CHAPTER 8

AUTUMN BIRD MIGRATION REGISTERED WITH VERTICAL RADAR AT THE THORNTON BANK IN THE BELGIAN PART OF THE NORTH SEA

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Abstract

The Belgian part of the North Sea (BPNS) is part of a very important seabird migration route through the Southern North Sea. Also, large numbers of non-seabirds (mainly songbirds) are known to migrate at sea. The development of offshore wind farms in the North Sea might impact these migrating birds as they can collide with the turbines, which results in an increased mortality rate.

Radar observations greatly contribute to the understanding of the spatial and temporal patterns of bird migration because of the ability to register birds continuously at a large spatial scale and at high altitudes. Using a bird radar, installed in an offshore wind farm, the objectives of this study are to determine (1) the seasonal phenology of migrating birds across the North Sea; (2) the diurnal patterns of migrating birds at sea; (3) the vertical distribution (altitude) of migrating birds and (4) the link between bird migration and meteorological conditions.

Elaborate tests have shown that the radar antenna used in this study is performing suboptimally at detecting birds at low altitude (0-150 m above sea level). This has led to the decision to replace this antenna with a conventional magnetron X-band antenna. However, some conclusions could still be drawn from our data.

The migration traffic rates (MTR, birds.km^{-1}.hr^{-1}) values show that migration at sea, as registered by the radar, was most intense during the nights of October and early November.

The observed diurnal pattern of these months is similar to the pattern measured in the Dutch part of the North Sea. Especially in October a clear peak in MTR values occurs at dusk. A second smaller peak is noticeable at dawn.

For this study period, no clear pattern with weather conditions could be revealed, although it seems that MTR values are higher if the wind was coming from the N, NE, E and SE and when wind speed was lower than 13 m/s.

The altitude profile suggests that migration at night is happening at higher altitudes compared to daytime movements. While passerines (*i.e.*, non-seabird species) tend to dominate nighttime migration, daytime

migration tends to be a mixture of seabird and non-seabird species.

1. Introduction

Twice a year, during autumn and spring, hundreds of millions of birds fly over Europe during their migration towards and from their wintering grounds. The Belgian part of the North Sea (BPNS) is part of a very important seabird migration route through the Southern North Sea. Because of its shape, this part of the North Sea acts as a migration bottleneck, concentrating birds during migration (Stienen *et al.* 2007). Also, large numbers of non-seabirds (mainly songbirds) are known to migrate at sea (Bourne 1980; Buurma 1987; Alerstam 1990; Lensink 2002). 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 millions (estimates of Helgoland mentioned in Hüppop *et al.* 2006). This songbird migrations mainly occurs along two routes: (1) between breeding grounds on the mainland of northern Europe / Scandinavia and the UK; (2) between northern Europe / Scandinavia and wintering grounds in southern Europe and Africa (Lack 1959-1963; Lensink *et al.* 2002; Krijgsveld *et al.* 2015).

Migrating birds fly at all altitudes from sea-level up to 10 km and a general phenomenon is that birds fly high with tailwind and that they fly at a lower altitude with headwind (Bruderer 1971; Buurma 1987; Lensink *et al.* 2002).

Migrating birds suffer from ever increasing human pressures (*e.g.*, increased mortality due to desertification, loss of suited stop-over places or collision with man-made structures; Erickson *et al.* 2005; Strandberg *et al.* 2009). The development of offshore wind farms in the North Sea might impact these migrating birds as they can collide with the turbines, which results in an increased mortality rate.

Both from a purely scientific and a conservation point of view, it is crucial to understand and monitor bird migration. Radar observations greatly contribute to the understanding of the spatial and temporal patterns of bird migration because of the ability to register birds continuously at a large spatial scale and at high altitudes (Eastwood 1967; Bruderer 1997; Gauthreaux *et al.* 2003). Radars offer several advantages compared to visual observations as they are not limited to lower altitudes, daylight and good visibility. They also do not suffer from observer bias. However, there are also several restrictions to this technique: the recorded radar data have low taxonomic resolution and radars record objects other than birds (*e.g.*, sea surface, ships, rain). The latter unwanted detections are referred to as clutter.

The objectives of this study are to determine:

- the seasonal phenology of migrating birds across the North Sea;
- the diurnal patterns of migrating birds at sea;
- the vertical distribution (altitude) of migrating birds;
- the link between bird migration and meteorological conditions.

2. Material and methods

2.1. Radar hardware

In this study, we make use of a Merlin bird radar (DeTect-inc., Florida, USA) which is installed on the offshore platform inside the C-Power wind farm on the Thornton Bank in the BPNS (fig. 1). The radar antenna (Kelvin-Hughes Sharpeye solid state S-band) is rotating in the vertical pane, creating a vertical “radar screen” that registers all the targets moving through that screen. As this “radar screen” is fairly narrow (opening angle 22°), every registration can be seen as one or a group of birds passing through that area. The flux of birds is expressed as migration

