Seabird monitoring at offshore wind farms in the Belgian part of the North Sea

Updated results for the Bligh Bank & first results for the Thorntonbank

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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 in the Belgian part of the North Sea. For the first time since its completion in 2013 we report our findings for the C-Power wind farm at the Thorntonbank, and we also give an update of the results for the Bligh Bank wind farm after five years of post-impact monitoring.

Compared to earlier reports and publications, we introduced some improvements in our modelling strategy. To correct for decreasing detectability with distance, the seabird numbers observed were now distance-corrected, and by allowing the detection functions to vary with wind force or wave height, temporal variation due to observation conditions was further reduced. We also included a fishery factor in the model, allowing to correct for the presence of beam trawlers in the vicinity of our survey tracks. As expected, this factor often explained a significant part of the variation in the counted numbers of gulls and northern fulmars.

Based on the resulting impact models, we found significant avoidance by northern gannet and common guillemot at both sites. Common guillemot decreased in densities by 68% and 75% at the Thorntonbank and Bligh Bank respectively, and northern gannet by 99% and 82%. Razorbill decreased in numbers at the two sites, this decrease being significant at the Bligh Bank only (67%). Both sites attracted great black-backed gulls, this species having increased in numbers significantly by a factor 6.4 and 3.6 at the Thorntonbank and Bligh Bank respectively. The previously reported attraction effects of lesser black-backed gull and herring gull at the Bligh Bank were confirmed after two more years of monitoring, but no such effect was observed at the Thorntonbank. Finally, Sandwich tern appeared to be attracted to the offshore wind farm at the Thorntonbank, this effect being significant only for the buffer zone. This is in line with the results for the phase I of the C-Power wind farm when we also found attraction of Sandwich tern to the immediate surroundings of the six turbine wind farm.

While the avoidance of common guillemot and northern gannet seems readily interpretable from a disturbance perspective, it is still difficult to pinpoint the observed increases in seabird numbers, even more so because these are not always consistent between both sites under study. Gaining more insight in the diurnal and tidal-dependent variation in numbers and behaviour of birds occurring inside the offshore wind farms seems indispensable for understanding the observed patterns and learning whether birds come to the wind farms merely for roosting and the related stepping stone function, or whether offshore wind farms also offer increased food availability. This should be investigated through oriented research making use of bird radar data, GPS tracking data of tagged gulls, fixed cameras and/or visual observations from a fixed location inside the wind farm.

Samenvatting

Het zeevogelteam van het Instituut voor Natuur- en Bosonderzoek voert sinds 2005 onderzoek uit naar de effecten van offshore windmolenparken op de aantallen aanwezige zeevogels. Er werden maandelijks zeevogeltellingen uitgevoerd in hiertoe afgebakende controle- en impactgebieden. Ruim 5 jaar na de bouw van het park op de Bligh Bank geeft dit rapport een update van de eerder gepubliceerde resultaten voor deze locatie. Ondertussen werden ook fases 2 & 3 op de Thorntonbank voltooid, en presenteren we voor eerst onze bevindingen voor dit pas sinds 2013 volledig operationele park.

Vergeleken met eerdere rapporten en publicaties werden een aantal verbeteringen doorgevoerd in onze modellen. Zo werden de waargenomen aantallen zeevogels gecorrigeerd voor de afnemende detectiekans bij toenemende afstand, en lieten we bovendien de zogenaamde detectiefuncties variëren met windkracht of golfhoogte. Op die manier beperkten we de temporele variatie als gevolg van observatie-omstandigheden. We namen voor het eerst ook een visserij-factor in rekening, die corrigeert voor de aanwezigheid van vissersboten in de nabijheid van onze monitoringroutes. Zoals verwacht verklaarde deze factor meestal een groot aandeel van de variatie in de getelde aantallen meeuwen en noordse stormvogels.

De resulterende impactmodellen tonen aan dat jan-van-gent en zeekoet de beide parken mijden. Zeekoet nam in aantal af met respectievelijk 68% en 75% op de Thorntonbank en Bligh Bank. Jan-van-gent nam zelfs nog sterker in aantal af, meer bepaald met 99% en 82%. Ook alk toonde een afname in beide studiegebieden, maar met een daling van 67% was die enkel significant op de Bligh Bank. Anderzijds namen de aantallen grote mantelmeeuw significant toe in beide windparken, en wel met een factor van respectievelijk 6.4 en 3.6 op de Thorntonbank en Bligh Bank. Voorheen werd reeds een sterke aantrekking gemeld van kleine mantelmeeuw en zilvermeeuw op de Bligh Bank, en deze effecten konden na 2 jaar extra monitoring nog steeds statistisch hard gemaakt worden. Op de Thorntonbank echter vertoonde geen van beide soorten ook maar enige aanwijzing van aantrekkingsgedrag. Grote sterns vertoonden dan wel weer verhoogde aantallen in en rond het windpark op de Thorntonbank, met een voor het buffergebied significante toename. Dit is in lijn met de eerder gerapporteerde aantrekking van grote sterns tot de onmiddellijke omgeving van het Thorntonbank windpark tijdens fase 1, dat toen nog slechts uit een enkele rij van zes windmolens bestond.

Een afname van echte zeevogels zoals jan-van-gent en zeekoet is vrij gemakkelijk te interpreteren als een gevolg van verstoring door de aanwezigheid van reusachtige, bewegende constructies in hun gewoonlijk wijds en open leefgebied. De toename van meeuwen en ook grote sterns is moeilijker te duiden, temeer deze effecten voor sommige soorten op de ene plek wel en op de andere plek niet werden vastgesteld. Nochtans is het begrijpen van de waargenomen veranderingen belangrijk om onze resultaten te kunnen extrapoleren en uitspraken te kunnen doen over de mogelijke impact van toekomstige windparken. Er ontbreekt echter nog een belangrijk stuk van de puzzel, want tijdens zeevogeltellingen spenderen we telkens slechts korte tijd in de windparken zelf en hebben we daarom weinig inzicht in dagritmiek en getij-afhankelijke patronen in het voorkomen en gedrag van zeevogels in de windparken. Hier inzicht in krijgen is wellicht van wezenlijk belang om te kunnen begrijpen waarom zeevogels naar de windparken toe komen. Is het puur omwille van de aanwezige rustplaatsen en fungeren de windparken aldus als een zogenaamde 'stepping stone', of komen vogels ook omwille van een verhoogd voedselaanbod, en zo ja, wat is dan het draagvlak? Dit zou verder onderzocht kunnen worden aan de hand van georiënteerd onderzoek gebruik makend van radargegevens, GPS-data van gezenderde meeuwen, vaste camera's en/of visuele waarnemingen vanaf vaste locaties binnen het park.

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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 fast and at the end of 2015, 3,230 offshore wind turbines were fully grid-connected in European waters, totalling 11.0 GW (EWEA 2016). Currently, three offshore wind farms 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, in 2013 Northwind NV built 72 more turbines at the Lodewijckbank, 37 km offshore.

Since 2005, the Research Institute for Nature and Forest (INBO) performs seabird counts specifically aimed at studying seabird displacement caused by the presence of offshore wind turbines. Due to logistic constraints, the study effort was concentrated on the Thorntonbank and Bligh Bank wind farms only. Here we present the results of our seabird displacement study at the respective OWFs after 3 and 5 years of operation.

2 Methods

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 ('distance correction') afterwards. 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 same transect, however, would cause an overestimation and would be a measure of bird flux rather than actual bird density. The birds' flying speed is significantly higher than the ship's movement, and therefore more birds will be flying through the surveyed area in the course of any observation period, compared to numbers present at any one instance (Tasker *et al.* 1984). Flying birds are therefore counted by performing instantaneous counts in one minute intervals ('snapshot counts') within a quadrant of 300 by 300 m inside the transect. 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 is linked to the corresponding GPS-coordinates saved 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 observed per km², i.e. a seabird density at a specified location. Up to 2012, observations were aggregated in ten-minute bouts, which were cut off to the nearest minute at waypoints. Since 2013, resolution is 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 occurring in 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, behaviour, flight direction and association with objects, vessels or other birds.

2.2 Monitoring set-up

Monitoring was performed according to a **Before-After Control-Impact** (**BACI**) set-up. Both wind farm areas were 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 can 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. The distance between control and impact areas 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, while the Bligh Bank study area was studied from April 2008 to April 2015 (Figures 1, 2 & 3). During this dedicated monitoring program both sites 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 above 2 m and/or poor visibility). Before this dedicated monitoring program, the sites were 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.

Table 1. Definition of the reference, construction and impact periods at the Thorntonbank and Bligh Bank study areas 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)
Bligh Bank	Reference period	< 09/2009
	1st construction period	09/2009 –> 09/2010 (highly restricted access)
	Impact period (phase I)	10/2010 –> present (55 turbines)

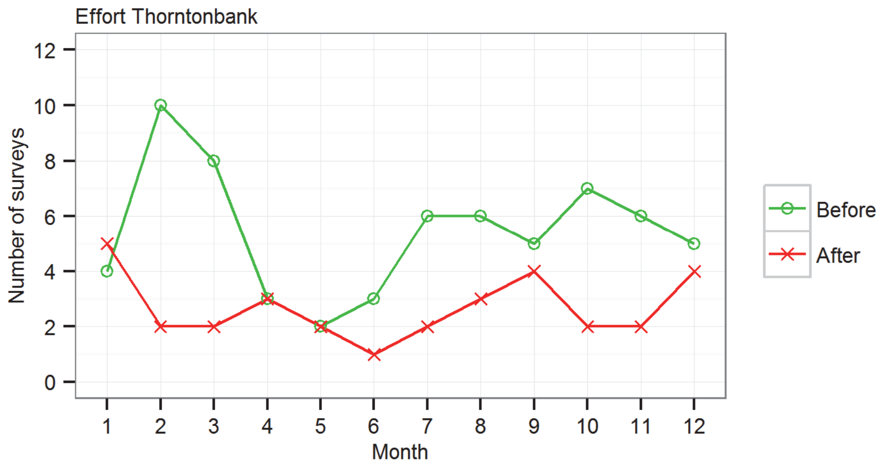

Figure 1. Count effort in the Thorntonbank study area with indication of the number of surveys performed before the construction of the phase I turbines (<04/2008), and after the construction of the phase II & III turbines (>09/2012).

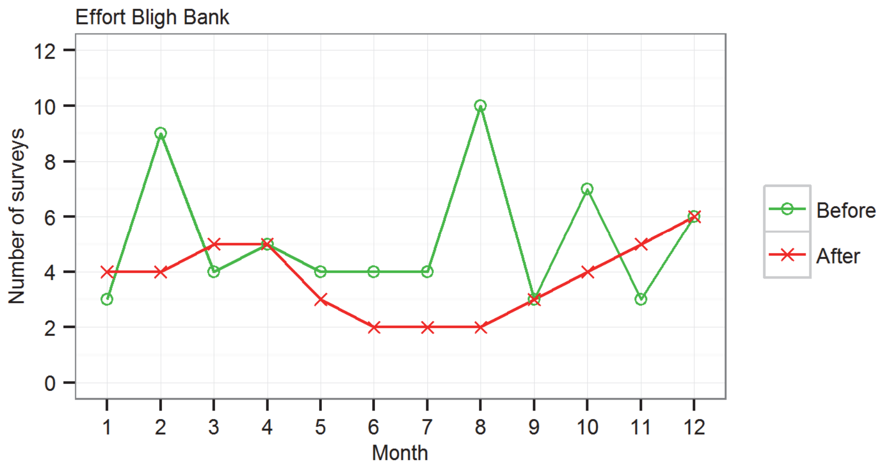

Figure 2. Count effort in the Bligh Bank study area with indication of the number of surveys performed before (<09/2009) and after (>09/2010) the construction of the turbines.

