

# SEABIRDS & OFFSHORE WIND FARMS

## MONITORING RESULTS 2010

### power & impact analyses

Nicolas Vanermen, Eric W.M. Stienen, Thierry Onkelinx, Pieter Verschelde, Wouter Courtens &  
Marc Van de walle



Study commissioned by the Royal Belgian Institute for Natural Sciences, Management Unit of the  
North Sea Mathematical Models



Research Institute for Nature and Forest  
Ministry of the Flemish Government  
Kliniekstraat 25  
B-1070 Brussels

Report INBO.R.2011.22  
July 2011



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# 1 Introduction

Despite its limited surface, the Belgian Part of the North Sea (BPNS) holds internationally important numbers of seabirds. The area is exploited by birds in a number of ways, and its specific importance varies throughout the year. During winter, maximum numbers are present with an average of 42 000 seabirds (Vanermen & Stienen 2009). The offshore bird community is dominated by auks and kittiwakes, while important numbers of grebes, scoters and divers reside inshore. In summer, fewer birds are present (on average 17 000 birds), but large numbers of terns and gulls exploit the area in support of their breeding colony located in the port of Zeebrugge. Furthermore, the BPNS is part of a very important seabird migration route through the southern North Sea: each autumn, an estimated 1.0 to 1.3 million seabirds migrate through this 'migration bottleneck' (Stienen *et al.* 2007).

The near future will see large scale exploitation of offshore wind energy, and a concession zone comprising almost 10% of the waters under Belgian jurisdiction is reserved for wind farms. Presently, six wind turbines have already been installed at the Thorntonbank (C-Power), while 55 turbines are present at the Blighbank (Belwind). Inevitably, this will affect the local seabird community and effects of wind turbines on birds range from direct mortality through collision, to more indirect effects like habitat change, habitat loss and barrier-effects (Desholm 2005, Drewitt & Langston 2006,...).

A monitoring study was set up to assess to what extent local densities of seabirds are affected by the presence of the turbines. It may be expected that some birds will avoid the wind farms, while others may be attracted to them due to an increase in food availability and roosting possibilities.

In the previous monitoring report (Vanermen *et al.* 2010) we presented our modelling set-up for the future impact analyses. Here we present an update of the results based on the data gathered over the year 2010. Secondly, to learn more about the statistical value of our count data we performed an extensive power analysis based on the data gathered during reference years.



## 2 Material & Methods

### 2.1 Reference areas

The study is based on a Before-After Control-Impact comparison (BACI design). Migrating birds show deflections in flight orientation from up to a distance of 1-5 km (Pettersen *et al.* 2005, Petersen *et al.* 2006) but little is known about the avoidance of swimming birds. However, a significant post-construction decrease in densities of divers, scoters and Long-tailed ducks was shown by Petersen *et al.* (2006) out to a distance of 3 km away from the Nysted wind farm in Denmark.

Therefore, we applied a buffer zone of at least 3 km around the future Belwind and C-Power wind farms to define our 'impact areas'. Following, we delineated two control areas based on the comparability in numbers and seasonality of seabirds occurring (see previous reports, e.g. Vanermen *et al.* 2010). Considering the large day-to-day variation in observation conditions and seabird densities, the distance between impact and control area had to be small enough to be able to count them both on the same day by means of a research vessel. The resulting control and impact areas are 1.5 km apart, equalling the geographical error on our transect counts. The control areas' surface spreads out from at least 4.5 to almost 20 km away from the nearest turbine, an area in which we do not expect overall densities of seabirds to be affected by the presence of turbines in the impact areas.

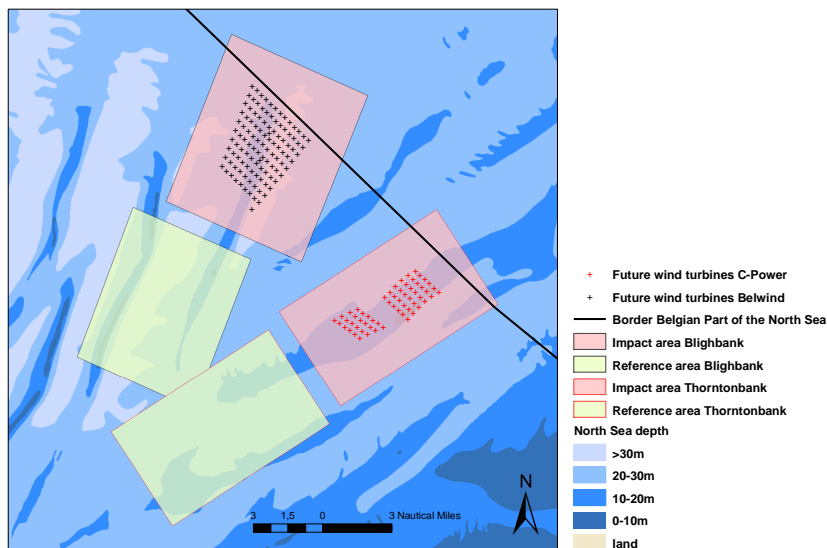
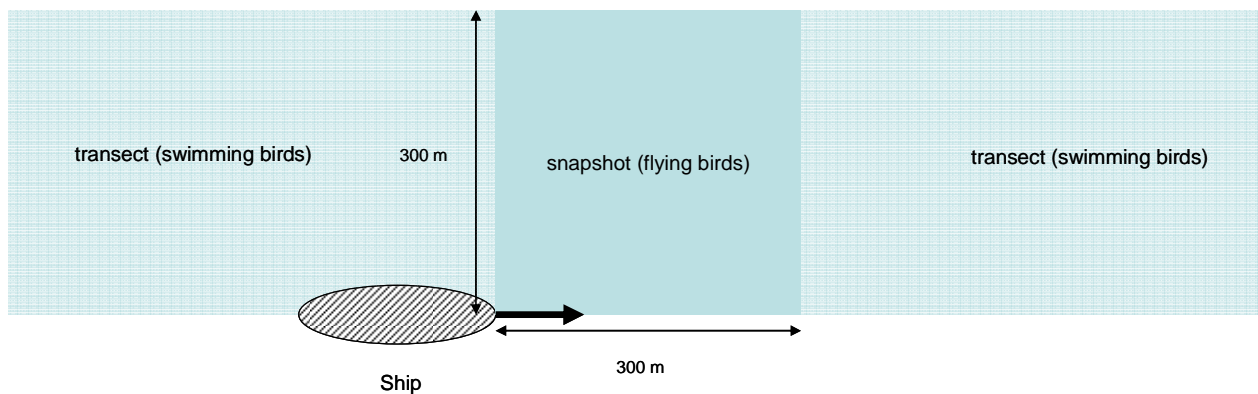


Figure 1. Control and impact areas for both future wind farms at the Thorntonbank and Blighbank.



