Chapter 8. Radar research on the impact of offshore wind farms on birds: Preparing to go offshore

R. Brabant[1*], L. Vigin[1], E.W.M. Stienen[2], N. Vanermen[2] & S. Degraer[1]

[1]Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models (MUMM), Marine Ecosystem Management Section, Gulledelle 100, 1200 Brussels
[2]Research Institute for Nature and Forest (INBO), Ministry of the Flemish Government, Kliniekstraat 25, 1070 Brussels

[*]Corresponding author: R.Brabant@mumm.ac.be

Photo A. Norro / RBINS / MUMM

Abstract

Wind farms have three possible effects on birds. One of them is the barrier effect. Fox *et al.* (2006) and Krijgsveld *et al.* (2011) both described that birds change their direction of flight in the vicinity of a wind farm. It is unknown if this will also be the case for the offshore wind farms in the Belgian part of the North Sea and what the extent of this effect will be. To study the barrier effect there is a need for a technique that provides continuous data on a large scale. Automated radar systems offer such a tool.

The objectives of this study are (1) to develop an analytical procedure to assess the quality of the radar data and to process the data to effectively remove noise (i.e. data reduction); (2) to develop and test a methodology for radar data analysis, including the influence of co-variables, such as wind direction; and (3) to draft the analytical procedure for future radar research in offshore wind farms (i.e. lessons learnt).

The radar system was tested in the port of Zeebrugge, which holds in important tern breeding colony, to get acquainted with the system and the data processing. Foraging flights of terns are typically in a well-defined direction, as is the case for migrating birds. Therefore the foraging flights can be used as a proxy for the migration flights of migrating birds offshore. Variation in the direction of those foraging flights might be in function of co-variables such as wind direction and wind speed. The barrier effect created by offshore wind farms also makes migrating birds change their direction of flight when they approach a wind farm (Petersen *et al.*, 2006; Krijgsveld *et al.*, 2011). This is thus a co-variable that influences the direction of flight of migrating birds. Both parallels allow us using the data that were recorded near the tern colony as a proxy for the future offshore radar research. Lessons learnt will be directly applicable to the offshore work.

The Zeebrugge case study offered a good opportunity to focus on a specific type of birds and flight behaviour with the radar system. A lot of experience was gained and the methodology was developed and fine-tuned for the future research offshore. It can be concluded that the radar system is an appropriate tool to monitor bird movements. It offers a possibility to show significant patterns in bird movements, even if that pattern is rather small.

Samenvatting

Windmolenparken hebben drie mogelijke effecten op vogels. Een daarvan is het barrière-effect. Fox *et al.* (2006) en Krijgsveld *et al.* (2011) toonden beiden aan dat vogels hun vliegrichting aanpasten in de nabijheid van een windmolenpark. Het is onbekend of dit ook het geval zal zijn voor de offshore windmolenparken in het Belgisch deel van de Noordzee en wat de omvang van dit effect zal zijn. Om dit te bestuderen is er nood aan een techniek die continue data aanlevert op een grote schaal. Automatische radarsystemen beantwoorden aan deze vereisten.

Om vertrouwd te raken met het system en het verwerken van de data, werd het radarsysteem getest in de haven van Zeebrugge. Deze herbergt een belangrijke broedkolonie sternen. Foerageervluchten van sternen zijn typisch rechtlijnig in een bepaalde richting. Dit is ook het geval voor vluchten van migrerende vogels. Daarom kunnen deze foerageervluchten als een proxy worden gebruikt voor migrerende vogels op zee. Wijzigingen in de richting van die foerageervluchten zijn mogelijks in functie van co-variabelen zoals windrichting en –snelheid. Het barrière-effect zorgt ervoor dat migrerende vogels hun richting aanpassen bij het naderen van een windmolenpark (Petersen *et al.*, 2006; Krijgsveld *et al.*, 2011). Dit is dus een co-variabele die de vliegrichting van migrerende vogels beïnvloedt. Beide parallellen laten het toe om de data die verzameld werden in de buurt van de sternenkolonie te gebruiken als een proxy voor het toekomstige offshore radaronderzoek.

De test fase in Zeebrugge boodt de mogelijkheid om met het radarsysteem te focussen op een bepaalde soort en het vlieggedrag van die soort. Er werd veel ervaring opgedaan en de methodologie voor het toekomstige onderzoek offshore werd ontwikkeld. Er kan geconcludeerd worden dat het radarsysteem een geschikt middel is om vliegbewegingen van vogels te onderzoeken. Het biedt de mogelijkheid om significante patronen in vliegbewegingen aan te tonen, zelfs indien dit patroon eerder zwak is.

8.1. Introduction

The European directive on the promotion of electricity produced from renewable energy sources imposes upon each Member State a target figure of the contribution of the production of electricity from renewable energy sources. Offshore wind farms are expected to make an important contribution to achieve that target figure. A zone in the Belgian part of the North Sea (BPNS), with a total surface of 238 km², is reserved for the production of electricity. This zone starts at about 20 km from the coast and is orientated perpendicular to the coast. Once the construction of the different wind farms is finished, there will be several hundreds of wind turbines in that area. The UK and the Netherlands are also planning to construct wind farms in the Southern North Sea.

Wind farms have three possible impacts on birds (Exo *et al.*, 2003; Fox *et al.*, 2006; Drewitt & Langston, 2006): (a) collision of birds with the structures (direct impact); (b) the disturbance and alteration of the distribution / behaviour of local birds during foraging and resting, this is called displacement (indirect impact) and (c) a barrier effect, i.e. the disturbance of flying birds by the presence of the wind farms (indirect impact). Collisions of birds with fixed and rotating structures of wind turbines have been recorded in several wind farms on land (Everaert & Stienen, 2006; Barclay *et al.*, 2007; etc.). For obvious reasons it is more difficult to know the number of collision victims from an offshore wind farm. Collision models offer a tool to estimate that number. Several collision models already exist (Bolker *et al.*, 2006; Troost, 2009; Band *et al.*, 2007) and they take certain specifications of the wind farm and wind turbines into account. To make a realistic estimate of the number of collisions, it is necessary to know the flux of birds trough the wind farm. This will be tackled in the future by the vertical radar and visual flux counts (to validate the vertical radar data). Second, displacement of local birds is shown to be highly species specific (Petersen *et al.*, 2006). In the wind farms of Nysted and Horns Rev in Denmark, avoidance behaviour was most notable for divers, scoters, auks and long-tailed ducks (Petersen *et al.*, 2006). Leopold *et al.* (2010) showed a similar response of divers, grebes, gannets, little gulls and auks in the Dutch part of the North Sea. Ship-based visual counts are performed on a monthly base and give insight in the species-specific displacement behaviour. Finally, Fox *et al.* (2006) and Krijgsveld *et al.* (2011) both described a barrier effect of wind farms of birds in Denmark and the Netherlands, respectively. Both studies showed that birds change their direction of flight in the vicinity of a wind farm. It is unknown if this will also be the case for the offshore wind farms in the BPNS and what the extent of this effect will be. An estimated number, based on land based and ship based counts, of 1 to 1.3 million birds migrate through the southern North Sea each year (Stienen *et al.*, 2007). However, little is known about migration at night and intensive migration events at sea. The Southern part of the North Sea has the shape of a bottleneck. Offshore wind farms may act as barriers for birds migrating through that bottleneck. It is unknown if the extent of this barrier effect changes during different circumstances (e.g. at night, during periods with low visibility). In the future, birds will encounter several wind farms during their migration through the southern North Sea and thus, may suffer from the cumulative effect of the encountered wind farms. That cumulative effect of the wind farms along their migration trajectory might affect their energy expenditure, although the impact on populations of long-lived seabirds are probably only marginal (Masden *et al.*, 2009, 2010; Poot et al., 2011).