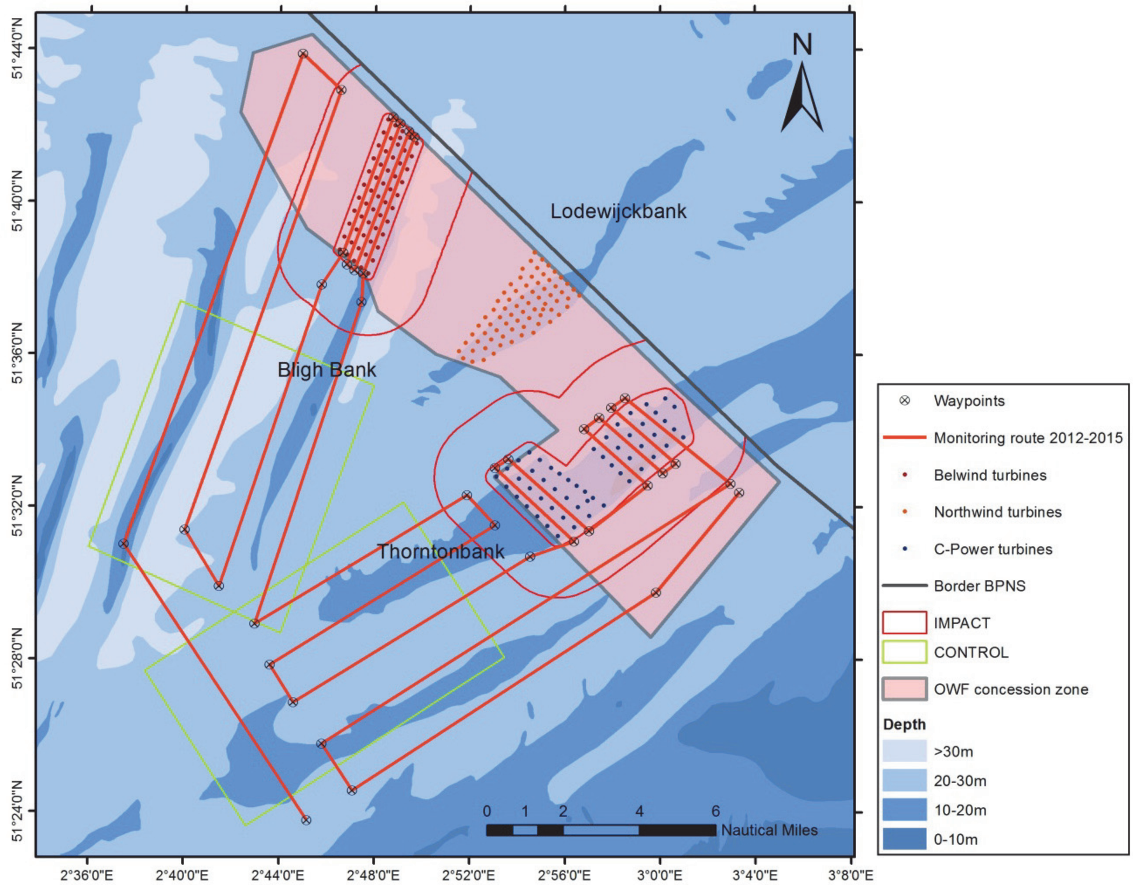

Figure 3. Monitoring route through the OWF study area in the period 2012-2015.

2.3 Offshore wind farms

The two wind farms under study were the C-Power wind farm at the Thorntonbank and the Belwind wind farm at the Bligh Bank (Figure 3).

The Thorntonbank wind farm is located 27 km off the coast of Zeebrugge, and consists of 2 subareas of respectively 24 and 30 wind turbines (see Figure 3), measuring 10.7 and 9.2 km² and with a water depth between 12 and 27.5 m (C-Power 2016). The distance between the turbines ranges 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

The wind farm at the Bligh Bank is located 46 km off the Belgian coast. It has an area of 17 km² with a water depth range of 15 to 37 m. The farm consists of 5 rows of eleven 3 MW turbines (with 500 – 650 m distance in between) and a transformation platform, all of which were installed on steel monopile foundations (Belwind 2016). The first construction activities took place in September 2009, and the wind farm became fully operational in December 2010.

2.4 Distance analysis

Before performing impact analyses 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 0-0.5m / 0.5-1.0m / 1.0m-2.0m / 2.0-3.0m, …), both 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. We thus 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.

2.5 BACI analysis

For the BACI analysis we aggregated our count data per area (control / impact) and per monitoring day, resulting in day totals for both zones, thus avoiding auto-correlation between subsequent counts and minimizing overall variance. We only selected days on which both the control and impact area were visited, minimizing variation resulting from short-term temporal changes in seabird abundance. 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, however, often occur strongly aggregated in (multi-species) flocks, typically resulting in count data with a high proportion of zeros, relatively few but sometimes very large positive numbers and a high variance exceeding the mean, resulting in high over-dispersion. Such count data can be analyzed through a generalized linear model with a negative binomial (NB) distribution (Ver Hoef & Boveng 2007, Zuur *et al*. 2009). When data appeared to exhibit (much) more zeros than can be predicted by a Poisson or NB distribution, zero-inflated (ZI) models were used (Potts & Elith 2006, Zeileis *et al.* 2008), which consists of two parts: (1) a 'count component' modelling the data according to a Poisson or NB distribution and (2) a 'zero component' modelling the excess in zero counts. In ZI models, the zero-component was limited to an intercept.

Our **response variable** equals the number of birds observed (inside the transect and during snapshot counts) per survey in the control or impact area. 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) an area factor CI (Control / Impact area), (ii) a time factor BA (Before / After construction), (iii) an offshore wind farm factor OWF (wind farm present / absent) and (iv) a fishery factor (fishing vessels present / absent). For the latter we only considered fishing vessels observed within a distance of 3 km from the monitoring track. Finally, the continuous variable 'month' was used to model seasonal fluctuations by fitting a cyclic smoother or a cyclic sine curve, the latter described by 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 or an asymmetric seasonal pattern. During the process we considered five different possibilities for explaining seasonal variation in numbers:

1. Intercept model (no seasonal variation)
2. 12 month period sine curve
3. 12 + 6 month period sine curve
4. 12 + 4 month period sine curve
5. Cyclic smoother

At first, all 5 full models (above sine curves and smoother added with the aforementioned factors, but without interactions) were fitted using 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 5 full models were fitted applying the selected distribution. Based on the resulting AIC matrix the most likely factor-seasonality combination was chosen. Note that for each species and each OWF, three different analyses were performed based on three different impact datasets (impact + 0.5 km, impact + 3 km, buffer 0.5-3 km, see Figures 4 & 5). In most cases, the same covariate combination resulted in the lowest AIC for all 3 data selections, and in all cases, at least 2 out of 3 datasets favoured the same factor combination. Whatever the outcome, the most favoured covariate combination was applied over all 3 datasets to estimate the OWF displacement effect. When the best-fitting model did not contain the OWF factor, this was added to the model afterwards in order to estimate its effect.

In the results section (§3) we often refer to (i) the OWF coefficient, being the model coefficient for 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 BA / CI factor combination, with the offset variable set to 1 km².

At the Thorntonbank we encountered a specific situation. The corridors between the C-Power turbines used for seabird monitoring vary in width between 650 and 850 m. For security reasons, the research vessels aim to sail right in the middle of these corridors, implying that the turbines and associated birds are always just outside our 300 m wide count transect, and are not included in the impact analysis. Therefore, we also analysed an adjusted response variable for species very often observed roosting on the jacket foundations (herring, lesser black-backed and great black-backed gull). This response variable is calculated by adding (i) the number of birds that should have been counted inside the transect if the turbine-associated birds would have occurred homogenously spread across the area to (ii) the actual number of birds counted inside the transect (assuming this number is representative for the whole area). 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, and merely 1 bird was observed inside our transect, 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. Assuming these birds would have occurred homogenously spread across the area, and knowing we counted 7.4 km², we thus recalculate the number of birds inside the transect as: $1 + (5.6*7.4) \approx 42$. The original and recalculated response variable are always analysed both, and the difference is clearly indicated in the graphs and tables.

BACI modelling was performed for thirteen seabird species occurring regularly in the wind farm areas, 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 tern (*Sterna hirundo*), common guillemot (*Uria aalge*) and razorbill (*Alca torda*). Both tern species are largely absent at the Bligh Bank and therefore tern data were only analysed for the Thorntonbank study area.

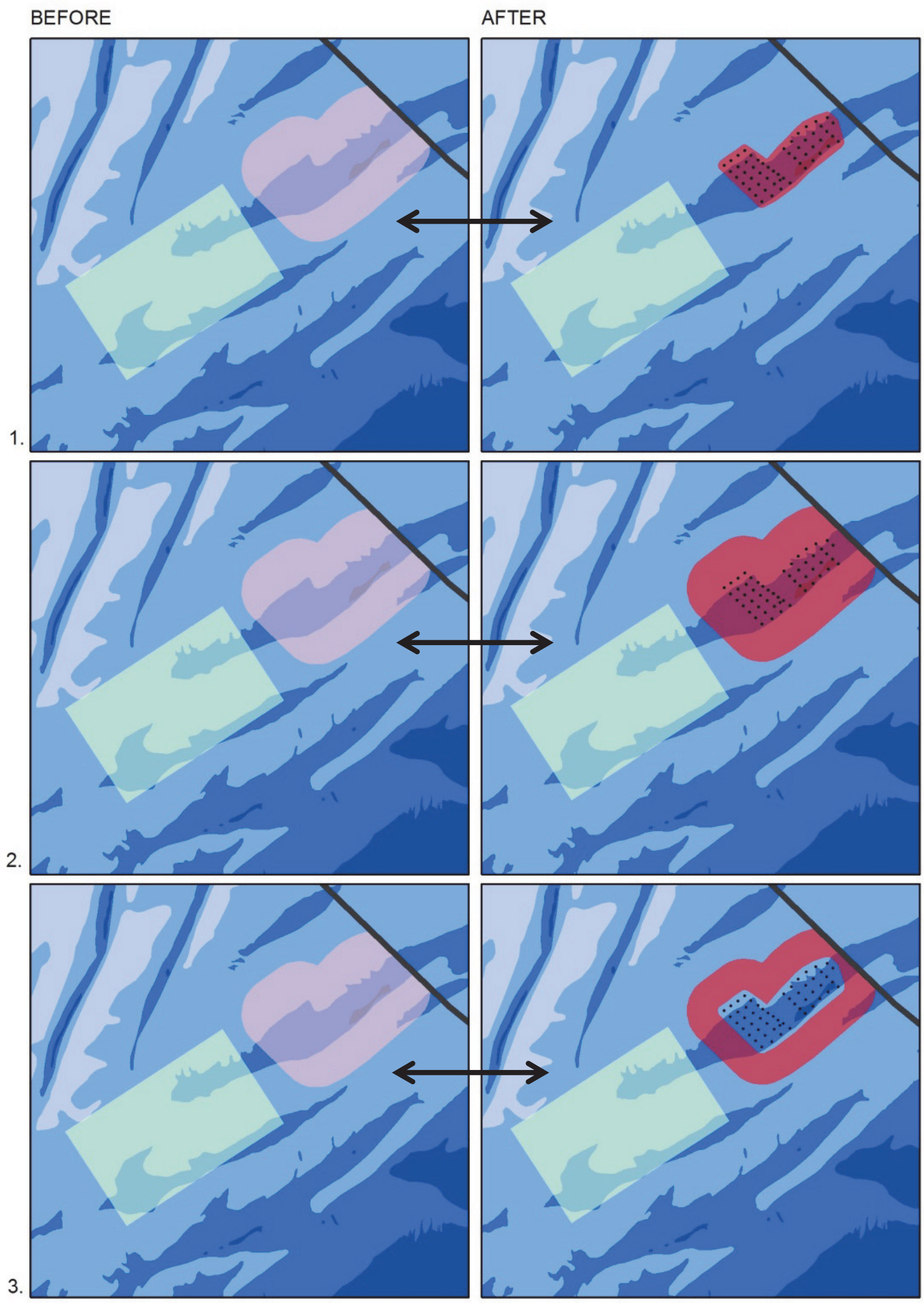

Figure 4. Overview of the BACI polygons used to study OWF induced seabird displacement at the Thorntonbank (green = control area / red = impact area).