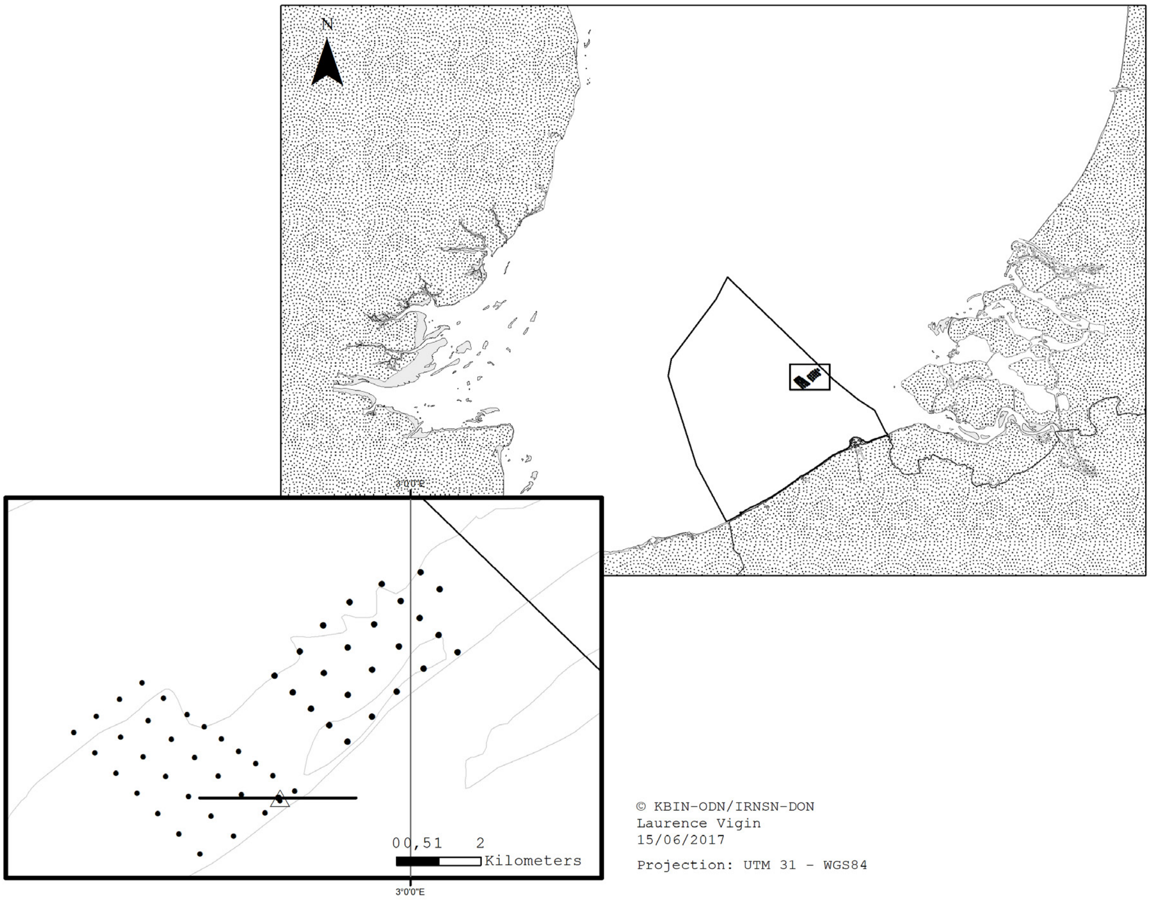

Figure 1. Map of the Belgian part of the North Sea (black polygon) with indication of the C-Power wind farm on the Thornton Bank (black marks). The location of the individual turbines (dots) and the radar location on the transformer platform (triangle) are shown in detail. The black line indicates the orientation of the vertical radar from east to west.

traffic rate (MTR), *i.e.*, number of birds that pass across a one kilometre line during an hour (birds.km^{-1}.hr^{-1}; Schmaljohann 2008). The orientation of the radar is east to west (fig. 1, zoom), which was the only possible practical set-up due to restrictions on the top deck of the platform. Ideally, the radar antenna should be positioned perpendicular to the main migration direction (*i.e.*, mainly northeast-southwest, which is perpendicular to the coastline).

2.2. Radar software and data post-processing

The detection range of the radar antenna can be specified in the system's settings and is set at one nautical mile. The radar operates continuously year-round and the system is remotely controlled. The system is operated by the Merlin software 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.

However, these processed data still contain a large amount of clutter coming from different sources (*e.g.*, rain, waves, ships, wind turbines, side lobes). As we use the radar data to determine the flux of birds in the area, it is very important to remove clutter as accurate as possible. To do so, we have developed a data-filter. The reader is referred to Brabant *et al.* (2016) for more details on the data filtering.

After the data filtering, two columns of 500 m wide were selected from the entire measurement volume. We only retained data

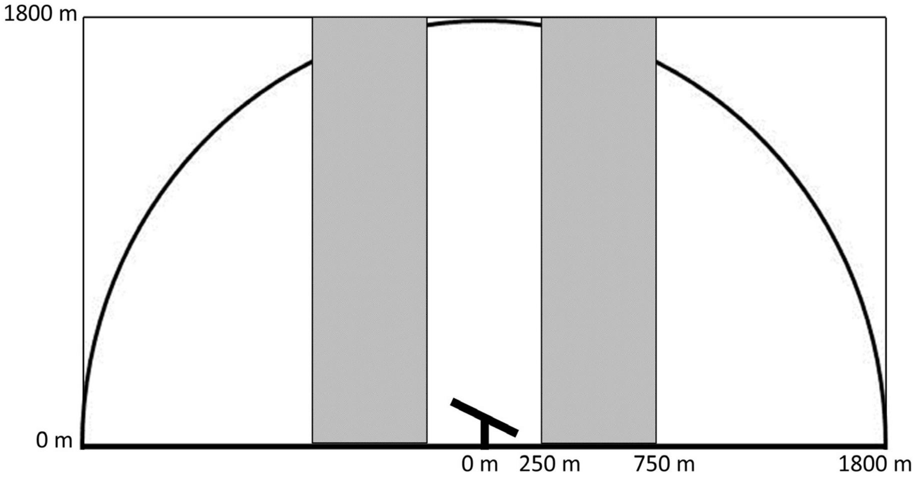

Figure 2. Vertical radar data used to determine the MTR.

