Seabird monitoring at the Thorntonbank offshore wind farm

Updated seabird displacement results & an explorative assessment of large gull behavior inside the wind farm area

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Summary

Since 2005, the Research Institute for Nature and Forest (INBO) performs monthly BACI-designed surveys to study seabird displacement following the construction of offshore wind farms (OWFs) in the Belgian part of the North Sea. Here we report our findings for the C-Power wind farm at the Thorntonbank after four years of post-construction monitoring. Following the concern on potentially high levels of collision mortality among large gull species, we also report the first results of our behavioral study, making use of our transect count data, GPS tracking data and observations with a fixed camera installed on turbine I5 in Thorntonbank OWF.

As expected, considering the rather small amount of data added during the monitoring year 2016, our displacement study results are highly similar to those reported in the previous monitoring report (Vanermen *et al*. 2016). The impact area appeared to be avoided by four species, being northern gannet, little gull, black-legged kittiwake and common guillemot, these having dropped in numbers by no less than 97%, 89%, 75% and 69% respectively. The Thorntonbank OWF attracted great black-backed gulls, numbers of which increased by a factor 6.6 compared to the control area and the period before impact. Sandwich tern too was attracted to the OWF at the Thorntonbank, the effect being significant for the buffer zone only, where we observed a factor 5.7 increase in numbers. Only for herring gull there was a shift in the estimated wind farm effect since the latest report. While the OWF coefficient for herring gull was estimated to be close to zero after three years of monitoring, it now showed a (borderline) significant increase in numbers (factor 2.9). The buffer zone, however, saw a significant decrease in numbers of herring gull.

Though it is still too soon to draw any definite conclusions out of our behavioral monitoring, there were already some indicative results. Great black-backed gulls for example clearly favor outer turbines for roosting, suggesting a partial barrier effect. Based on our tracking data, lesser black-backed gulls seemed to spend half of their time inside the OWF area roosting on the jacket foundations, and spent less time flying inside compared to outside the wind farm. While mostly observed roosting, with the fixed camera we assessed that 9% of the large gulls observed on the jacket foundations were actually foraging. Sustaining the current effort throughout 2017 will allow us to analyse tidal and diurnal patterns in the presence and behavior of large gulls inside the Thorntonbank OWF. Importantly, the results of this behavioral study might shed new light on the currently expected collision risk of large gulls at OWFs, and may highlight the need for proper post-construction monitoring. Because next to a possible post-construction change in numbers, any behavioral shift (i.e. a decrease in time flying) will have a strong effect on the anticipated collision mortality among large gulls.

Samenvatting

Het zeevogelteam van het Instituut voor Natuur- en Bosonderzoek (INBO) voert sinds 2005 onderzoek uit naar de effecten van offshore windmolenparken op de aantallen aanwezige zeevogels. Er werden hiervoor maandelijks zeevogeltellingen uitgevoerd in speciaal daartoe afgebakende controle- en impactgebieden. Ruim 4 jaar na de bouw van het C-Power windpark op de Thorntonbank geeft dit rapport een update van de eerder gepubliceerde resultaten voor deze locatie. Naar aanleiding van de bezorgdheid rond de mogelijk hoge aantallen aanvaringsslachtoffers onder grote meeuwen zijn we dit jaar gestart met een gedragsstudie. Voor deze gedragsstudie baseren we ons op drie databronnen, met name de reguliere zeevogeltellingen, GPS-data van gezenderde kleine mantelmeeuwen en gerichte observaties met een vaste camera op turbine I5 van het Thorntonbank windpark.

Zoals enigszins verwacht, gezien het gering aantal zeevogeltellingen in 2016, zijn de resultaten grotendeels analoog aan deze gerapporteerd in Vanermen *et al.* (2016). Jan-van-gent, dwergmeeuw, drieteenmeeuw en zeekoet vertoonden alle een significante afname in aantallen met respectievelijk 97%, 89%, 75% en 69%. Anderzijds namen de aantallen grote mantelmeeuwen en grote sterns sterk toe met een factor van respectievelijk 6.6 en 5.7. Voor grote stern was deze toename enkel significant voor het drie kilometer brede buffergebied rondom het windpark. De enige soort waarvoor we een verschuiving zagen in het ingeschatte windparkeffect was zilvermeeuw. Terwijl de impactmodellen vorig jaar nog geen windparkeffect aan het licht brachten, bleek er nu toch een (licht) significante toename te zijn in de aantallen zilvermeeuw. Dit geldt althans voor de windparkzone zelf, want in de bufferzone bleken de aantallen te zijn afgenomen.

Hoewel het nog te vroeg is om gegronde conclusies te trekken uit onze gedragsstudie waren er toch reeds enkele opvallende resultaten. Zo blijken rustende grote mantelmeeuwen een duidelijke voorkeur te hebben voor turbines langs de rand van het park, en lijkt er dus ondanks de gerapporteerde aantrekking tot de Belgische offshore windparken ook sprake van enige barrièrewerking. Op basis van zendergegevens blijken kleine mantelmeeuwen de helft van hun tijd binnen het park te rusten op de turbinefunderingen, en bleken ze bovendien meer te rusten binnen dan buiten het park. Tellingen via de vaste camera toonden dan weer aan dat 9% van alle grote meeuwen waargenomen op de turbinefunderingen actief foerageerden op de intertidale zone. De huidige inspanningen zullen worden aangehouden doorheen 2017, wat ons in staat zal stellen om na te gaan of er sprake is van dag- en getijritmiek in de aanwezigheid en het gedrag van grote meeuwen in het Thorntonbank windpark. De hieruit voortvloeiende resultaten kunnen belangrijk zijn in het correct berekenen en modelleren van de verwachte aanvaringsrisico's onder grote meeuwen. Behalve natuurlijk een wijziging in de aanwezige aantallen kunnen namelijk ook gedragsveranderingen, zoals bijvoorbeeld een afname in vliegtijd, van groot belang zijn voor de verwachte aanvaringsmortaliteit.

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1 Introduction

In order to meet the targets set by the European Directive 2009/28/EG on renewable energy, the European Union is aiming at a total offshore wind farm (OWF) capacity of 43 GW by the year 2020. Meanwhile, the offshore wind industry is growing steadily and at the end of 2016, 3,589 offshore wind turbines were fully grid-connected in European waters, totalling 12.6 GW (EWEA 2017). Currently, three OWFs are operational in the Belgian part of the North Sea (BPNS). In 2008, C-Power installed the first six wind turbines (30 MW) at the Thorntonbank, located 27 km offshore, followed by the construction of 48 more turbines in 2012 and 2013 (295 MW). In 2009-2010, Belwind constructed 55 turbines (165 MW) at the Bligh Bank, 46 km offshore. Located in between these two wind farms, Northwind NV built 72 turbines at the Lodewijckbank, 37 km offshore, in the course of 2013.

Since 2005, the Research Institute for Nature and Forest (INBO) performs seabird counts specifically aimed at studying seabird displacement caused by OWFs. In this report we present the results of our seabird displacement study at the Thorntonbank OWF after 4 years of operation ('*baseline monitoring*').

Earlier results from the Bligh Bank OWF showed attraction of large gull species and therefore increased levels of collision risk, which could lead to population level effects in a (realistic) scenario of 10,000 wind turbines across the North Sea (Brabant, Vanermen *et al*. 2015). The behavior and presence of large gulls inside OWF areas should therefore be subject of a '*targeted monitoring*' scheme. The design of such a monitoring scheme, however, is hampered by ongoing budgetary and logistic constraints. Nonetheless, the GPS tracking of large gulls breeding along the Belgian and Dutch coast does open possibilities to study their behavior inside OWFs more closely. A fixed camera located at one of the jacket foundations on the edge of the Thorntonbank OWF further allows for behavioral observations of gulls on and around the turbines. Here we report the results of a first and explorative analysis of presently available behavioral data, mainly focusing on the gulls' association with the turbine foundations.

2 Methods

2.1 Thorntonbank offshore wind farm

The Thorntonbank wind farm is located 27 km off the coast of Zeebrugge, and consists of 2 subareas of 24 and 30 wind turbines, measuring 10.7 and 9.2 km² respectively (see Figure 2). The water depth of the turbine-built area ranges between 12 and 28 m (C-Power 2016). Distances between the turbines range from 500 up to 800 m.

The wind farm was built in three phases:

- Phase 1: 6 x 5 MW turbines (gravity-based foundations), operational since May 2009
- Phase 2: 30 x 6.15 MW turbines (jacket foundations), operational since October 2012
- Phase 3: 18 x 6.15 MW turbines (jacket foundations), operational since September 2013

2.2 Displacement study

2.2.1 Seabird counting

Ship-based seabird counts were conducted according to a standardized and internationally applied method, combining a '**transect count**' for birds on the water and repeated '**snapshot counts**' for flying birds (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 count'). Importantly, the distance of each observed bird (group) to the ship is estimated, allowing to correct for decreasing detectability with increasing distance afterwards ('distance analysis'). The transect is therefore divided in four distance categories (A = 0-50 m, B = 50-100 m, C = 100-200 m & D = 200-300 m). Counting all flying birds crossing this transect, however, would cause an overestimation and would be a measure of bird flux rather than bird density (Tasker *et al.* 1984). Flying birds are therefore counted through one minute interval counts of a quadrant of 300 by 300 m inside the transect ('snapshot counts'). As the ship covers a distance of approximately 300 m per minute when sailing the prescribed speed of 10 knots, the full transect length is covered by means of these subsequent 'snapshots'.

Afterwards, observation time was linked to the corresponding GPS coordinates registered by the ship's board computer. Taking in account the transect width and distance travelled, the combined result of a transect and snapshot count can be transformed to a number of birds observed per km², i.e. a seabird density at a specific location. Up to 2012, observations were aggregated in ten-minute bouts, which were cut off to the nearest minute at waypoints. Since 2013, resolution was increased and seabird observations are pooled in two-minute bouts, again cut off to the nearest minute at waypoints.

In practice, we count all birds observed, but those not satisfying above conditions (i.e. not recorded inside the transect nor during snapshots) are given another code and are not included in the density analyses afterwards. We also record as much information as possible regarding the birds' age, plumage, behavior, flight direction and association with objects, vessels or other birds.

2.2.2 Distance analysis

We corrected the numbers of seabirds observed on the water for **decreasing detection** probability with **distance** to the ship (Buckland *et al*. 2001, Thomas *et al*. 2010). Detection probability is further likely to depend on group size and observation conditions (Marques & Buckland 2003). Observation conditions were included in the detection models as 'wind force' (Beaufort scale) or 'wave height' (categorized as 0-0.5 m / 0.5-1.0 m / 1.0-2.0 m / 2.0-3.0 m, …), both variables being estimated at the time of observation.

We fitted half-normal and hazard-rate detection functions to our data. Adding cosine or polynomial adjustments in the presence of group size as a covariate often resulted in non-monotonic detection functions (implying that detection probability would increase with increasing distance which is assumed not very plausible) and these adjustments were therefore no longer considered. As such, we fitted following 'full models' with a non-adjusted half-normal and hazard-rate detection function:

- group size + wind force
- group size + wave height
- log(group size) + wind force
- log(group size) + wave height

The best fitting full model was chosen based on the 'Akaike Information Criterion' (AIC), and backward model selection was applied to refine the detection function. In the end, this distance analysis resulted in species-specific detection probabilities varying with the selected covariates, and observed numbers were corrected accordingly.

2.2.3 Monitoring set-up

Monitoring was performed according to a **Before-After Control-Impact** (**BACI**) set-up. The OWF footprint area was surrounded by a buffer zone of 3 km to define the 'impact area', being the zone where effects of the wind farm on the presence of seabirds could be expected. Next, a comparably large control area was delineated, harbouring comparable numbers of seabirds before OWF construction, and showing a similar range in water depth and distance to the coast (Vanermen *et al*. 2005). Meanwhile, the distance between the control and impact area was kept small enough to be able to survey both on the same day by means of a research vessel (RV).

Following fixed monitoring tracks, the Thorntonbank study area was counted on a highly regular basis from 2005 until present (Figures 1 & 2). During this dedicated monitoring program the study area should have been visited monthly, but research vessels were not always available and planned trips were sometimes cancelled due to adverse weather conditions (significant wave heights higher than 2 m and/or poor visibility). Before this dedicated monitoring program, the study area was counted on a much more irregular basis, but we did include surveys dating back to 1993 provided that the control and impact area were visited on the same day.