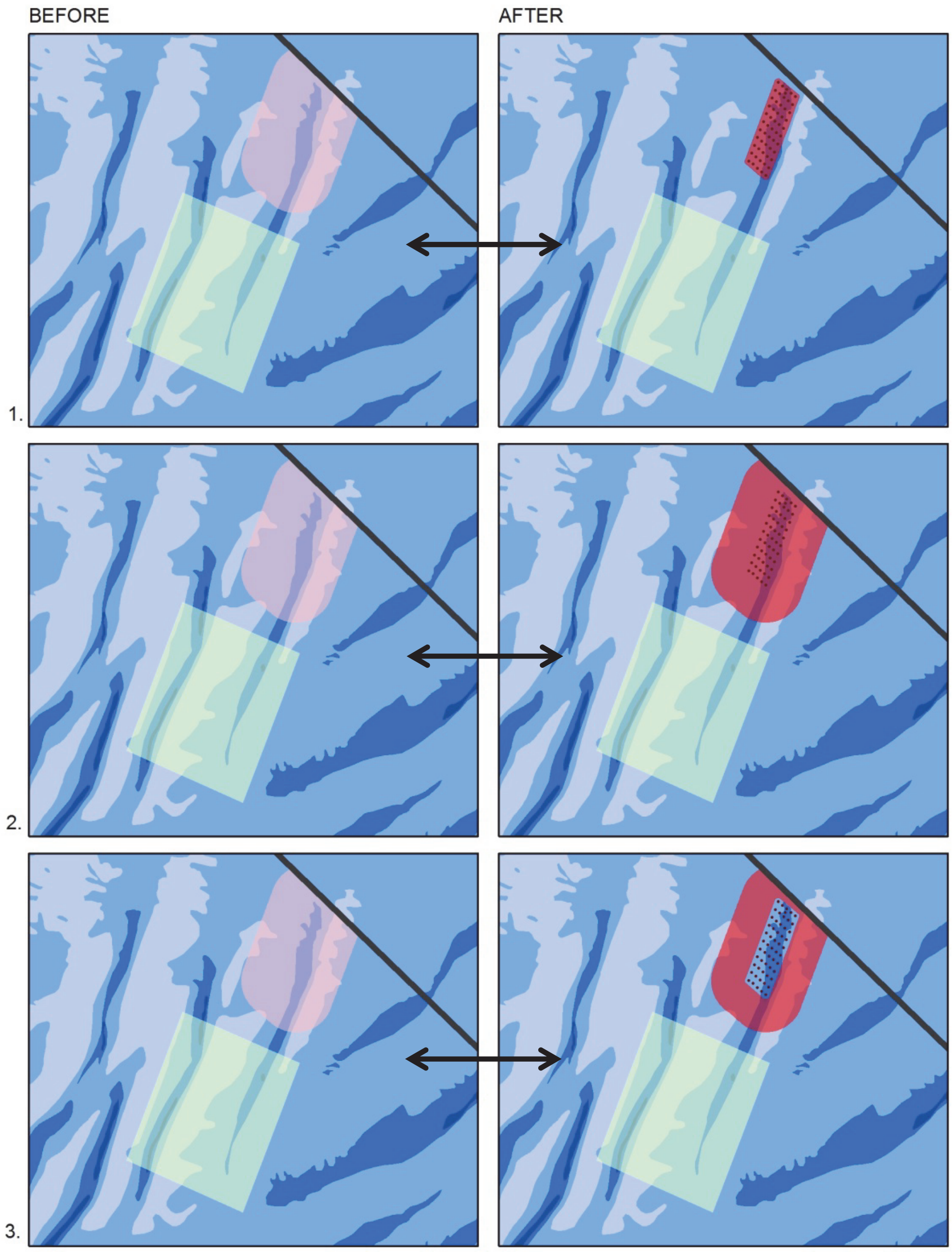

Figure 5. Overview of the BACI polygons used to study OWF induced seabird displacement at the Bligh Bank (green = control area / red = impact area).

2.6 Statistics

All data handling and modelling was performed in R.3.2.1 (R Core Team 2015a), making use of the following packages:

RODBC (Ripley & Lapsley 2013), foreign (R Core Team 2015b), date (Therneau 2014), ggplot2 (Wickham 2009), compare (Murrell 2014), reshape (Wickham 2007), plyr (Wickham 2011), MASS (Venables & Ripley 2002), mgcv (Wood 2011), glmmADMB (Skaug *et al.* 2014), Distance (Miller 2015) & mrds (Laake *et al.* 2015).

3 Results

3.1 General observations

By far the most commonly observed bird species in both OWFs during operation are gulls, making up a highly similar percentage of 93.0 and 93.4% of all non-passerine birds observed in the Thorntonbank & Bligh Bank OWF respectively (Table 2). Gulls were observed roosting on the turbine (jacket) foundations or transformation platforms in relatively large numbers, which is particularly true for great black-backed gull at the Thorntonbank (670 out of 840 birds in total). Clearly, jacket foundations offer much more roosting possibilities compared to monopiles, and a resulting 62.8% of the large gull species observed at the Thorntonbank were associated with man-made structures, compared to 18.0% at the Bligh Bank. Despite the reported avoidance effects (Vanermen *et al*. 2015a), auks (common guillemot and razorbill) are relatively often observed inside the OWF boundaries, totaling 188 and 102 individuals at the Bligh Bank and Thorntonbank respectively. Quite unexpected were the regular observations of shag (in total 17 individuals seen), a species which is otherwise rare in the BPNS.

Also worth mentioning is the regular occurrence of sea mammals inside the OWFs. In total, 45 harbour porpoises and 5 white-beaked dolphins were observed inside the Bligh Bank wind farm.

Table 2. Number of birds and sea mammals observed inside the Thorntonbank (526 km of surveying) and Bligh Bank (714 km of surveying) OWFs during operation.

		Bligh Bank		Thorntonbank	
		Total	Roosting on constructions	Total	Roosting on constructions
BIRDS					
Northern fulmar	*Fulmarus glacialis*	1	0	1	0
Northern gannet	*Morus bassanus*	27	0	10	0
Great cormorant	*Phalacrocorax carbo*	2	2	30	25
European shag	*Phalacrocorax aristotelis*	8	3	9	9
Unidentified cormorant	*Phalacrocorax* sp.	0	0	2	1
Barnacle goose	*Branta leucopsis*	4	0	0	0
Brent goose	*Branta bernicla*	11	0	0	0
Eurasian sparrowhawk	*Accipiter nisus*	0	0	1	0
Bar-tailed godwit	*Limosa lapponica*	0	0	1	0
Whimbrel	*Numenius phaeopus*	1	0	0	0
Eurasian curlew	*Numenius arquata*	23	0	0	0
Pomarine skua	*Stercorarius pomarinus*	1	0	0	0
Mediterranean gull	*Ichthyaetus melanocephalus*	1	0	0	0
Little gull	*Hydrocoloeus minutus*	0	0	10	0
Black-headed gull	*Chroicocephalus ridibundus*	45	0	16	0
Common gull	*Larus canus*	1689	0	100	2
Lesser black-backed gull	*Larus fuscus*	538	38	592	128
Herring gull	*Larus argentatus*	210	4	67	18
Yellow-legged gull	*Larus michahellis*	5	0	0	0
Great black-backed gull	*Larus marinus*	434	182	840	670
Unidentified large gull	*Larus* sp.	60	0	472	421
Black-legged kittiwake	*Rissa tridactyla*	884	0	235	1
Unidentified gull		34	0	0	0
Sandwich tern	*Thalasseus sandvicensis*	4	0	17	0
Common tern	*Sterna hirundo*	0	0	1	0
Common guillemot	*Uria aalge*	80	0	59	0
Unidentified auk	*Uria aalge* or *Alca torda*	20	0	11	0

Razorbill	*Alca torda*	88	0	32	0
Atlantic puffin	*Fratercula arctica*	1	0	0	0
Domestic pigeon	*Columba* sp.	3	0	1	0
Short-eared owl	*Asio flammeus*	1	0	0	0
Common starling	*Sturnus vulgaris*	382	2	122	3
Other passerines		72	2	27	4
SEA MAMMALS					
White-beaked dolphin	*Lagenorhynchus albirostris*	5	0	0	0
Harbour porpoise	*Phocoena phocoena*	45	0	4	0
Grey seal	*Halichoerus grypus*	1	0	1	0

3.2 Distance analysis

For every species except for great skua, hazard-rate detection models fitted our data better than half-normal detection functions (Table 3). Observation conditions proved to affect detectability of seabirds significantly and either wave height or wind force was retained in all species except for great skua and both tern species. The natural logarithm of group size was retained for most species except for northern gannet and great skua, while for common guillemot group size was preferred over log(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 3. Results of distance analysis.

Species	Detection function	Covariates	Cluster 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	0.64
Common gull	Hazard-rate	log(group size) + wave height	0.52
Lesser black-backed gull	Hazard-rate	log(group size) + wind force	0.67
Herring gull	Hazard-rate	log(group size) + wind force	0.66
Great black-backed gull	Hazard-rate	log(group size) + wind force	0.72
Black-legged kittiwake	Hazard-rate	log(group size) + wave height	0.56
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	0.56
Razorbill	Hazard-rate	log(group size) + wind force	0.63

3.3 BACI modelling results

3.3.1 Northern fulmar

In both study areas, northern fulmars showed a strong overall decrease in densities. After impact, only two positive observations occurred in the impact areas, one in the Thorntonbank OWF buffer zone and one inside the Bligh Bank OWF. No observations were thus made in the ‘impact + 0.5 km’ area at the Thorntonbank and the ‘buffer 0.5-3 km’ area at the Bligh Bank. In these cases meaningful statistics are no longer possible (see Tables 4 & 5: p=0.999, implying almost 100% unreliability), explaining the empty spaces in the left panels of Figures 6 & 7. Apart from these absences, other results also suggest avoidance by northern fulmars. However, due to the very low number of positive observations, confidence intervals are broad and effects are only significant for the ‘impact + 3 km’ area at the Bligh Bank, for which our models estimate a negative coefficient of -3.13, corresponding to a decrease in numbers of 96%.

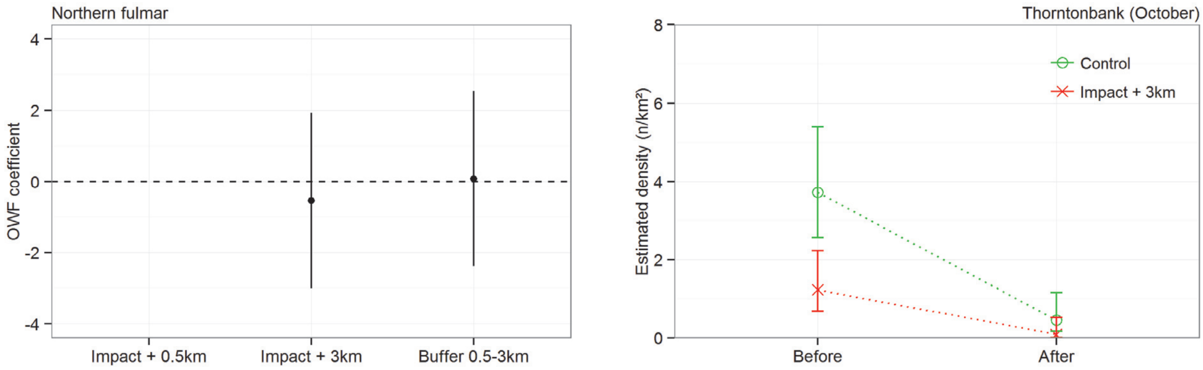

Figure 6. Modelling results for northern fulmar in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right (but note that zero-inflation equals 75%).

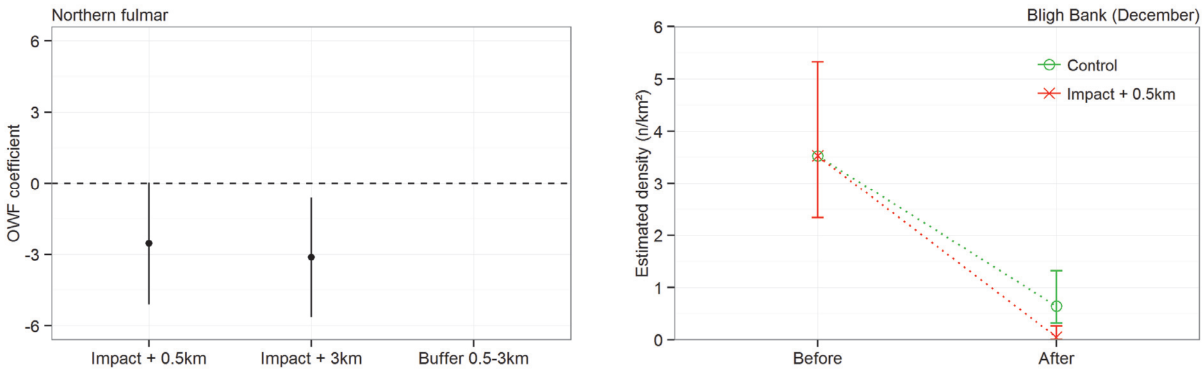

Figure 7. Modelling results for northern fulmar in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right (but note that zero-inflation equals 68%).

3.3.2 Northern gannet

Northern gannets avoided both the Thorntonbank and the Bligh Bank OWF. At the Thorntonbank there was only one positive count inside the OWF after impact, while in the Bligh Bank OWF northern gannets were observed inside the transect on six surveys, totaling 15 birds. Transforming the resulting negative OWF coefficients learns that gannet numbers significantly decreased with 99% & 82% in the 'impact + 0.5 km' areas at the Thorntonbank and Bligh Bank respectively. These results are quite consistent with the estimate obtained after three years of post-impact monitoring at the Bligh Bank when a decrease of northern gannets by 85% was reported (Vanermen *et al*. 2015a). In the buffer zones, decrease in densities was more moderate with 60% & 26% for the Thorntonbank and Bligh Bank respectively, the effect being no longer significant at the latter.