## 2.2 Ship-based seabird counts

In the study areas, intensive monitoring took place through ship-based seabird counts from 2005 onwards. These are conducted according to a standardized and internationally applied method, as described by Tasker *et al.* (1984). While steaming, all birds in touch with the water (swimming, dipping, diving) located within a 300 m wide transect along one side of the ship's track are counted ('transect count'). For flying birds, this transect is divided in discrete blocks of time. During one minute the ship covers a distance of approximately 300 m, and at the start of each minute all birds flying within a quadrant of 300 by 300 m are counted ('snapshot count'). Taking the travelled distance into account, the count results can be transformed to seabird densities.



**Figure 2. Methodology of standardized seabird counts using a 300 m wide transect for swimming birds, and 'snapshot' counts (each minute) for flying birds.**

Our count method is in accordance to the ESAS-prescriptions, but the way of dealing with the count results is different. While the ESAS-database collects the results of ten-minute tracks, we lumped the count results per area (control/impact) and per monitoring month. This way, we avoided auto-correlation effects, and we minimized overall variance. To further minimize variation due to short-term temporal changes in seabird abundance and in weather and observation conditions, we included only those days at which both the impact and reference area were visited. Naturally, the current monitoring routes always include both of these areas, but this was not always the case in our historical data.



### 2.3 Monitoring species

Based on the reference data, Vanermen & Stienen (2009) concluded that the wind farm area at the Thorntonbank:

- has no particular value to Red-throated diver, Great crested grebe, Northern fulmar, Common scoter, Great skua and Herring gull
- is not particularly valuable to the following species, although high densities may occur: Northern gannet, Common gull, Lesser black-backed gull, Great black-backed gull, Black-legged kittiwake, Common guillemot, Razorbill
- is of particular value to Little gull, Sandwich tern and Common tern

A similar study on the Blighbank reference data resulted in the conclusions that the Blighbank wind farm area:

- is of no particular value to Red-throated diver, Great crested grebe, Northern fulmar, Common scoter, Common gull, Herring gull, Great black-backed gull, Sandwich tern, Common tern and Razorbill
- is not particularly valuable to the following species, although increased or high densities may occur: Northern gannet, Lesser black-backed gull, Black-legged kittiwake, Common guillemot
- is probably of particular value to Great skua and Little gull

Of course, special focus should go to those species for which the wind farm area is indicated to be of particular value. But also, we are interested in the general displacement effects caused by the presence of offshore wind farms. This includes avoidance by species that were present during the reference situation, as well as attraction of species that were uncommon or even absent during reference years. To anticipate on the full spectrum of possible displacement effects, we investigate a broad range of species, listed in Table 1.

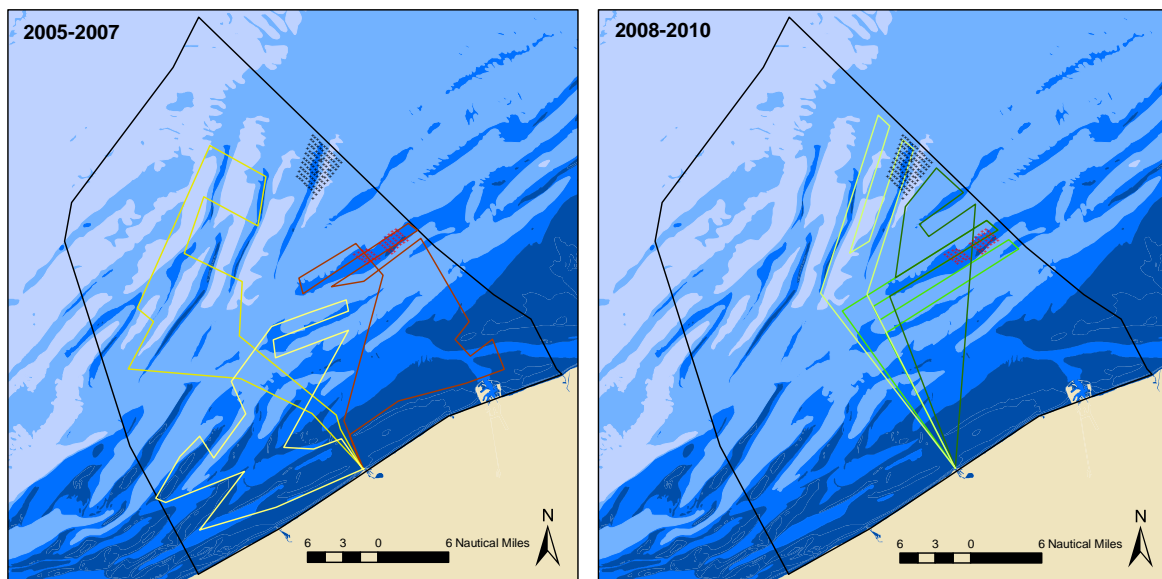
Because of their almost complete absence and clear coast bound distribution, Red-throated diver, Great crested grebe and Black scoter are left out of the analyses in this report. For the Blighbank this also accounts for the Annex I species Common tern and Sandwich tern, and for the Thorntonbank we did not include Great skua due to its rarity. Of course, all birds are counted during monitoring surveys, and if necessary, we may include any species in the analysis at any time.