from 250 until 750 m distance from the radar, both to the east and west (fig. 2). Doing so, we avoid using the data close to the radar location, which is saturated with reflections of the radar platform, and further than 750 m from the radar to avoid detection loss at further distance from the radar (Fijn *et al.* 2015). The number of bird tracks within those two columns in one hour equals the MTR. As the radar is not able to differentiate single birds from a small group of birds, the MTR for this type of radar is actually the number of groups of birds.km^{-1}.hour^{-1} or a minimum estimate of the number of birds.km^{-1}.hour^{-1}.

2.3. Data analyses

Four different analyses were done with the radar registrations between the 23 August 2016 and the 16 November 2016, here representing the autumn migration season.

1. Mean MTR values were calculated for every day and night. We used the daily time of sunrise and sunset to determine the length of day and night.

2. The diurnal pattern for every month was calculated by averaging the MTR and associated standard error for every hour of day (HoD) for the different months (*e.g.*, the mean of all MTR values from 0:00 to 1:00 am, for all days in October).

3. The total number of counts per night and per day, within altitude layers of 50 m were calculated. We considered data up to an altitude of 1800 m ASL, although it is known that there is detection loss at higher altitudes. Fijn *et al.* (2015) describe that for a magnetron radar (25 kW Furuno FR1525 MK3 X-ba nd), this detection loss starts at 900 m for smaller birds. In this case, a solid state antenna is being used which has three different pulses (short, medium and long). For this type of radar, detection loss will occur within every pulse. However, at this point, it is not possible to quantify this and is hence here considered more or less random throughout the altitudinal range.

4. We investigated how migration intensity was influenced by the wind direction and speed. Wind direction and speed were taken from the C-Power meteorological observations from a wind turbine near the offshore platform (temporal resolution: 10 minutes).

It is important to note that we know the radar antenna is performing suboptimal at detecting birds at low altitude (0-150 m above sea level [ASL]). This was shown during elaborated tests in collaboration with the radar supplier and could not be resolved at this point. Krijgsveld *et al.* (2011; 2015) and Fijn *et al.* (2015) however showed that in similar circumstances a large part of the migration at sea is occurring in those lower altitude layers. This has led to the decision to replace this antenna with a conventional magnetron X-band antenna. Replacement is foreseen in summer 2017.

Calculations and graphs were made in R version 3.2.2. (R Core Team 2015), making use of the packages ggplot2 (Wickham 2009), cowplot (Wilke 2016), reshape2 (Wickham 2007) and plyr (Wickham 2011).

3. Results

3.1. Autumn migration phenology

In general, the nighttime mean MTR values (fig. 4, lower panel) are higher than during daytime (fig. 4, upper panel). Highest numbers are recorded in October, especially during the first few days of that month. In August, MTR values are very low, both during day and night.

A scatterplot of the log-transformed mean daytime versus the log-transformed mean nighttime MTR shows there is a significant relation between both (p-value: $3.531e^{-09}$, R-squared = 0.37; fig. 3).

3.2. Diurnal pattern

All months showed a diurnal pattern with a peak at sunset (fig. 5). This is especially the case for the month of October where MTR values peak at sunset and decrease during the night. A smaller second peak at sunrise is also noticeable in October and November.

3.3. Flying altitudes

As was already shown in figure 4, absolute numbers are much higher during the night compared to daytime (fig. 6). During day, the highest number of counts was recorded from 100 to 150 m ASL. At night, this was the case in the layers from 200 to 300 m.

Given the radar's poor performance in the lower altitudes (up to 100-150 m, *i.e.*, the two to three lowest bars in figure 6), the number of birds counted in these altitude layers is therefore considered not reliable (see materials and methods).

