
CHAPTER 5

Bird monitoring at the Belgian offshore wind farms: results after five years of impact assessment

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To monitor the impact on birds following the construction of two offshore wind farms in the Belgian part of the North Sea, a twofold strategy was followed. Monthly ship-based seabird surveys allowed for a detailed displacement effect assessment, while radar research aimed at studying avoidance behaviour and barrier effects. Both methods provided input data for collision risk modelling in order to assess bird collision rates. Three years after the completion of the wind farm at the Bligh Bank, it showed that northern gannet, common guillemot and razorbill avoid the wind farm, while numbers of lesser black-backed and herring gull increased significantly. Collision risk modelling learned that gulls in particular are at risk of colliding with the turbine blades, with up to 2.4 bird strikes per turbine per year.

INTRODUCTION

Despite its limited surface, the Belgian part of the North Sea (BPNS) holds internationally important numbers of seabirds. Its specific importance to seabirds varies throughout the year. During winter, maximum numbers are present with over 46,000 seabirds, of which more than 20,000 auks. Offshore, the wintering community is dominated by common guillemots *Uria aalge*, razorbills *Alca torda* and black-legged kittiwakes *Rissa tridactyla*. Meanwhile, large numbers of grebes, scoters and divers reside inshore. In summer, fewer birds are present (on average 15,000), but high numbers of terns and gulls exploit the area in support of their breeding colony located in the port of Zeebrugge. During autumn and spring, the BPNS makes part of a very important seabird migration route through the Southern North Sea and an estimated number of no less than 1.0 to 1.3 million seabirds annually migrate through this 'migration bottleneck' (Stienen et al., 2007). For a number of species, the BPNS hosts more than 1% of the biogeographical populations involved, i.e. northern gannet *Morus bassanus* (autumn), little gull *Hydrocoloeus minutus* (spring), lesser black-backed gull *Larus fuscus* (summer), great black-backed gull *Larus marinus* (winter) and common tern *Sterna hirundo* (summer) (Vanermen et al., 2013).

Possible effects of offshore wind farms on seabirds range from indirect effects (habitat change, habitat loss and barrier-effects) to direct mortality through collision (Exo et al., 2003; Langston and Pullan, 2003; Fox et al., 2006; Drewitt and Langston, 2006). The installation of an offshore wind farm indeed changes the impacted area drastically, not only because of the impressive physical appearance in the wide open seascape, but also due to the underwater changes following the introduction of hard substrates in a soft-bottom marine ecosystem. On the one hand, some seabirds can be expected to avoid the huge vertical structures in much the same way as they avoid the coast or are scared off by ship traffic. As such, seabirds can be displaced out from an area which was used for foraging prior to the construction of the wind farm, resulting in habitat loss. In an offshore context, the impacted area is generally surrounded by a huge surface of turbine-free marine habitat, which however does not necessarily include equally suitable feeding grounds. Birds bound to shallow waters are thus the most at risk of losing large areas of valuable and irreplaceable habitat, since wind farms too are generally built on shallow sandbanks. On the other hand however, there are numerous examples of seabirds being attracted to offshore constructions, as for example gas platforms. Mostly, this attraction effect is hypothesised to result from increased food availability and roosting possibilities (Tasker et al., 1986; Wiese et al., 2001). The same of course can be expected to happen at offshore wind farms. But with wind farms acting as a magnet to seabirds, more birds face the risk of colliding with the turbine blades. Importantly, as seabirds are long-lived species with a delayed maturity and small clutch size, even the smallest change in adult survival may have a substantial impact at a population level (Stienen et al., 2007).

Wind farms may finally also act as barriers for local flight movements as well as for migration, resulting in longer flight paths and an increased energy expenditure. Petersen et al. (2006) and Krijgsveld et al. (2011) demonstrated birds to change their flight direction as they approach a wind farm (i.e. macro-avoidance). The extent of this effect is yet unknown but might be particularly important in case of wind farms oriented perpendicular to the main migration direction, as is the case in the BPNS.

Based on data collected during the first six years of offshore wind farm monitoring at the BPNS, this chapter addresses (1) the displacement effects of offshore wind farms, (2) the possible barrier-effect and (3) the expected number of birds colliding with the turbines.

RESEARCH STRATEGY

Two techniques were used in this investigation. Visual censuses from research vessels aimed at estimating local seabird densities, allowing to assess seabird displacement effects as well as to predict bird collision rates. This method provides a high taxonomic resolution and direct information on seabird behaviour, but is restricted to daylight and good weather conditions only. Radar research complemented the visual census data with continuous observations, and aimed to study barrier effects and – again – bird collision rates, yet with a significantly lower taxonomic resolution. While visual censuses are already at full maturity allowing for an in depth impact assessment, radar research first had to cope with various technical and analytical problems, some of which are addressed in this chapter.

Displacement

Since 2005, three years before the construction of the first offshore wind turbine, seabird displacement effects were investigated performing monthly BACI-designed seabird surveys across impact and control areas. Seabird surveys were conducted according to the internationally applied European Seabirds at Sea (ESAS) method (Tasker et al., 1984). The focus is on a 300 m wide transect along one side of the ship's track. While steaming, all birds in touch with the water (swimming, dipping, diving) located within this transect are counted ('transect counts'). In contrast, the density of flying birds was assessed through so-called 'snapshot counts': right at the start of each minute, the number of birds flying within a quadrant of 300 by 300 m inside the transect is counted. Taking account of the distance travelled, these count results can be transformed to seabird densities.