**Table 1. Species included in the monitoring study at the Thorntonbank & Blighbank wind farms.**

<b>Species</b>	<b>Thorntonbank</b>	<b>Blighbank</b>
Northern fulmar	X	X
Northern gannet	X	X
Great skua		X
Little gull	X	X
Common gull	X	X
Herring gull	X	X
Lesser black-backed gull	X	X
Great black-backed gull	X	X
Black-legged kittiwake	X	X
Sandwich tern	X	
Common tern	X	
Common guillemot	X	X
Razorbill	X	X

## 2.4 Monitoring scheme and count effort

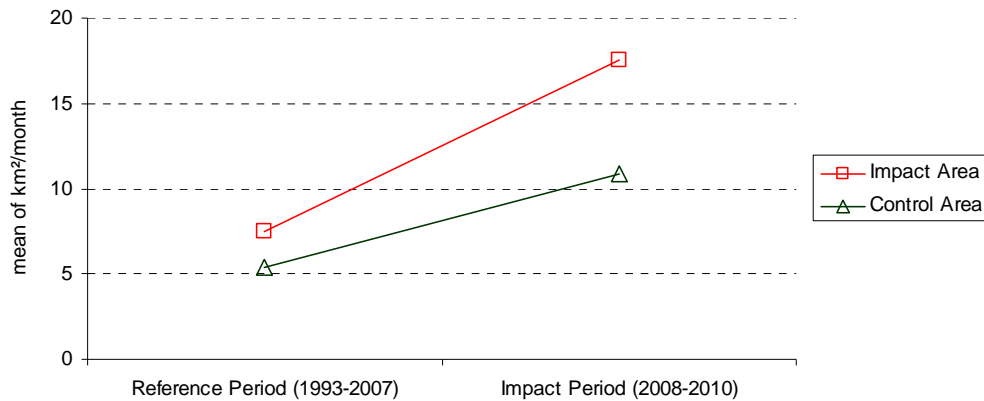
Since 1993, the Research Institute for Nature and Forest (INBO) carries out standardised seabird counts at the BPNS. From 2002 onwards, this was performed on a monthly base along three fixed monitoring routes, sailed by the research vessel 'Zeeleeuw'. In the course of time, monitoring effort shifted from an integral monitoring of the BPNS to an actual wind farm monitoring program. The period 2005-2007 was a transition period, in which two routes were partly dedicated to the monitoring of the Thorntonbank wind farm site and the nearby Gootebank. Since 2008 however, all three monthly monitoring routes focus on the wind farm concession zone and adjacent control areas, also including the Oosthinderbank, Blighbank and Bank zonder Naam (Figure 3).



**Figure 3. Monitoring routes sailed during the periods 2005-2007 (left) and 2008-2010 (right), with indication of the (future) location of the turbines of C-Power (Thorntonbank) and Belwind (Blighbank).**

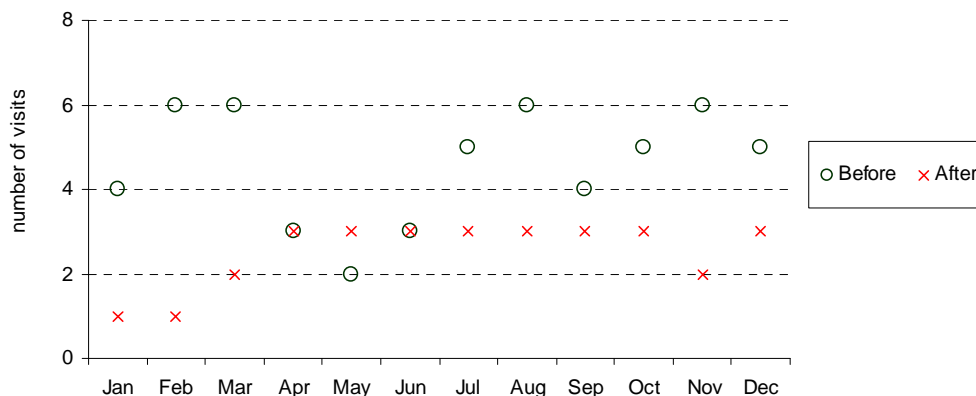
### 2.4.1 Count effort Thorntonbank

Figure 4 displays the count effort in the impact and control areas at the Thorntonbank study area. Hereby, count effort is expressed as the mean number of square kilometres of transect that was counted per monitoring month, equalling the number of kilometres sailed multiplied by the transect width (0.3 km). Average monitoring intensity has more than doubled after the turbine impact (from 6.4 to 14.2 km<sup>2</sup>), and was consistently higher in the impact area compared to the reference area.



**Figure 4. Count effort in the Thorntonbank study area, expressed as the mean number of km<sup>2</sup> of transect counted per monitoring month.**

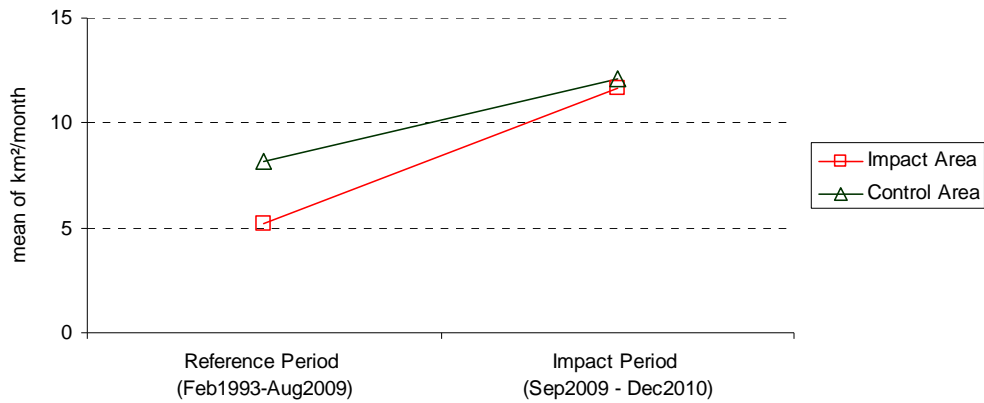
Figure 5 shows the number of 'monitoring months' before and after the first turbines were erected. During the reference period (1992-2007), visits were irregular, and count effort is therefore not equally distributed throughout the year (o). Our dataset also includes data resulting from three years of impact monitoring. Since turbine impact took place, we planned at least one monitoring route per month, which should have resulted in a total of 36 'monitoring months'. However, due to weather conditions or ship repair, some surveys were cancelled, explaining why there was only one 'monitoring month' in January & February, and two in March & November (x), thus totalling 30 'monitoring months'.