To study the barrier effect there is a need for a technique that provides continuous data on a large scale. Radars have been used in similar research for several years abroad, for instance in Denmark (Petersen *et al.*, 2006) and the Netherlands (Krijgsveld *et al.*, 2011). They provide continuous data, also during conditions where it is very difficult to gather visual data (e.g. at night, during bad weather conditions, far offshore). The range in which data are gathered depends on the system and settings, but is typically around 3 nm in similar studies. This allows studying patterns of flight movements in a wide range. However, there are also several restrictions to this technique: the recorded radar data have a low taxonomic resolution, quantification of the data is very difficult and the radar also records objects other than birds (e.g. sea surface, ships and rain). All unwanted detections are being referred to as clutter.

The objectives of this study are (1) to develop an analytical procedure to assess the quality of the radar data and to process the data to effectively remove noise (i.e. data reduction); (2) to develop and test a methodology for radar data analysis, including the influence of co-variables, such as wind direction; and (3) to draft the analytical procedure for future radar research in offshore wind farms (i.e. lessons learnt).

8.2. Materials and methods

8.2.1. Radar system

In 2010, MUMM purchased a Merlin radar system from DeTect Inc. (Florida, USA). The system consists of two identical solid state S-band radar antennas, one scanning in the horizontal pane and one in the vertical. The horizontal scanning radar (HSR) provides information on flight tracks and therefore on the possible avoidance behaviour. The vertical scanning radar (VSR) provides data on the flight altitudes and the flux of birds trough the area. The range of the radars can be specified in the system's settings. The radars are usually operated at a range between two and four nautical miles for the HSR and 0.75 nautical miles for the VSR. This type of system records birds continuously year-round and is remotely manageable.

The Merlin software of the radar is designed to record and track moving objects. The objects of interest are in this case birds. When the radar energy reflects on a bird and this is received by the radar antenna, a radar echo then appears on the raw radar screen. If the echo meets certain (plotting) criteria (minimum size, intensity, etc.) it will be plotted on the processed Merlin screen. If the radar detects the same echo in four consecutive scans, it is considered as a confirmed 'track' and will be written to the database, together with its own, unique track identification code. The radar further registers for every record over 40 variables (e.g. time, location, speed, heading, size).

Obviously not only birds are recorded by the radar; this also happens for rain, waves, boats, wind turbines, etc. These unwanted echoes are being referred to as 'clutter'. For offshore studies the biggest source of clutter is the sea surface (further referred to as 'sea clutter') and the clutter created by the high reflectance of the steel surfaces of large vessels (further referred to as 'boat clutter'). This clutter needs to be filtered out of the database (i.e. data processing). Visual observations (further referred to as 'groundtruthing) are helpful in that process as they allow to validate the radar registrations. During the groundtruthing one person is looking at the radar screen and another person is outside to locate the targets visually. If an object is both seen visually and on the radar screen, then it is tagged on screen and visually confirmed information is added. That way it is possible to mark targets as birds (and add the species and number of birds), but also as boats, sea clutter, etc. This renders a separate database of the radar tracks (and all the variables that are recorded by the radar) combined with the visually confirmed information. With such a database it is possible to determine which variables discriminate the most between the groundtruthed classes.

8.2.2. Case study: breeding tern flight patterns as a proxy for offshore migration patterns

The port of Zeebrugge was chosen as a test location for the radar system because it has easy access and it overlooks the sea. The test phase aimed at getting acquainted with the system and the data processing. The site also holds an internationally important breeding colony of terns, nesting on an artificial peninsula on the inside of the eastern port jetty (Figure 1). There is also a wind farm on that jetty, consisting of 14 turbines, causing a high number of collisions (Everaert & Stienen, 2006).

During the breeding season in 2011, 1354 couples of common tern *Sterna hirundo* bred on the artificial peninsula. Also lower numbers of sandwich tern *Sterna sandvicensis* (54 breeding couples) and little tern *Sternula albifrons* (102 breeding couples) bred in Zeebrugge. Hence, 90% of the birds in the area of the breeding colony were common terns.

Figure 1. Radar test location in the port of Zeebrugge.

During the incubation phase and once the chicks have hatched, the adult terns make regular foraging flights to feed themselves or to feed their partners and chicks.

These foraging flights were used as a proxy for the seasonal migration flights to be targeted by the offshore wind farm monitoring programme. There are two parallels between migrating birds, that will encounter the offshore wind farms twice a year during spring and autumn migration and the foraging flights that common terns make during the breeding season. Firstly, radar tracks of foraging common terns are actually very similar to tracks of migrating birds. As mentioned earlier, 1 – 1.3 million birds migrate through the 'migration bottleneck' of the Southern North Sea twice a year on their way to and from the breeding colonies and the wintering grounds (Stienen *et al.*, 2007). Foraging flights of terns are typically very directional flights from the breeding colony to the foraging grounds. So, in both cases the birds fly in a well-defined direction and more or less maintain that heading. Therefore the foraging flights can be used as a proxy for the migration flights of birds offshore. Secondly, variation in the direction of those foraging flights might be in function of co-variables such as wind direction and wind speed. The barrier effect created by offshore wind farms also makes migrating birds change their direction of flight when they approach a wind farm (Petersen *et al.*, 2006; Krijgsveld *et al.*, 2011). This is thus a co-variable that influences the direction of flight of migrating birds, similar to co-variables that influence the terns during their foraging flights.

Both parallels allow us using the data that were recorded near the tern colony as a proxy for the future offshore radar research. Lessons learnt will be directly applicable to the offshore work.