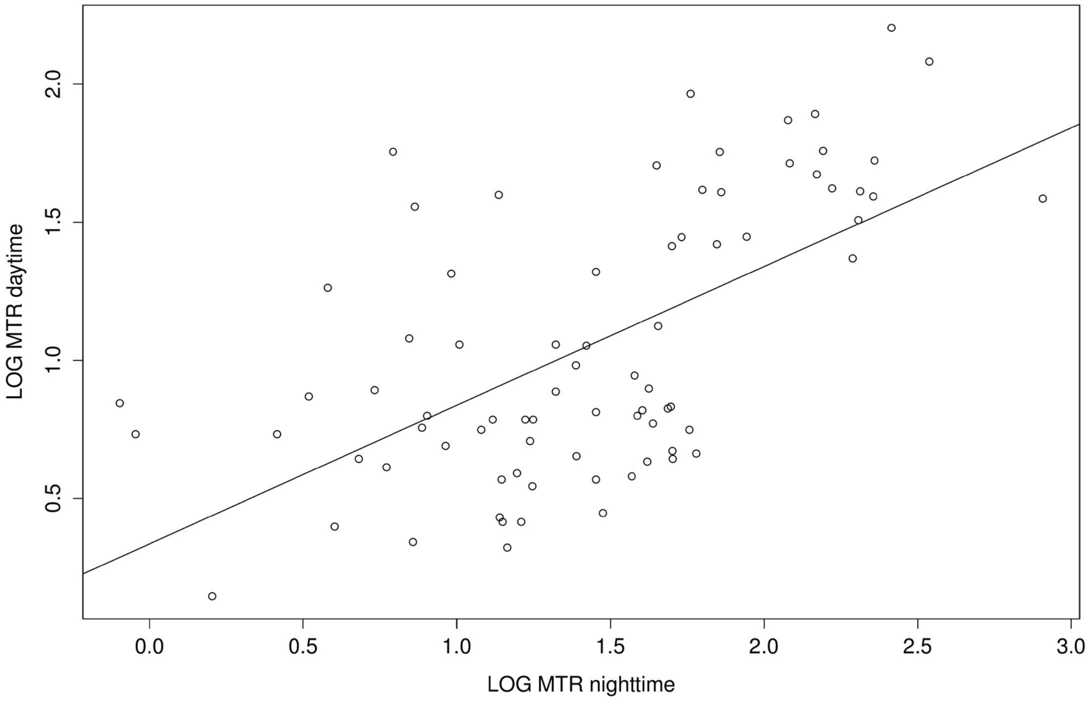

Figure 4. Scatterplot of the mean MTR at nighttime versus at daytime (log transformed).

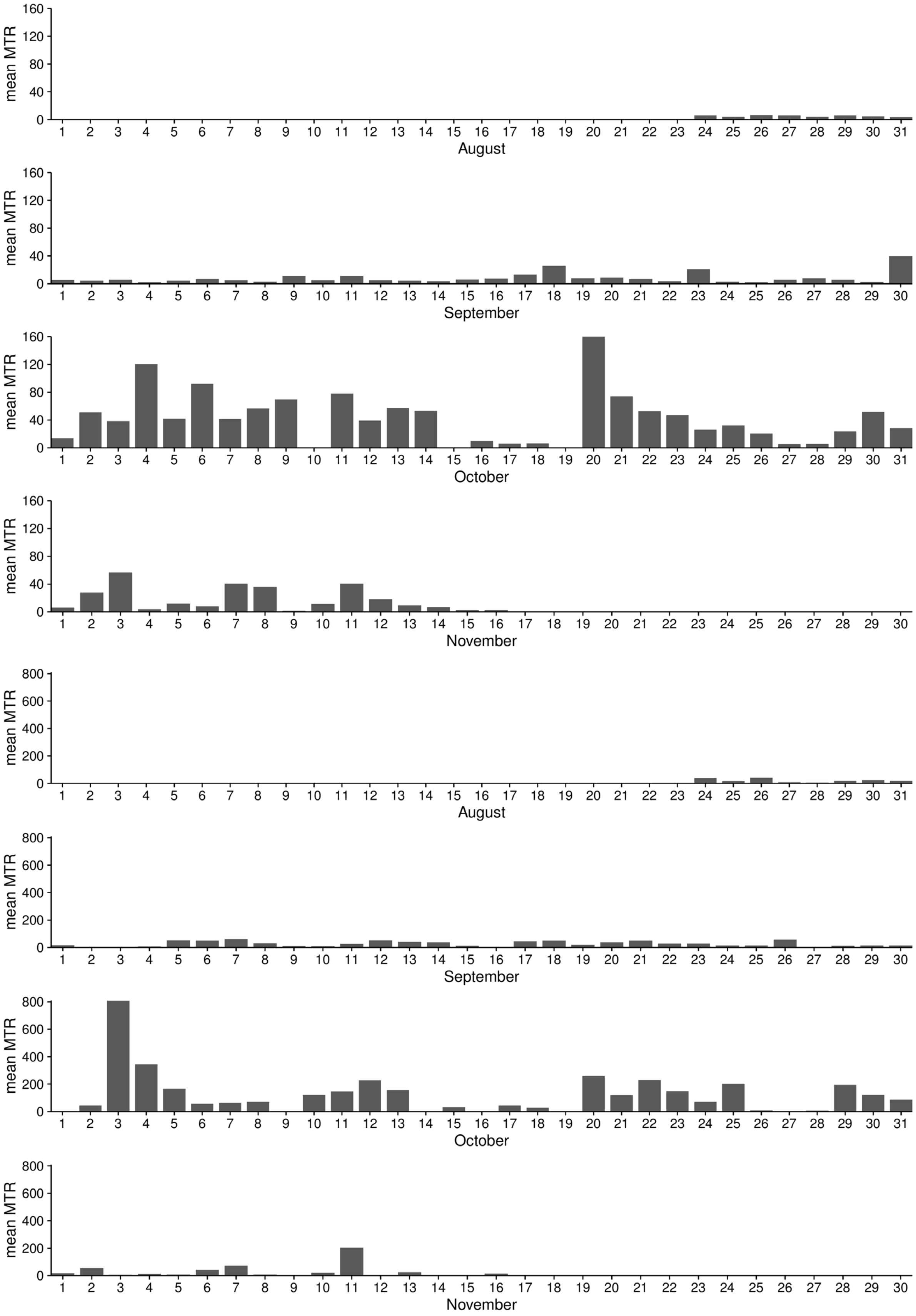

Figure 3. Average MTR ([groups of] birds.km^{-1}.hour^{-1}) per day (upper panel) and night (lower panel) for the autumn of 2016. Note that the Y-axis scale is different for the two plots.