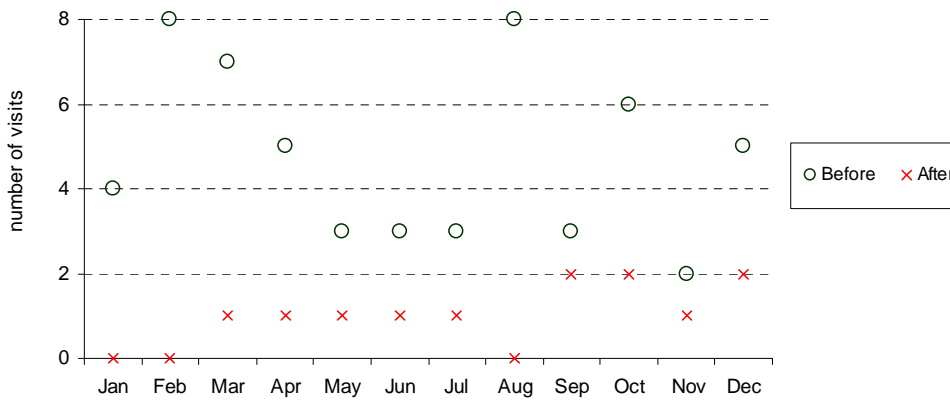
**Figure 5. Number of 'monitoring months' before and after the construction of the first turbines at the Thorntonbank in 2008.**

### 2.4.2 Count effort Blighbank

At the Blighbank study area too, monitoring intensity strongly increased since the first turbines were built (from 6.7 to 11.9 km<sup>2</sup> - see Figure 6). As in the previous paragraph, we observe an erratic distribution of the number of 'monitoring months' during reference years (o in Figure 7). The impact period started off quite recently in September 2009, explaining the poor number of 'monitoring months' (x).



**Figure 6. Count effort in the Blighbank study area, expressed as the mean number of km<sup>2</sup> of transect counted per monitoring month.**



**Figure 7. Number of 'monitoring months' before and after the construction of the first turbines at the Blighbank in September 2009.**



## 2.5 Data-analysis: modelling the reference data

### 2.5.1 Quasi-Poisson model

The monitoring results of the reference period were modelled through a 'generalised linear' approach, in which the relationship between the response and the linear equation is defined by a 'link-function', noted as follows:

$$g(E(y)) = \alpha + \sum_{j=1}^p \beta_j x_j$$

In the above equation, the function  $g(\cdot)$  is the 'link-function',  $E(y)$  the expected value of the response variable  $y$ ,  $\alpha$  the intercept,  $x_j$  a vector of  $j$  explanatory variables and  $\beta_j$  a vector of  $j$  coefficients (Yee & Mitchell 1991, Clarke *et al.* 2003).

When the counted subject is randomly dispersed, count results respond to a poisson-distribution and can thus be linked to the linear predictors using a logarithmic transformation:

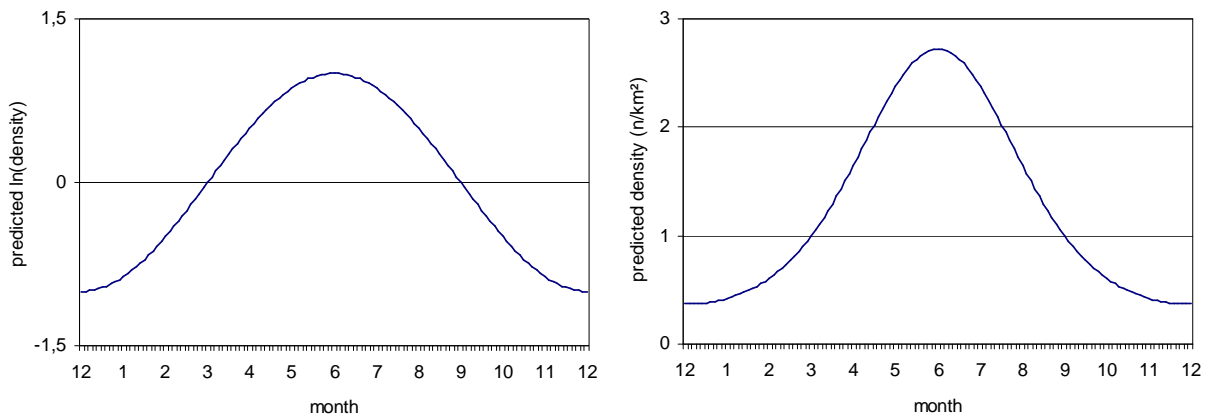
$$\ln(E(y)) = \alpha + \sum_{j=1}^p \beta_j x_j$$

This model is referred to as a standard Poisson regression (McCullagh & Nelder 1989, Potts & Elith, 2006). To allow for over-dispersion caused by aggregated distribution of seabirds, we applied a quasi-poisson model (quasi-likelihood estimation with a logarithmic link-function) (McDonald *et al.* 2000, Potts & Elith, 2006). In quasi-poisson modelling, coefficient estimation is equal to the results of a poisson regression. However, the standard errors on the predicted coefficients are much higher, and explanatory variables are less likely to contribute significantly to the model.

Whether counts were performed in the control or the impact area, is defined in the models by the factor variable 'CI' (Control-Impact). Since seabird occurrence is subject to large seasonal fluctuations, we included 'month' as an explanatory variable. Seasonal density patterns can be described through a sine curve, which can be defined by a linear sum of a sine and a cosine term (Onkelinx *et al.* 2008), including 'month' as a continuous variable:

$$\ln(\text{density}) = a_1 \times \sin\left(2 \times \Pi \times \frac{\text{month}}{p}\right) + a_2 \times \cos\left(2 \times \Pi \times \frac{\text{month}}{p}\right)$$

Here,  $p$  is the period of the sine curve, and  $a_1$  and  $a_2$  are the coefficients to be predicted.