8.2.3. Data analysis

8.2.3.1. Data availability

8.2.3.1.1. Groundtruthing

On seven days in the months September, October and November visual counts were done to validate the radar data. Over 500 tracks were classified as birds (identified to species level, whenever possible), vessels, sea clutter or boat clutter.

8.2.3.1.2. Flight patterns

The system was installed on of the eastern jetty of the port of Zeebrugge in early January 2011. After dealing with several technical problems and gradually improving the tracking ability of the radar by changing the system settings, the system performed well and collected data on a continuous base. Before the tern breeding season the radar was moved closer to the colony (Figure 1) and the range was set at 0.5 nm. The radar collected data from May 19th until June 26th. The six weeks of data collection near the colony resulted in a total amount of 76 Gb of data.

In this study, only the data from June were used because this is the only period during which data from the breeding colony were recorded in a consistent manner, with the same system settings, radar range and without technical failures.

8.2.3.2. Analytical procedure to process the data

To effectively remove clutter from the radar data and to prepare the data for further analysis it is necessary to process the data. This also includes separating terns arriving in the colony from the terns that are departing. Otherwise it is impossible to assess the impact of co-variables on the flight direction. An analytical procedure was created for this data processing (Figure 2).

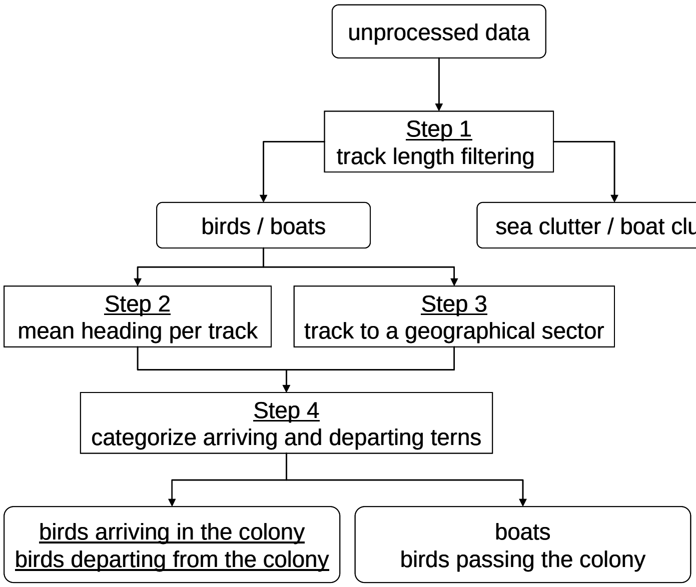


Figure 2. Model to process the radar data

To successfully remove clutter from the database, the data were filtered on track length in the first step of the data processing. All tracks shorter than a certain cut off value were removed. The cut off value was chosen based on the groundtruthed data. This step also removed bird tracks with a track length shorter than this cut off value. After this step, tracks of birds and boats longer than this cut off value were retained.

For further analysis it was necessary to know the mean direction of a track. Therefore, in step 2, the mean direction of every track was calculated, based on the direction values of the individual records of the tracks. To calculate the average value of the heading of a track, every heading value was split in its sin and cos value and the average of the sin and cos was calculated per track. Those values were then converted back to degrees using the arctan2 function.

Step 3 of the model is assigning every track to a certain geographical sector around the colony. To do so, the area around the breeding colony was divided in eight sectors of 45°. The area with the highest breeding density of terns in 2011 was chosen as the center point of this spatial analysis. Sector 1 is the direction straight from the colony to the sea, and thus over the port jetty. The boundaries of the sectors and the heading of the tracks were re-scaled to values between -90 and 90°, with 0° being the direction perpendicular to the coastline, to make the results more comprehensible. The boundaries of sector 1 are therefore 0° to 45° (Figure 3). Using GIS (Spatial Analyst ArcGIS v.9.3), every track's center point was determined, and used to assign the track to a sector.

Step 4 separated birds arriving in the colony from birds flying away from it and from birds passing by the colony. To do so it was necessary to combine the geographical sector and the mean heading of a track. For example, if a bird flew in sector 1 with a mean heading of 180°, the bird is arriving in the colony. A bird in sector 5 with that same heading is departing from the colony. An algorithm was created that categorizes birds as arriving in, departing from or passing by the colony. It combines the mean heading of the track, its sector and *a priori* defined heading intervals for arriving and departing birds. According to that algorithm, a bird is catalogued as departing from the colony when the heading is within the sector boundaries. For instance, tracks in sector 1 with a heading between 0° and 45° are departing from the colony. If their heading is between 180° and 225°, then they are considered as arriving in the colony. All tracks in sector 1, with a heading outside of those intervals are considered as birds passing the breeding colony. For this study, intervals of 45° wide were chosen. If the intervals would be wider, one risks including too much birds that pass by the colony, in the analysis. It is clear that also some arriving birds and birds departing from the colony are catalogued as passing birds, but since this happens randomly in all sectors and since this study is focusing on flight behaviour and is not quantitative, this can be accepted.

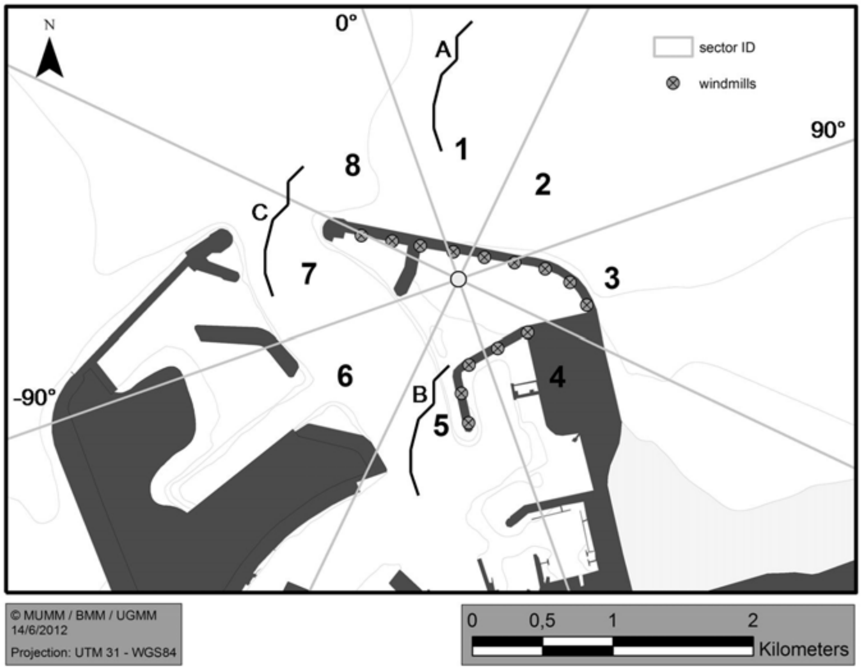


Figure 3. Geographical sectors around the center of the tern colony that were used in step 3 and 4 of the data processing model. The tracks A, B and C are identical and have the same mean heading of 180°. The tracks would, respectively, be catalogued as arriving, leaving and passing by the colony by the algorithm that is explained in step 4.