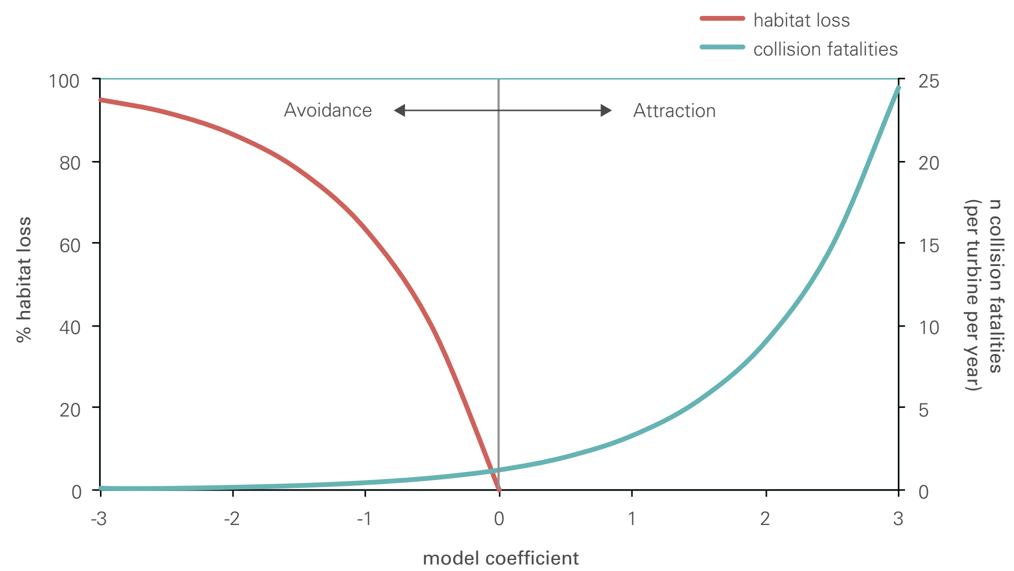
Based on the results gathered during the Danish pilot project on seabird displacement effects at offshore wind farms (Petersen et al., 2006), we surrounded the future wind farm areas by a buffer zone of 3 km to define the impact areas, being the zones where effects of turbine presence can be expected (Figure 1). Next, a more or less equally large control area was delineated, harbouring comparable numbers of seabirds, showing similar environmental conditions and enclosing a high number of historical count data (Vanermen et al., 2010). Considering the large day-to-day variation in observation conditions and seabird densities, the distance between the control and impact area was chosen to be small enough to be able to survey both areas on the same day by means of a research vessel. To minimise overall variance and in order to avoid pseudo-replication resulting from autocorrelation between subsequent ten-minute counts, the applied unit in our seabird database, count data were summed per area (control/impact) and per monitoring day (Stewart-Oaten et al., 1986). Only those days during which both areas were surveyed, were used in this study.

Seabird survey from the RV Belgica at the Thorntonbank.

Figure 1. Location of the impact and control areas for the Thorntonbank and Bligh Bank wind farms, with indication of the monitoring route sailed in the course of 2012.

Seabirds mostly occur strongly aggregated in (multi-species) flocks, inducing count results with a high proportion of zeros and relatively few but sometimes very high positive values. To correctly handle this inherent over-dispersion and excess in zero values, a zero-inflated negative binomial (ZINB) model was used (Zeileis et al., 2008). This type of model consists of two parts, (1) a 'zero component' modelling the chance of not encountering birds with a logistic regression, and (2) a 'count component' modelling the data according to a negative binomial (NB) distribution. Seasonality was added to the models as a covariate and was modelled as a cyclic sine curve, which can be described through a linear sum of a sine and a cosine term (Stewart-Oaten and Bence, 2001). Next, we included the two-level factor variable BA (before/after wind farm construction) and, depending on the outcome of the model selection process, CI (control/impact area) or T (turbines absent/present). The wind farm displacement effect is then estimated by the coefficient of the interaction between BA & CI or by the coefficient of the factor variable T. How the value of this coefficient relates to the impact of wind farm presence on seabirds is illustrated in Figure 2. A negative model coefficient value indicates that birds are avoiding the wind farm, resulting in habitat loss yet a decreasing number of collision fatalities, while a positive value suggests attraction of seabirds and increased bird mortality. The exponential relation between the model coefficient and the number of collision fatalities is explained by the logarithmic link between the response and the linear regression equation incorporated in the NB model structure.

Figure 2. Relation between the displacement-related model coefficient and the anticipated negative impact on seabirds (estimation of collision fatalities being based on the characteristics of lesser black-backed gull and a hypothetical density of 0.02 birds/km² at rotor height).



BOX:
Radar systems as a tool to study large scale effects of offshore wind farms on birds

The Merlin radar system (DeTect Inc., Florida, USA) 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) is rotating 360° in the horizontal pane and provides information on flight tracks and therefore on the possible avoidance behaviour of birds around the wind farm. By rotating in the vertical pane, the vertical radar (VSR) creates a 'radar screen' that registers all targets moving through that screen. As this 'radar screen' is fairly narrow, every registration can be seen as one (or a group of) target(s) passing through that area. This way of data collection allows deriving the flux of birds through the area. It also provides data on the flight altitudes.
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 – 1 nautical mile 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 obviously birds. When the radar energy reflects on a bird and this is received by the radar antenna, an echo appears on the raw radar screen. If the echo meets certain (plotting) criteria (e.g. minimum size, intensity of the echo, 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 over 40 variables (e.g. time, location, speed, heading, size) for every record.

Figure 3. Unprocessed data during the fall migration of 2012. Upper panel: 15 minutes of horizontal radar data from October 22nd (8:45 – 9:00 pm). The horizontal radar range is set at 4 NM (7408 m); lower panel: one hour of vertical radar data from October 6th (11 to 12 am). The vertical radar range is set at 1 NM (1852 m). On both figures some bird tracks are notable, but also wind turbines, rain, etc. Certain areas have few or no detections at all, due to some issues with the detectability of the radar signal, which have been improved now. The direction in which an object is moving is indicated by the color.

After a test-phase in the port of Zeebrugge, the radar system was moved to the transformer platform on the Thorntonbank, about 25 km from the coast. The radar antennas are installed on the top deck, about 36 m above the sea-surface, on the south-western side of the platform.

Merlin dual radar system installed on the top deck of the transformer platform of the C-Power wind farm at the Thorntonbank.