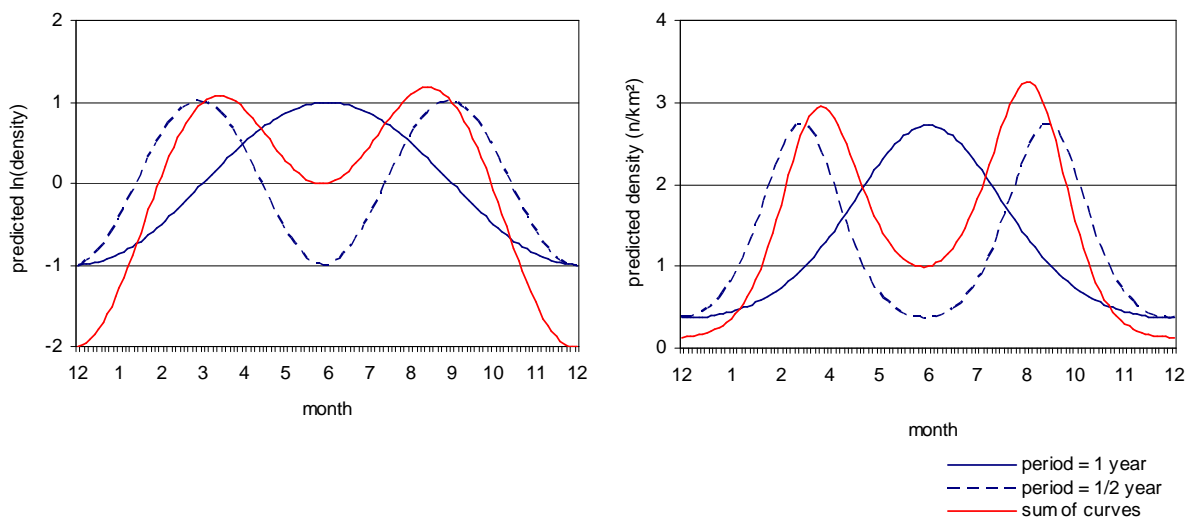


**Figure 8. Example of a sine curve in logarithmic scale (left) and the same curve transformed into the linear scale.**

Figure 8 presents a fictitious example of a summer visitor, in which the period of the seasonality curve is one year with peak numbers in June. Of course, seasonal occurrence might be much more complex, and needs to be described by adding up several linear sums, as for example in:

$$\ln(\text{density}) = a_1 \times \sin\left(2 \times \Pi \times \frac{\text{month}}{12}\right) + a_2 \times \cos\left(2 \times \Pi \times \frac{\text{month}}{12}\right) + a_3 \times \sin\left(2 \times \Pi \times \frac{\text{month}}{6}\right) + a_4 \times \cos\left(2 \times \Pi \times \frac{\text{month}}{6}\right)$$

Here, a sine curve with a period of 12 months is added up with a curve with a period of 6 months. This situation might arise when a bird is present only during summer months (period of one year), but occurs in increased numbers during migration periods, for example March & September (period of 6 months) (Figure 9).



**Figure 9. Example of combining two sine curves with different periods, in the logarithmic scale (left) and after transformation into the linear scale (right).**

## 2.5.2 Model selection

To test the contribution of the explanatory variables, we ran several models, successively dropping one variable, and comparing these models with each other using ANOVA. During this process, the linear sum of sine and cosine terms is always treated as one undividable term, called 'Seasonality' from hereon.

We performed backward selection by starting from the most complex model, including an interaction term. The first test investigates whether there is a difference in seasonality pattern between both areas. If so ( $p < 0.05$ ), we need to hold on to the interaction model, if not, we may drop the interaction term and we continue the testing procedure. The next step is to investigate whether there is an additive effect of 'CI', which would indicate a difference between the control and impact area. For most species, we do not expect there to be an area effect, since the control area is supposed to hold more or less equal numbers of seabirds compared to the impact area, at least during reference years. In contrast, we do expect 'Seasonality' to explain a major deal of the variance in our data, and hence was tested for last, forming the base of our model.

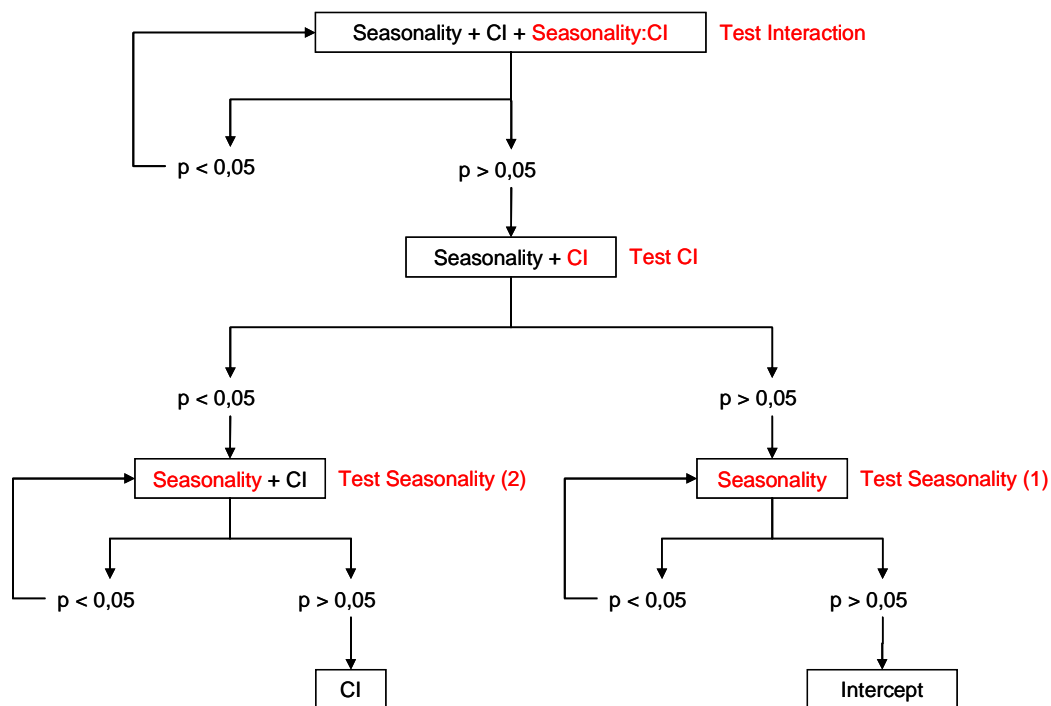


Figure 10. Flowchart of tests performed to select a reference model (the terms indicated in red are those tested for).