After those steps it is possible to statistically analyze the processed data to investigate how the co-variables wind direction and velocity influence the direction of flight of arriving and departing birds (dependent variable heading). Wind direction and speed were recorded by the Flemish hydrographic service on the eastern port jetty of the port of Zeebrugge. All tracks were pooled in eight groups according to the wind direction during the time of the recording (N, NE, E, SE, S, SW, W and NW). This way it was possible to assess if the heading of arriving and departing terns differs significantly at different wind directions.

In those analyses only the data from the sectors oriented towards the open sea were retained (sectors 1, 2, 7, 8) because study is focusing on the direction of flight of terns that are foraging out at sea (and not in the port). All statistical analyses were performed in Statistica (v.10).

Since the center of the analysis is the hart of the colony, and not the radar location, the area where the radar recorded is different in the different sectors. Therefore the number of tracks in the different sectors was multiplied by a unique factor, to correct for this size difference.

8.3. Results

8.3.1. Data processing

The groundtruthed data show that the track length of sea and boat clutter is shorter than the recorded tracks for birds and vessels. Sea clutter (ANOVA post-hoc Tukey test, p= 0.0001) and boat clutter (p= < 0.0001) consist of significantly shorter tracks than birds. The mean track length of sea and boat clutter is around five records per track. Tracks of small vessels are significantly longer than bird tracks (p= < 0.0001). Track length of large vessels is similar to those of birds (p= 0.8431; Figure 4a). Based on these results the cut off value of seven records as minimum track length was chosen for the first step of the data processing model.

The speed of birds is significantly different from the speed of sea clutter (ANOVA post-hoc Tukey test, p= <0.0001) and boat clutter (p= <0.0001) (Figure 4b). This means, that also the variable speed makes it possible to discriminate between sea clutter / boat clutter and birds / ships.

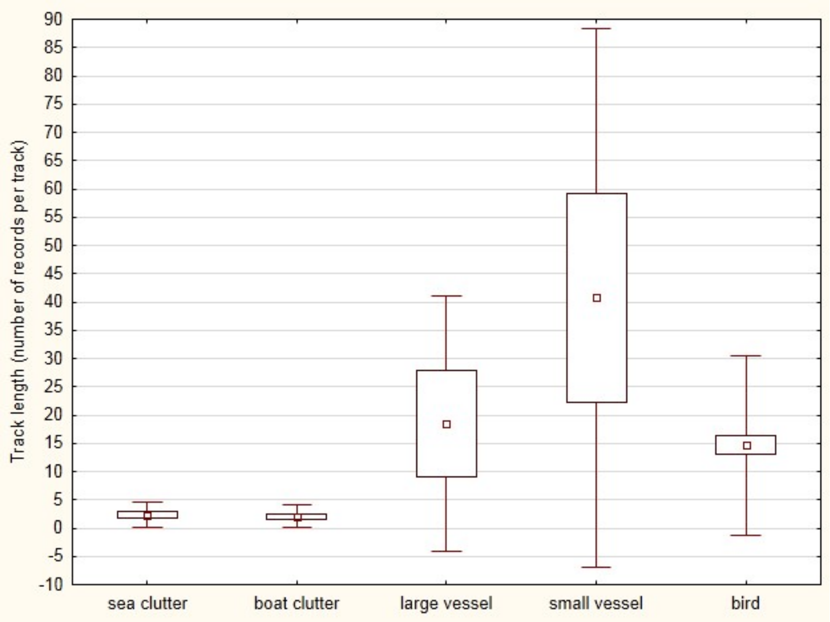


Figure 4a. Track length of groundtruthed tracks assigned to sea clutter, boat clutter, large vessels, small vessels and birds. Mean ± standard deviation (whiskers) and 95% confidence intervals (box).

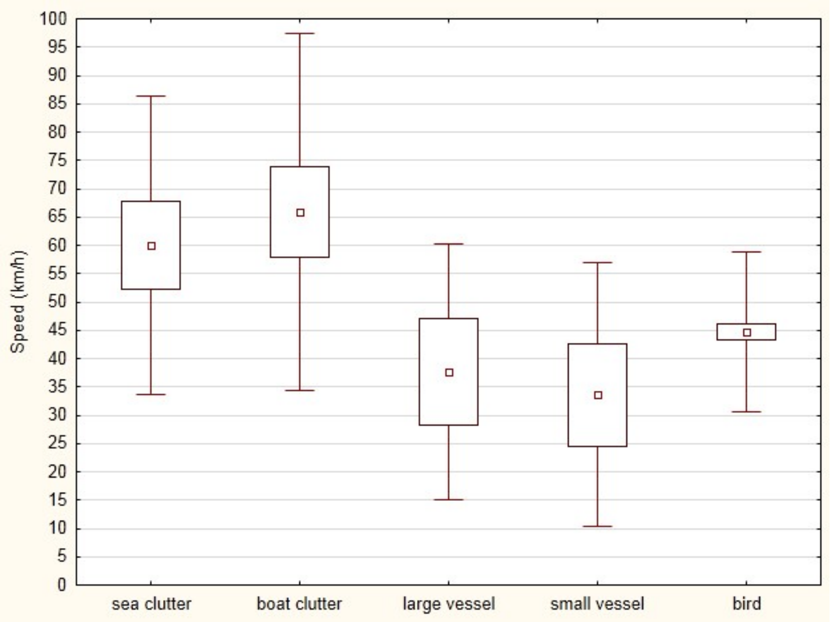


Figure 4b. Speed (km/h) of groundtruthed tracks assigned to sea clutter, boat clutter, large vessels, small vessels and birds. Mean ± standard deviation (whiskers) and 95% confidence intervals (box).

Sea clutter and boat clutter were removed from the dataset based on the track length (step 1 of the data processing). Boats themselves were still in the database after step 1 because they usually have tracks longer than the cut off value of seven records (Figure 4a.). As boats were obviously not sailing towards the breeding colony, they were removed by the algorithm in step 4 of the data processing.

After step 1 of the data processing model the database size was already reduced to approximately 600 MB. This is less than 1% of the Merlin data. After the entire data processing, 50711 arriving and 46117 departing tracks were retained in the four sectors that are facing the sea.

8.3.2. Results on foraging flights:

Significant differences in the headings of bird tracks were found between all wind directions, except for SW-E, NW-N and SE-S for arriving terns and for NW-SE, NW-E and SE-E for departing terns (Table 1, Table 2 and Figure 5).