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'). The VSR is typically less vulnerable to sea clutter than the HSR. A first challenge in radar data analysis was to effectively remove this clutter from the radar database. Based on visually ground truthed radar observations during the test phase at Zeebrugge, we quantified the differences in echo characteristics between birds and other objects (e.g. vessels, sea clutter, etc.). A good example of a differentiating variable is the track length of a target. With a mean track length of about five records, the track length of sea clutter was found to be significantly shorter than the tracks for birds and vessels (Figure 4). Combining radar data variables and extensive ground truthing will hence allow us to further filter birds from the radar data for future seabird investigations.

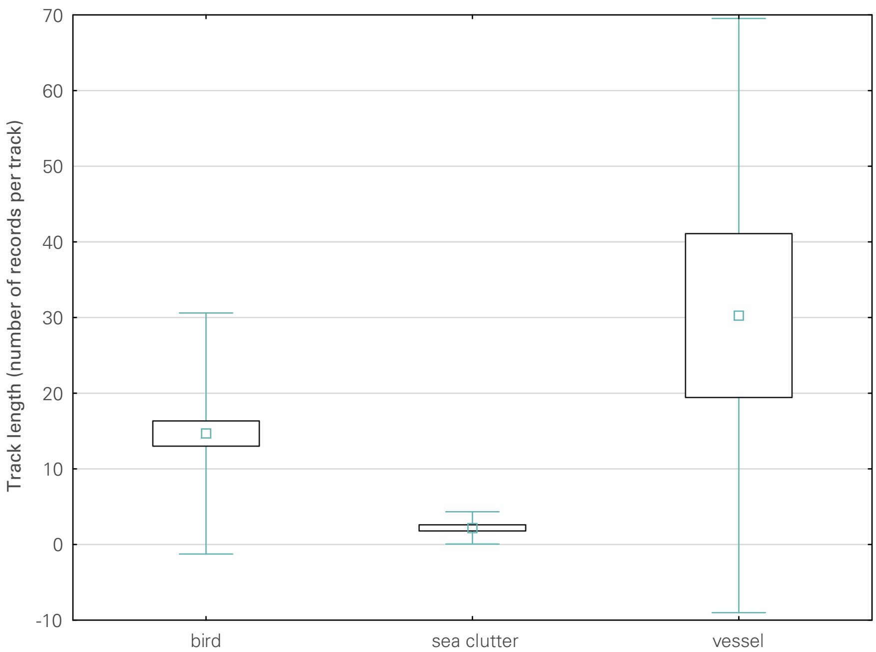


Figure 4. Track length of ground truthed tracks assigned to sea clutter, vessels and birds. Mean ± standard deviation (whiskers) and 95% confidence intervals (box).

Barrier-effect

Radar observations provide continuous data on flight movements over a wide area, allowing to assess barrier effects and avoidance behaviour on a large scale. Radars have been used for similar offshore research programs abroad, for instance in Denmark (Desholm, 2006) and the Netherlands (Krijgsveld et al., 2011). GIS processing of horizontal radar data allows to determine changes in seabird flight directions as they approach the wind farm (i.e. avoidance) and at what distance from the wind farm they show this avoidance behaviour. Although successfully applied in the tern breeding colony at the harbour of Zeebrugge (presented in Brabant et al., 2012a), we were not yet able to run such analysis for the offshore wind farm environment due to issues with the radar signal detectability.

Collision rate

Collisions of birds with fixed and rotating structures of wind turbines have been recorded in numerous wind farms on land (Everaert and Stienen, 2007; Barclay et al., 2007; etc.). For obvious reasons it is more difficult to assess the number of collision victims at an offshore wind farm, and at this point, actual data on offshore collision rates are lacking. Band (2012) however developed a (theoretical) collision risk model (CRM) to estimate the bird collision risk based on technical turbine specifications and wind farm configuration, combined with bird-related parameters. In this study, data on wingspan and flying speed were taken from Cramp (1977-1985) and Alerstam et al. (2007). The CRM also includes a micro-avoidance rate, accounting for last-minute avoidance actions. This factor is hard to assess, but is considered to be very high and is generally set to at least 95% (Chamberlain et al., 2006). Importantly, the number of estimated victims is proportional to the percentage of birds that *does not* perform avoidance actions (= 1 - % micro-avoidance). A seemingly small difference in avoidance rate between 95% and 99.5% therefore results in a factor 10 difference in terms of estimated collision victims. To estimate collision rate in this study, we applied the micro-avoidance value of 97.6% as found by Krijgsveld et al. (2011) based on their extensive radar research.

The ‘snapshot counts’ as performed during the seabird surveys allowed estimating densities of flying birds within the Bligh Bank wind farm, which were used as input for the CRM. Meanwhile, the flight height of all observed seabirds was categorised as ‘in’, ‘under’ or ‘above’ the rotor sweep zone (30-150 m). Radar observations too were used to determine bird densities, which were deducted from the flux of birds through the vertical radar beam. As the radar does not differentiate between individual and flocks of birds, the flux is expressed as the number of (groups of) birds/hr/km. The flux and estimated number of collisions were calculated for two days during the fall migration of 2012 (October 21st and 22nd 2012) and for two days in the winter of 2013 (January 22nd and 23rd 2013).

Lesser black-backed gull approaching the rotor sweep zone in the Bligh Bank wind farm.