## 2.6 Impact analysis

The applied impact analysis depends on the selected reference model. If we observed an interaction- or area-effect during the reference years, the model is added only with a 'Before-After' (BA) factor variable:

- *impact model 1:* BA \* (Seasonality + CI + Seasonality:CI)
- *impact model 2:* BA \* (Seasonality + CI)
- *impact model 3:* BA \* (CI)

In case 'CI' is not included in the reference model, we also need to include the factor variable 'T', indicating turbine presence:

- *impact model 4:* (BA + T) \* (Seasonality)
- *impact model 5:* (BA + T) \* (Intercept)

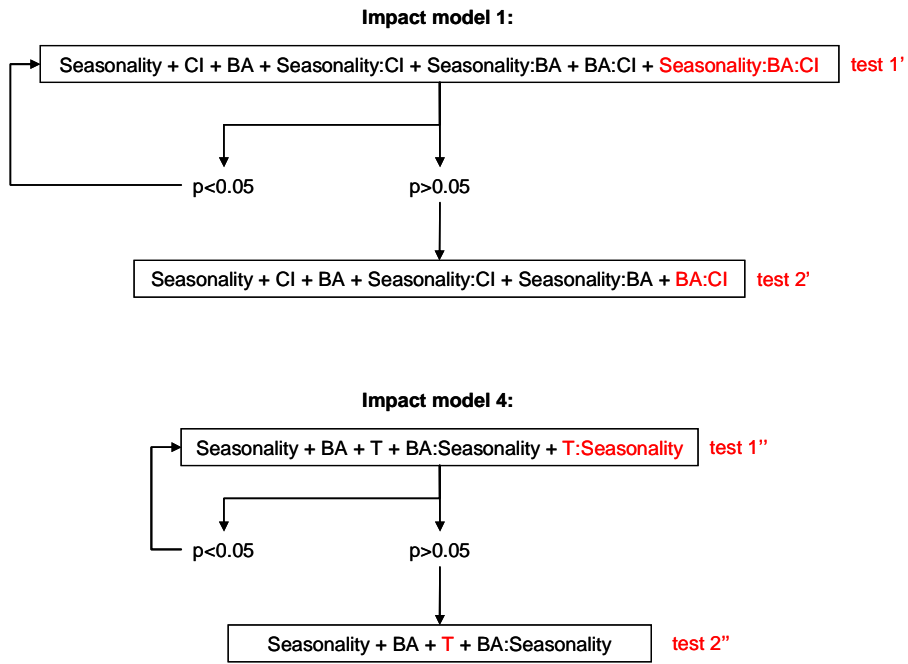
There is no interaction possible between 'BA' & 'T', since the level of 'BA' is fixed when 'T' equals 1 (indicating that turbines are present).

**Table 2. Overview of the unique combinations of factor variables used in the impact analysis (green=reference data / red=impact data).**

Control/Impact Area	Before/After Impact	BA - CI	BA - T
Control Area	Before	0 – 0	0 – 0
Impact Area	Before	0 – 1	
Control Area	After	1 – 0	1 – 0
Impact Area	After	1 – 1	1 – 1

In the first place, we want to know if there is an additive effect of the turbines' presence on seabird densities, and therefore we need to test for the effect of the interaction term 'BA:CI' in impact models 1, 2 & 3 (e.g. tests 2' in Figure 11), and for the effect of 'T' in impact models 4 & 5 (e.g. test 2'' in Figure 11). When the higher degree interaction terms appears to contribute significantly to the model (tests 1' & 1'' in Figure 11), it is no longer possible to test for the main effects included in these interaction terms. Following, interpretation of a possible turbine effect is – unfortunately – no longer possible.

Since changes in numbers in the study area are not necessarily related to the turbine presence, subsequent tests are performed to investigate the effect of 'BA:Seasonality' and 'BA'.



**Figure 11. Graphic scheme on how to tests for turbine effects based on impact models 1 & 4 (the terms indicated in red are those tested for).**

## 2.7 Power analysis

We performed power analyses to investigate the statistical value of our data. Crucial in this respect are the reference models, which form the base for the generation of random datasets.

For random data simulation based on a quasi-poisson distribution, we applied a gamma distribution, which is described by two variables: shape  $a$  and scale  $s$ . The mean and variance are defined as:

$$\mu = a * s$$

$$\sigma = a * s^2$$

Imagine  $\lambda$  being the mean, and  $\theta$  the over-dispersion parameter describing a quasi poisson distribution, then we should define shape and scale as follows:

$$a = \lambda / \theta$$

$$s = \theta$$

And thus:

$$\mu = a * s = (\lambda / \theta) * \theta = \lambda$$

$$\sigma = a * s^2 = (\lambda / \theta) * \theta^2 = \theta * \lambda$$

First, we calculated the power for a number of theoretical scenarios, with varying monitoring set-up characteristics and different types of seabird occurrence. Both the reference and impact data are simulated, and put into the modelling set-up as set out in the above chapters.

For each scenario, 10 000 random datasets were simulated, for which we calculated the p-value of the turbine effect. The resulting power equals the percentage of p-values below the significance level of 0.05 (see §2.7.1).

Secondly, we calculated powers based on the actual reference count results, only simulating the impact data. Again, we worked out several scenarios regarding monitoring set-up and several levels in decrease in numbers. For each scenario, the power was calculated based on 1 000 simulations (see § 2.7.2).