Table1. Post-hoc Tukey test p-values for arriving common terns

	NE	E	N	NW	S	SW	W	SE
NE		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
E	< 0.0001		< 0.0001	< 0.0001	< 0.0001	0.9964	< 0.0001	< 0.0001
N	< 0.0001	< 0.0001		0.5222	< 0.0001	< 0.0001	0.0001	< 0.0001
NW	< 0.0001	< 0.0001	0.5222		< 0.0001	< 0.0001	< 0.0001	< 0.0001
S	< 0.0001	< 0.0001	< 0.0001	< 0.0001		< 0.0001	< 0.0001	0.2047
SW	< 0.0001	0.9964	< 0.0001	< 0.0001	< 0.0001		< 0.0001	< 0.0001
W	< 0.0001	< 0.0001	0.0001	< 0.0001	< 0.0001	< 0.0001		< 0.0001
SE	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.2047	< 0.0001	< 0.0001	

Table 2. Post-hoc Tukey test p-values for departing common terns

	NE	N	NW	W	S	SE	SW	E
NE		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
N	< 0.0001		0.0145	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0002
NW	< 0.0001	0.0145		< 0.0001	0.0074	0.9702	< 0.0001	1
W	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

S	< 0.0001	< 0.0001	0.0074	< 0.0001		0.0004	< 0.0001	< 0.0001
SE	< 0.0001	< 0.0001	0.9702	< 0.0001	0.0004		< 0.0001	0.9452
SW	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		< 0.0001
E	< 0.0001	0.0002	1	< 0.0001	< 0.0001	0.9452	< 0.0001	

In case of S and SE winds the terns arrive with the lowest mean direction, -44.5° and -47.2° respectively. In case of other wind directions the mean heading increases to a maximum when the wind was coming from the N (-25.8°) and NW (-23.6°).

Terns departing from the colony have the lowest mean heading (-45.8°) when the wind was coming from the NE. When the wind was coming from the W, the mean heading was the highest (-9.8°).

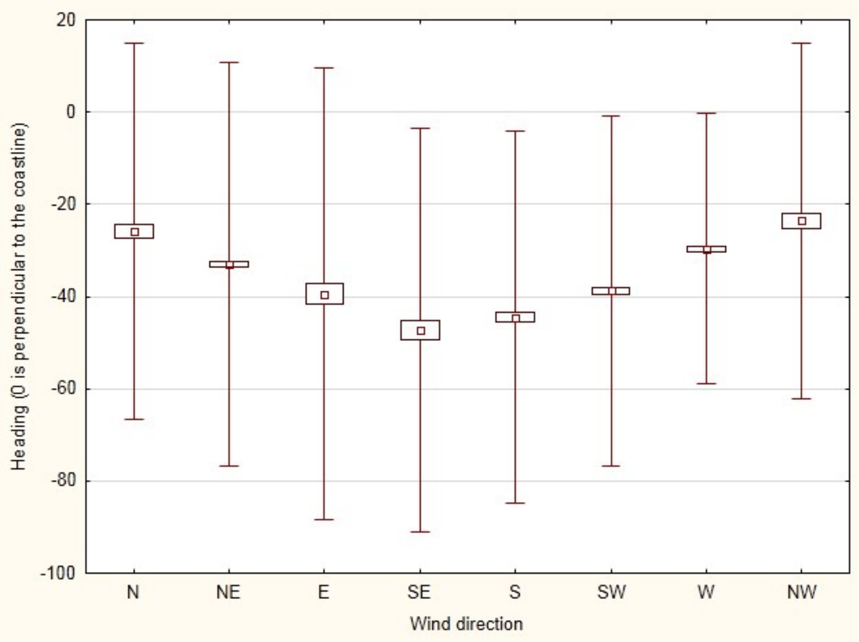


Figure 5a. Heading of terns arriving in the colony, grouped by wind direction. Mean ± standard deviation (whiskers) and 95% confidence intervals (box). A heading of 0° represents a direction perpendicular to the coastline.

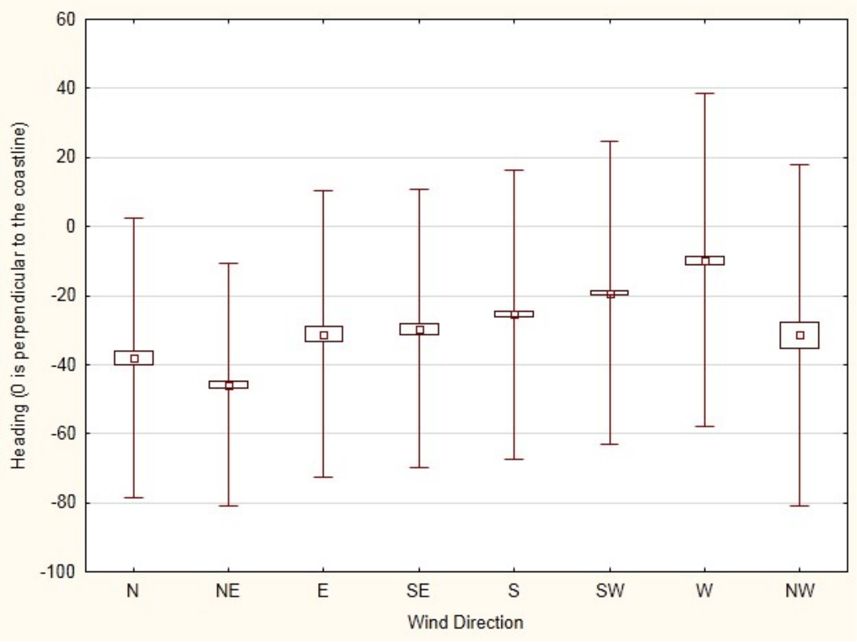


Figure 5b. Heading of terns departing from the colony, grouped by wind direction. Mean ± standard deviation (whiskers) and 95% confidence intervals (box). A heading of 0° represents a direction perpendicular to the coastline.

Both arriving and departing birds are influenced by the wind directions. In June 2011 the wind was coming predominantly from the Southwest (45% of the time) and the Northeast (16% of the time). The wind speeds were not significantly different (p= 0.0769) when the wind was coming from those two directions. Average wind speed was rather low (mean <4m/s) when the wind was coming from the E and the SE (Figure 6).