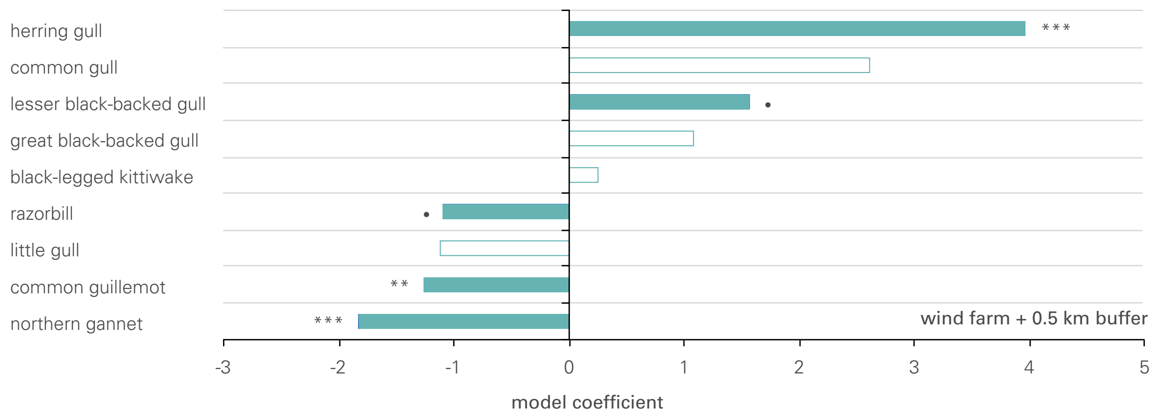
DISPLACEMENT EFFECTS REVEALED

Because the large difference in configuration between the wind farms at the Bligh Bank (five rows of 11 turbines) and the Thorntonbank (a single row of six turbines at the time of the surveys) can be expected to trigger different displacement effects, we analysed both areas separately.

Bligh Bank

Three species significantly avoided the Bligh Bank wind farm, i.e. northern gannet and both auk species (Figure 5). For razorbill, this effect was limited to the wind farm area itself, but northern gannet and common guillemot also avoided the area up to at least 3 km from the nearest turbines. Little gull numbers decreased after the wind farm construction, but this change was not statistically significant. The distribution maps show that the avoidance by northern gannet (Figure 6, upper panel) was almost absolute while common guillemot (Figure 6, lower panel), despite its avoidance behaviour, was regularly observed inside the wind farm.

Figure 5. Seabird displacement effects at the Bligh Bank wind farm based on the results of 63 surveys before and 30 surveys after the turbines were built and indicated by the displacement-related model coefficient (blue bars indicate significance: . ~ p<0.1, * ~ p<0.05, ** ~ p<0.01, *** ~ p<0.001).



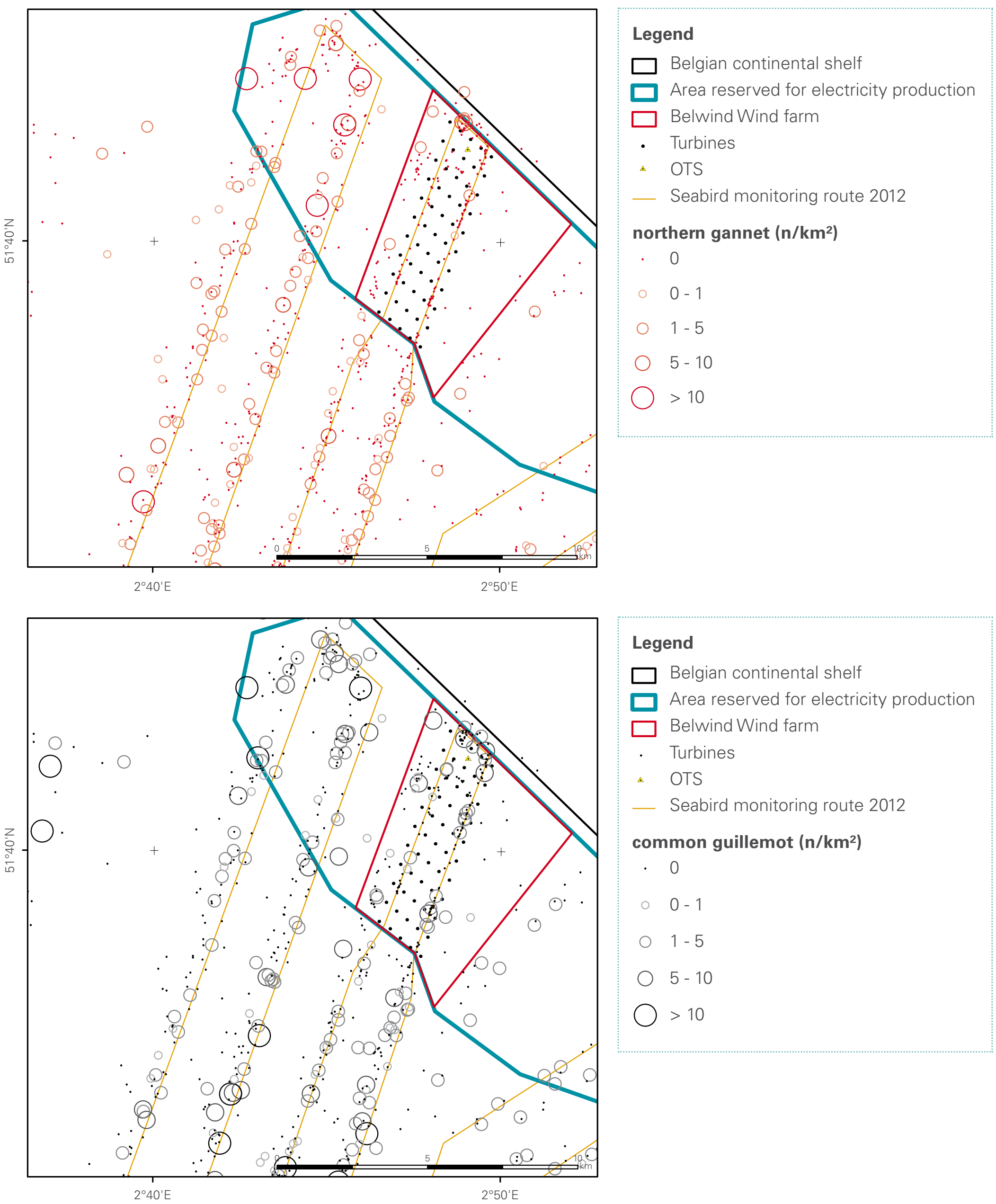
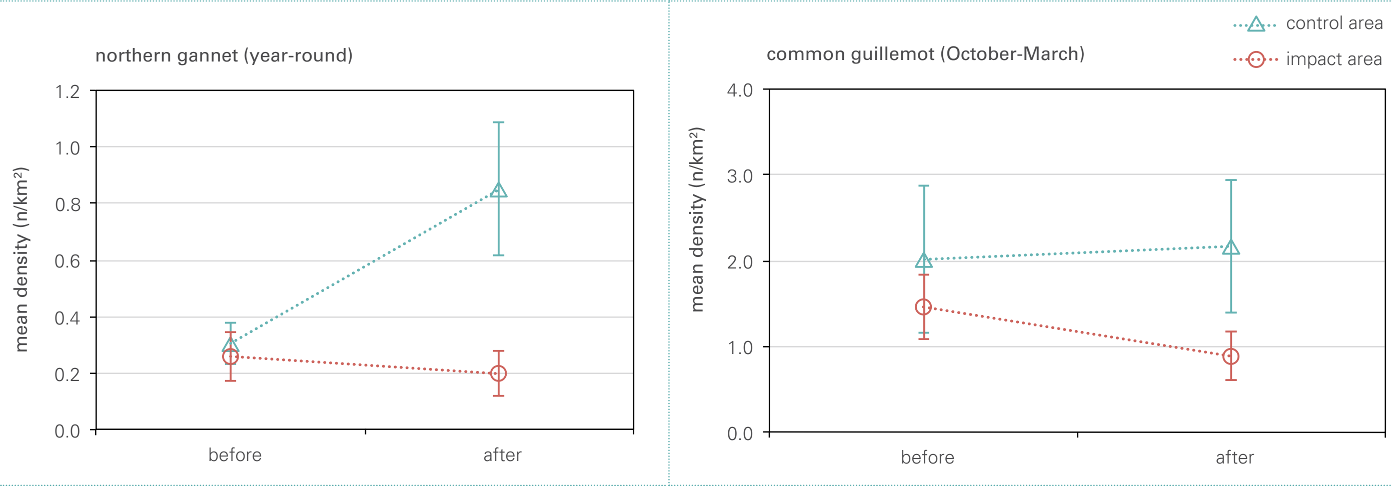