For our displacement analysis, only data falling within the "reference period" and "impact period (phase I, II & III)" were used (Table 1). Note that phase III was not yet operational before September 2013, while the impact period defined in Table 1 starts in October 2012 (when phase II became operational). This is justified by the fact that access for monitoring was not allowed where active construction activities of phase III were going on, so data collected during that period account for the operational part of the OWF only.

Compared to the previous monitoring report (Vanermen *et al*. 2016), data from eight monitoring days could be added to the dataset. During only four of these, however, we visited the OWF footprint area itself. The four other trips were sailed for reference monitoring of the future Norther OWF, during which monitoring inside the study area was confined to the two most south eastern tracks as shown in Figure 2, only partly crossing the Thorntonbank OWF buffer zone.

Table 1. Definition of the reference, construction and impact periods at the Thorntonbank study area as applied in the impact analyses.

OWF	Phase	Period
Thorntonbank	Reference period	< 04/2008
	1st construction period	04/2008 –> 05/2009 (highly restricted access)
	Impact period (phase I)	06/2009 –> 04/2011 (6 turbines)
	2nd construction period	05/2011 –> 09/2012 (variable access)
	Impact period (phase I, II & III)	10/2012 -> present (54 turbines)

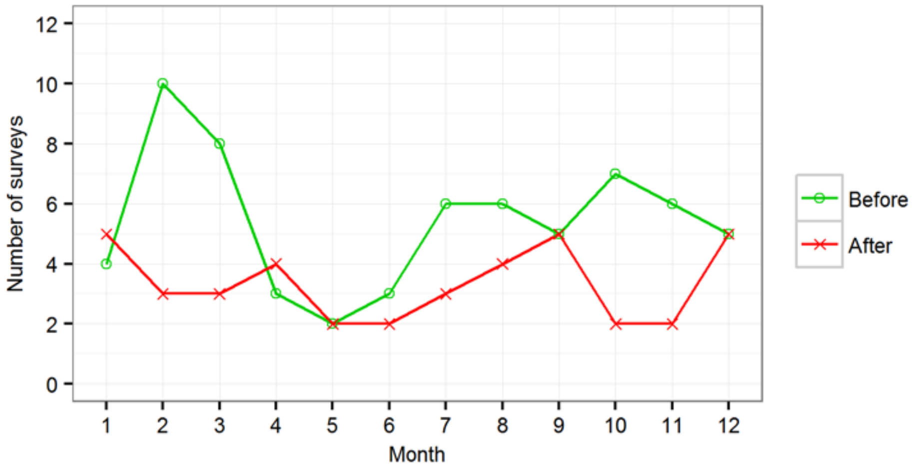

Figure 1. Count effort in the Thorntonbank study area indicated by the number of surveys performed before the construction of the phase I turbines (<04/2008) and after the construction of the phase II turbines (>09/2012).

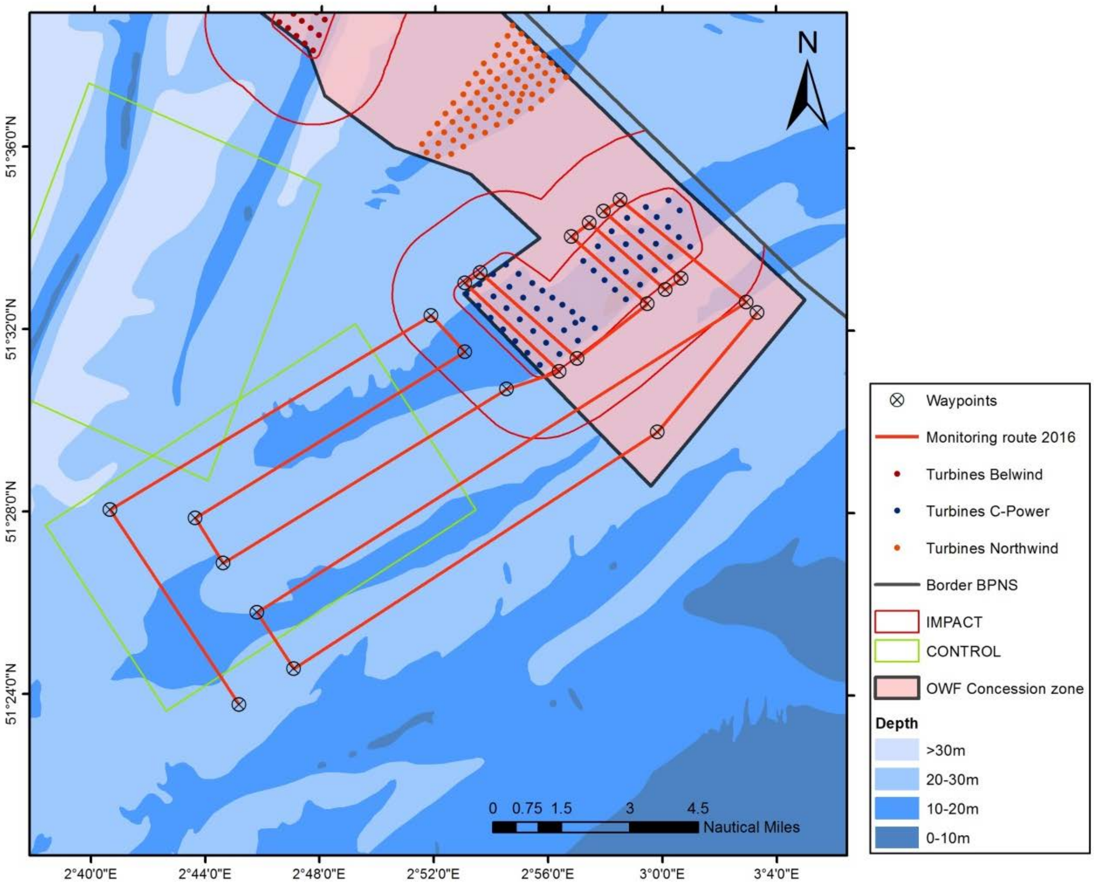

Figure 2. Monitoring route through the Thorntonbank OWF study area in 2016.

2.2.4 BACI analysis

2.2.4.1 Introduction

For the BACI modelling, we **aggregated** our **count data per area** (control / impact) and **per monitoring day**, resulting in day totals for both zones. As such, we avoided spatio-temporal correlation between counts. We further selected only those days on which both the control and impact area were visited, minimizing day-to-day variation in seabird abundance.

Modelling was performed for twelve seabird species occurring regularly in the OWF area, i.e. northern fulmar (*Fulmarus glacialis*), northern gannet (*Morus bassanus*), great skua (*Stercorarius skua*), little gull (*Hydrocoloeus minutus*), common gull (*Larus canus*), lesser black-backed gull (*Larus fuscus*), herring gull (*Larus argentatus*), great black-backed gull (*Larus marinus*), black-legged kittiwake (*Rissa tridactyla*), Sandwich tern (*Thalasseus sandvicensis*), common guillemot (*Uria aalge*) and razorbill (*Alca torda*). For each of these species, we modelled three different impact datasets (OWF footprint + 0.5 km, OWF footprint + 3 km, buffer 0.5 - 3 km, see Figure 3).

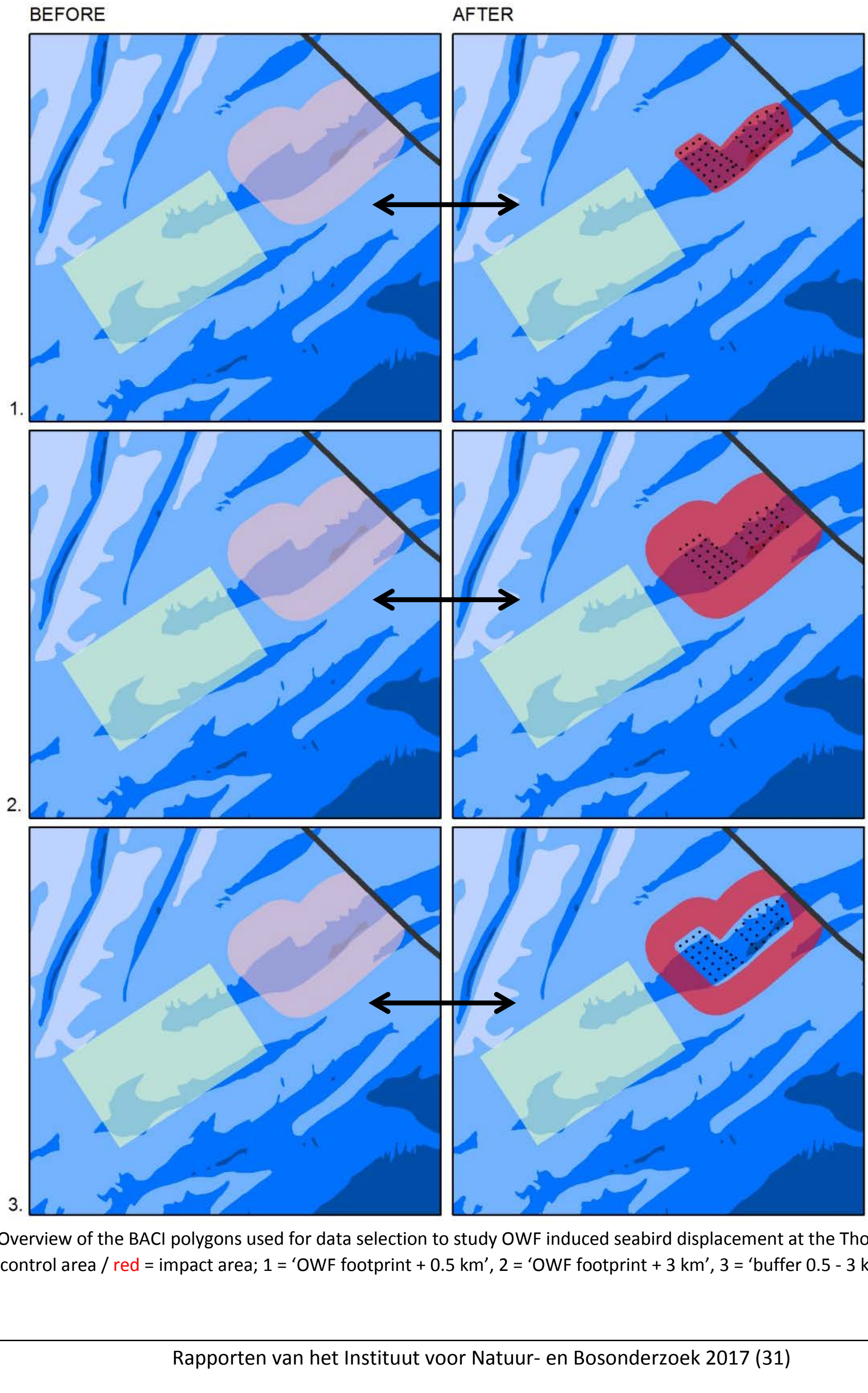

Figure 3. Overview of the BACI polygons used for data selection to study OWF induced seabird displacement at the Thorntonbank (green = control area / red = impact area; 1 = 'OWF footprint + 0.5 km', 2 = 'OWF footprint + 3 km', 3 = 'buffer 0.5 - 3 km')

2.2.4.2 Response variable

The **response variable** (Y) of our displacement models equaled the number of birds observed inside the transect and during snapshot counts, aggregated per area and per monitoring day. For the large gull species herring, lesser black-backed and great black-backed gull we also modelled an '**adjusted response variable**'. Because (i) the corridors between the C-Power turbines used during seabird monitoring (Figure 2) vary in width between 650 and 850 m, and (ii) the research vessels aimed to sail right in the middle of these corridors for security reasons, birds associated with the turbines were always right outside our 300 m wide transect. Our adjusted response variable is therefore calculated by adding (i) the number of birds that would have been counted inside the transect if the turbine-associated birds would have occurred homogenously spread across the area to (ii) the number of birds counted inside the transect and during snapshot counts (i.e. the original response variable). This is best illustrated with an example: at 28/08/2015 we counted no less than 161 great black-backed gulls resting on the jacket foundations, as opposed to only 1 bird observed inside our transect (the original response) despite a survey effort of 7.4 km² inside the impact area. As we checked 43 turbines out of a total of 54 turbines, we estimate the number of great black-backed gulls associated with turbines in the Thorntonbank OWF as a whole at 202 birds. The wind farm area surrounded by a 500 m wide buffer zone measures 36 km², and the density of turbine-associated great black-backed gulls in this area is thus 5.6 birds/km². If these birds would have occurred homogenously spread across the area, and knowing we counted 7.4 km², the number of birds inside the transect would be about 42 (≈ (5.6*7.4) + 1), which is our adjusted response. The original and adjusted response variable were always analysed both, and the difference is clearly indicated in the graphs and tables.