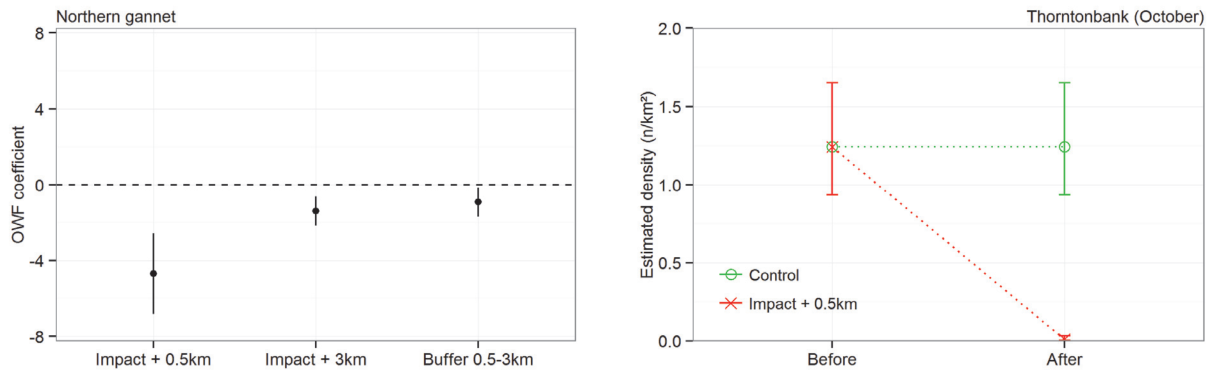

Figure 8. Modelling results for northern gannet in the Thorntonbank study area with OWF coefficients and their 95% CI's on the left and BACI density estimates for the month with maximum numbers on the right.

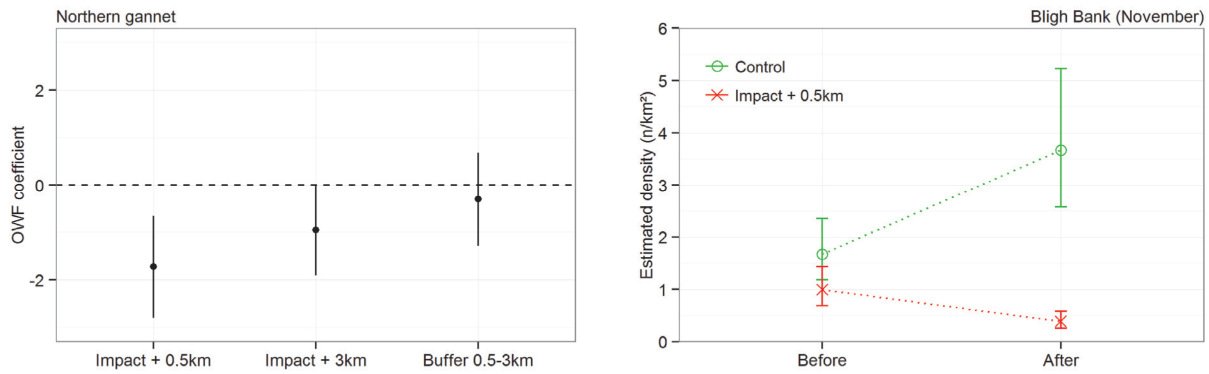

Figure 9. Modelling results for northern gannet in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.3 Great skua

Great skua showed contradictory results with slightly positive OWF coefficients at the Thorntonbank study area and negative coefficients at the Bligh Bank. Due to the low number of positive observations after impact (no positive observations inside the OWFs and only one positive count in each of the buffer zones) and resulting broad 95% confidence intervals, none of these effects are statistically significant.

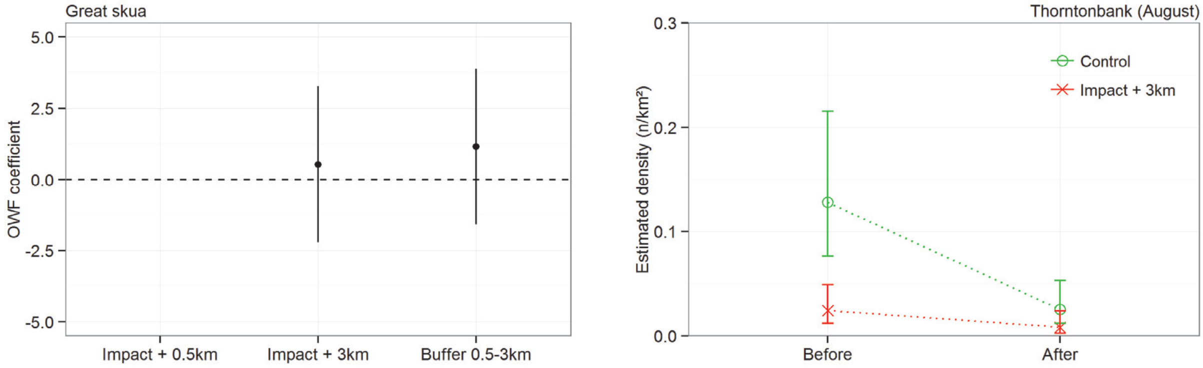

Figure 10. Modelling results for great skua in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

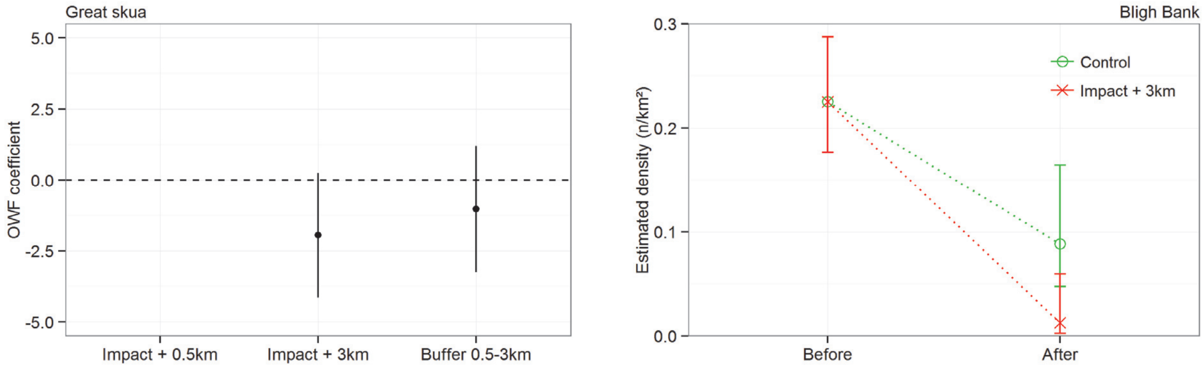

Figure 11. Modelling results for great skua in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and year-round BACI density estimates on the right (but note that zero-inflation equals 79%).

3.3.4 Little gull

Our BACI analysis detected a significant decrease of little gull density by 87% in the 'impact + 0.5 km' area at the Thorntonbank. Interestingly, OWF coefficients show a similar pattern in both study areas, being negative for the OWF area itself and positive in the buffer zone, suggesting local displacement out of the turbine-built area towards the near surroundings. However, only the aforementioned decrease in the Thorntonbank OWF proved statistically significant.

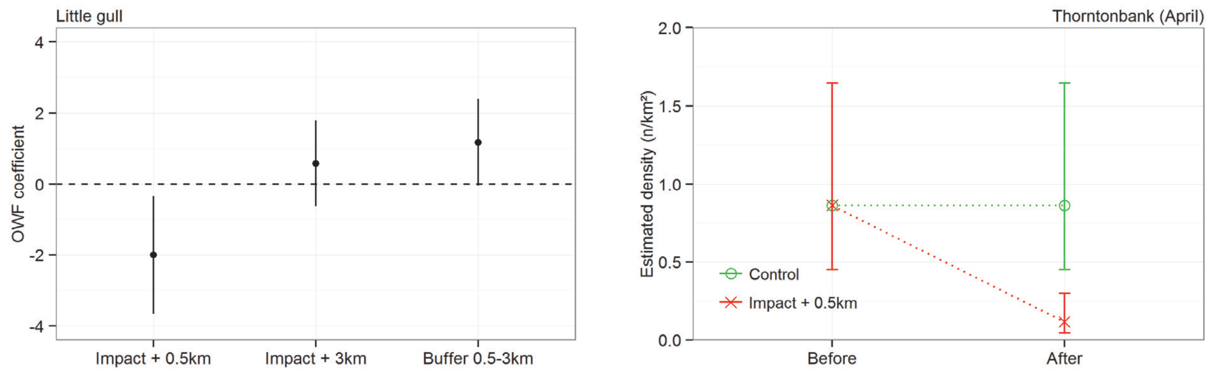

Figure 12. Modelling results for little gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

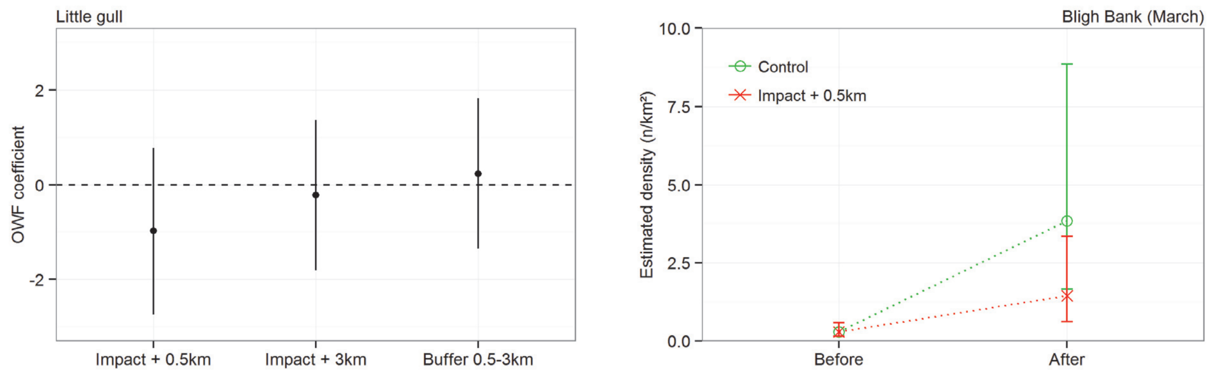

Figure 13. Modelling results for little gull in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.5 Common gull

Common gull showed contradictory results with negative OWF coefficients at the Thorntonbank study area and positive coefficients at the Bligh Bank, however, none of these coefficients significantly differed from zero due to broad 95% confidence intervals. Importantly, the strongly positive coefficient (1.79) found for the Bligh Bank OWF is fully determined by the survey of 20/12/2010 when no less than 1,071 common gulls were observed between the turbines and inside the transect! This high number is very exceptional, as positive counts in the Bligh Bank OWF occurred in only 10 out of the 41 remaining surveys, totaling 64 birds. Hence, over a period of 5 years we counted 94% of the birds on one single day. Leaving out the count of 20/12/2010 results in a completely different coefficient estimate of -0.67, being much more similar to the -0.98 coefficient found for the Thorntonbank.

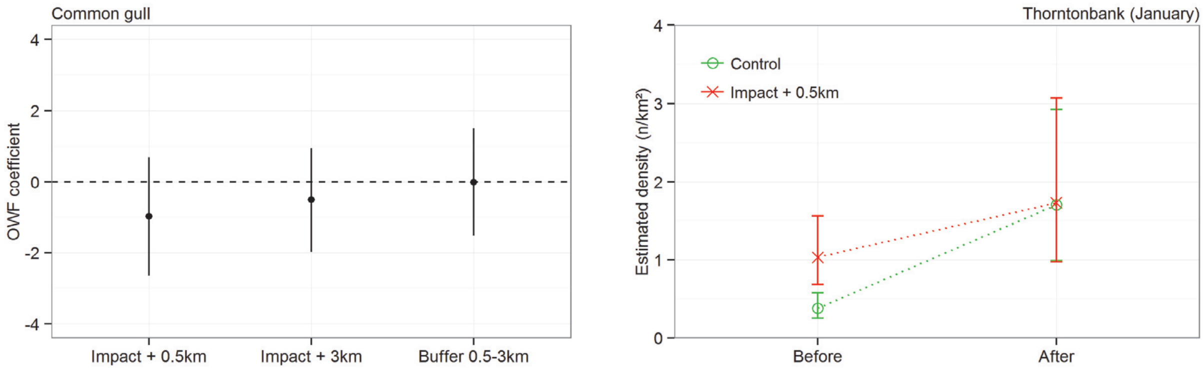

Figure 14. Modelling results for common gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