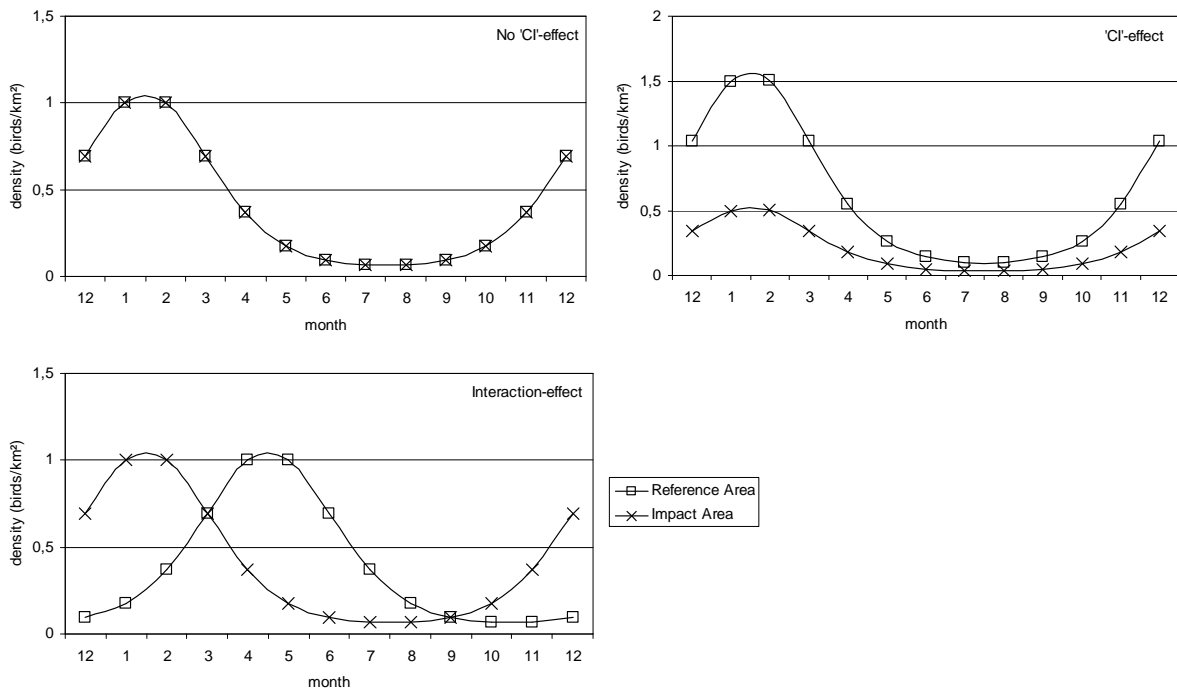
### 2.7.1 Scenario-based power calculations

As already mentioned, we produced a number of imaginary scenarios, in order to obtain insight in the way the power of our impact analysis is affected by the monitoring set-up and the kind of seabirds involved.

During the reference period already, seabird occurrence can strongly differ between control and impact area. As such, we regarded following scenarios (see Figure 12) of occurrence, resulting in three different reference models:

- No 'CI'-effect: Density ~ Seasonality

- 'CI'-effect: Density ~ CI + Seasonality
- Interaction-effect: Density ~ CI + Seasonality + CI:Seasonality



**Figure 12. Three scenarios of seabird occurrence used as a base for the power analysis.**

While in Figure 12, the maximum abundance averaged over both areas equals 1 bird/km<sup>2</sup>, we varied the abundance by multiplying the numbers in the above graphs with four factors (1/5, 1, 5 & 25). The resulting range of abundances obtained as such is a realistic reflection of the actual observed reference situation, as modelled according to the methodology described in §1.1.

Another bird distribution characteristic is the over-dispersion factor. When the over-dispersion equals 1, this means that numbers are randomly dispersed (either in time or in space), thus following a poisson distribution. Count results of seabirds are always over-dispersed to some extent and this variable is varied with five levels (factors 1.2, 2, 10, 50 & 250). Again, these levels reflect the range of actual observed over-dispersion factors in the reference data of both wind farm study areas (see Table 4 & Table 7 in §1).

The variation in scenarios described above is fully determined by the distribution characteristics of the seabirds involved, and cannot be 'controlled'. But we *can* control our monitoring intensity (km<sup>2</sup>), equalling the number of kilometres sailed per month per area, multiplied by the transect width (generally 300 m). Monitoring intensity is varied by three levels, being 5, 10 and 15 km<sup>2</sup>/month.

Resulting, we regarded 180 different scenarios, for which power was calculated based on 10 000 simulations, assuming a decrease in numbers of 50%, after a monitoring period of 10 years (5 years before & 5 years after the impact, totalling 120 'monitoring months'). For a few of these scenarios, we

extended the analysis by calculating the power for varying lengths of the impact monitoring (5 years before the impact, versus 5, 10 & 15 years after).

### **2.7.2 Reference data based power calculations**

For both study areas, the mean monitoring intensity during the impact period was at least 10 km<sup>2</sup> per area per monitoring month (see Figure 4 & Figure 6), which is taken as a base for the power calculations. To study the effect of doubling our monitoring intensity, powers were also calculated for a mean of 20 km<sup>2</sup> counted per area per month. Thus, we regarded following scenarios:

- varying decrease: 30, 50 & 70%
- varying monitoring intensity: 10 & 20 km<sup>2</sup> per month per area
- varying monitoring period: 1, 3, 5, 7, 9, 11, 13 & 15 years *after* impact

For each of these 48 scenarios and for each seabird species included in the analysis (Table 1), we simulated 1 000 impact datasets, on which the turbine effect was tested. Comparing the resulting p-values with two levels of significance (0,05 & 0,10) results in 2 power values per scenario per species.