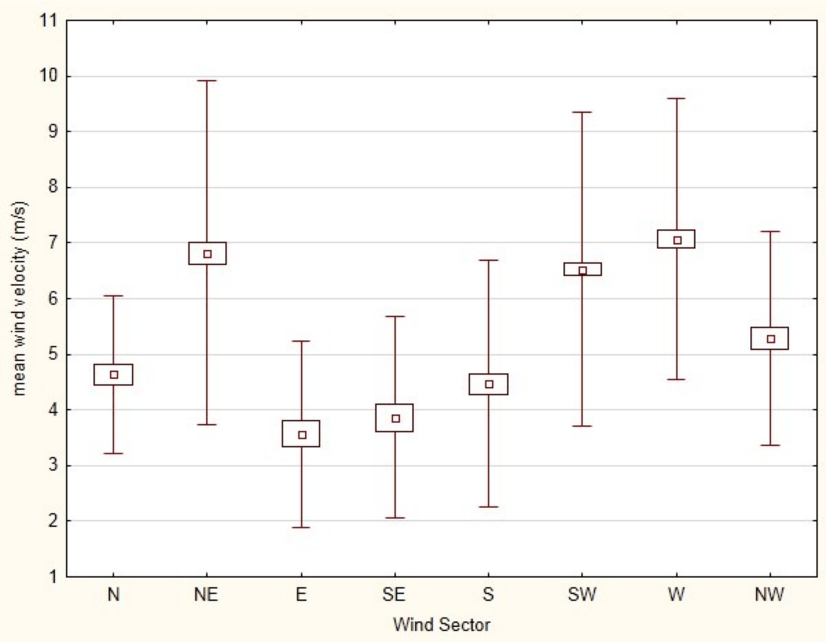
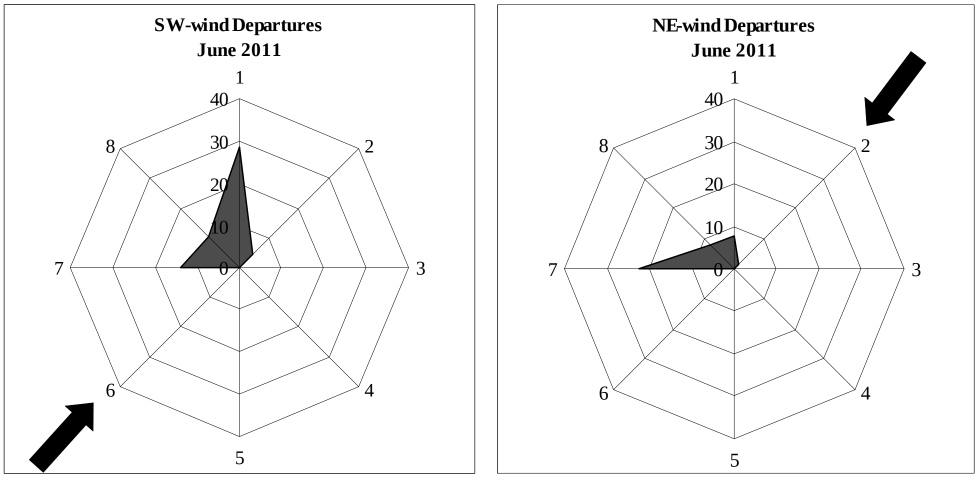


Figure 6. Wind direction and wind speed in the month of June 2011.

In case of southwesterly wind, a large portion of terns (28%) used sector 1 to leave the colony. This was not the case when the wind was coming from the NE. During those periods not a lot of birds were using the sea facing sectors to depart from the colony. However, 23 % of the birds used sector 7 to depart from the colony.

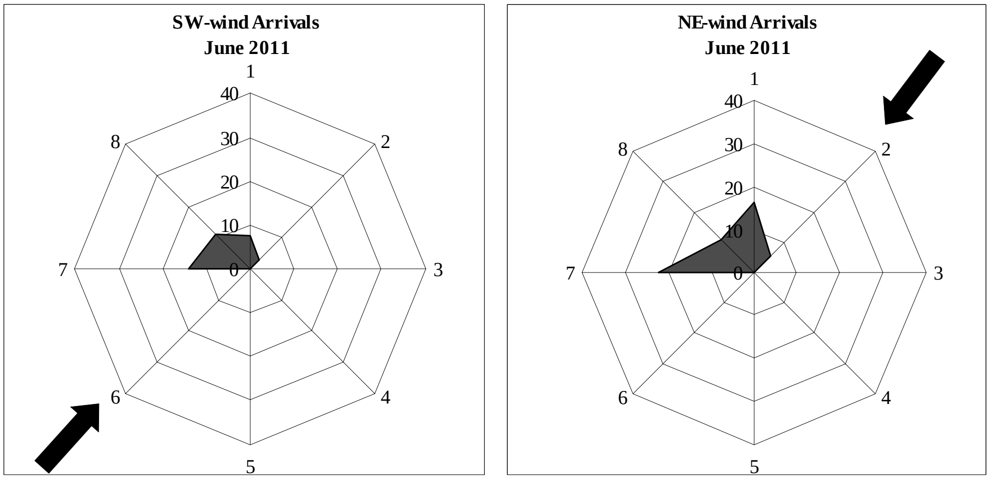
Arriving terns showed a very different pattern from departing terns during southwesterly winds. Few birds used the sea facing sectors to arrive in the colony. When the wind was coming from the NE the terns were arriving very dispersed. A notable portion (16%) was however arriving via sector 1 (Figure 7).



SW-wind Departures
June 2011

NE-wind Departures
June 2011

Figure 7a. Percentage of terns departing from the colony via the sea facing sectors when the wind was coming from the SW (left) versus wind coming from the NE (right). The black arrows indicate the wind direction.



SW-wind Arrivals
June 2011

NE-wind Arrivals
June 2011

Figure 7b. Percentage of terns arriving in the colony via the sea facing sectors when the wind was coming from the SW (left) versus wind coming from the NE (right). The black arrow indicates the wind direction.

8.4. Discussion

8.4.1. Flight behaviour of foraging common terns during the breeding season.

The areas just around the port of Zeebrugge and especially those to the west of the port (as far as the Wenduinebank), are the most important feeding grounds for the common terns that are breeding in the port of Zeebrugge (Figure 8, Vanaverbeke *et al.*, 2011).