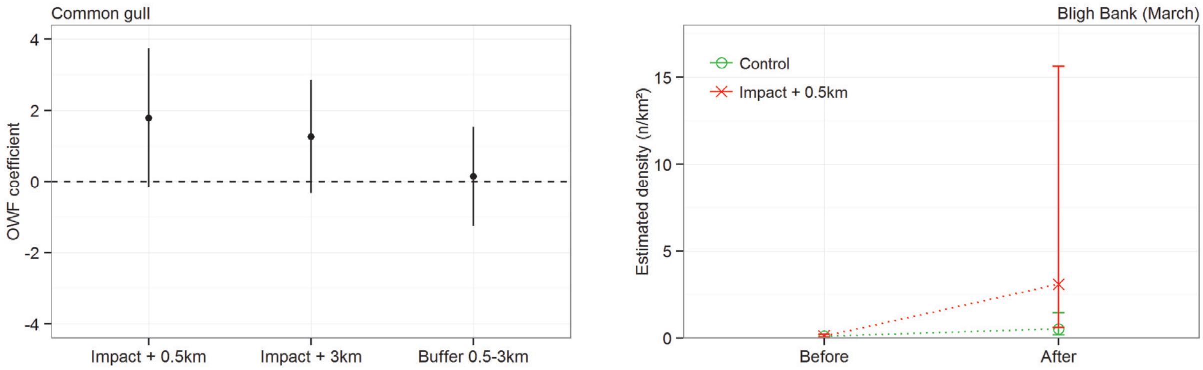

Figure 15. Modelling results for common gull in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.6 Lesser black-backed gull

The highly positive OWF coefficients found for the Bligh Bank three years after impact (Vanermen *et al*. 2015a) still prevailed after 5 years of post-impact monitoring, and the increase in numbers is now estimated at a factor 8.1 for the 'impact + 0.5 km' area and a factor 7.7 for the buffer area, illustrating a strong attraction effect. At the Thorntonbank, however, no such effect was observed and densities remained at a high level of almost 6 birds/km² throughout the study area. Adjusting for birds associated with the turbines did not result in major changes in the outcome. Interestingly, there is a clear onshore-offshore gradient in the occurrence of lesser black-backed gulls in the BPNS with numbers dropping quickly beyond 20 nautical miles offshore (Vanermen *et al.* 2013). This is also illustrated by the background densities as measured in both study areas with almost 6 birds/km² at the Thorntonbank and only about 1 bird/km² at the Bligh Bank. The marked difference in response of lesser black-backed gulls towards the presence of an OWF between these two locations seems to support the stepping stone theory, in which the presence of OWFs with its numerous roosting possibilities allow birds to extend their natural distribution further offshore.

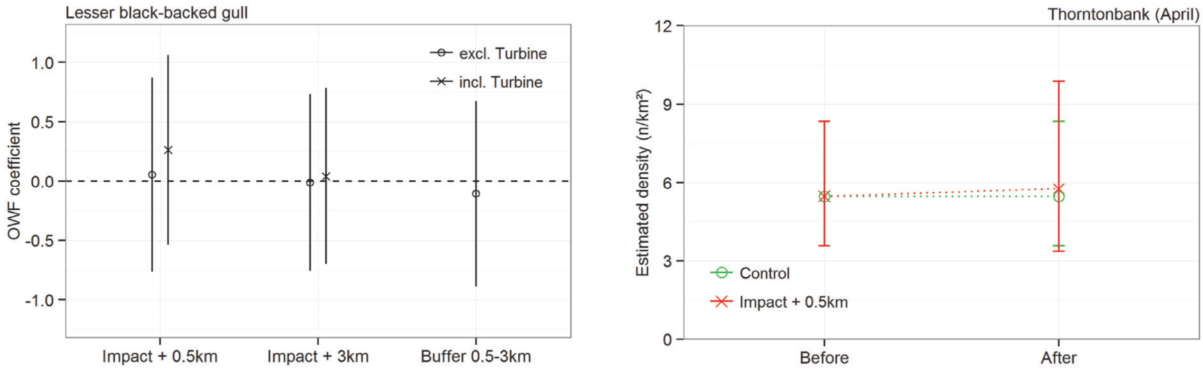

Figure 16. Modelling results for lesser black-backed gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers (exclusive turbine associated birds) on the right.

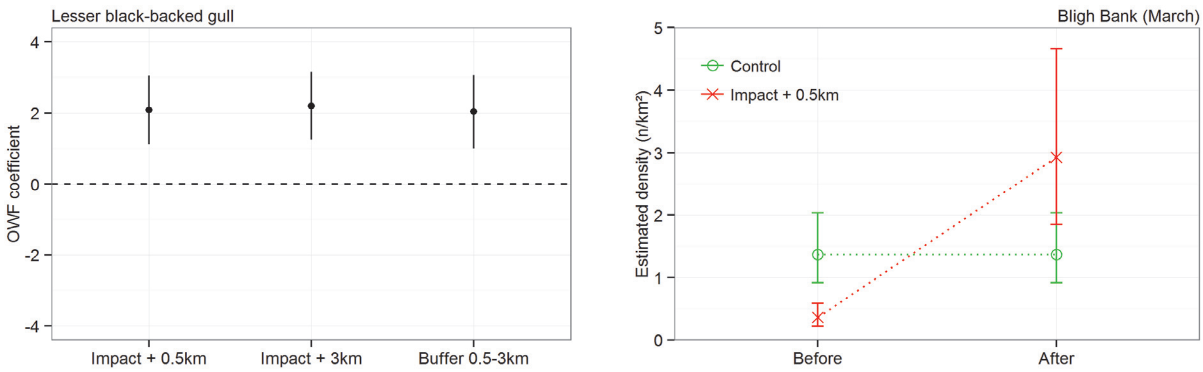

Figure 17. Modelling results for lesser black-backed gull in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.7 Herring gull

At the Thorntonbank, fairly constant spring densities (≈0.4 birds/km²) of herring gull were observed throughout the study period. The OWF coefficient for the wind farm area itself (‘impact + 0.5 km’) is about zero, and accounting for birds associated with the turbines did not result in major changes in the estimated OWF coefficients. For the buffer area, we found a significant negative effect of -1.66, corresponding to a drop in numbers of 81%. From an ecological point of view, however, this drop in density is hard to explain.

The highly positive OWF coefficient found for herring gull densities at the Bligh Bank after 3 years of impact monitoring (Vanermen *et al*. 2015a) did not fully withstand the test of time. After 2 more years of post-impact monitoring the OWF coefficient dropped from 2.25 to 1.47, and is now only borderline significant. This drop in effect is fairly easy explained by the fact that only one high count is responsible for the positive coefficients obtained at the Bligh Bank (see also common gull). On 20/12/2010, 139 herring gulls were observed inside the transect and inside the wind farm. Later on, herring gulls were observed on 7 occasions only. When dropping this single survey from the analysis the OWF coefficient drops from 1.47 to 0.05.

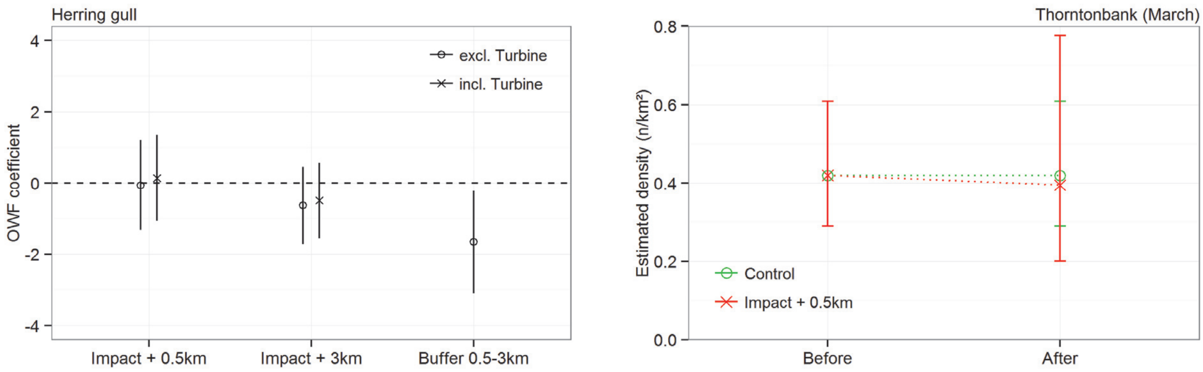

Figure 18. Modelling results for herring gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers (exclusive turbine associated birds) on the right.

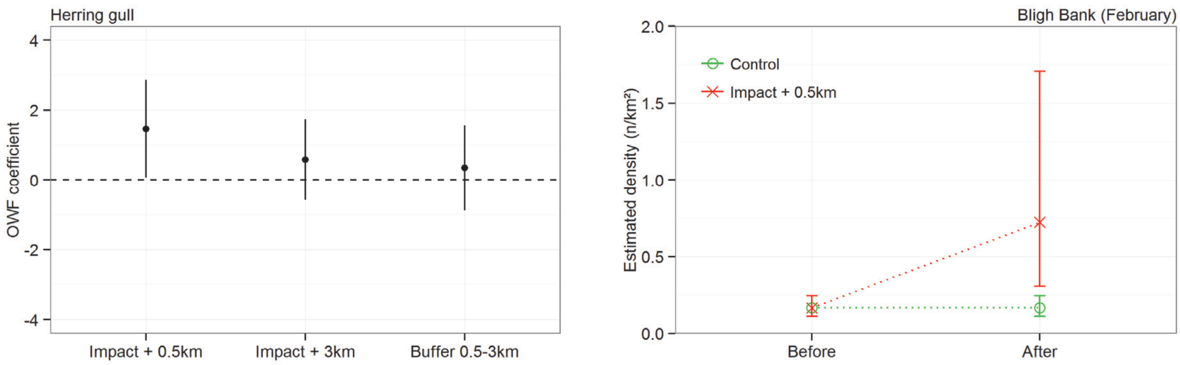

Figure 19. Modelling results for herring gull in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.8 Great black-backed gull

In contrast to the two previous species, great black-backed gull does show some consistency in results between both investigated sites. At the Thorntonbank, the standard analysis results in OWF coefficients close to zero. But when taking in account the numerous birds observed roosting on the jacket foundations, OWF coefficients become highly positive, with e.g. a value of 1.86 for the 'impact + 0.5 km' area, corresponding to an increase in numbers by a factor 6.4. At the Bligh Bank too, strongly positive and significant OWF coefficients were found, i.e. 1.29 for the 'impact + 0.5 km' area (~ factor 3.6 increase), the positive effect of 0.61 in the buffer area being no longer significant. The effect at the Bligh Bank has thus become much stronger than the previously reported 0.38 OWF coefficient after three years of post-impact monitoring (Vanermen *et al*. 2015a).

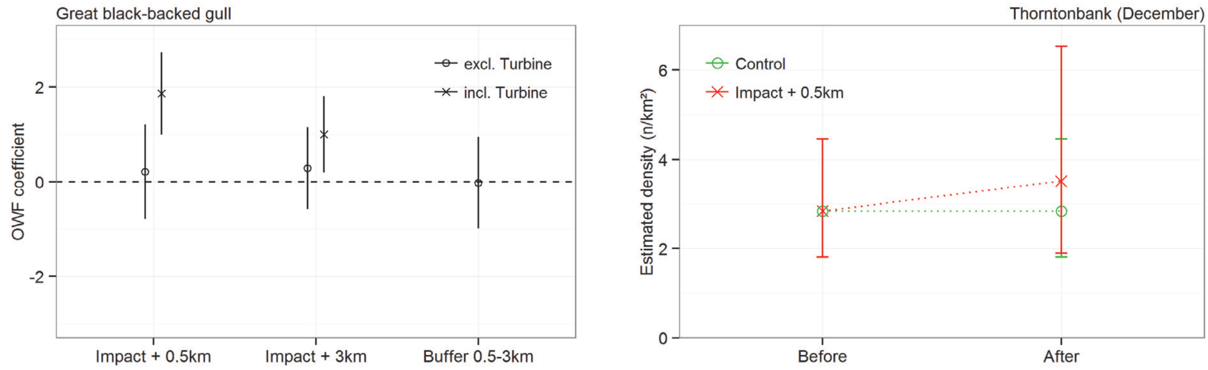

Figure 20. Modelling results for great black-backed gull in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers (exclusive turbine associated birds) on the right.

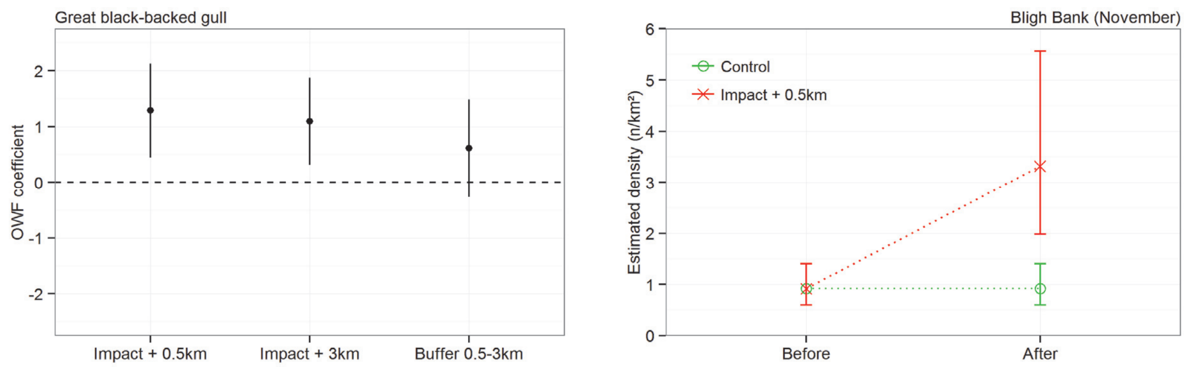

Figure 21. Modelling results for great black-backed gull in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.9 Black-legged kittiwake

Results for black-legged kittiwake strongly differed between locations, with slightly positive non-significant coefficients at the Bligh Bank (0.26-0.43) compared to significantly negative coefficients at the Thorntonbank. According to our BACI models, black-legged kittiwakes decreased in numbers by 86% and 57% in the Thorntonbank 'impact + 0.5 km' and 'buffer 0.5 - 3 km' areas respectively.