Figure 6. Observations of northern gannet and common guillemot during the seabird monitoring program at the Bligh Bank after wind farm construction.

Figure 7. Densities of northern gannet and common guillemot at the Bligh Bank study area before and after wind farm construction.



Lesser black-backed gulls and herring gulls *Larus argentatus* on the other hand showed a significant increase in numbers after the wind farm was constructed (Figure 5, see also Chapter 15 – Figure 1). For lesser black-backed gull the attraction effect was significant for up to at least 3 km from the wind farm, which was not the case for herring gull. The attraction of herring gulls is nicely illustrated by the distribution pattern in Figure 8 (lower panel), with high numbers being observed exclusively near or inside the wind farm. In contrast, the distribution pattern of lesser black-backed gull (Figure 8, upper panel) suggests indifference rather than attraction. Lastly, an increase in numbers was observed in three other gull species: common gull *Larus canus*, great black-backed gull and black-legged kittiwake, but these effects were not found to be statistically significant.

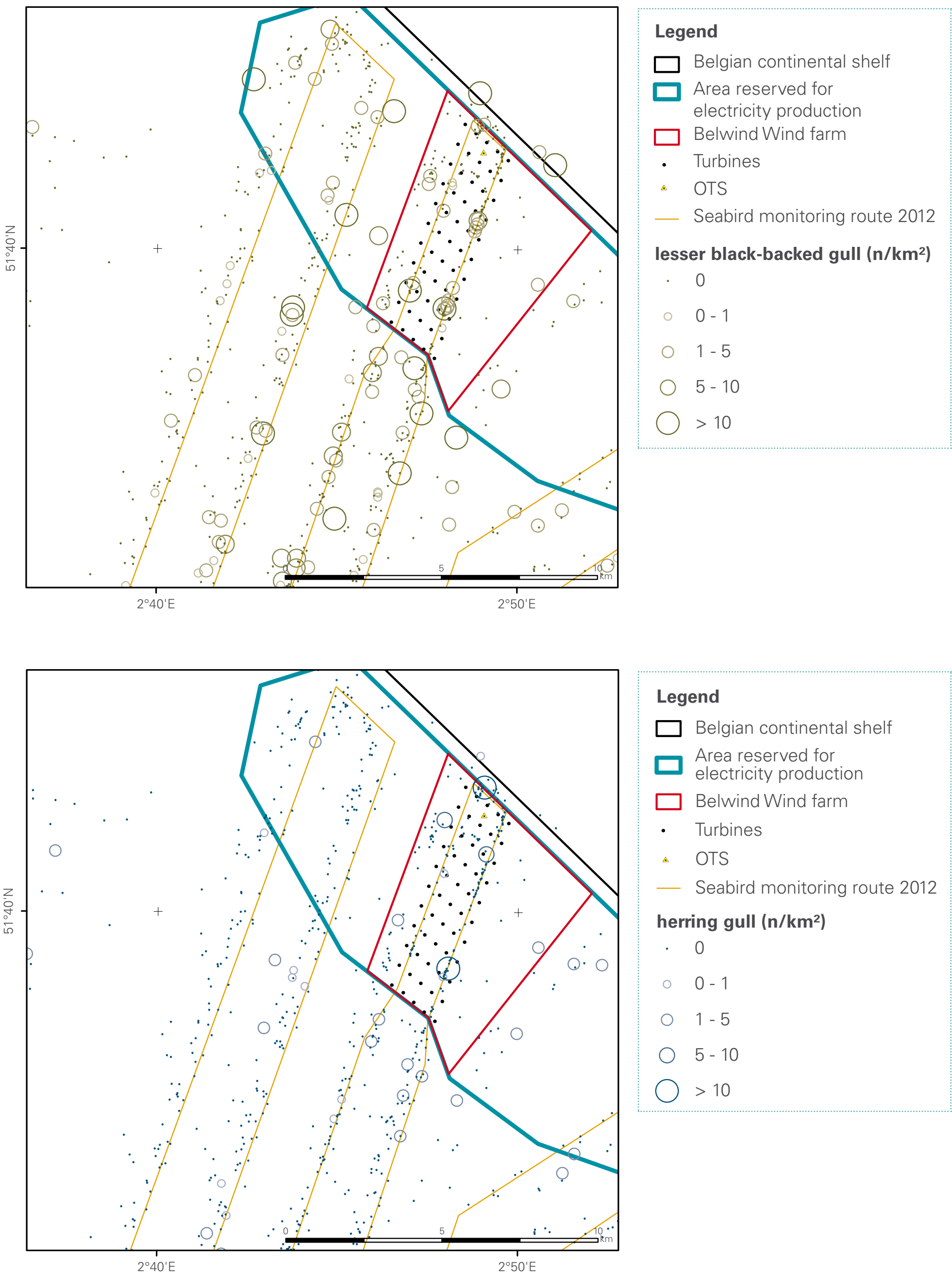
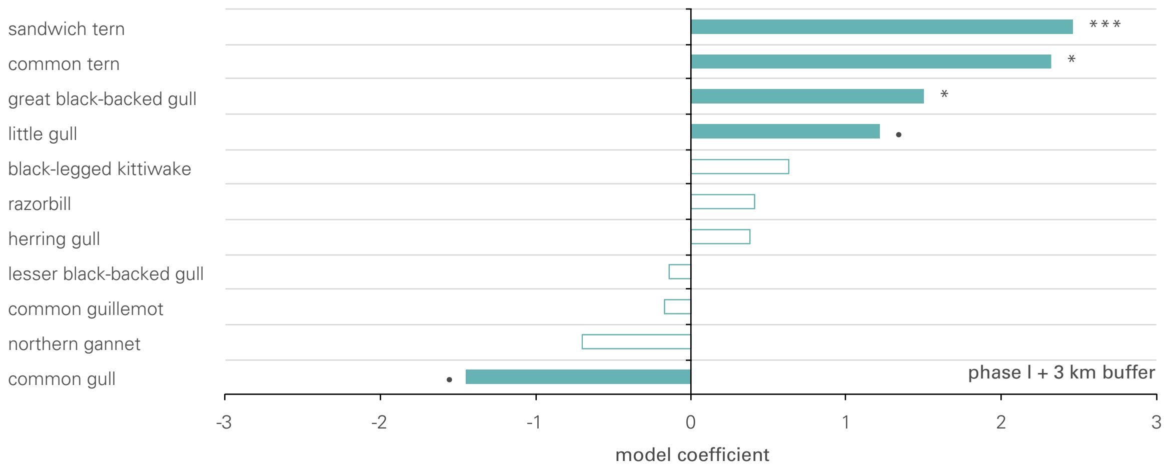


Figure 8. Observations of lesser black-backed and herring gull during the seabird monitoring program at the Bligh Bank after wind farm construction.

Thorntonbank

Four species occurred in significantly higher numbers after the construction of the first six turbines (phase I), i.e. little gull, great black-backed gull, sandwich tern *Sterna sandvicensis* and common tern (Figure 9). Common gull however avoided the area during the time of our research, opposite to what was found at the Bligh Bank. Data collected in 2012, i.e. during the construction period of phases II & III, showed significantly higher numbers of sandwich tern to occur in and around the wind farm under construction.

Figure 9. Seabird displacement effects at the Thorntonbank wind farm based on the results of 66 surveys before and 33 surveys after the turbines were built and indicated by the displacement-related model coefficient (blue bars indicate significance: . ~ p<0.1, * ~ p<0.05, ** ~ p<0.01, *** ~ p<0.001).



Razorbill

Seabird avoidance and attraction!