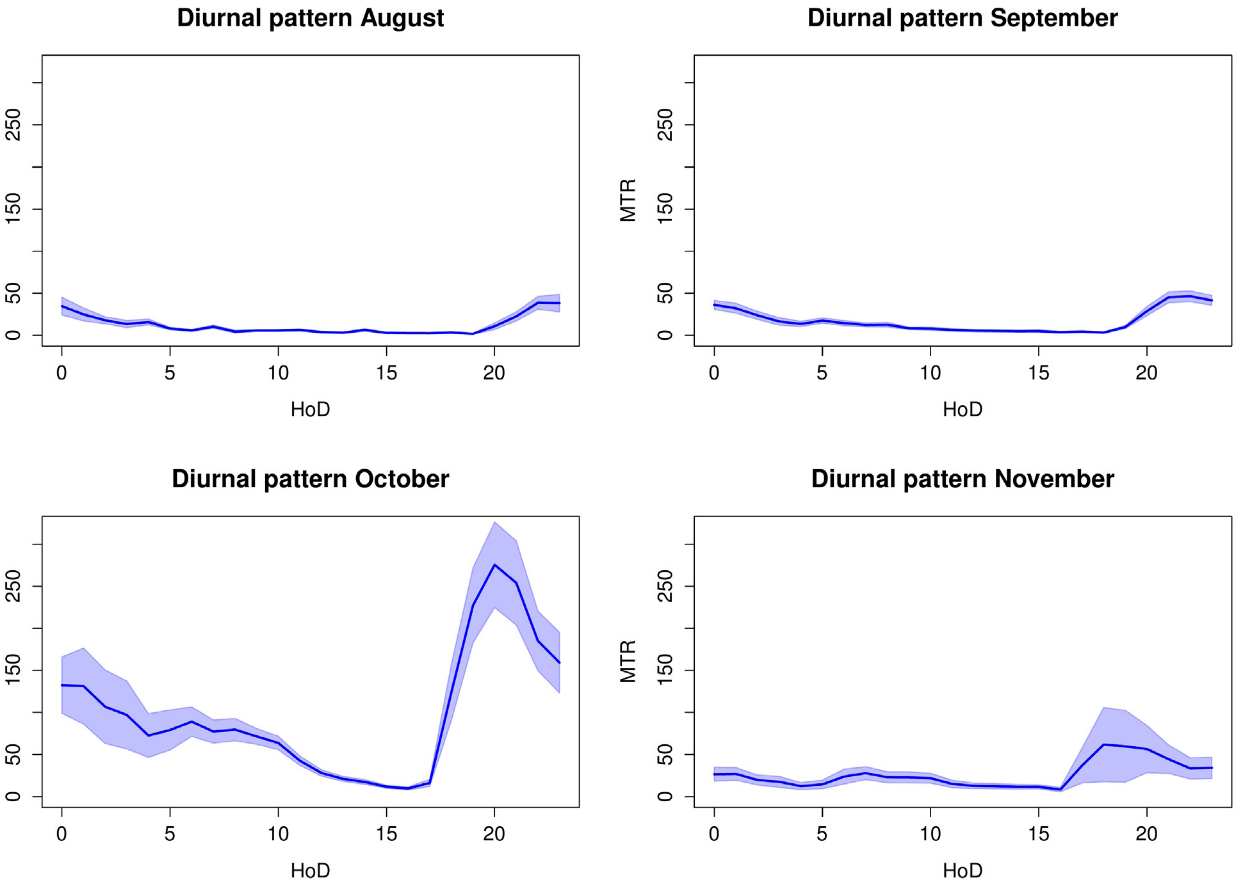

Figure 5. Average MTR value per hour of day (HoD) in UTC (blue line) ± standard error (light blue polygon).