2.2.4.3 Explanatory variables

To correct for varying monitoring effort, the number of km² counted was included in the model as an offset-variable. The explanatory variables used were (i) a **time factor BA** (Before / After construction), (ii) an **area factor CI** (Control / Impact area), (iii) an **offshore wind farm factor OWF** (wind farm present / absent) and (iv) a **fishery factor F** (fishing vessels present / absent in the area). For the latter we only considered fishing vessels observed within a distance of 3 km from the monitoring track, and was considered only for species known to aggregate around fishing vessels (and therefore not used for little gull, Sandwich tern, common guillemot and razorbill). Finally, the continuous variable **month (m)** was used to model seasonal fluctuations by fitting a cyclic smoother or alternatively a cyclic sine curve, the latter described through a linear sum of sine and cosine terms (Stewart-Oaten & Bence 2001, Onkelinx *et al*. 2008). Seasonal patterns can often be modelled applying a single sine curve with a period of 12 months, but sometimes even better by adding another sine curve with a period of 6 or 4 months, thus allowing to model more than one peak in density per year and/or an asymmetric seasonal pattern. Eventually, we considered five different 'full' models:

1. no seasonal variation: $Y \sim BA + CI + OWF + F$
2. 12 month period sine curve: $Y \sim BA + CI + OWF + F + \sin(2\pi*m/12) + \cos(2\pi*m/12)$
3. 12 + 6 month period sine curve: $Y \sim BA + CI + OWF + F + \sin(2\pi*m/12) + \cos(2\pi*m/12) + \sin(2\pi*m/6) + \cos(2\pi*m/6)$
4. 12 + 4 month period sine curve: $Y \sim BA + CI + OWF + F + \sin(2\pi*m/12) + \cos(2\pi*m/12) + \sin(2\pi*m/4) + \cos(2\pi*m/4)$
5. cyclic smoother: $Y \sim BA + CI + OWF + F + s(m)$

2.2.4.4 Model selection

For the distribution and model selection we first considered the 'OWF footprint + 3 km' dataset (Figure 3). When a counted subject is randomly dispersed, count results tend to be **Poisson**-distributed, in which the mean equals the variance (McCullagh & Nelder 1989). Seabirds on the other hand mostly occur strongly aggregated in (multi-species) flocks, resulting in 'over-dispersed' count data which can often be analyzed with a **negative binomial (NB)** distribution (Ver Hoef & Boveng 2007, Zuur *et al*. 2009). On the other hand, when the data exhibit (much) more zeros than can be predicted through a Poisson or NB distribution, it may be necessary to apply a **zero-inflated (ZI)** distribution (Potts & Elith 2006, Zeileis *et al.* 2008), which consists of two parts: (i) a 'count component' modelling the data according to a Poisson or NB distribution and (ii) a 'zero component' modelling the excess in zero counts.

As such, the five different full models were fitted applying these four different distributions (Poisson, NB, ZI Poisson, ZI NB). Based on the resulting AIC values, the best fitting distribution was selected. Next, all possible models nested within the five full models were fitted applying the selected distribution. Again based on the resulting AIC matrix, the most likely covariate combination was chosen. When the best-fitting model did not contain the OWF factor, it was added to the model afterwards in order to estimate its effect. Next, the selected model was also applied to the 'OWF footprint + 0.5 km' and 'buffer 0.5 - 3 km' datasets.

In the results section we often refer to (i) the OWF coefficient, being the model coefficient of the OWF factor variable and an estimator of the displacement effect, and (ii) the estimated density, being the model prediction for a specific month and factor combination, with the offset variable set to 1 km². Note that the OWF coefficient is always reported in its untransformed form, and that it is actually a **factorial term**. A coefficient of 0 for example is transformed by taking the exponential function *e* to the power 0, which equals 1, meaning no effect. On the other hand, a coefficient of 1 is transformed by doing *e* to the power 1, equalling 2.718, implying that numbers inside the OWF area are almost three times higher compared to the control area.

2.3 Behavioral study of large gulls inside the offshore wind farm

2.3.1 Observations of turbine-associated birds during transect counts

During the seabird monitoring tracks through the OWF at the Thorntonbank (Figure 2) we carefully checked each adjacent turbine foundation on the presence of birds. Ever since September 2014 we also registered the turbine number of all counted turbines, resulting in turbine-specific information on the presence of birds on 13 monitoring days, totaling 487 records. When the full monitoring route was sailed, 43 turbines could be counted reliably. Due the circumstantial situations – mostly adverse weather conditions – the monitoring route as displayed in Figure 2 sometimes needed to be cut off, explaining the lower number of counted turbines on 6 out of 13 occasions (Table 2).

After selecting the best-fitting distribution based on an information theoretic criterion (AIC), we applied a mixed modelling strategy (including random effects *date* & *turbine*) to test the effect of *distance to edge* (fixed effect) on the numbers of birds associated with the turbines (response variable).

Table 2. Count effort regarding turbine-specific information on the presence of birds.

Date	Number of turbines
09/09/2014	43
29/10/2014	36
18/11/2014	43
16/12/2014	16
27/01/2015	34
22/04/2015	43
25/09/2015	39
21/01/2016	43
16/02/2016	43
17/03/2016	43
30/09/2016	39
14/12/2016	43
24/03/2017	22
Total	487

2.3.2 Tracking data of lesser black-backed gull

Between 2013 and 2016, 112 lesser black-backed gulls breeding at Zeebrugge (Belgium) and Vlissingen (the Netherlands) have been equipped with a UvA-BiTS tracker (Bouten *et al*. 2013). Some of these birds visited the Thorntonbank OWF, allowing a characterization of their behavior in and around this specific OWF. In a first and explorative analysis we focused on their association with the turbine foundations, the proportion between flying versus resting in and around the OWF and diurnal patterns in their presence and behavior. As the resolution of the recorded tracks varied strongly from 10 to 3600 seconds, we selected one data point per hour in all calculations except when assessing the actual time spent in a certain area. This way we avoided a higher weight of birds tracked at higher resolutions and also avoided temporal correlation between records (Ross-Smith *et al*. 2016).

2.3.3 Fixed camera

A fixed camera (AXIS Q6044-S) located at one of the jacket foundations in the Thorntonbank OWF (turbine I5) allowed to count and observe gulls associated with the turbine foundations within the viewing and/or zooming range of the camera. The view is limited to one side of the jacket foundation of turbine I5, but in good weather conditions it was also possible to assess the presence of gulls on turbines I4 & J2. As such, we have performed 349 counts since January 2017, allowing to look for tidal and diurnal patterns in the gulls' presence and behavior. Current efforts will be sustained at least throughout 2017, and the first data analysis results will be reported in the 2018 monitoring report. Below, however, we do already report on the numbers and species observed up until now, and we further show some tentative graphs of tidal and diurnal patterns.

2.4 Statistics

All data handling and modelling was performed in R.3.3.3 (R Core Team 2017), making use of the following packages:

- RODBC (Ripley & Lapsley 2016)
- foreign (R Core Team 2016),
- date (Therneau *et al*. 2017),
- ggplot2 (Wickham 2009),
- compare (Murrell 2015),
- reshape (Wickham 2007),
- plyr (Wickham 2011),
- MASS (Venables & Ripley 2002),
- mgcv (Wood 2011),
- pscl (Jackman 2015),
- glmmADMB (Skaug *et al.* 2016),
- distance (Miller 2016),
- mrds (Laake *et al.* 2016),
- rgdal (Bivand *et al*. 2016),
- data.table (Dowle & Srinivasan 2017),
- rgeos (Bivand & Rundel 2017),
- sp (Pebesma & Bivand 2005) &
- spatialEco (Evans 2016)

3 Results

3.1 General observations

Since the Thorntonbank OWF became operational, most of the birds observed inside the OWF footprint area were gulls (92% of all non-passerine birds – see Table 3). Most of these belong to one of the three 'large gull' species, i.e. herring, lesser black-backed and great black-backed gull. With over 1.000 individuals observed, great black-backed gull was by far the most numerous species of all. Great black-backed gull also showed a much higher preference to the turbine foundations compared to the other two large gull species (79% versus 21% and 36% for lesser black-backed and herring gull, respectively). Cormorants too showed a clear preference to the turbines, as 89% of the great cormorants and 79% of the European shags were observed roosting on the jacket foundations.

Despite the reported avoidance of OWFs by gannets and auks, these birds did regularly enter the OWF footprint area. As such, we observed 42 northern gannets, 69 common guillemots and 32 razorbills.

Table 3. Number of birds and sea mammals observed inside the Thorntonbank (626 km of surveying).

		Total	Number present on turbines	Percentage present on turbines
BIRDS				
Northern fulmar	*Fulmarus glacialis*	1	0	
Northern gannet	*Morus bassanus*	42	0	
Great cormorant	*Phalacrocorax carbo*	53	47	89%
European shag	*Phalacrocorax aristotelis*	14	11	79%
Unidentified cormorant	*Phalacrocorax sp.*	3	1	33%
Eurasian sparrowhawk	*Accipiter nisus*	1	0	
Bar-tailed godwit	*Limosa lapponica*	1	0	
Arctic skua	*Stercorarius parasiticus*	1	0	
Little gull	*Hydrocoloeus minutus*	10	0	
Black-headed gull	*Chroicocephalus ridibundus*	16	0	
Common gull	*Larus canus*	122	3	2%
Lesser black-backed gull	*Larus fuscus*	622	131	21%
Herring gull	*Larus argentatus*	109	39	36%
Great black-backed gull	*Larus marinus*	1033	817	79%
Unidentified large gull		551	418	76%
Black-legged kittiwake	*Rissa tridactyla*	255	1	0%
Sandwich tern	*Sterna sandvicensis*	17	0	
Common tern	*Sterna hirundo*	1	0	
Common guillemot	*Uria aalge*	69	0	
Unidentified auk	*Alca torda* or *Uria aalge*	14	0	
Razorbill	*Alca torda*	32	0	
Domestic pigeon	*Columba livia 'domestica'*	1	0	
Common starling	*Sturnus vulgaris*	122	3	2%
other passerines		31	4	13%
SEA MAMMALS				
Harbour porpoise	*Phocoena phocoena*	4	0	
Grey seal	*Halichoerus grypus*	1	0	

3.2 Distance analysis

For all species except for great skua, hazard-rate detection models fitted our data better than half-normal detection functions (Table 4). In general, either wave height or wind force proved to affect the detectability of seabirds significantly, except for great skua and both terns. The natural logarithm of group size was retained for all species except for northern gannet and great skua, while for common guillemot group size was preferred over the logarithm of group size.

Cluster detection probabilities were highest (>80%) for conspicuous species like great skua and northern gannet, and lowest (<60%) for northern fulmar, common gull, black-legged kittiwake and common guillemot.

Table 4. Results of the multi-covariate distance analysis.

Species	Detection function	Covariates	Detection probability
Northern fulmar	Hazard-rate	log(group size) + wave height	0.57
Northern gannet	Hazard-rate	wave height	0.80
Great skua	Half-normal	/	0.83
Little gull	Hazard-rate	log(group size) + wind force	0.65
Common gull	Hazard-rate	log(group size) + wind force	0.52
Lesser black-backed gull	Hazard-rate	log(group size) + wind force	0.68
Herring gull	Hazard-rate	log(group size) + wind force	0.66
Great black-backed gull	Hazard-rate	log(group size) + wind force	0.73
Black-legged kittiwake	Hazard-rate	log(group size) + wave height	0.57
Sandwich tern	Hazard-rate	log(group size)	0.73
Common tern	Hazard-rate	log(group size)	0.60
Common guillemot	Hazard-rate	group size + wind force	0.57
Razorbill	Hazard-rate	log(group size) + wind force	0.64

3.3 BACI modelling results

3.3.1 Northern fulmar

During the operational phase of the Thorntonbank OWF, numbers of northern fulmar were low both in the control area and impact area, in line with an overall decrease in densities as observed in the BPNS. Within the 'OWF footprint + 0.5 km' area no birds were observed at all, explaining the empty space in Figure 4 and the extreme values in Table 5 (a strongly negative OWF coefficient of -23.08 opposed to a high p-value of 0.999). In both the 'OWF footprint + 3 km' and 'buffer 0.5 - 3 km' areas, the OWF coefficients were strongly negative (-2.13 and -1.52), yet neither one was proved significantly different from zero. In conclusion, despite indications of avoidance, no significant effect of the Thorntonbank OWF on the numbers of northern fulmar could be found.