The wind farm monitoring programme revealed significant attraction of large gulls towards offshore wind farms at the BPNS. This was rather surprising since in contrast, no clear-cut attraction effects were found for large gulls during the Danish and Dutch monitoring programs (Petersen et al., 2006; Leopold et al., 2011). In general, at-sea gull distribution is strongly determined by the presence of fishing trawlers. The main anticipated effect of wind farms on gull distribution patterns was thus a decrease in densities resulting from the prohibition for trawlers to fish inside the farm boundaries. Yet, we found an increase in numbers, which can be caused by increased resting and feeding opportunities (see Chapter 15). For common gull and black-legged kittiwake results did not show unambiguous effects. Both species were however regularly observed between the turbines, suggesting indifference towards wind farm presence. On the other hand, three species displayed avoidance, being northern gannet, common guillemot and razorbill. Interestingly, strong avoidance by gannets and auks is reported by the Dutch researchers at the OWEZ wind farm (Leopold et al., 2011; Krijgsveld et al., 2011) and avoidance by auks was also found by Petersen et al. (2006) at the Horns Rev wind farm in Denmark.

Furthermore, we found significant attraction effects of three Annex I species (i.e. little gull, common tern and sandwich tern) to the operational phase I at the Thorntonbank. Importantly, high proportions of these species' biogeographical populations migrate through the Southern North Sea (Stienen et al., 2007).

Clearly it is impossible to count 'inside' a one-dimensional farm of six turbines, and the revealed attraction effects account for the wind farm *buffer* zone, rather than the wind farm area itself. This finding nevertheless agrees well with findings done by the Danish researchers Petersen et al. (2006), who observed a significant post-construction increase in numbers of little gull just outside the Horns Rev wind farm boundaries (up to 2 km), and a slight (non-significant) increase in numbers inside the wind farm. The same authors found a clear post-construction increase in numbers of common tern in the immediate vicinity of the farm (1 to 8 km), opposed to a total absence of the species inside the wind farm up to 1 km of its boundaries. Similarly, increased presence of sandwich terns foraging on the borders of the OWEZ wind farm was observed by our Dutch colleagues. Apart from this, Krijgsveld et al. (2011) report both tern species and little gull to regularly enter the wind farm, with little gull being observed in higher numbers inside compared to outside OWEZ. Unfortunately, densities of all three species were mostly too low to draw firm conclusions on displacement effects (Leopold et al., 2011).