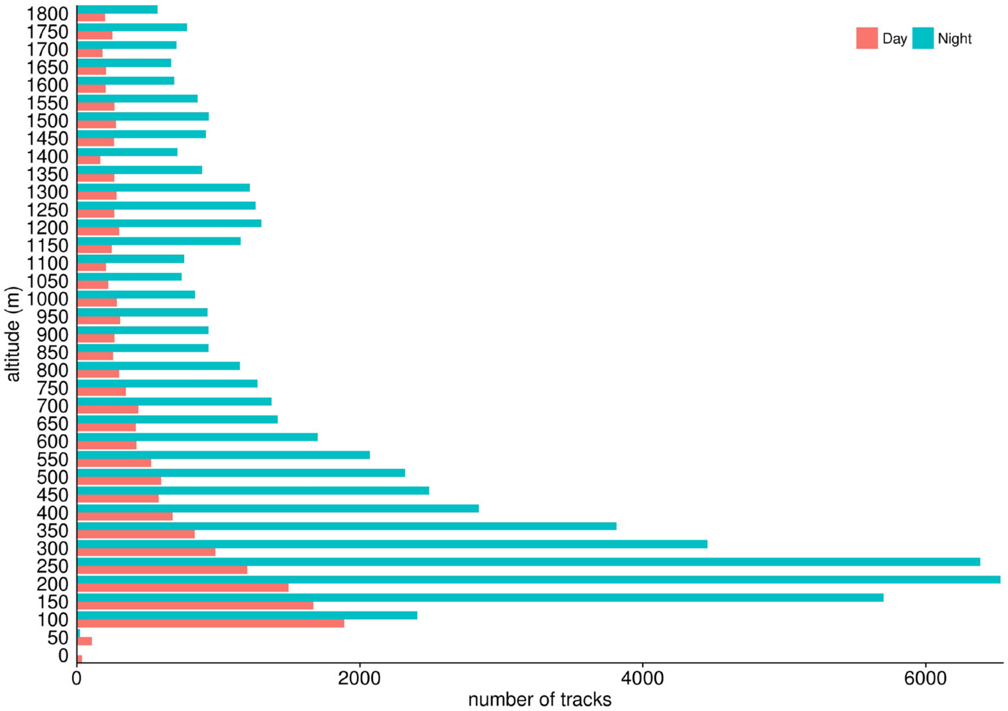

Figure 6. Absolute number of counts during day and night per 50 m altitude layer.

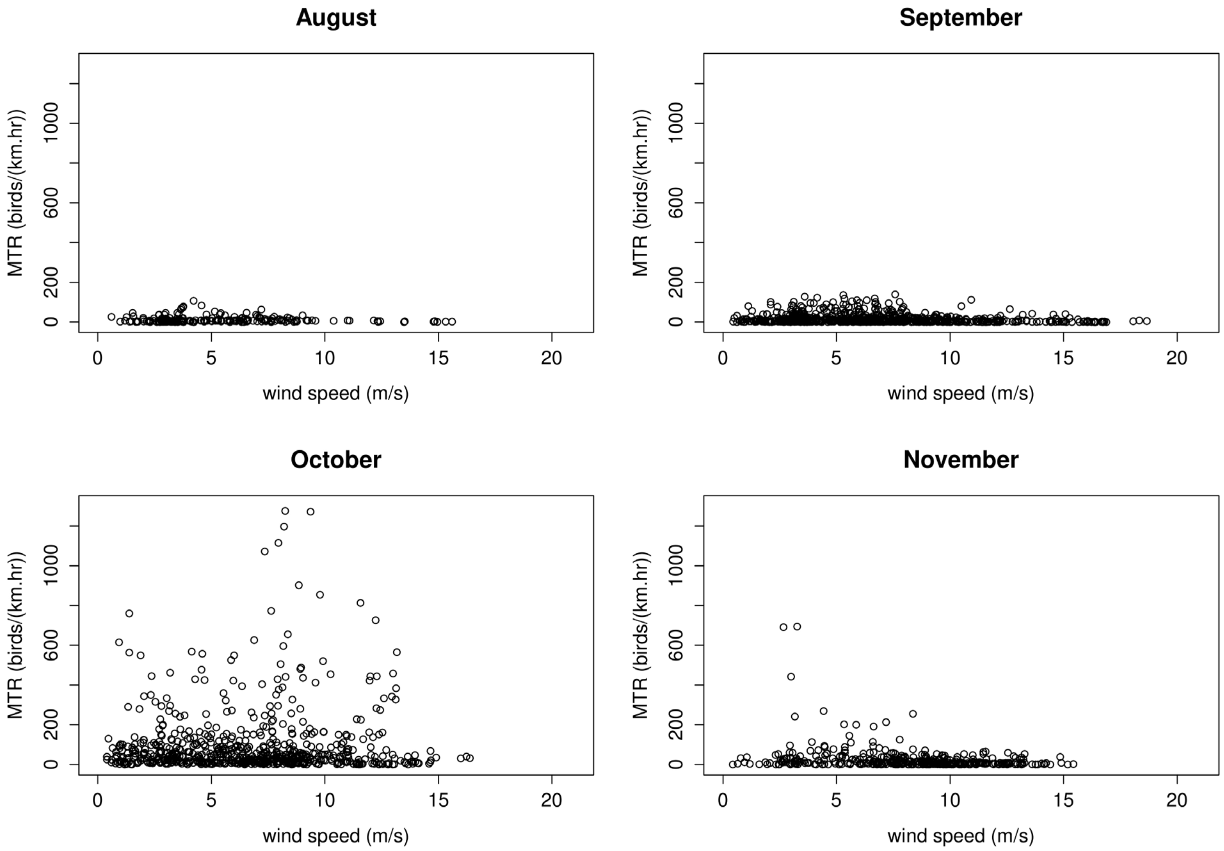

Figure 7. Scatterplot of the hourly MTR (birds.km^{-1}.hr^{-1}) and wind speed (m/s).