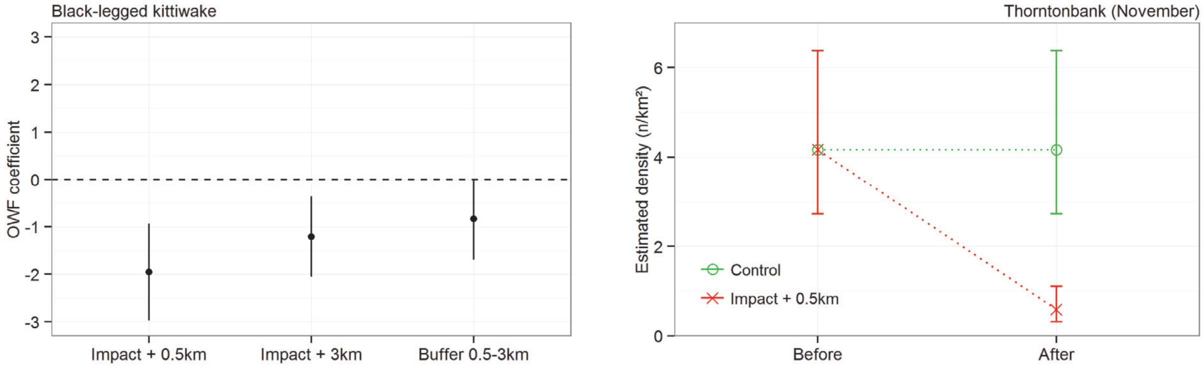

Figure 22. Modelling results for black-legged kittiwake in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

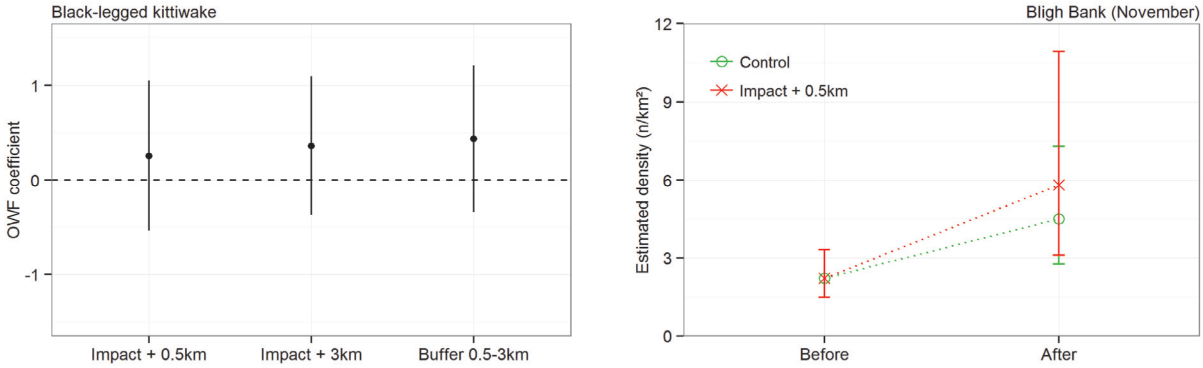

Figure 23. Modelling results for black-legged kittiwake in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.10 Sandwich tern

In the Thorntonbank study area, numbers of Sandwich tern show a less marked decrease in the impact area as opposed to the control area, resulting in positive OWF coefficients. In the buffer zone, the model predicts a significant increase in numbers by a factor 5.6. Despite statistical significance, results should be interpreted with care due to the very low number of positive observations after impact (2 observations inside the OWF and 4 in the buffer zone). On the other hand, when only 6 turbines were present (phase I – see Table 1) we also found a significantly positive OWF coefficient for the 3 km buffer zone (Vanermen *et al*. 2013).

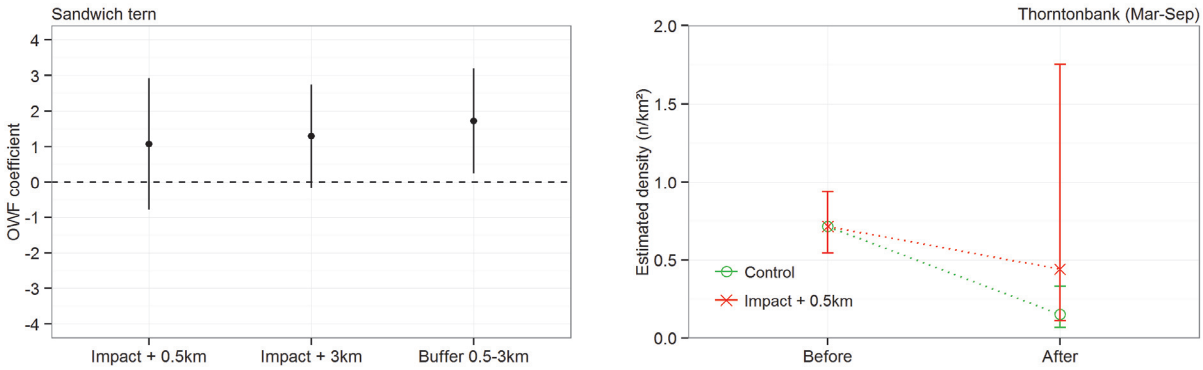

Figure 24. Modelling results for Sandwich tern in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the period March to September on the right (but note that zero-inflation equals 74%).

3.3.11 Common tern

Before the construction of the OWF at the Thorntonbank, positive observations of common tern were already few (2 in the control area & 5 in the impact area). After impact, however, no positive observations were made at all, neither in the impact nor in the control area (see Figure 25). As a 100% decrease in numbers occurred in both areas, there can be no demonstrable effect of the presence of the wind farm.

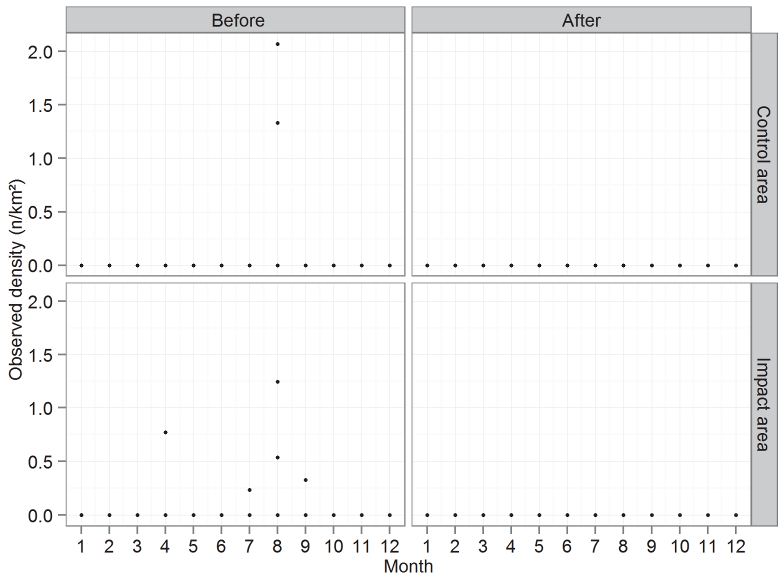

Figure 25. Observed densities of common tern in the control and impact area before and after the construction of the OWF at the Thorntonbank.

3.3.12 Common guillemot

Our BACI study showed common guillemots to avoid both wind farms under study. The significantly negative OWF coefficients of -1.13 and -1.39 correspond to a decrease in numbers of 68% and 75% respectively. In the buffer area coefficients are still negative with -0.27 at the Thorntonbank and -0.68 at Bligh Bank, corresponding to a decrease of 24 and 49% respectively. In case of the former, however, the decrease in the buffer area proved not statistically significant. These results are highly comparable to the decrease of 71% reported three years after turbine construction at the Bligh Bank (Vanermen *et al*. 2015a).

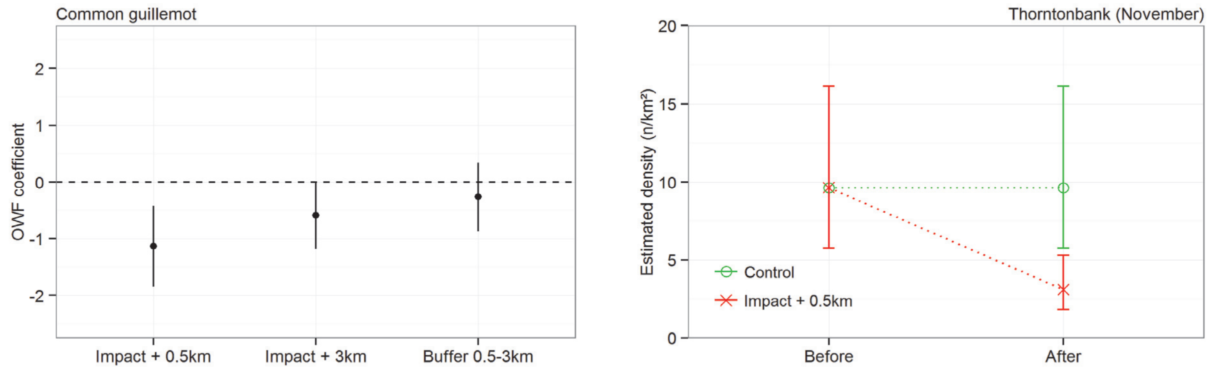

Figure 26. Modelling results for common guillemot in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right (but note that zero-inflation equals 10%).

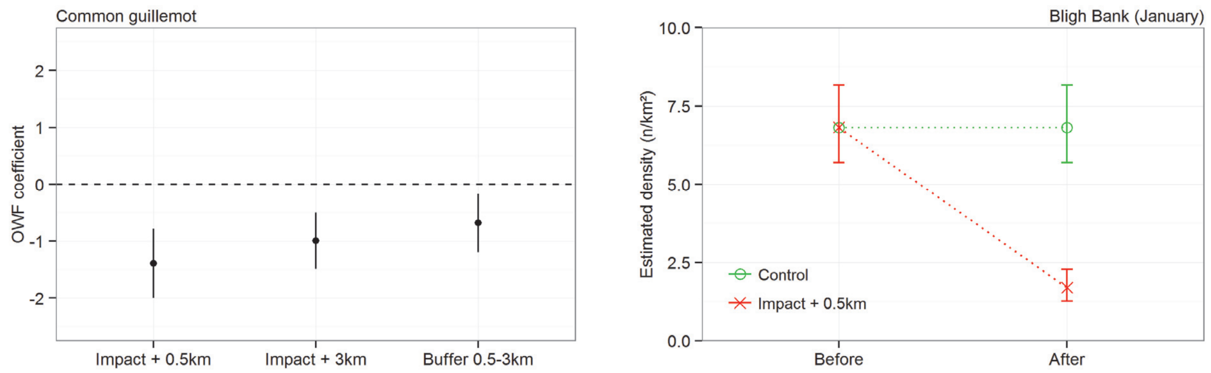

Figure 27. Modelling results for common guillemot in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.3.13 Razorbill

Results for razorbill suggest avoidance of offshore wind farm areas. At the Bligh Bank study area, the significantly negative OWF coefficient found for the 'impact + 0.5 km' area equals -1.12 and corresponds to a decrease in numbers by 67%. This result is very similar to the OWF coefficient of -1.01 reported in Vanermen *et al.* (2015a). On the other hand, the OWF coefficient calculated for the 'buffer 0.5 - 3 km' area is limited to -0.39 (~ 32% decrease), and does not differ significantly from zero. At the Thorntonbank, none of the OWF coefficients proved to be statistically significant, but a negative coefficient of -0.80 (~ 55% decrease) was found for the 'impact + 0.5 km' area.