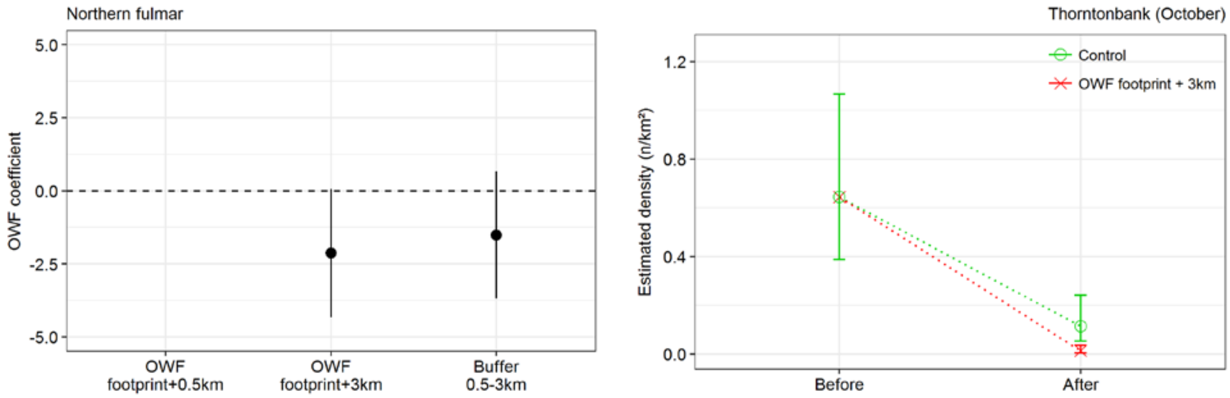

Figure 4. Modelling results for northern fulmar in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.2 Northern gannet

Northern gannets showed clear avoidance of the OWF at the Thorntonbank, and compared to the control area and the period before impact, numbers dropped by 97% in the 'OWF footprint + 0.5 km' area, by 70% in the 'OWF footprint + 3 km' area and by 53% in the 'buffer 0.5 - 3 km' area. All three OWF coefficients proved statistically significant (P<0.05, see Table 5). These results confirm earlier results from the Thorntonbank and the strong decrease in densities of 82% found at the Bligh Bank OWF (Vanermen *et al*. 2016).

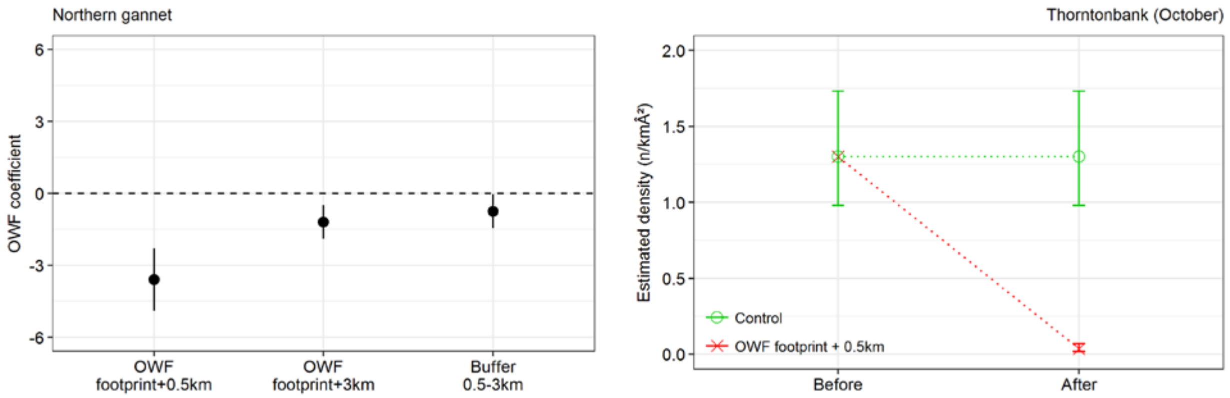

Figure 5. Modelling results for northern gannet in the Thorntonbank study area with OWF coefficients and their 95% CI's on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.3 Great skua

As for northern fulmar, no great skuas were observed inside the 'OWF footprint + 0.5 km' area after impact, hampering meaningful statistics and explaining the empty space in the left panel of Figure 6. For the 'OWF footprint + 3 km area', the OWF coefficient was close to zero (illustrated by the highly parallel BACI graph in the right panel of Figure 6), while it was slightly positive (0.62) yet not significantly different from zero for the 'buffer 0.5 - 3 km' area (P=0.525). In conclusion, there was no apparent effect of the Thorntonbank OWF on great skua numbers.

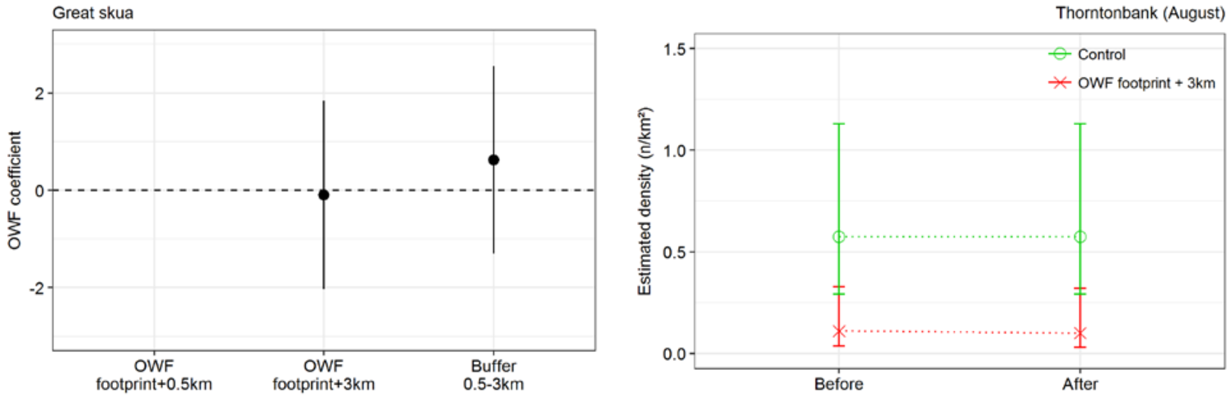

Figure 6. Modelling results for great skua in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right (but note a zero-inflation of 72%).

3.3.4 Little gull

As already reported in Vanermen *et al*. (2016), little gull showed a distinct pattern of avoidance of the OWF footprint area as opposed to increased numbers in the surrounding buffer zone. Compared to the control area and the period before impact, little gulls significantly decreased in numbers by 89% in the 'OWF footprint + 0.5 km' area (OWF coefficient=-2.22, P=0.006), and showed a (non-significant) increase in numbers in the 'buffer 0.5 - 3 km' area (OWF coefficient=1.02, P=0.088).

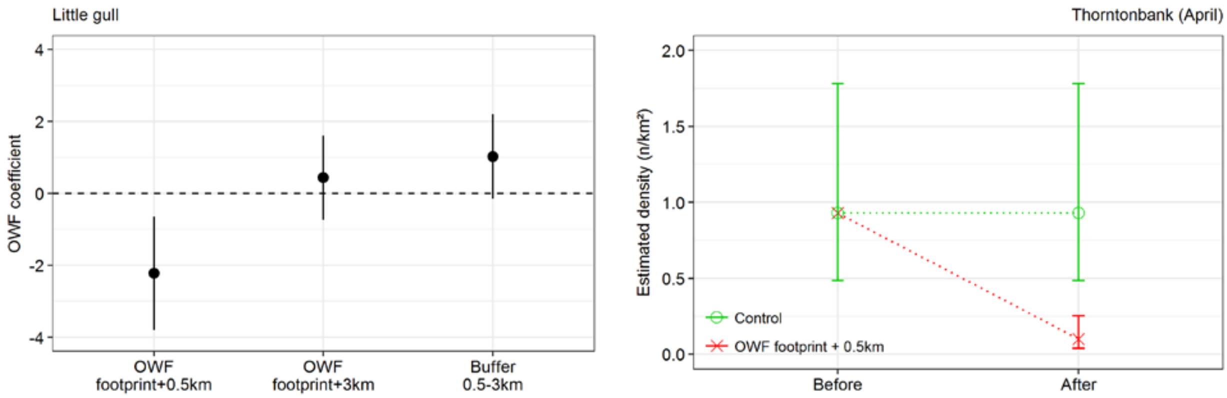

Figure 7. Modelling results for little gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.5 Common gull

Between the reference and impact period, numbers of common gull strongly increased in the study area as a whole. This increase, however, is less prominent in the wind farm area and its immediate surroundings resulting in quite strongly negative OWF coefficients (ranging between -0.81 and -1.30) for all three data selections. As none of these significantly differed from zero we conclude that there was no apparent effect of the Thorntonbank OWF on the presence of common gull.

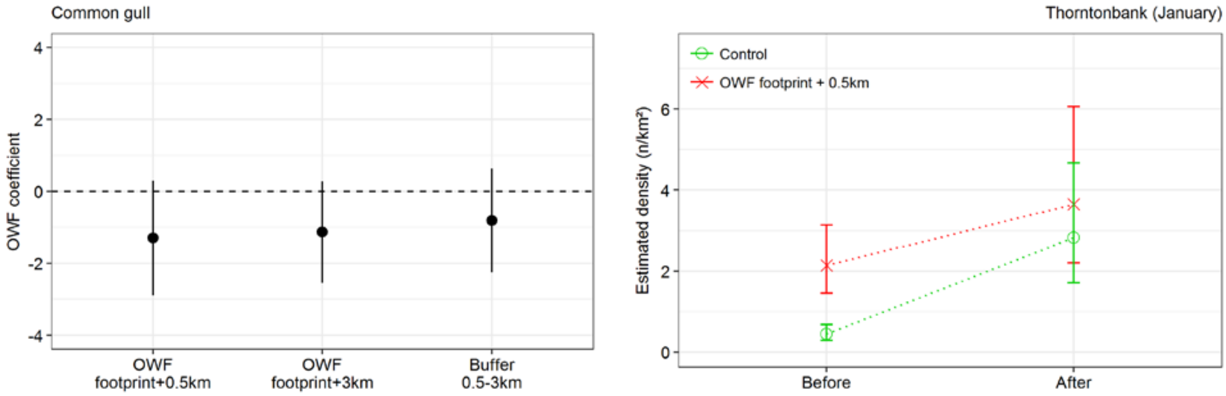

Figure 8. Modelling results for common gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.6 Lesser black-backed gull

The OWF coefficients found for lesser black-backed gull were all close to zero, also when taking in account birds roosting on the turbine foundations (i.e. model results based on the adjusted response variable). As opposed to the strong attraction effect reported at the Bligh Bank OWF (Vanermen *et al*. 2015, Vanermen *et al*. 2016), there were no signs of attraction of lesser black-backed gulls to the Thorntonbank OWF area.

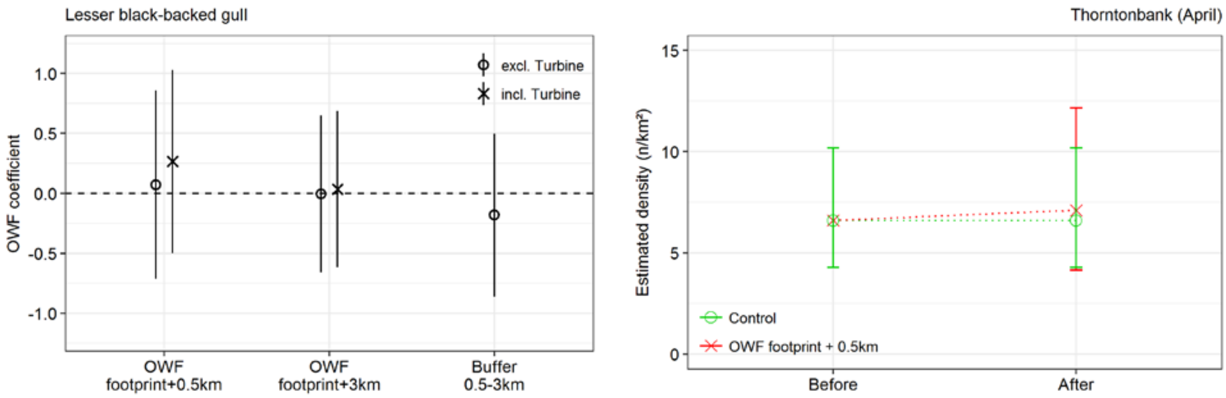

Figure 9. Modelling results for lesser black-backed gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers (exclusive turbine-associated birds) on the right.