Two common guillemots near the Bligh Bank wind farm

BIRD COLLISIONS

Visual census results

The species-specific flight height is of large influence on the expected collision risk, and forms a crucial input for the CRM. Table 1 shows our results of flight height estimations as performed during ship-based seabird surveys. While large gull species were seen flying at rotor height quite frequently (15-22%), common guillemots and razorbills were never observed flying above 30m.

Based on the densities of flying seabirds assessed during our ship-based surveys in the Bligh Bank wind farm and the corresponding CRM results, we expect one or more casualties per year for five seabird species (all gulls) at this specific location, up to more than one victim per turbine per year for lesser black-backed gull (see Table 2). For all other seabird species occurring in the study area, the density of individuals flying at rotor height was close to zero and the number of expected collision fatalities is regarded to be insignificantly low. In total, the number of gull victims is estimated at 134 per year (2.4 per turbine), which is almost half the number obtained by Poot et al. (2011), reporting an estimated 243 gull victims at the OWEZ wind farm (6.8 per turbine). This substantial difference in estimated collision rate can partly be explained by the far more offshore location of the Bligh Bank compared to the OWEZ wind farm, respectively 40 versus 10 km from the coast, which is inevitably reflected in lower gull densities.

Table 1. Species-specific percentages of birds flying at rotor height (30-150 m) as observed during seabird surveys at the BPNS.

	% at rotor height
northern gannet	5
little gull	2
common gull	15
lesser black-backed gull	22
herring gull	15
great black-backed gull	20
black-legged kittiwake	9
sandwich tern	2
common tern	1
common guillemot	0
razorbill	0

Table 2. Estimated collision victims based on observed densities of flying birds inside the Bligh Bank wind farm and an assumed micro-avoidance rate of 97.6%.

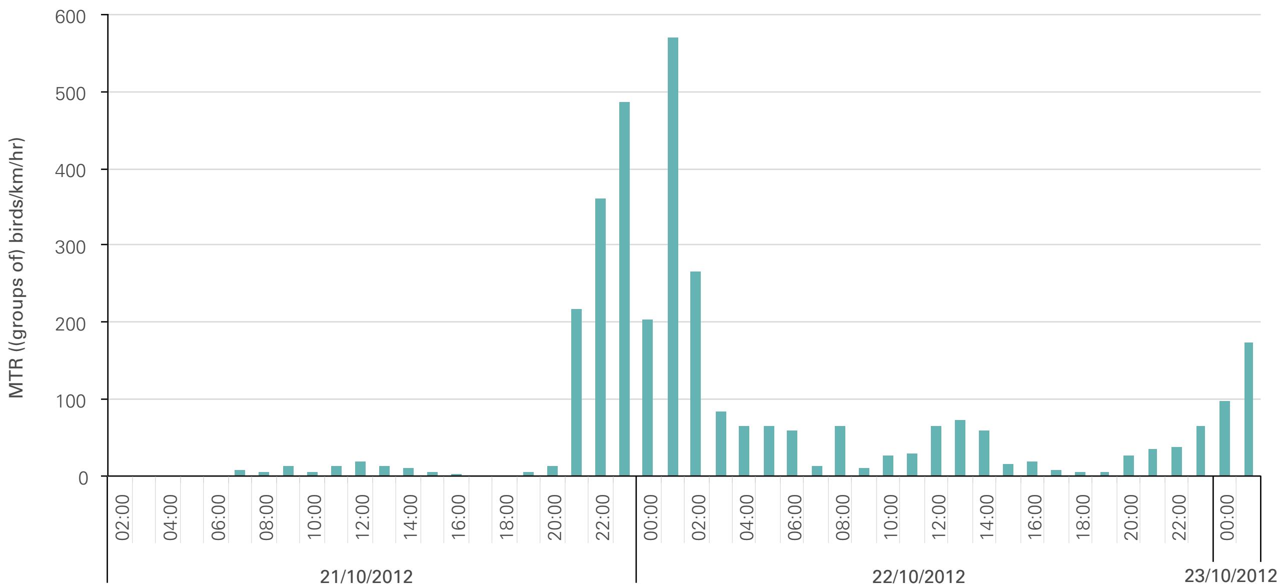
	common gull	lesser black-backed gull	herring gull	great black-backed gull	black-legged kittiwake
winter	3	0	3	3	19
spring	0	40	3	4	10
summer	0	22	0	0	0
autumn	0	3	0	21	3
number/year	3	65	6	28	32
number/(turbine*year)	0.05	1.18	0.11	0.51	0.58

Radar results

On October 21st, 1,176 (groups of) birds were recorded at rotor height in 17 hrs, with an average flux of 69.3 (groups of) birds/hr/km. The flux went up as high as 570 (groups of) birds/hr/km around midnight (Figure 10). On October 22nd, 1,864 (groups of) birds flew on rotor height in 24 hrs, with an average flux of 77.7 (groups of) birds/hr/km.