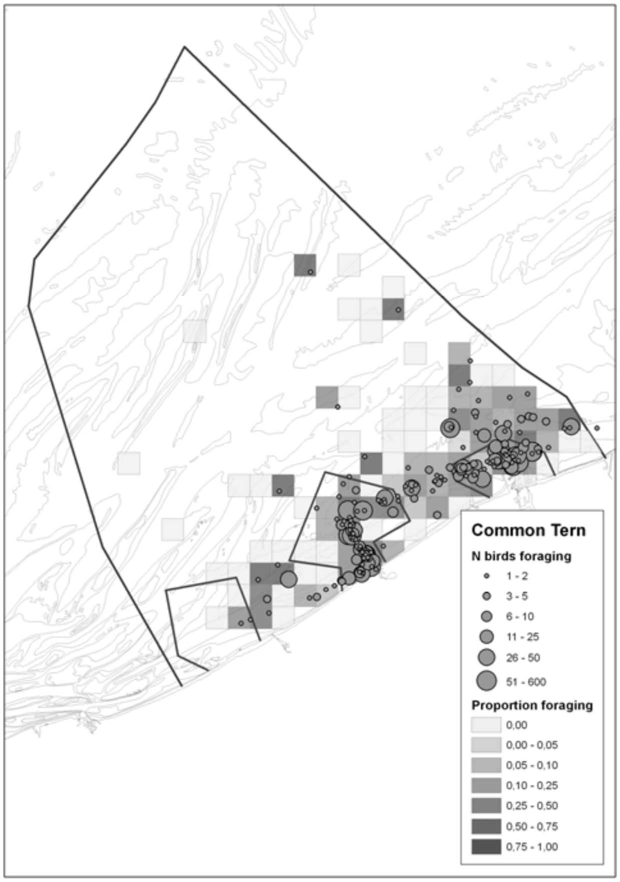


Figure 8. Foraging activity of common tern during the breeding season in 1992-2010. Dots show the numerical occurrence of foraging terns and shaded grids represent foraging frequency (i.e. number of actively foraging individuals/ total numbers). Drawn lines indicate the border of the BPNS and the three special protection areas under the birds directive (Vanaverbeke et al., 2011).

The results of this radar study show that wind direction plays an important role in the foraging behaviour of common terns in Zeebrugge. A portion of the common terns is always foraging in the port itself or is flying via sectors 3 and 6 towards/from the sea, but a large number forages at sea leaving/entering the harbour via sectors 1, 2, 7 or 8. The direction in which these birds arrive in and depart from the colony is clearly influenced by the wind direction and probably also by the wind speed.

Our results suggest that a lot of birds leave the colony with side- or tailwind, then forage with headwind, so they can use the headwind whilst hovering, and come back with side- or headwind. As such it looks as if they make a loop from the colony to the feeding ground and back, as was the case the colonies in Norfolk and Anglesey, United Kingdom (Perrow *et al.*, 2011). The direction in which they fly in that loop depends on the wind direction. Visual observations of arriving and departing terns in Zeebrugge, made by Alvarez del Villar D’Onofrio (2005), indeed show that most of the common terns arrived from the West and the North of the colony and departed towards the West and the Southwest. These observations confirm the radar observations and also support the theory that the common terns make a loop during their foraging.

Unfortunately the radar range was set at only 0.5 nm during the time of recording, because we wanted to register micro-avoidance of common terns around a single turbine. A longer range would have allowed for a better interpretation of the direction of the foraging flights.

8.4.2. Evaluation of parallels between the study of foraging terns and the assessment of the impact of offshore wind farm on birds with an automated radar system.

Although the case of the foraging terns in Zeebrugge is very different from an offshore wind farm site, there are many parallels in the processing and the analysis of the data that were gathered in Zeebrugge and the data that will be gathered offshore. Lessons-learnt here will hence have a direct added value for the future research offshore.

The analytical procedure to process radar data that was developed in this study showed that it is possible to successfully remove clutter and retain high quality data on bird movements. Ground truthed data made it possible to discriminate between different types of targets by using the variables that are logged by the radar (track length, speed, etc.). A large advantage of the case study in Zeebrugge was that one species was very dominant in the breeding colony area. Because all bird tracks in the area belonged to (almost) one species, the filtering of the data could be done in a very straightforward way. This filtering also removed a lot of bird tracks (with track length shorter than seven records), but since this is not a quantitative study, but a study focusing on flight patterns, this is acceptable. The data that will be collected offshore will need to be processed in a similar way as was done with the Zeebrugge data. The species composition offshore is a lot more diverse than in the breeding colony in Zeebrugge. Several seabird species are present in that area and a wide range of species, from geese to small passerines, is migrating through the area twice a year. If the offshore data would be filtered in the same way as we filtered the tern data, one risks loosing a specific segment of bird species and as such bias the data. Since the detection loss of the radar increases with the distance from the radar, especially for smaller birds, a lot of the smaller species would possibly be lost. That is why the track length criterion will need to be re-assessed for offshore conditions.

Instead of using only one variable (as was done with the tern data), a combination of several discriminating variables will be used to filter the offshore radar data into different target groups (e.g. clutter, boats, large gulls, terns, passerines). The quality of that filter will off course depend on the data that were groundtruthed to be used as input to build such a filter. Therefore it will be important to do visual groundtruthing of the radar data on site on a regular base. This will also render the necessary information on the sampling efficiency and the taxonomic resolution (i.e. to what level species (groups) can be separated) of the radar system.

The processed data from this study were further analyzed with GIS, an essential step to be able to interpret the ecological relevance of the data. This will also be necessary for the offshore data. However, instead of assigning the data to sectors around a breeding colony, the offshore data will be assigned to a grid cell of a grid that covers the wind farm and the area around it. This is similar to what was done by Petersen *et al.* (2006) and Krijgsveld *et al.* (2011). Therefore the number of tracks and their heading in grid cells within the wind farm will be compared to the number of tracks and heading in grid cells outside wind farm. As such, avoidance behaviour of birds in response to the wind farm can be quantified. The way the data are handled in GIS and the way the tracks are assigned to a certain grid cell is identical to what was done with the test data. After this step it is also possible to test the importance of co-variables such as wind direction, visibility, etc.

A third parallel between the test phase in Zeebrugge and the offshore study is the use of multiple regression modeling to study the importance of several (explanatory) co-variables that influence the flight behaviour (i.e. response variable) of birds. The most interesting co-variables to include are wind speed and direction, visibility, sea-state and activity of the turbines. For the Zeebrugge test phase we tried to explain the heading of arriving or departing terns (i.e. response variable) by the co-variable wind direction and wind speed. We here encountered the problem that wind direction is an angular variable. This means, for instance, that the values 1 and 359 are almost the same, so this value can not be used in a linear manner. This problem could not be solved so far. Fisher & Lee (1992) describe of solution for this kind of problems, but it was not possible to include this in this study.

An attempt was done to register birds in the vicinity of a single turbine and therefore study micro-avoidance of birds around a turbine. This was the reason why the HSR range was set at only 0.5 nm. This appeared not to be possible due to the high clutter environment created by the concrete jetty. Krijgsveld *et al.* (2011) operated their radar system offshore at 0.75 nm and were able to register birds down to 10 m and less from the turbine. Therefore this should be possible in the offshore study location.