3.3.7 Herring gull

The updated results for herring gull differ from the results in the previous monitoring report (Vanermen *et al*. 2016). While earlier no post-construction change in numbers was observed in the OWF, we now found 2.9 times higher numbers in the 'OWF footprint + 0.5km' area compared to the control area and the period before impact. This estimated increase applies to data including birds roosting on the turbines and the corresponding coefficient was found borderline significant (OWF coefficient=1.06, P=0.050). The model results for the data in- and excluding turbine-associated birds, however, were highly comparable. In contrast, but meanwhile similar to the result reported by Vanermen *et al*. (2016), we observed significantly lower numbers in the buffer zone (OWF coefficient = -1.88, P=0.008).

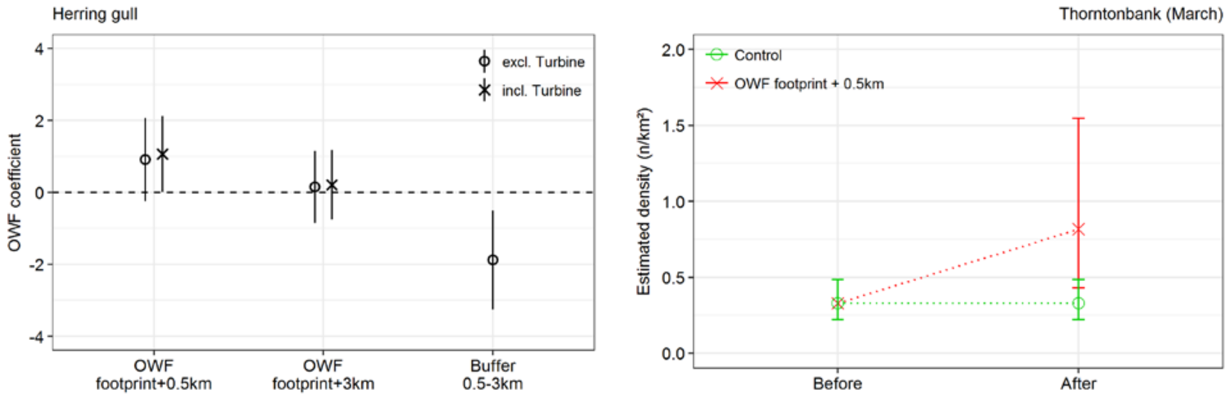

Figure 10. Modelling results for herring gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers (exclusive turbine-associated birds) on the right.

3.3.8 Great black-backed gull

We found significant attraction of great black-backed gull towards the Thorntonbank OWF, provided we include birds roosting on the turbines. This was not unexpected considering the high numbers observed in the area and the high percentage associated with the turbines (Table 3). For the 'OWF footprint + 0.5 km' area the OWF coefficient equaled 1.88, implying a significant increase in numbers with a factor 6.6 compared to the control area and the period before impact (P<0.001). In the 'buffer 0.5 - 3 km' area, the OWF coefficient approached zero while the result for the 'OWF footprint + 3 km' area was intermediate between the footprint and buffer area results.

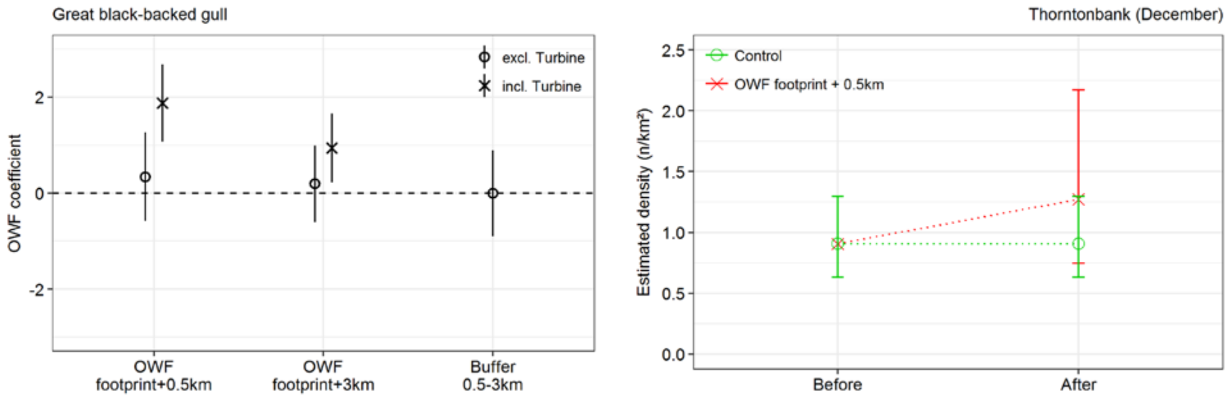

Figure 11. Modelling results for great black-backed gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers (exclusive turbine-associated birds) on the right.

3.3.9 Black-legged kittiwake

Post-construction numbers of black-legged kittiwake in the impact area appeared to be significantly lower compared to the period before impact, as opposed to a stable trend in the control area. In the 'OWF footprint + 0.5 km' area numbers significantly decreased by no less than 75% (OWF coefficient=-1.39, P=0.009), and decreased by 51% in the 'buffer 0.5 - 3 km' area, the latter coefficient no longer being significantly different from zero (OWF coefficient=-0.72, P=0.123).

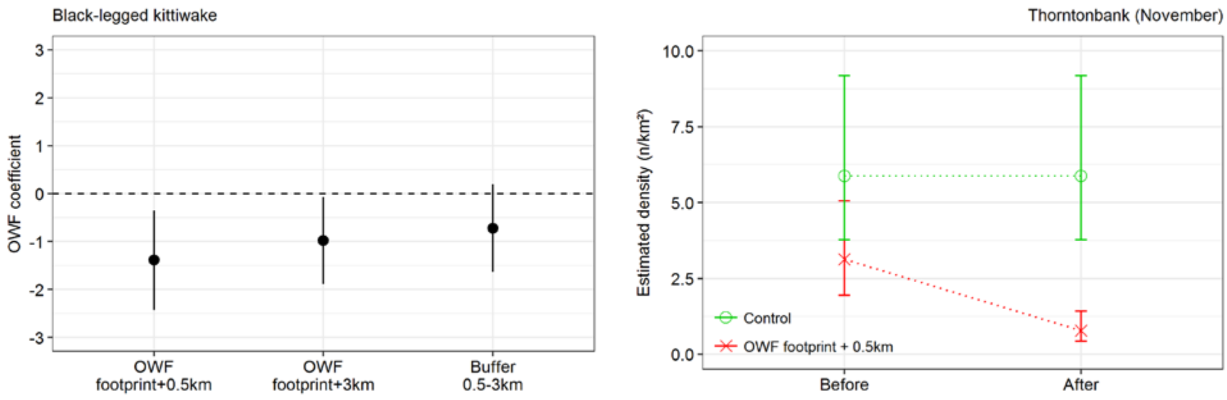

Figure 12. Modelling results for black-legged kittiwake in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.10 Sandwich tern

Generally we used year-round data for modelling, but due to fitting problems, we only used Sandwich tern data collected from March till September, while no longer considering seasonal variation. In doing so, Sandwich terns showed a less marked decrease in numbers in the impact area compared to the control area, resulting in positive OWF coefficients for all three data selections. For the buffer zone only, the effect was significant (OWF coefficient=1.74, P=0.018). Despite this statistical significance, results should be interpreted with care considering the low number of positive observations after impact. On the other hand, this result is in line with the attraction of Sandwich terns to the 3 km buffer zone around the phase I Thorntonbank OWF (Vanermen *et al*. 2013), when only six turbines were present (OWF coefficient=2.46, P=0.001).

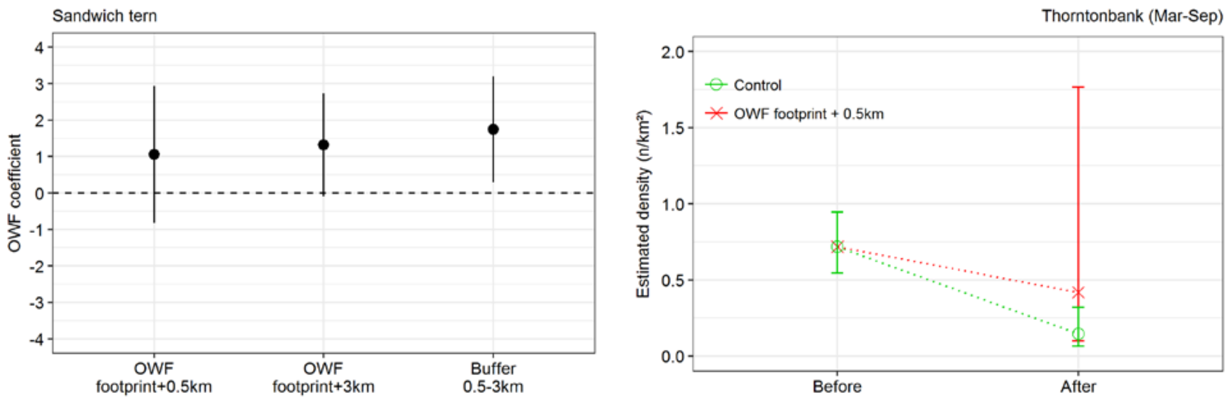

Figure 13. Modelling results for Sandwich tern in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the period March to September on the right (but note that zero-inflation equals 75%).

3.3.11 Common guillemot

With a negative OWF coefficient of -1.16 (P=0.001), common guillemots significantly avoided the 'OWF footprint + 0.5 km' area. In the buffer zone too numbers decreased, but the latter change was no longer significant (OWF coefficient=-0.33, P=0.252). Back-transforming the coefficient of -1.16, the corresponding decrease of 69% as found for the Thorntonbank is highly comparable to the 75% decrease reported for the Bligh Bank (Vanermen *et al*. 2016).

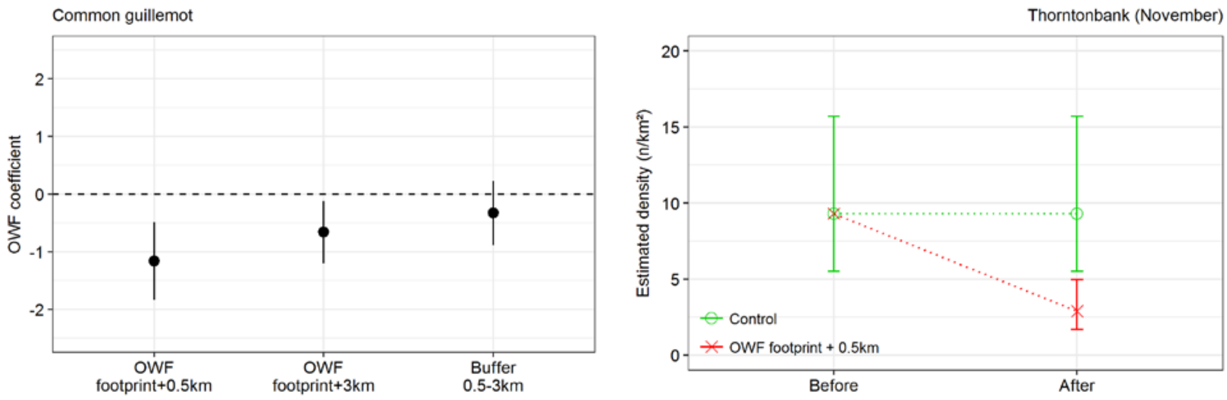

Figure 14. Modelling results for common guillemot in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right (but note that zero-inflation equals 10%).

3.3.12 Razorbill

The models for razorbill estimated a negative OWF coefficient for the 'OWF footprint + 0.5 km' area, a positive coefficient for the buffer area and an intermediate result of almost zero when both areas are analyzed together ('OWF footprint + 3km'). None of these coefficient values, however, significantly differed from zero (P>0.05), and therefore no apparent effect of the Thorntonbank OWF on the numbers of razorbill was observed.