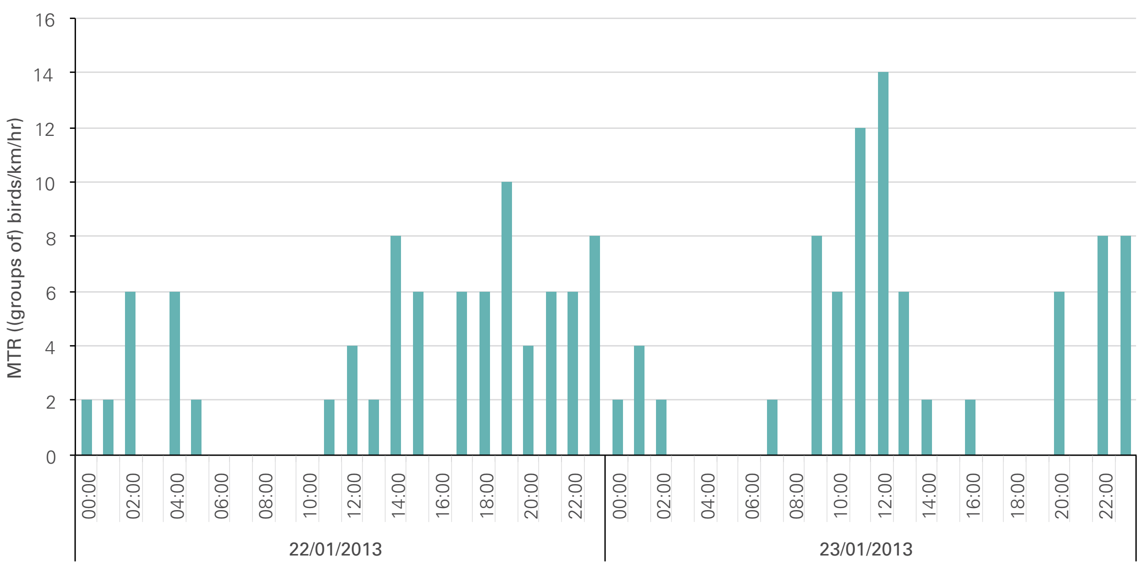
Isolating the radar results obtained during the night of October 21st and 22nd (sunset to sunrise), we observed an average flux at rotor height of no less than 204 (groups of) birds/km/hr. This massive night time bird movement can without doubt be assigned to thrush migration, the more considering the visual observation of large numbers of thrushes arriving at the port of Zeebrugge during the early morning of October 22nd. Wind conditions during that time were E-NE and thus favourable for southwest bound migration. Applying the CRM results in an estimated number of 21 collision victims during that specific night at the Thorntonbank (micro-avoidance rate set at 97.6%).

Figure 10. Bird flux (groups of birds/hr/km) at rotor height for October 21st and 22nd 2012.



Under normal circumstances however, less birds frequent the study area. For example, on January 22nd and 23rd, respectively 86 and 82 (groups of) birds/km were recorded at rotor height (Figure 11), resulting in an average flux of 3.5 (groups of) birds/km/hr. Applying the CRM results in an estimated 58 collision victims during the winter months December, January and February (micro-avoidance rate of 97.6%). Based on the known species-spectrum occurring at the Thorntonbank in winter, these collision victims are most likely to be common gulls, lesser black-backed gulls, herring gulls, great black-backed gulls and black-legged kittiwakes.

Figure 11. Bird flux (groups of birds/hr/km) at rotor height for January 22nd and 23rd 2013.



Extrapolating and nuancing bird collision estimates

Current plans are to construct seven wind farms at the BPNS, with a maximum number of turbines of 530. Extrapolating the earlier results leads to an estimated 209 thrushes to collide with offshore turbines at the BPNS during a single night with comparable migration (micro-avoidance rate 97.6%). Based on daytime observations, each year up to 1,291 birds are expected to collide with the turbines (micro-avoidance rate 97.6%), for the major part gulls. Such extrapolations should be handled with care as the results presented here are yet based on flux and density measurements collected during small time frames. While ship-based visual censuses were limited to a single daytime visit each month, it allows for a large spatial coverage. In contrast, radar observations are bound to one location but provide continuous measurements when fully operational. Applying both techniques is therefore invaluable for an integrated assessment of bird mortality at the Belgian concession zone for wind energy.

FUTURE MONITORING

With the wind farms at the BPNS being operational since the end of 2009 (Thorntonbank) and 2010 (Bligh Bank), the results presented here are still based on a relatively limited impact dataset. Power analyses showed that even for quite substantial changes in seabird densities (e.g. a decrease of 75%), up to ten years of monitoring may be needed to obtain sufficient statistical power (Vanermen et al., 2012). Indeed, at both wind farms we saw numbers of several seabird species to have changed, without the difference in density being statistically significant. With more years of monitoring ahead of us, our data will allow to better distinguish between true displacement and indifference. Long-term monitoring at the various wind farm sites is also needed to anticipate the possible habituation of seabirds to the presence of wind turbines (temporal variation) or the fact that displacement effects might differ between wind farm sites (spatial variation). The results from the Dutch and Danish research programs further show that the occurrence of increased numbers just outside an offshore wind farm (as was found near the single row of turbines at the Thorntonbank) cannot be extrapolated to the wind farm area itself. Continuing the monitoring of seabird presence in the now fully operational (and two-dimensional) Thorntonbank wind farm is therefore highly important. Clearly, if the attraction effects as found in this study persist during the coming years, the associated increased collision risk is of serious conservational concern considering the involved species' high protection status.

The main technical challenges currently being tackled in close collaboration with the radar developers are (1) the negative correlation between seabird detectability and distance and (2) the substantial shadow effects created by individual wind turbines. Once these issues are solved, the radar research will further focus on the barrier and collision effects, using a similar approach as was demonstrated above and taking account of radar data filtering. Also, Chamberlain et al. (2006) showed how small differences in estimated avoidance rates result in proportionally large changes in estimated mortality. To improve the outcome of the CRM, radar observations should be combined as much as possible with simultaneous visual observations at the spot, to assess species-specific flight heights and avoidance rates, taking account of differing bird behaviour under a range of conditions. The CRM however remains a theoretical model, and to know actual collision rates, devices that measure collisions of birds with turbines are still needed. Finally, the construction of a new wind farm in the area south of the radar location in the near future will provide an ideal opportunity for the comparison of pre- and post-impact patterns, which was not possible for earlier projects.

Northern gannet