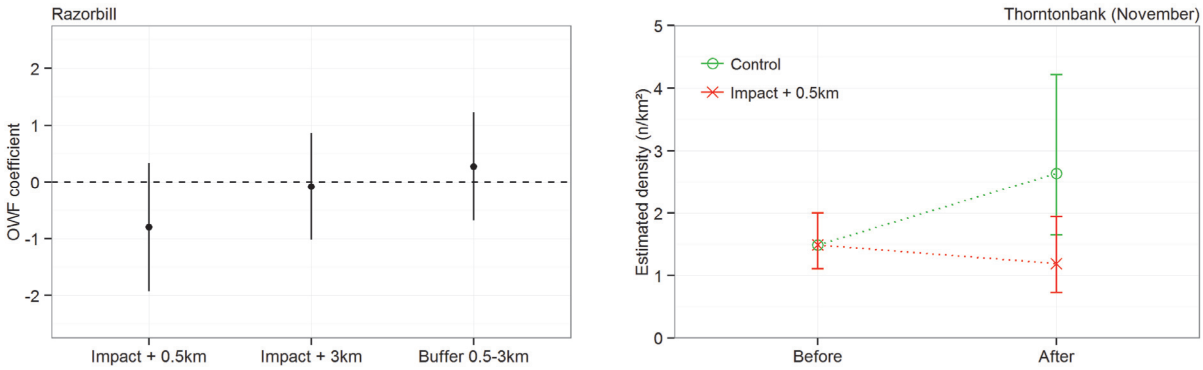

Figure 28. Modelling results for razorbill in the Thorntonbank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

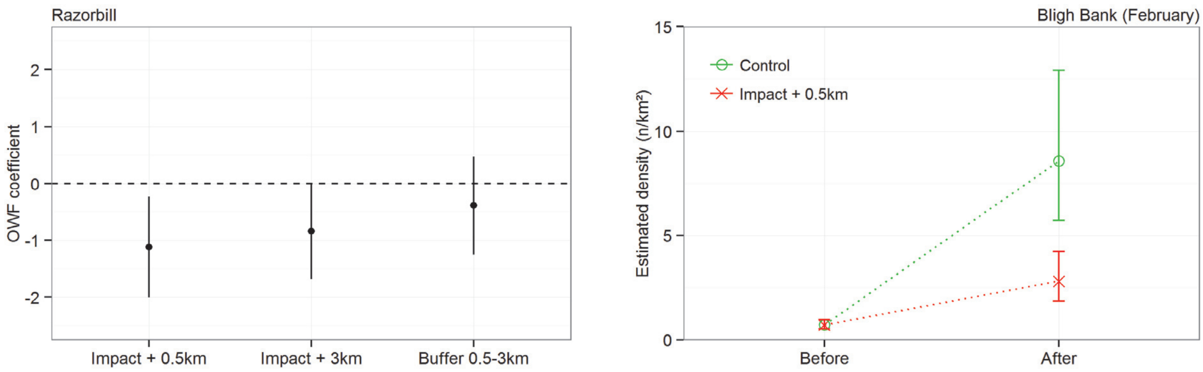

Figure 29. Modelling results for razorbill in the Bligh Bank study area with OWF coefficients and their 95% confidence intervals on the left and BACI density estimates for the month with maximum numbers on the right.

3.4 Summarizing tables

Our BACI results are summarized in Table 4 & 5, which list all OWF coefficients and corresponding P values as estimated during the modelling process. All impact model coefficients are displayed in the Tables 6 & 7 in appendix.

Table 4. BACI modelling results for the C-Power wind farm at the **Thorntonbank** after 3 years of operation, with indication of the displacement-related OWF model coefficients and their respective P values; model results based on an adjusted response variable including turbine-associated birds 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).

	Impact + 0.5 km		Impact + 3 km		Buffer 0.5-3 km	
	OWF Coefficient	P-Value	OWF Coefficient	P-Value	OWF Coefficient	P-Value
Northern fulmar	-20.98	0.999	-0.54	0.669	0.08	0.949
Northern gannet	-4.70	0.000***	-1.40	0.000***	-0.92	0.020*
Great skua	-23.08	1.000	0.54	0.701	1.15	0.409
Little gull	-2.01	0.018*	0.59	0.345	1.18	0.058.
Common gull	-0.98	0.252	-0.51	0.493	-0.01	0.989
Lesser black-backed gull	0.05	0.899	-0.01	0.972	-0.11	0.786
Lesser black-backed gull (T)	0.26	0.519	0.04	0.914		
Herring gull	-0.06	0.923	-0.63	0.258	-1.66	0.024*
Herring gull (T)	0.14	0.818	-0.49	0.365		
Great black-backed gull	0.21	0.676	0.28	0.522	-0.02	0.960
Great black-backed gull (T)	1.86	0.000***	1.00	0.014*		
Black-legged kittiwake	-1.95	0.000***	-1.21	0.005**	-0.84	0.055.
Sandwich tern	1.07	0.258	1.29	0.082.	1.72	0.022*
Common guillemot	-1.13	0.002**	-0.59	0.048*	-0.27	0.392
Razorbill	-0.80	0.167	-0.08	0.869	0.27	0.577

Table 5. BACI modelling results for the Belwind wind farm at the **Bligh Bank** after 5 years of operation, with indication of the displacement-related OWF model coefficients and their respective P values (P<0.10., P<0.05*, P<0.01**, P<0.001***; red cells indicate significant avoidance, green cells indicate significant attraction).

	Impact + 0.5 km		Impact + 3 km		Buffer 0.5-3 km	
	OWF Coefficient	P-Value	OWF Coefficient	P-Value	OWF Coefficient	P-Value
Northern fulmar	-2.54	0.053.	-3.13	0.015*	-22.93	0.999
Northern gannet	-1.72	0.002**	-0.95	0.051.	-0.30	0.551
Great skua	-19.45	0.998	-1.95	0.083.	-1.03	0.364
Little gull	-0.98	0.277	-0.22	0.784	0.23	0.773
Common gull	1.79	0.074.	1.26	0.122	0.14	0.842
Lesser black-backed gull	2.09	0.000***	2.20	0.000***	2.04	0.000
Herring gull	1.47	0.040*	0.58	0.326	0.35	0.578
Great black-backed gull	1.29	0.003**	1.09	0.006**	0.61	0.168
Black-legged kittiwake	0.26	0.525	0.36	0.332	0.43	0.273
Common guillemot	-1.39	0.000***	-0.99	0.000***	-0.68	0.009**
Razorbill	-1.12	0.013*	-0.84	0.049*	-0.39	0.376

4 Discussion

In this report we presented the results of our monitoring study on seabird displacement effects following the construction of offshore wind farms in the BPNS. For the first time after its completion in 2013 we did so for the C-Power wind farm at the Thorntonbank, and we also gave an update of the results for the Bligh Bank wind farm after five years of post-impact monitoring. Monitoring at the Bligh Bank has now been temporarily put on hold and the program is to be resumed during post-impact years 10 to 12, to study whether earlier observed effects still prevail or otherwise if some form of habituation towards the wind farm presence has occurred among residing seabirds.

In order to further increase the reliability of our data analyses, we introduced some adjustments to our methodology. In the first place we performed multi-covariate distance sampling to correct the observed numbers of seabirds for decreasing detectability with distance, allowing the species-specific detection functions to vary with observation conditions and group size (Buckland *et al*. 2001, Thomas *et al*. 2010, Marques & Buckland 2003). Typically, detection probability decreased with wave height or wind force and increased with group size. Correcting the observed seabird numbers according to the estimated detection probabilities thus reduced temporal variation resulting from varying observation conditions.

Secondly, we applied a different model selection approach compared to earlier reports (e.g. Vanermen *et al*. 2013), moving away from a step by step model selection strategy. Instead we identified a relatively large set of candidate models and chose a single best model based on the ‘Akaike Information Criterion’ (AIC). While the resulting model will mostly be the same as the one obtained through step by step model selection, a major advantage of this so-called information-theoretic approach is that listing all AIC values in one matrix gives a good and instantaneous overview of how different candidate models relate to one another in terms of likelihood (AIC being a log-likelihood based criterion). Using this strategy clarifies that differences in AIC are sometimes very small (<1), implying there is more than one ‘good’ model, each of them estimating the wind farm effect somewhat differently. The differences in AIC values among a set of models can be recalculated to relative model probabilities (‘Akaike weights’), and the ratio between two of these model probabilities can be regarded as the odds. For example, when two models differ in AIC by 1 unit, the model with the lowest value is only 1.6 times more likely to be the best of both. On the other hand, the relation between difference in AIC and model probability is highly non-linear and when models differ in AIC by 10 units, the odds are already 148 to 1 in favour of the model with the lowest AIC. Knowing all this, it was tempting to perform multi-model inference (MMI, Burnham & Anderson 2002), in which ‘Akaike weights’ are calculated for a set of candidate models, which in turn can be used to calculate a weighted average of their coefficient estimates. When performing an exploratory MMI for several species (at least for those showing marked OWF effects), the multi-model inferred OWF coefficient estimate was always very close to the value estimated by the single best model strategy. Coefficients of the single best models of common guillemot for example were -1.13 and -1.39 for the Thorntonbank and Bligh Bank, while through MMI, values of respectively -1.16 and -1.36 were obtained. For northern gannet, single best model coefficients were -4.70 and -1.72, compared to MMI coefficients of -4.68 and -1.86. Great black-backed gull at last showed OWF coefficients of 1.86 and 1.29 for the Thorntonbank and Bligh Bank, with the MMI exercise resulting again in highly comparable coefficients of 1.80 and 1.35. These results show that our modelling strategy leads to quite balanced and robust results, emphasizing the qualitative and quantitative value of the OWF coefficients found and listed in Tables 4 & 5.

A third and last optimization in our modelling strategy was the inclusion of a fishery factor in the models. As expected, the presence of fishery activity in or in the vicinity of the study area greatly influenced the number of scavenging seabirds present and often explained a significant part of the variation in our count data (Tables 6 & 7 in appendix). On the other hand, we should emphasize that a simple true-false covariate based on the observation of one or more beam trawlers within 3 km of the monitoring track is a very raw measure of fishing activity and it would be much better to obtain a quantitative measure of actual trawling activity in the hours preceding the seabird surveys based for example on AIS vessel tracking information.

In the context of seabird displacement monitoring and offshore wind farming, a before-after gradient (BAG) design has recently been recommended as a preferred alternative to the classic BACI design (JNCC 2015). In a BACI framework, the impact effect is calculated based on the assumption that without the impact a parallel trend in numbers as observed in the control area(s) would have occurred in the impact area. A reliable BACI analysis thus largely depends on the possibility of being able to delineate one or more suitable control areas, which might not always be the case. A BAG approach on the other hand assumes any pre- and post-impact changes to be a function of distance and that any impact-related effects are the same in all directions from the impact source (Oedekoven *et al.* 2013). When abundance and distribution of animals would change over time in an area without the introduction of any anthropogenic impact, one would expect such post-impact changes to be distributed without major reference to the impacted location. On the contrary, impact-related changes are most likely to occur in and around the impacted site and significant changes centered around the impact site therefore provide compelling evidence for impact-related effects (MacKenzie *et al*. 2013). In preliminary analyses we tested whether our BACI designed monitoring data could in fact be processed applying a BAG analysis, and for some species this appeared to work out beautifully. However, a well-designed BAG study is supposed to generate data of a wide area with the wind farm located in the middle, allowing to test the aforementioned assumption that a potential OWF effect declines with distance in all directions. Our survey tracks on the other hand were designed in a way that the study area has a rectangular shape with the OWF located in the corner, implying we can test the 'gradient' assumption sufficiently in only one direction. More problematic is the fact that both our OWFs are located at the edge of the study area polygon and that spatial smoothers suffer from edge effects exactly at our points of interest. At the moment, we feel that pushing our BACI designed data in a BAG analysis can provide nice visual presentation of OWF related impact effects, but can never match the potential additive value in terms of statistical evidence of an a priori BAG designed monitoring study.

With five years of post-impact monitoring at the Bligh Bank and three years at the Thorntonbank, there are now two relatively well-studied offshore wind farms in the Belgian part of the North Sea. Ideally, both sites could be regarded as 'replicates', but this is clearly not the case. On the contrary, both sites differ strongly in background densities of seabirds, environmental variables, wind farm layout and turbine characteristics, and each of these factors may influence displacement effects in their own way. It is therefore very interesting to compare the results obtained at both sites, and we see that for some species there is a striking consistency, while for others we observed opposite effects.

Northern gannet and common guillemot avoid both the Thorntonbank and Bligh Bank OWF, while great black-backed gull is attracted to both. Razorbill decreased in numbers at the two sites, this decrease being significant at the Bligh Bank only. As shown through power analyses, it might be a simple matter of time before the observed decrease of razorbill at the Thorntonbank proves to be statistically significant as well (Vanermen *et al.* 2015b). Interestingly, the previously reported significant effects after three years of post-impact monitoring at the Bligh Bank (Vanermen *et al*. 2015a) were all confirmed after five years, illustrating the robustness in results.