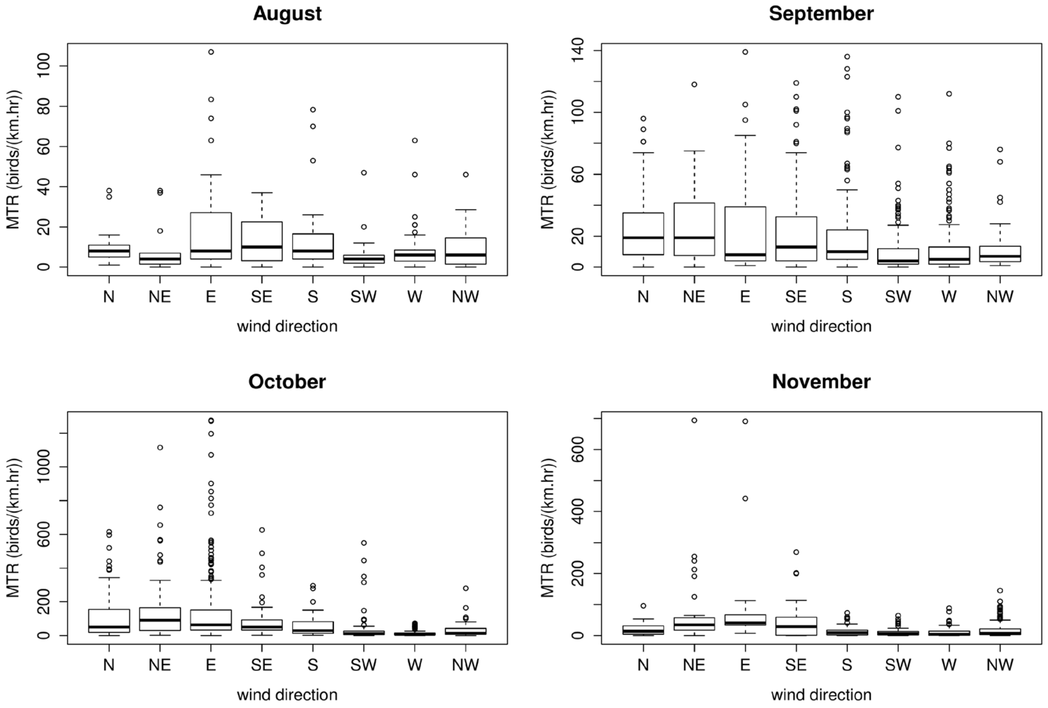

Figure 8. Boxplot of the hourly MTR (birds.km-1.hr-1) and the wind direction. Line in the box is the median value. Lower and upper limits of the box represent 25th and 75th percentile of the data, respectively. The upper whisker is defined as 75th percentile + (1.5 x spread). The lower whisker is 25th percentile - (1.5 * spread), the spread being 75th - 25th percentile.

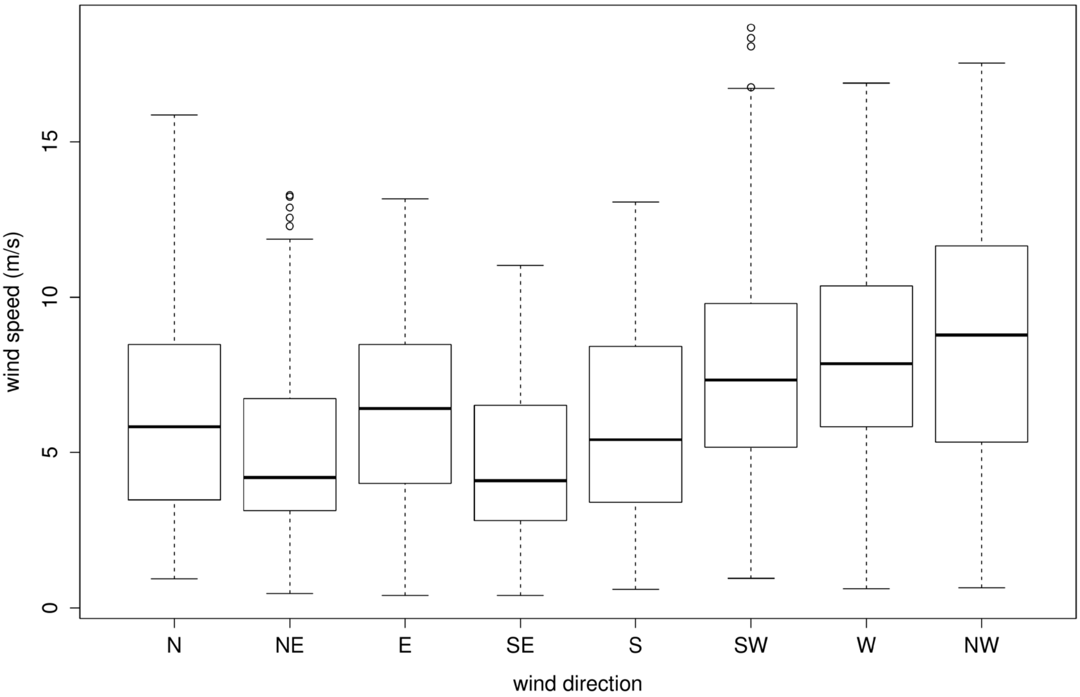

Figure 9. Boxplot of the wind direction and wind speed during the entire measurement period. Line in the box is the median value. Lower and upper limits of the box represent 25th and 75th percentile of the data, respectively. The upper whisker is defined as 75th percentile + (1.5 x spread). The lower whisker is 25th percentile - (1.5 * spread), the spread being 75th - 25th percentile.

3.4. MTR in relation to wind speed and wind direction

There is no clear observed pattern between MTR and wind speed (fig. 7). The highest MTR were recorded in October and November. High MTR values (> 200 birds. km^{-1}.hr^{-1}) were however never recorded when the wind speed was higher than 13 m/s. The maximum wind speed during the study period was 20.9 m/s.