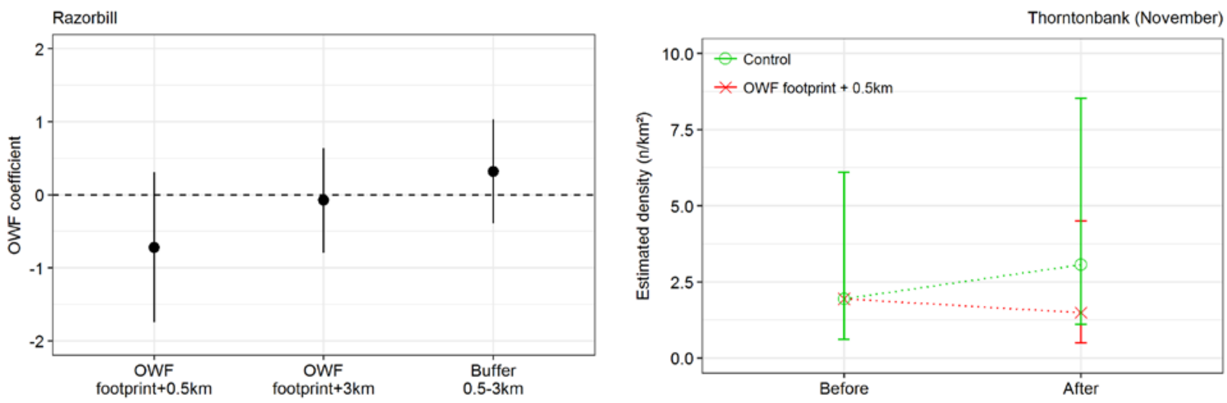

Figure 15. Modelling results for razorbill in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right (but note that zero-inflation equals 18%).

3.3.13 Summarizing tables

Our BACI monitoring results are summarized in Table 5, which lists all OWF coefficients and corresponding P values as estimated through the modelling process. All impact model coefficients are displayed in Table 7 in the Appendix.

After four years of post-impact monitoring at the Thorntonbank OWF, the impact area appeared to be avoided by four species, i.e. northern gannet, little gull, black-legged kittiwake and common guillemot. In the 'OWF footprint + 0.5 km' area, these species dropped in numbers by no less than 97%, 89%, 75% and 69% respectively. The Thorntonbank OWF further attracted great black-backed gulls, this species having increased in numbers by a factor 6.6. Sandwich tern too appeared to be attracted to the OWF at the Thorntonbank, the effect being significant for the buffer zone only. All of these results are highly similar to the results reported last year. Only for herring gull we observed a shift in the estimated wind farm effect. While the OWF coefficient for herring gull was estimated to be close to zero after three years of monitoring, it now showed a borderline significant increase in numbers by a factor 2.9. In contrast, a significant decrease in numbers of herring gull was observed in the buffer zone.

Table 5. BACI monitoring results for the C-Power wind farm at the Thorntonbank after 4 years of operation, with indication of the displacement-related OWF model coefficients and their respective P values; model results of the adjusted response variable are indicated by "(T)" in the species column (P<0.10., P<0.05*, P<0.01**, P<0.001***; red cells indicate significant avoidance, green cells indicate significant attraction).

	OWF footprint + 0.5 km		OWF footprint + 3 km		Buffer 0.5-3 km	
	OWF Coefficient	P-Value	OWF Coefficient	P-Value	OWF Coefficient	P-Value
Northern fulmar	-23.08	0.999	-2.13	0.057.	-1.52	0.171
Northern gannet	-3.60	0.000***	-1.19	0.001***	-0.75	0.036*
Great skua	-18.56	0.998	-0.10	0.922	0.62	0.525
Little gull	-2.22	0.006**	0.43	0.468	1.02	0.088.
Common gull	-1.30	0.110	-1.13	0.117	-0.81	0.271
Lesser black-backed gull	0.07	0.857	0.00	0.989	-0.18	0.600
Lesser black-backed gull (T)	0.27	0.495	0.03	0.917		
Herring gull	0.91	0.125	0.15	0.767	-1.88	0.008**
Herring gull (T)	1.06	0.050.	0.21	0.670		
Great black-backed gull	0.34	0.473	0.19	0.636	0.00	0.992
Great black-backed gull (T)	1.88	0.000***	0.94	0.011*		
Black-legged kittiwake	-1.39	0.009**	-0.98	0.035*	-0.72	0.123
Sandwich tern	1.06	0.269	1.32	0.066.	1.74	0.018*
Common guillemot	-1.16	0.001***	-0.66	0.017*	-0.33	0.252
Razorbill	-0.72	0.169	-0.08	0.836	0.32	0.376

3.4 Association with turbines

3.4.1 Transect counts

We used data of 13 monitoring days during which we crossed the Thorntonbank OWF and checked the adjacent turbine foundations (n=487) on the presence of birds. This resulted in a total number of 3 European shags, 33 great cormorants, 9 lesser black-backed gulls, 29 herring gulls, 510 great black-backed gulls and 30 unidentified large gulls. Figure 16 shows the distribution of the mean numbers per turbine of great cormorant and great black-backed gull, illustrating both species' preference to the outer turbines.

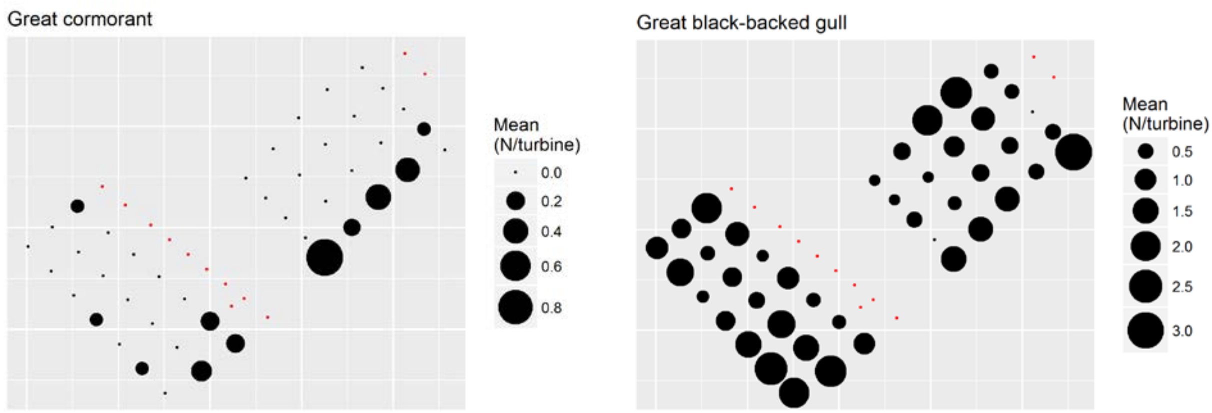

Figure 16. Mean number of great cormorant and great black-backed gull present per turbine during 13 seabird monitoring days through the Thorntonbank OWF (turbines coloured red were not counted).

We tested the hypothesis that the number of great cormorants and great black-backed gulls associated with the turbines decreases towards the center of the OWF through a mixed model with *distance to edge* as a fixed effect, and *date* and *turbine* as random effects. For great cormorant a negative binomial distribution model was selected, and *distance to edge* did negatively affect the number of birds present on the turbine foundations (P=0.012). For great black-backed gull too we selected a negative binomial distribution and again *distance to edge* proved significant (P<0.001). Model predictions are illustrated in Figure 17.

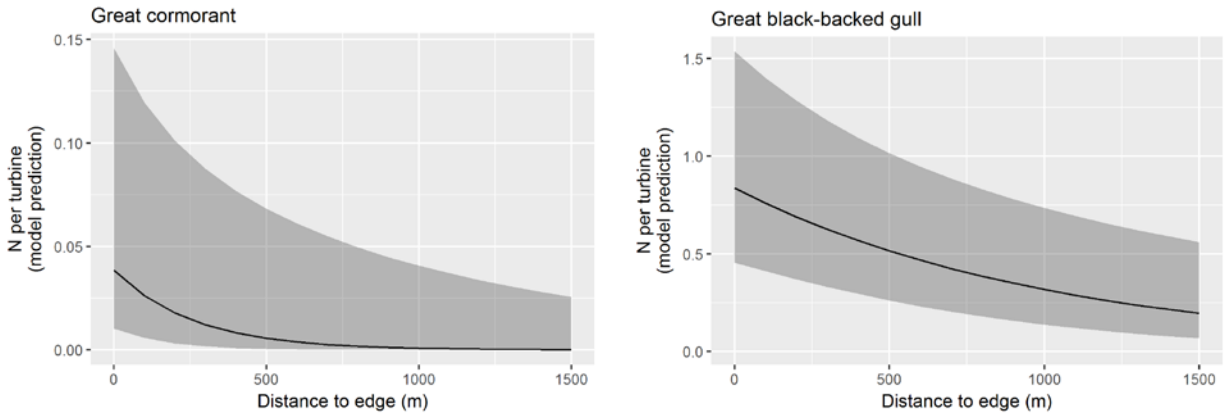

Figure 17. Model predictions of the numbers of great cormorant and great black-backed gull present on the turbine foundations in relation to *distance to edge* at the Thorntonbank OWF.

3.4.2 Tracking data

In order to assess potential attraction of lesser black-backed gulls towards the jacket foundations in the Thorntonbank OWF, track log positions were overlaid with 100 m buffer areas around the turbines. Out of a total of 41 individual birds logged inside the Thorntonbank OWF boundaries, 20 individuals were recorded at least once inside these 100 m buffer areas. Exploring the characteristics of the selected logs, most (96%) referred to *non-flying* birds (i.e. logs with a speed below 4 m/s) located at a mean height of 17 m above sea level, and were therefore considered to be resting on the jacket foundations. The fact that tracked lesser black-backed gulls were often resting on the turbine foundations is also nicely illustrated when comparing the histograms of the logged altitudes of *non-flying* birds in the Thorntonbank control versus footprint area (see Figure 18). While the histogram centres around zero for *non-flying* birds logged in the control area (i.e. swimming birds), there are two peaks of logged altitudes in the 'OWF footprint + 0.5 km' area: one around zero, and one at about 20 m above sea level.

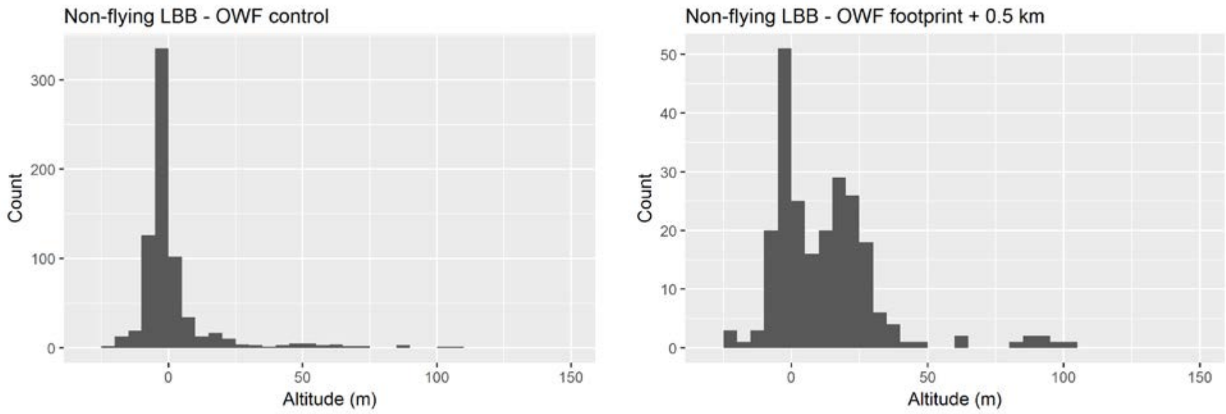

Figure 18. Distribution of logged altitudes of tracked lesser black-backed gulls in the Thorntonbank control versus footprint area (see also Figure 3).

Next, we calculated the total time spent in (i) the OWF as a whole and (ii) the turbine buffer areas by summing the time intervals between the first and last log of each visit to the respective areas. This implies that single 'isolated' logs were not taken into calculation, but also that we assume that birds stay within the area boundaries between two subsequent logs inside these boundaries. As such, lesser black-backed gulls appeared to spend 51% of their time inside the Thorntonbank OWF resting on the jacket foundations. When using the selection of one log per hour (see methods section) and calculating the proportion of the number of logs within the turbine buffer areas versus the total number of logs inside the OWF, we obtained a very similar result of 49%. Considering the huge difference in surface between the OWF footprint area and the turbine buffer areas, we can safely conclude that the tracked lesser black-backed gulls showed a high preference towards the turbine foundations.

Figure 19 illustrates the total time spent per turbine. As in the previous paragraph, we tested the hypothesis that birds prefer the outer turbines. Based on a negative binomial model, however, *distance to edge* did not significantly affect the time spent on the turbines (P=0.249).