8.5. Conclusions

Wind direction was demonstrated to play an important role in the foraging behaviour of common terns in Zeebrugge. The direction in which these birds arrive in and depart from the colony is clearly influenced by the wind direction and probably also by the wind speed.

The Zeebrugge case offered a good opportunity to focus on a specific type of birds and flight behaviour with the radar system. This was relevant for the future impact assessment of offshore wind farms because the approach and methodology are very similar. With this case study, a lot of experience was gained and the methodology was developed and fine-tuned for the future research offshore. It can be concluded that the radar system is an appropriate tool to monitor bird movements. It offers a possibility to show significant patterns in bird movements, even if the pattern's strength is rather small.

It was not possible to register birds in close vicinity of a single turbine because of the clutter created by the port jetty. However, based on the results of Krijgsveld *et al.* (2011), we are confident that this will be possible in the offshore wind farms.

8.6. References

Alvarez del Villar D'Onofrio, Adriana M. (2005). FORAGING AREAS FOR SANDWICH AND COMMON TERNS IN BELGIAN MARINE WATERS. Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Ecological Marine Management. 57 pp.

Bolker E.D., Hatch J.J. & Zara C. (2006) Modelling bird passage through a wind farm. http://www.cs.umb.edu/~eb/windfarm

Band, W., Madders, M. & Whitfield, D.P., (2007). Developing field and analytical methods to assess avian collision risk at wind farms. M. de Lucas, G.F.E. Janss & M. Ferrer. Birds and Wind Farms: Risk Assessment and Mitigation. Quercus. Madrid. pp. 259 – 275.

Barclay, R.M.R., Baerwald, E.F. & Gruver, J.C., (2007). Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. (Can. J. Zool.) 85, 381 – 387.

Brabant R. & Jacques T.G. (2009) Research strategy and equipment for studying flying birds in wind farms in the Belgian part of the North Sea. In: Degraer, S. & Brabant, R. (Eds.) (2009) Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute for Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. pp. 223-235.

De Groote, D. & Roggeman, W. (2006) Gebruik van radarsystemen voor monitoring van de avifauna op de Thorntonbank. 49 pp.

Desholm, M., Fox, A.D., Beasley, P.D.L. & Kahlert, J., (2006). Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. (Ibis) 148, 76 – 89.

Drewitt, A.L. & Langston, R.H.W., (2006). Assessing the impacts of wind farms on birds. (Ibis) 148, 29 – 42.

Exo, Klaus-Michael, Huppop, O.& Garthe., S., (2003). Birds and Offshore wind farms: a hot topic in marine ecology. Wader Study Group Bulletin 100: 50-53.

Everaert, J. & Stienen, E.W.M., (2006). Impact of wind turbines on birds in Zeebrugge (Belgium). Significant effect on breeding tern colony due to collisions. Biodivers. Conserv. 15(10).

Fisher N.I. & Lee A.J., (1992). Regression Models for an Angular Response. Biometrics 48, 665-677.

Fox, A.D., Desholm, M., Kahlert, J., Christensen, T.K. en Petersen, I.B.K., (2006). Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds (Ibis) 148, 129 – 144.

Krijgsveld, K.L., Fijn, R.C., Japink, M., van Horssen, P.W., Heunks, C., Collier, M.P., Poot, M.J.M., Beuker, D. & Dirksen, S., (2011). Effect studies Offshore Wind Farm Egmond aan Zee, Final report on fluxes, flight altitudes and behaviour of flying birds. Bureau Waardenburg. 330 pp.

Langston R.H.W. & Pullan J.D., 2003. Windfarms and birds: An analysis of the effects of windfarms on birds, and guidance on environmental assessment criteria and site selection issues. Report by Birdlife International on behalf of the Bern Convention. Council of Europe T-PVS/Inf (2003) 12. See also Bern Convention 'Draft Recommendation' T-PVS (2003) 11.

Leopold, M.F., Dijkman, E.M., Teal, L. & the OWEZ-Team (2010). Local Birds in and around the Offshore Wind Park Egmond aan Zee (OWEZ) (T-0 & T-1, 2002-2010) IMARES, Wageningen UR Report number: OWEZ R 221 T1 20111220, pp. 269.

Masden, E.A., D.T. Haydon, A.D. Fox, R.D. Furness, R. Bullman & M. Desholm, (2009). Barriers to movement: impacts of wind farms on migrating birds. ICES Journal of Marine Science 66: 746-753.

Masden, E.A., Fox, A.D., Furness, R.W., Bullman, R., & Haydon, D.T. (2010). Cumulative impact assessments and bird/wind farm interactions: developing a conceptual framework. Environmental Impact Assessment Review. *Environmental Impact Assessment Review*. 30:1-7

Petersen, I.K., Christensen, T.K., Kahlert, J., Desholm, M. & Fox, A.D. (2006). Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark. NERI Report request. Commissioned by DONG energy and Vattenfall A/S. National Environmental Research Institute. Ministry of the Environment. Department of Wildlife Ecology and Biodiversity. 161 pp.

Perrow, M.R., Skeate, E.R., Gilroy, J.J. (2011) Visual tracking from a rigid-hulled inflatable boat to determine foraging movements of breeding terns. (Journal of Field Ornithology) 82, 68-79.

Poot, M.J.M., M.P. Collier, P.W. van Horssen, R. Lensink & S. Dirksen, 2011. Effect studies Offshore Wind Egmond aan Zee: Cumulative effects on seabirds. A modelling approach to estimate effects on population levels in seabirds. NoordzeeWind Report OWEZ_R_212_20111021_Cumulative_Effects. Bureau Waardenburg report 11-026. Culemborg, Netherlands.

Stienen, E.W.M., Van Waeyenberghe, J. en Kuijken, E., 2007. Trapped within the corridor of the southern North Sea: the potential impact of offshore wind farms on seabirds. In: de Lucas, M., Guyonne, F.E. en Ferrer, M., 2007. Birds and wind farms: risk assessment and mitigation, p. 71 – 80.

Troost Tineke, "Estimating the frequency of bird collisions with wind turbines at sea. Guidelines for using the spreadsheet 'Bird collisions Deltares v1-0.xls'." (Deltares, 2008).

Vanaverbeke J, Braarup Cuykens A, Braeckman U, Courtens W, Cuveliers E, Deneudt K, Goffin A, Hellemans B, Huyse T, Lacroix G, Larmuseau M, Mees J, Provoost P, Rabaut M, Remerie T, Savina M, Soetaert K ,Stienen EWM, Verstraete H,Volckaert F, Vincx M. (2011) *Understanding benthic, pelagic and airborne ecosystem interactions in shallow coastal seas.* "*WestBanks*". Final Report. Brussels: Belgian Science Policy Office 2011 – 82 p. (Research Programme Science for a Sustainable Development)