Figure 8 suggests that the October and November MTR values are higher when the wind is coming from the N, NE, E and SE. In August and September, this is not the case. During the measurement period, the wind speed was highest coming from the SW, W and NW (fig. 9). Wind from the NE and SE had the lowest speed.

4. Discussion

Overall, the measured MTR values are lower than expected. This has three reasons. (1) As mentioned in the methodology section, the radar is performing suboptimally in the lowest 150 m ASL. Looking at the results of Krijgsveld *et al.* (2015) and Fijn *et al.* (2015), in similar circumstances, it was shown that 50% of the total flux occurred below 115 m. The pattern we see in this study is caused by the limits of the solid state S-band radar antenna which is currently being used. (2) The current antenna has a wavelength in the S-band spectrum (7.5-15 cm), which is less suited to register smaller birds. So, presumably, the number of songbirds is being underestimated. (3) Lastly, the orientation (E-W) of the radar antenna is not ideal. An orientation perpendicular to the main migration direction is preferred to correctly measure the flux of birds (van Gasteren *et al.* 2002). This was logistically not possible in this case. If the flight direction is other than perpendicular to the radar orientation, the bird numbers is inevitably underestimated. Van Gasteren *et al.* (2002) describe a formula to compensate for this by correcting the surface area of the sampled air of the radar. If the flight direction is 45°, relative to the radar orientation, the correction factor is 1.41. If it is 22.5°, then the correction is 1.08 (Fijn *et al.* 2015). Fijn *et al.* (2015) also made the argument that the vertical radar has a specific beam width and thus records flux in a volume rather than along a line, the underestimation is therefore at least smaller and in many cases close to the measured flux. Because no confirmed flight direction data is available in this study, no corrections could be made.

Compared to the total flux measured in an entire autumn season (September-November) by Fijn *et al.* (2015), the total flux in this study is about a factor 10 smaller. Not taking the lowest 150 m into account, this is still a factor 5. This has led to the decision to replace the currently deployed antenna with a conventional magnetron X-band antenna, similar to the one successfully being used in the Dutch part of the North Sea (Krijgsveld *et al.* 2011; Fijn *et al.* 2015). By then, the horizontal radar will be operational again, providing flight direction data. This will then be used to correct the measured flux, if necessary.

Although this antenna was not ideal to register bird migration, some useful information is gained from the data. The MTR values show that migration at sea, as registered by the radar, was most intense during the nights of October and early November. Field observations (auditory recordings of vocal calls) carried out at night by Krijgsveld *et al.* (2011) at the OWEZ wind farm in the Dutch part of the North Sea, indicate that these high nocturnal fluxes reflected mostly migrating passerines. Especially Blackbird *Turdus merula*, Song Thrush *Turdus philomelos*, Redwing *Turdus iliacus* and Robin *Erithacus rubecula* were recorded. This is supported by earlier studies by Bourne (1980), Buurma (1987), Alerstam (1990) and Lensink (2002).

High daytime fluxes measured in October and November, correspond with coastal observations of high numbers of migrating meadow pipits *Anthus pratensis*, European starling *Sturnus vulgaris* and Chaffinches *Fringilla coelebs* (www.trektellen.nl). Also large numbers of Brant *Branta bernicla* were counted, a species regularly seen in the BPNS (Vanermen *et al.* 2006). As this latter species tends to fly at a lower altitude, it is unlikely that it was detected by the radar.

The observed diurnal pattern of these months is similar to the pattern measured by Fijn *et al.* (2015). Especially in October a clear peak in MTR values occurs at dusk. A second smaller peak is noticeable at dawn.

Wind direction is the main driver of autumn migration (Alerstam 1990). For this period, no clear pattern with weather conditions could be revealed. It seems that MTR values are higher if the wind was coming from the N, NE, E and SE and when wind speed was lower than 13 m/s. In autumn, easterly winds are known to give rise to concentrated migration near the coast and at sea (Lensink *et al.* 2002). This was also the case in the beginning of October, when the highest fluxes of this study were measured. At that time, a storm front covered Germany and Poland, forcing birds to a more westerly migration route, which led to high numbers of birds in Belgium and the Netherlands.

Birds are registered up to 1800 m (highest altitude bin taken into account in this study). The altitude profile, although not complete, suggests that migration at night is happening at higher altitudes compared to daytime movements. This is also what Fijn *et al.* (2015) observed during autumn. While passerines (*i.e.*, non-seabird species) tend to dominate nighttime migration, daytime migration tends to be a mixture of seabird and non-seabird species. Seabird migration (divers, terns, seaducks) migrate at an altitude lower than 25 m. This can sometimes go up to 50 m, but rarely higher (Krüger & Garthe 2001). The current radar configuration hence is not suited to monitor seabird migration.

Starting autumn 2017, the recorded bird flux data will be analysed with an explanatory model approach, to identify the variables driving the observed migration at sea (*e.g.*, wind direction and speed, hour of day, Julian day, bird flux at the previous day). This can then lead to prediction models which can be used to apply mitigation measures for offshore wind farms. For instance, a requirement for the neighbouring Dutch Borssele wind farms is to shut down the turbines when the bird flux at rotor height exceeds 500 birds.km^{-1}.hr^{-1}. To practically apply such a measure will require a lot of cooperation of all involved parties and model results can assist in this process.

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