actual MTR. Fijn *et al.* (2015) expect, based on visual validation of radar recordings, that this results in underestimating the MTR with maximum 10%. The uncertainty of the CRM results and the fact that we do not exactly know which species were registered by the radar does not allow to assess whether the number of migrating songbirds colliding with wind turbines at sea could have a significant effect at population level. Poot *et al.* (2011) used a Potential Biological Removal (PBR) approach to assess the cumulative collision effects of 11 OWFs in the Dutch part of the North Sea (hypothetical scenario). They concluded that a worst-case scenario would not cause negative population trends in the considered passerine species. If this is still the case for cumulative effects of all planned wind farms in the (southern) North Sea is unknown.

To reduce the number of collisions with wind turbines during such events, an effective measure is to idle the turbines (Cook *et al.* 2011; Marques *et al.* 2014; May 2017; McClure *et al.* 2021). These curtailment measures are often applied in onshore wind farms for local and migrating raptors and soaring birds. To our knowledge, no such stand-still procedures are currently being applied in OWFs. The Borssele measure, which imposes wind farm operators to idle turbines when the bird flux exceeds 500 birds.km^{-1}.hour^{-1} at rotor height, will be applied as from January 1st, 2023.

Our results demonstrate that we can monitor in near real-time if the bird flux at rotor height exceeds the Borssele threshold to idle turbines. However, using the threshold value for a near-real time application has proved impossible after consultation of the wind farm operators (pers. comm. Jos de Visser, Rijkswaterstaat). For the sake of not posing risks to the stability of the electricity network, offshore wind farm operators need to know at least 24 hours in advance, and preferably 48 hours, if turbines need to be idled. To remedy this, the University of Amsterdam is now developing a prediction model of intense bird migration, based on meteorological and bird radar data. The main focus is to predict intense migration events, based on which idling wind turbines can be carefully planned for well in advance. To collect sufficient data in the area for the development of this model, the Dutch government invested in a network of dedicated bird radars at sea. Rijkswaterstaat has purchased six Robin Radar Max (3D) systems (personal comm. Jos de Visser, Rijkswaterstaat). One is already installed on the Borssele alpha platform. A second one will be installed in the Ørsted OWF in the North of the Borssele area and another one in Gemini OWF. The other three locations are to be decided. The Belgian radar data are also available for the development of this model, if needed.

Currently, there is no stand-still procedure imposed in Belgian OWFs during intense bird migration. If no stand-still procedure would be imposed in the OWFs in Belgian waters, the Borssele wind turbines will be idled during events of intense bird migration, while Belgian turbines on the other side of the border are not. The environmental permits of the Belgian OWFs however foresee the possibility to start with such a procedure, so measures on both sides of the border could be aligned in the future.

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