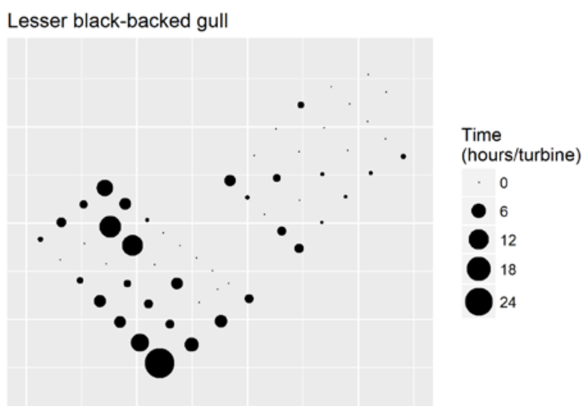

Figure 19. Time spent per turbine by lesser black-backed gulls tracked inside the Thorntonbank OWF.

3.5 Activity patterns in- versus outside the Thorntonbank OWF (tracking data)

In total, 41 tracked individuals were logged inside the Thorntonbank OWF boundaries, with the number of logs varying from only 1 for gulls *Annelies* & *Imme* to 440 for gull *Romelo*. Apart from the actual time spent inside the OWF, the number of logs strongly depended on the logging resolution, the latter varying from 10 to 3600 seconds. As already mentioned in the methods section we therefore selected one log per hour for all calculations in the paragraph below.

Birds were classified as *flying* when having a calculated speed of over 4 m/s. Resulting, 44% of the logs in the BPNS were identified as *flying*, opposed to a much lower 19% in the Thorntonbank study area. Within the study area itself there was less difference in the proportion of birds flying, with 20% and 15% flying in the control and impact area respectively (Figure 20). Hence, despite the rather small difference, lesser black-backed gulls appeared to spend more time resting (*non-flying*) inside compared to outside the Thorntonbank OWF.

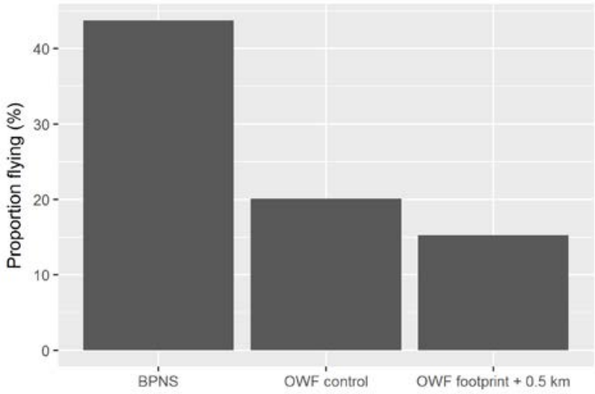

Figure 20. The proportion of GPS-logged birds flying in the BPNS as a whole on the one hand, and in the Thorntonbank OWF control and impact area on the other hand (see also Figure 3).

Regarding the diurnal rhythm in flying activity, the study area (including both the wind farm and control area) was also found to be markedly different from the BPNS as a whole.

At the BPNS, the presence of the tracked birds was lowest during night hours (from 9 pm to 2 am), while peaking in the early morning (4 am) and the evening (7 pm). More than 70% of the birds staying out at sea between 9 pm and 2 am were classified as *non-flying*. This percentage was about 50% during the rest of the day with a slight secondary peak in the *non-flying* proportion around noon (11am) (Figure 21). Strikingly, this pattern of increased presence and activity in the morning and afternoon was highly consistent throughout the year (not illustrated).

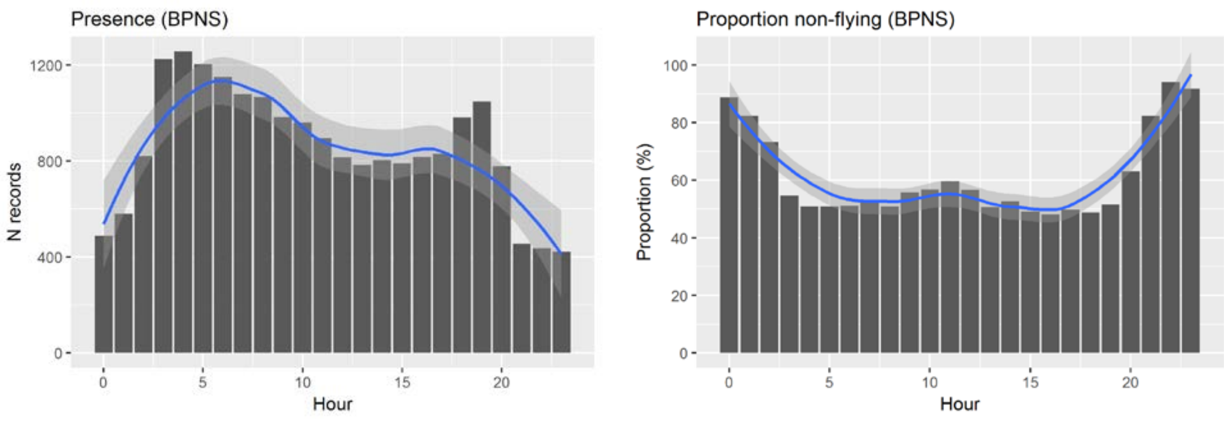

Figure 21. Diurnal pattern of the presence and *non-flying* behavior of tracked lesser black-backed gulls in the BPNS.

In contrast, presence in the study area was highest before midday from 6 am to 12 am, showing only one peak instead of two, while the proportion of *non-flying* birds kept a much higher level during the full diurnal cycle (mostly above 70%). As in Figure 21, the *non-flying* proportion did show (much less obvious) peaks during the night and around midday. Patterns in the control and impact area appeared very much alike (Figures 22-23).

While the Thorntonbank study area is on the boundary of the species' offshore distribution, it appears that the diurnal pattern and high level of flying activity at the BPNS as a whole is partly determined by commuting flights between land and offshore foraging areas. The early morning peak in flying activity at the BPNS (Figure 21, right panel) for example is followed by increased presence before noon in the Thorntonbank study area. The evening peak in flying activity on the other hand is not followed by increased presence in the study area, suggesting that the evening activity of lesser black-backed gulls reaches less far out at sea.

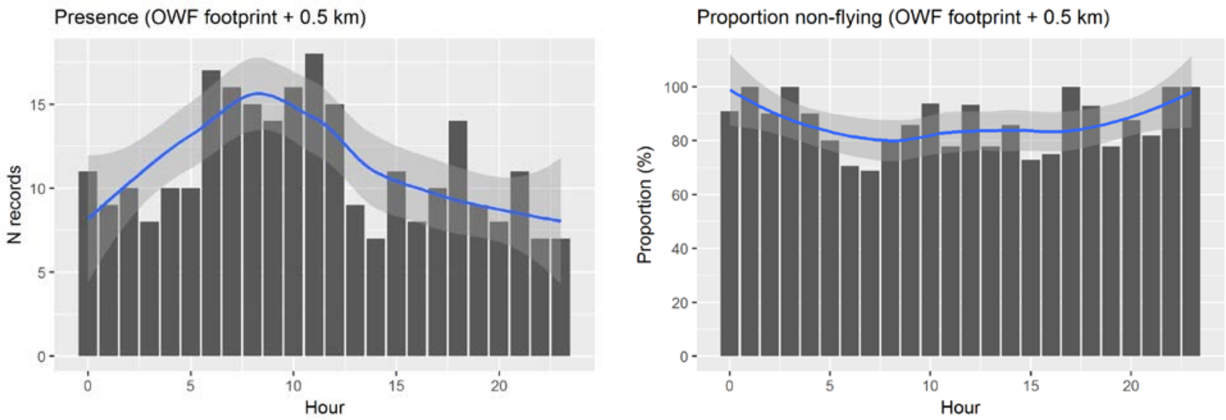

Figure 22. Diurnal pattern of the presence and *non-flying* behavior of tracked lesser black-backed gulls in the Thorntonbank 'OWF footprint + 0.5 km' area.

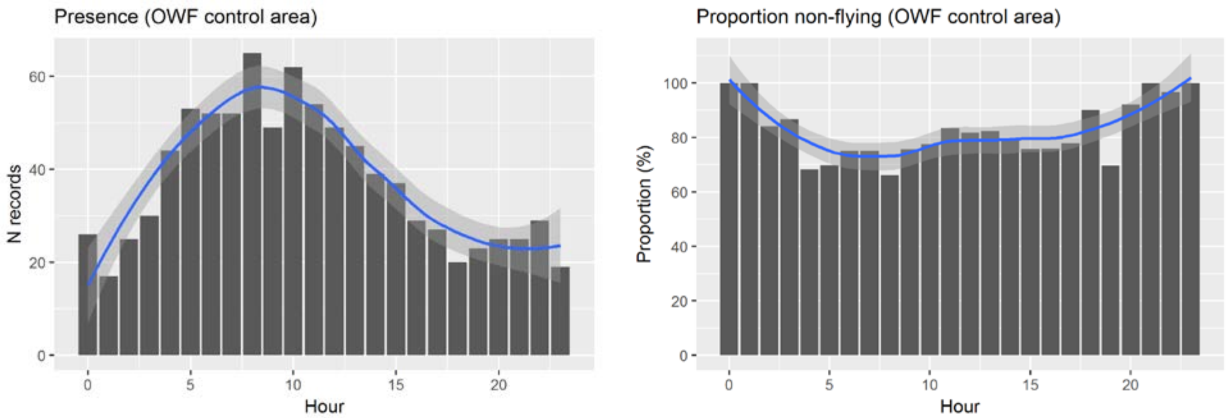

Figure 23. Diurnal pattern of the presence and *non-flying* behavior of tracked lesser black-backed gulls in the Thorntonbank OWF control area.

As calculated in §3.4.2, about 50% of the birds inside the OWF at the Thorntonbank concentrate around the turbines. But while we expected this proportion to be higher during the night, the opposite seems true. During midnight less than 30% of their time is spent on the turbines, while this proportion was about 60% during the day. Apparently, during the night, lesser black-backed gulls feel safer on the water than on the turbines.

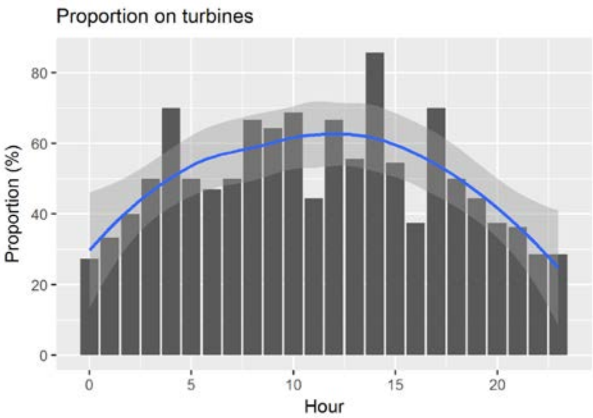

Figure 24. Diurnal pattern of the proportion of birds present on the turbines in the Thorntonbank OWF.

3.6 Fixed camera

From January until the beginning of May 2017 we performed 349 counts of birds associated with turbine I5, on the side of which the fixed camera is installed. Neighboring turbines I4 and J2 were counted 235 and 212 times respectively. Count results are shown in Table 6. Note that turbine I5 is only partly visible, and so numbers are not representative for the turbine as a whole.

Based on the counts of I4 and J2, the mean number of large gulls per turbine was 0.98. This is comparable with the mean number of 1.21 gulls per turbine as assessed during the transect counts. The proportion between species on the other hand is strikingly different from the proportion observed during transect counts. While on I5, herring gull made up for 34% of all large gulls, this proportion was only 5% during transect counts. We should note that the transect count results account for the OWF as a whole and were performed on a relatively limited number of (year-round) occasions. In contrast, counts with the fixed camera were performed during the period January to April of this year only and had only very limited spatial coverage.

Table 6. Number of species counted per turbine as observed with the fixed camera.

	I5	I4	J2
Great cormorant	0	1	0
European shag	1	0	0
Unidentified cormorant	0	1	5
Common gull	1	0	0
Lesser black-backed gull	3	0	0
Herring gull	62	0	0
Great black-backed gull	96	3	3
Unidentified large gull	19	161	272

Out of the 180 large gulls observed on turbine I5, 20 birds were actively foraging on the lower reaches of the jacket foundations (11.1%) (see Figure 25). These were mostly herring gulls (15 birds), as opposed to only 3 great black-backed gulls and 2 unidentified large gulls. Birds always seemed to feed on mussels growing on the lower intertidal zone of the jacket foundations. At turbines I4 and J2 we counted 36 birds foraging on the intertidal zone of the jacket foundations, which makes 8.2% of the total number of large gulls present.

Figure 25. Large gulls foraging on the lower intertidal reaches of the turbine I5 jacket foundation.