Other more or less consistent results, yet not necessarily significant, were obtained for northern fulmar and little gull. Numbers of northern fulmar significantly decreased at the Thorntonbank, while the species was not observed once inside the Bligh Bank OWF boundaries after impact. Little gull showed an interesting combination of negative coefficients in the OWF areas itself, opposed to positive coefficients in the surrounding buffer zones. This pattern is most marked at the Thorntonbank and accordingly, we reported attraction effects of little gull to the immediate surroundings of the phase I of the C-Power wind farm (Vanermen *et al*. 2013). Sandwich tern was not studied at the Bligh Bank because the species is largely absent there, but appeared to be attracted to the OWF at the Thorntonbank, this effect being significant for the buffer zone. As for little gull, this is in line with the results for the phase I of the C-Power wind farm during which we also found attraction of Sandwich tern to the surroundings of the six turbine row (Vanermen *et al*. 2013). The results for the latter two species correspond to findings in Denmark and the Netherlands where terns and little gulls were also observed to be attracted to the wind farm edges rather than to the OWF area itself (Petersen *et al*. 2006, Krijgsveld *et al*. 2011).

For other species, however, results appeared more inconsistent. Black-legged kittiwake avoided the Thorntonbank wind farm area while an opposite (yet non-significant) effect was observed at the Bligh Bank. The previously reported attraction effects of lesser black-backed and herring gull at the Bligh Bank were confirmed after two more years of monitoring, but no attraction seemed to occur in the more nearshore Thorntonbank wind farm. Interestingly, the Thorntonbank lies just within these two species' normal distribution range, while the Bligh Bank is located further offshore. With OWFs offering increased roosting possibilities, OWFs have been shown to serve as a stepping stone allowing birds to colonize areas that are otherwise off limit (Leopold *et al*. 2013). A stepping stone effect is likely to be much stronger outside compared to inside a bird's normal distribution and the marked difference in OWF effect between both sites therefore seems to support this theory. On the other hand it has also been hypothesized that seabirds may profit from increased food availability due to the so-called 'reef effect' following the introduction of turbine foundations as hard substrate in an otherwise sandy marine environment. But until this moment, this remains unproved and possibly also hard to detect based on ship-based seabird surveys. If birds would actually concentrate in OWFs for foraging purposes, this is likely to occur in a tidal-dependent way. Large gulls for example are now regularly observed feeding on mussels in the lower regions of the jacket foundations during low tide, and have also been observed foraging in the turbulent wake of the turbines during times of high tidal current. Unfortunately, during ship-based seabird surveys, the OWFs themselves are visited during limited time frames of about 1.5 hours. More ideally, repeated point-based observations are made over a full tidal cycle and the recently installed fixed camera at one of the turbines in the Thorntonbank OWF opens possibilities to do so without major logistical constraints. We therefore plan hourly counts of birds associated with the turbines, to look for possible tidal effects on their presence. At first sight, detecting birds on the water through this camera appears to be particularly challenging. Nevertheless, being able to do so seems indispensable to find out what birds are doing in the wind farms when they are not roosting on the foundations. Do they leave the area, thus supporting the stepping stone theory? Or do they remain within the OWF boundaries to look for food in the area itself? Analysing the GPS-data of lesser black-backed and herring gulls tagged in the colonies at Zeebrugge and Oostende may further help to understand patterns in the interaction between gulls and OWFs, provided of course that sufficient data of tagged birds coming to visit the OWFs can be gathered. If camera and GPS data would appear insufficient we still could go for full day observations from one of the turbine foundations or a transformation platform deck.

5 Conclusions

After five years of post-impact monitoring at the Bligh Bank OWF and three years at the Thorntonbank OWF we found significant avoidance by northern gannet and common guillemot at both sites. Common guillemot decreased in densities by 68% and 75% at the Thorntonbank and Bligh Bank respectively, and northern gannet by 99 and 82%. Razorbill decreased in numbers at the two sites, this decrease being significant at the Bligh Bank only (67%). Both sites attracted great black-backed gulls, this species having increased in numbers by a factor 6.4 and 3.6 at the Thorntonbank and Bligh Bank respectively. The previously reported attraction effects of lesser black-backed gull and herring gull at the Bligh Bank were confirmed after two more years of monitoring, but no such effect was observed at the Thorntonbank. Sandwich tern appeared to be attracted to the OWF at the Thorntonbank, this effect being significant for the buffer zone.

While the avoidance of common guillemot and northern gannet seems readily interpretable from a disturbance perspective, it is still difficult to pinpoint the observed increases in seabird numbers, even more so because these are not always consistent between both sites under study. Gaining more insight in the diurnal and tidal-dependent variation in numbers and behaviour of birds occurring inside the OWFs seems indispensable for understanding the observed patterns and learning whether birds come to the OWFs merely for roosting and the related stepping stone function, or whether OWFs also offer increased food availability.

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Appendix

Table 6. 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	Impact + 0.5 km	0.49	-0.70	0.53					-1.97	-1.14		-20.98	0.94	0.75
	Impact + 3 km	0.47	-0.77	0.35					-2.11	-1.11		-0.54	0.83	0.76
	Buffer 0.5-3 km	0.47	-0.78	0.34					-2.11	-1.10		0.08	0.82	0.76
Northern gannet	Impact + 0.5 km	-0.46	s(month)									-4.70	0.29	
	Impact + 3 km	-0.47	s(month)									-1.40	0.30	
	Buffer 0.5-3 km	-0.47	s(month)									-0.92	0.30	
Great skua	Impact + 0.5 km	-4.22	-2.59	0.49	0.82	1.02			-1.51	-1.68		-23.08	0.50	
	Impact + 3 km	-4.07	-2.25	0.61	0.96	0.89			-1.62	-1.66		0.54	0.50	
	Buffer 0.5-3 km	-4.08	-2.25	0.61	0.96	0.88			-1.62	-1.66		1.15	0.50	
Little gull	Impact + 0.5 km	-2.22	s(month)									-2.01	0.12	
	Impact + 3 km	-2.34	s(month)									0.59	0.13	
	Buffer 0.5-3 km	-2.33	s(month)									1.18	0.13	
Common gull	Impact + 0.5 km	-3.95	2.32	2.11					1.49	0.99	1.38	-0.98	0.26	
	Impact + 3 km	-3.84	2.21	2.04					1.30	1.11	1.05	-0.51	0.28	
	Buffer 0.5-3 km	-3.77	2.22	2.00					1.27	1.08	0.80	-0.01	0.26	
Lesser black-backed gull	Impact + 0.5 km	-0.51	s(month)								1.09	0.05	0.31	
	Impact + 0.5 km (T)	-0.51	s(month)								1.06	0.26	0.32	
	Impact + 3 km	-0.44	s(month)								0.77	-0.01	0.31	
	Impact + 3 km (T)	-0.44	s(month)								0.78	0.04	0.31	
	Buffer 0.5-3 km	-0.43	s(month)								0.67	-0.11	0.29	

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	Impact + 0.5 km	-2.48	1.62	0.03							0.96	-0.06	0.16	
	Impact + 0.5 km (T)	-2.49	1.61	-0.02							1.04	0.14	0.17	
	Impact + 3 km	-2.48	1.56	0.06							0.98	-0.63	0.19	
	Impact + 3 km (T)	-2.48	1.54	0.02							1.04	-0.49	0.19	
	Buffer 0.5-3 km	-2.58	1.59	0.13							1.32	-1.66	0.17	
Great black-backed gull	Impact + 0.5 km	-1.86	-0.05	2.18			0.10	0.72			1.33	0.21	0.22	
	Impact + 0.5 km (T)	-1.81	-0.02	1.83			0.12	0.48			1.51	1.86	0.26	
	Impact + 3 km	-1.82	s(month)								1.65	0.28	0.24	
	Impact + 3 km (T)	-1.65	s(month)								1.66	1.00	0.26	
	Buffer 0.5-3 km	-2.38	-0.17	2.58	0.88	-0.73					2.15	-0.02	0.21	
Black-legged kittiwake	Impact + 0.5 km	-0.76	s(month)								1.14	-1.95	0.26	
	Impact + 3 km	-0.80	s(month)								1.26	-1.21	0.28	
	Buffer 0.5-3 km	-0.80	s(month)								1.32	-0.84	0.27	
Sandwich tern	Impact + 0.5 km	-0.34							-1.55			1.07	1.55	0.74
	Impact + 3 km	-0.42							-1.63			1.29	1.17	0.69
	Buffer 0.5-3 km	-0.38							-1.62			1.72	1.29	0.71
Common guillemot	Impact + 0.5 km	-2.55	1.39	6.21	-1.13	-1.69						-1.13	0.97	0.10
	Impact + 3 km	-2.76	1.57	6.48	-1.30	-1.87						-0.59	0.94	0.12
	Buffer 0.5-3 km	-2.86	1.69	6.61	-1.39	-1.91						-0.27	0.89	0.11
Razorbill	Impact + 0.5 km	-6.33	0.99	9.43	-0.94	-3.51			0.57			-0.80	0.47	
	Impact + 3 km	-6.50	1.25	9.67	-1.27	-3.61			0.56			-0.08	0.50	
	Buffer 0.5-3 km	-6.43	1.25	9.56	-1.28	-3.60			0.55			0.27	0.49	

Table 7. Impact model coefficients for all species studied at the Bligh Bank 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	Impact + 0.5 km	-0.66	0.26	0.83	-0.27	1.09			-1.69		1.14	-2.54	1.13	0.68
	Impact + 3 km	-0.65	0.26	0.81	-0.27	1.08			-1.74		1.19	-3.13	1.13	0.68
	Buffer 0.5-3 km	-0.69	0.41	0.79	-0.31	1.26			-1.87		1.47	-22.93	1.26	0.68
Northern gannet	Impact + 0.5 km	-1.33	-0.07	1.10			-0.86	-0.22	0.79	-0.52		-1.72	0.47	
	Impact + 3 km	-1.31	0.03	1.07			-0.71	-0.26	0.73	-0.50		-0.95	0.49	
	Buffer 0.5-3 km	-1.31	0.06	1.09			-0.64	-0.30	0.74	-0.51		-0.30	0.45	
Great skua	Impact + 0.5 km	-1.48							-1.05			-19.45		0.80
	Impact + 3 km	-1.49							-0.93			-1.95		0.79
	Buffer 0.5-3 km	-1.49							-0.93			-1.03		0.79
Little gull	Impact + 0.5 km	-9.82	8.48	6.66	-5.11	-0.10			2.58			-0.98	0.10	
	Impact + 3 km	-9.13	7.62	5.96	-4.59	-0.01			2.45			-0.22	0.10	
	Buffer 0.5-3 km	-8.97	7.34	5.85	-4.64	-0.16			2.38			0.23	0.10	
Common gull	Impact + 0.5 km	-6.13	2.41	4.70	-1.04	-1.60			1.47		2.46	1.79	0.14	
	Impact + 3 km	-6.11	2.35	4.69	-1.05	-1.65			1.43		2.39	1.26	0.16	
	Buffer 0.5-3 km	-6.81	3.00	5.85	-1.79	-1.95			1.41		1.62	0.14	0.18	
Lesser black-backed gull	Impact + 0.5 km	-1.33	s(month)							-1.33	1.07	2.09	0.29	
	Impact + 3 km	-1.36	s(month)							-1.38	1.07	2.20	0.29	
	Buffer 0.5-3 km	-1.38	s(month)							-1.42	1.09	2.04	0.25	
Herring gull	Impact + 0.5 km	-4.04	1.64	1.65							1.79	1.47	0.13	
	Impact + 3 km	-3.72	1.65	2.25			0.24	0.64			1.00	0.58	0.16	
	Buffer 0.5-3 km	-3.91	2.10	2.24			-0.18	0.69			0.88	0.35	0.16	
Great black-backed gull	Impact + 0.5 km	-2.07	s(month)									1.29	0.20	
	Impact + 3 km	-2.02	s(month)									1.09	0.22	
	Buffer 0.5-3 km	-2.01	s(month)									0.61	0.19	

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)
Black-legged kittiwake	Impact + 0.5 km	-1.55	0.81	2.46			-0.62	-0.26	0.70		0.92	0.26	0.34	
	Impact + 3 km	-1.59	0.91	2.52			-0.76	-0.28	0.54		1.24	0.36	0.35	
	Buffer 0.5-3 km	-1.58	0.96	2.53			-0.84	-0.21	0.41		1.47	0.43	0.33	
Common guillemot	Impact + 0.5 km	-1.24	1.34	2.87								-1.39	0.61	
	Impact + 3 km	-1.21	1.26	2.80								-0.99	0.71	
	Buffer 0.5-3 km	-1.18	1.19	2.74								-0.68	0.74	
Razorbill	Impact + 0.5 km	-6.40	2.92	7.13	-1.23	-2.06			2.49			-1.12	0.39	
	Impact + 3 km	-6.68	3.02	7.57	-1.36	-2.29			2.40			-0.84	0.37	
	Buffer 0.5-3 km	-6.78	3.08	7.77	-1.52	-2.41			2.34			-0.39	0.37	