Below we show some preliminary graphs of the mean numbers of large gulls associated with the observed turbines in relation to wind, tide and time of day. In coming reports we will do the same analyses for each large gull species separately, but not before we have collected at least one cycle of year-round data.

Numbers of gulls associated with the jacket foundations seemed to peak early morning at 7 am, with a slight secondary peak at 3 pm. As expected, gull presence was negatively correlated with mean wind speed, and by far the highest numbers were observed on calm days with wind speeds below 5 m/s (Figure 26).

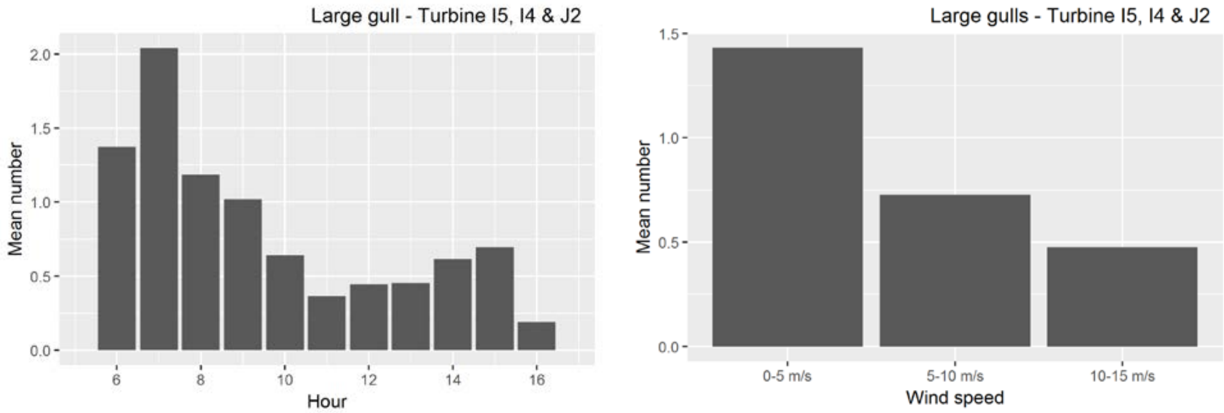

Figure 26. Mean number of large gulls present on the turbines I4, I5 & J2 in relation to time of day and to wind speed.

In relation to tidal height, numbers clearly peaked during the lowest tidal height category (< 0 cm above TAW) (Figure 27). Doing the same for foraging gulls only, we see highly increased numbers below 100 cm above TAW, and numbers dropping to zero for tidal heights higher than 300 cm above TAW (Figure 28).

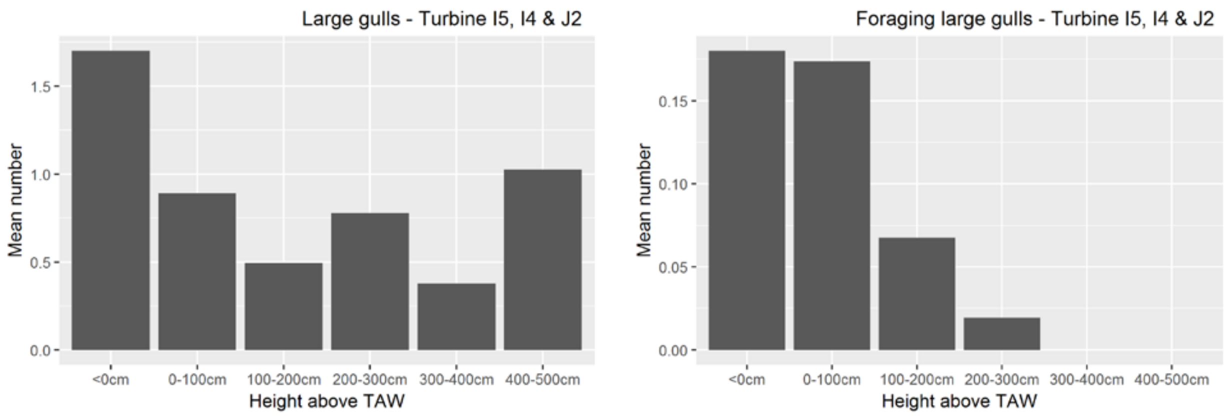

Figure 27. Mean number of large gulls present (left panel) and foraging (right panel) on the turbines I4, I5 & J2 in relation to tidal height.

4 Conclusions

After four years of post-impact monitoring at the Thorntonbank OWF, the impact area appeared to be avoided by four species, being northern gannet, little gull, black-legged kittiwake and common guillemot. In the OWF footprint area, these species dropped in numbers by no less than 97%, 89%, 75% and 69% respectively. Not unexpectedly, considering the rather small amount of data added in the course of the monitoring year 2016, these results are highly similar to those reported in the latest monitoring report (Vanermen *et al*. 2016). At the Bligh Bank, we also observed a significant decrease in numbers of northern gannet and common guillemot, while for the latter site, results for little gull and black-legged kittiwake remained inconclusive.

The Thorntonbank OWF attracted great black-backed gulls, this species having increased in numbers by a factor 6.6. Sandwich tern too appeared to be attracted to the OWF at the Thorntonbank, this effect being significant for the buffer zone only. Again, these results are highly similar to the results reported last year, but for herring gull there was in fact a shift in the estimated wind farm effect. While the OWF coefficient for herring gull was estimated to be close to zero after three years of monitoring, it now showed a borderline significant increase in numbers by a factor 2.9. On the other hand, a significant decrease in numbers of herring gull was observed in the buffer zone.

The reported attraction of large gulls to OWFs has raised concern on the number of expected collision victims, and considering the upcoming large scale exploitation of offshore wind in the North Sea, collision mortality might even affect these species on a population level (Brabant, Vanermen *et al*. 2015). Up until now, however, there is little information on the behavior of large gulls inside OWF areas, and it remains unclear whether these birds visit the wind farms because of enhanced foraging conditions or simply for roosting. Gaining more insight in this matter, however, is considered crucial for a reliable collision risk assessment. At the Thorntonbank OWF roosting possibilities are particularly numerous as 48 out of 54 turbines are built on jacket foundations which offer easy access to the intertidal fouling communities during low tide. In order to unravel part of the remaining knowledge gaps, we started studying the occurrence and behavior of large gull species in the Thorntonbank wind farm area using (i) the results of our dedicated ship-based seabird counts, (ii) GPS tracking data and (iii) observational data through a fixed camera installed on one of the turbines.

While the limited number of data collected up until now does not allow to draw any definite conclusions, first results showed that the time spent resting was higher inside compared to outside the wind farm. Based on our transect count data, almost 80% of the great black-backed gulls observed inside the OWF were associated with the turbine foundations. Tracking data of lesser black-backed gulls showed that birds entering the OWF spend about 50% of their time roosting on the jacket foundations. Great black-backed gulls further seemed to prefer the outer turbines, suggesting a partial barrier effect. Turbine foundations were mainly used for roosting, but during a short time period around low tide, small numbers of birds were observed foraging on mussels growing on the lower reaches of the foundations. In total, 9% of the large gulls observed on the jacket foundations within viewing range of the fixed camera were actually foraging. Herring gull in particular seemed to favour this temporary but daily available food source.

The results of our behavioral study might shed new light on the currently expected collision risk to large gulls at OWFs, and may highlight the need for proper post-construction monitoring. Pre-construction studies for example tend to extrapolate past and/or current numbers and behavior to feed collision risk models. But next to a possible post-construction change in numbers, any behavioral shift (i.e. a decrease in time flying) too will have a strong effect on the anticipated collision mortality among large gulls.

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Appendix

Table 7. Impact model coefficients for all species studied at the Thorntonbank OWF study area.

Species	Impact polygon	Intercept (Count)	Sin (1yr)	Cos (1yr)	Sin (1/2yr)	Cos (1/2yr)	Sin (1/4yr)	Cos (1/4yr)	BA	CI	Fishery	OWF	Theta	Intercept (Zero)
Northern fulmar	OWF footprint + 0.5 km	-1.40	-0.84	0.50					-1.79			-23.08	0.08	
	OWF footprint + 3 km	-1.37	-1.00	0.14					-1.73			-2.13	0.08	
	Buffer 0.5-3 km	-1.37	-1.00	0.14					-1.72			-1.52	0.08	
Northern gannet	OWF footprint + 0.5 km	-0.48	s(month)									-3.60	0.29	
	OWF footprint + 3 km	-0.55	s(month)									-1.19	0.30	
	Buffer 0.5-3 km	-0.55	s(month)									-0.75	0.30	
Great skua	OWF footprint + 0.5 km	-2.94	-2.03	-0.06			0.38	0.88		-1.91		-18.56		0.68
	OWF footprint + 3 km	-2.77	-1.76	0.00			0.54	0.70		-1.65		-0.10		0.72
	Buffer 0.5-3 km	-2.78	-1.78	0.00			0.56	0.69		-1.64		0.62		0.72
Little gull	OWF footprint + 0.5 km	-2.22	s(month)									-2.22	0.12	
	OWF footprint + 3 km	-2.44	s(month)									0.43	0.12	
	Buffer 0.5-3 km	-2.45	s(month)									1.02	0.12	
Common gull	OWF footprint + 0.5 km	-3.94	2.19	2.36					1.84	1.56		-1.30	0.24	
	OWF footprint + 3 km	-3.87	2.14	2.29					1.63	1.55		-1.13	0.27	
	Buffer 0.5-3 km	-3.86	2.09	2.32					1.61	1.51		-0.81	0.26	
Lesser black-backed gull	OWF footprint + 0.5 km	-0.37	s(month)								0.74	0.07	0.29	
	OWF footprint + 0.5 km (T)	-0.32	s(month)								0.59	0.00	0.32	
	OWF footprint + 3 km	-0.33	s(month)								0.48	-0.18	0.31	
	OWF footprint + 3 km (T)	-0.37	s(month)								0.73	0.27	0.30	
	Buffer 0.5-3 km	-0.33	s(month)								0.60	0.03	0.32	

Species	Impact polygon	Intercept (Count)	Sin (1yr)	Cos (1yr)	Sin (1/2yr)	Cos (1/2yr)	Sin (1/4yr)	Cos (1/4yr)	BA	CI	Fishery	OWF	Theta	Intercept (Zero)
Herring gull	OWF footprint + 0.5 km	-2.32	1.21	0.06							0.75	0.91	0.13	
	OWF footprint + 0.5 km (T)	-2.35	1.14	0.14							0.77	0.15	0.15	
	OWF footprint + 3 km	-2.55	1.48	0.19							1.37	-1.88	0.16	
	OWF footprint + 3 km (T)	-2.33	1.22	0.05							0.79	1.06	0.16	
	Buffer 0.5-3 km	-2.35	1.15	0.11							0.82	0.21	0.16	
Great black-backed gull	OWF footprint + 0.5 km	-1.73	s(month)								1.58	0.34	0.22	
	OWF footprint + 0.5 km (T)	-1.92	s(month)								1.65	0.19	0.25	
	OWF footprint + 3 km	-1.92	s(month)								1.65	0.00	0.21	
	OWF footprint + 3 km (T)	-1.62	s(month)								1.65	1.88	0.27	
	Buffer 0.5-3 km	-1.71	s(month)								1.64	0.94	0.28	
Black-legged kittiwake	OWF footprint + 0.5 km	-0.40	s(month)							-0.63	1.07	-1.39	0.25	
	OWF footprint + 3 km	-0.60	s(month)							-0.67	1.36	-0.98	0.27	
	Buffer 0.5-3 km	-0.62	s(month)							-0.69	1.50	-0.72	0.27	
Sandwich tern	OWF footprint + 0.5 km	-0.33							-1.60			1.06	1.52	0.75
	OWF footprint + 3 km	-0.40							-1.76			1.32	1.15	0.71
	Buffer 0.5-3 km	-0.36							-1.74			1.74	1.24	0.73
Common guillemot	OWF footprint + 0.5 km	-2.71	1.43	6.43	-1.14	-1.80						-1.16	0.96	0.10
	OWF footprint + 3 km	-2.95	1.62	6.72	-1.32	-2.00						-0.66	0.93	0.11
	Buffer 0.5-3 km	-3.04	1.74	6.84	-1.41	-2.03						-0.33	0.90	0.10
Razorbill	OWF footprint + 0.5 km	-6.17	1.03	9.49	-1.08	-3.61			0.46			-0.72	0.77	0.18
	OWF footprint + 3 km	-6.30	1.28	9.76	-1.42	-3.72			0.44			-0.08	0.95	0.21
	Buffer 0.5-3 km	-6.16	1.24	9.59	-1.39	-3.69			0.42			0.32	1.02	0.23