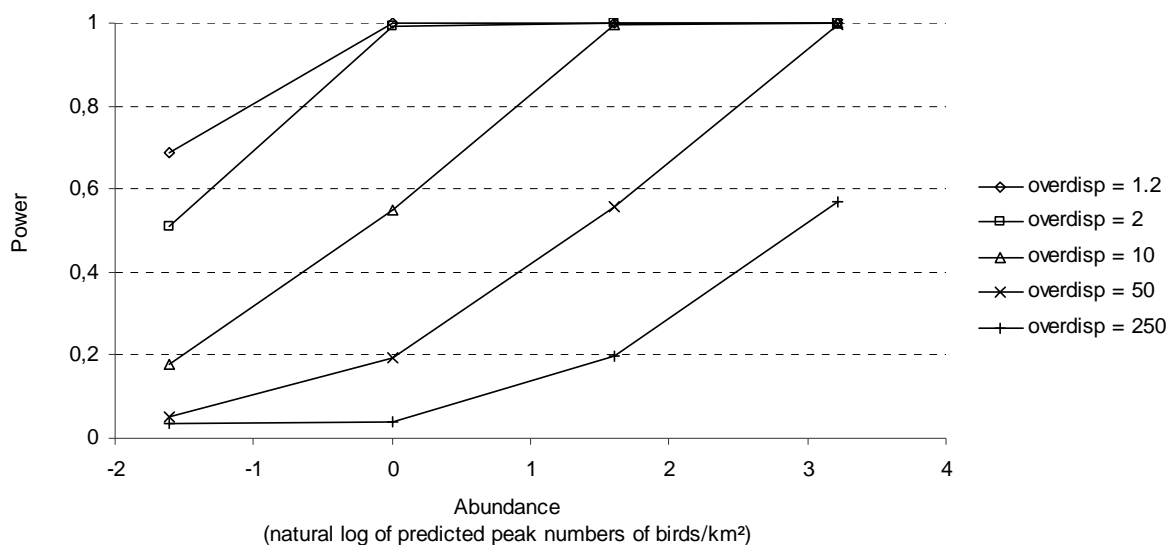
### 3 Results

#### 3.1 Scenario-based power analysis

There are striking differences in power results, and while bird abundance has a positive effect on the resulting power, the opposite is true for the over-dispersion parameter.

Figure 13 shows that for birds occurring in densities of 1 to 25 birds/km<sup>2</sup>, the power may exceed 99%, given that the over-dispersion stays *below* a certain 'critical level'. Hence, a relatively low abundance of 1 bird/km<sup>2</sup> can easily be compensated by a small over-dispersion factor ( $\leq 2$ ), while birds occurring in densities of 5 or 25 birds/km<sup>2</sup> may exhibit strong over-dispersion up to factors of respectively 10 & 50, and still reach such high power.

Nevertheless, under the assumptions of the example in Figure 13, in case of low bird abundance (0.2 bird/km<sup>2</sup>) power remains below 80% for all levels of over-dispersion. On the other extreme is a extremely high over-dispersion factor of 250, for which none of the investigated abundance levels result in satisfactory powers, remaining below 60%.

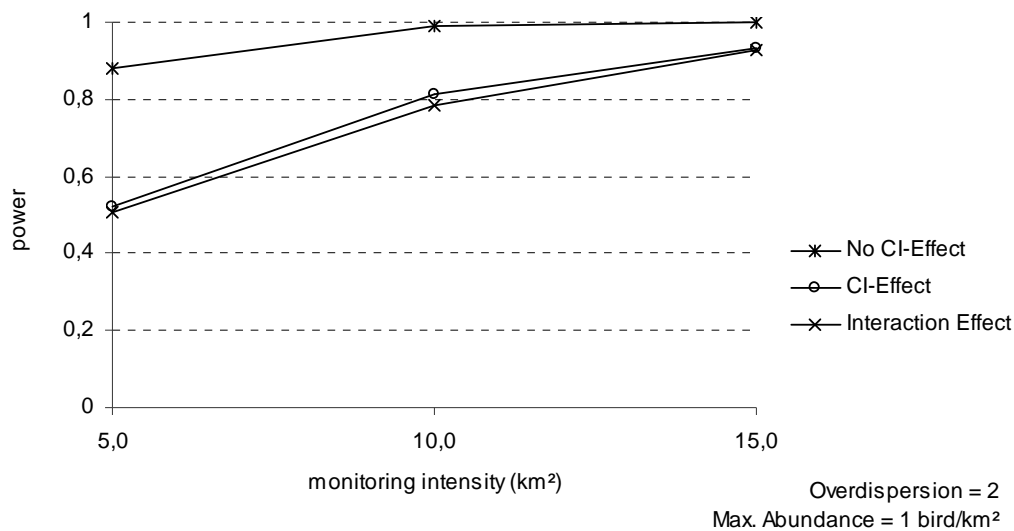


**Figure 13. Calculated power (10 000 simulations) for a 50% decrease in numbers after 10 years of monitoring (5 years before + 5 years after the impact), in relation to abundance (0,2 – 1 – 5 – 25 birds/km<sup>2</sup>) for five categories of over-dispersion (factors 1,2 – 2 – 10 – 50 – 250).**

When considering the variation in power results due to on the applied reference model, we see that the 'No Effect'-scenario shows the highest power levels, and the outcome is considerably lower for simulations based on the other two reference models (Figure 14).

The variation in scenarios described above is fully determined by the (uncontrollable) characteristics of seabird distribution during reference years. Figure 14 however shows that the power is also increased

with increasing monitoring intensity, as the calculated powers range between 51–88% for a monitoring intensity of 5 km<sup>2</sup>, while tripling the intensity results in powers ranging between 93–100%. Increasing monitoring intensity can be achieved by counting both sides of the ship, thus doubling the transect width, or by travelling more distance per month in both reference and impact area. Importantly, along with the increasing monitoring intensity, differences due to a different reference situation become increasingly smaller.



**Figure 14. Calculated power (10 000 simulations) for a 50% decrease in numbers after 10 years of monitoring (5 years before + 5 years after the impact), based on three different reference models, and with varying monitoring intensity (5 – 10 – 15 km<sup>2</sup>).**

Finally, instead of *intensifying the monitoring* by counting more square kilometres per month, power can be increased by *extending the monitoring period* and thus increasing the sampling size. We compared the power increase induced by doubling or tripling the total survey effort, through either one of these methods. Figure 15 proves that slightly better results are obtained when prolonging the monitoring period instead of intensifying the counts. However, the differences are negligible and if one has to choose, intensifying the surveys is preferred over prolonging the survey, since of course, the effects should to be detected as soon as possible.

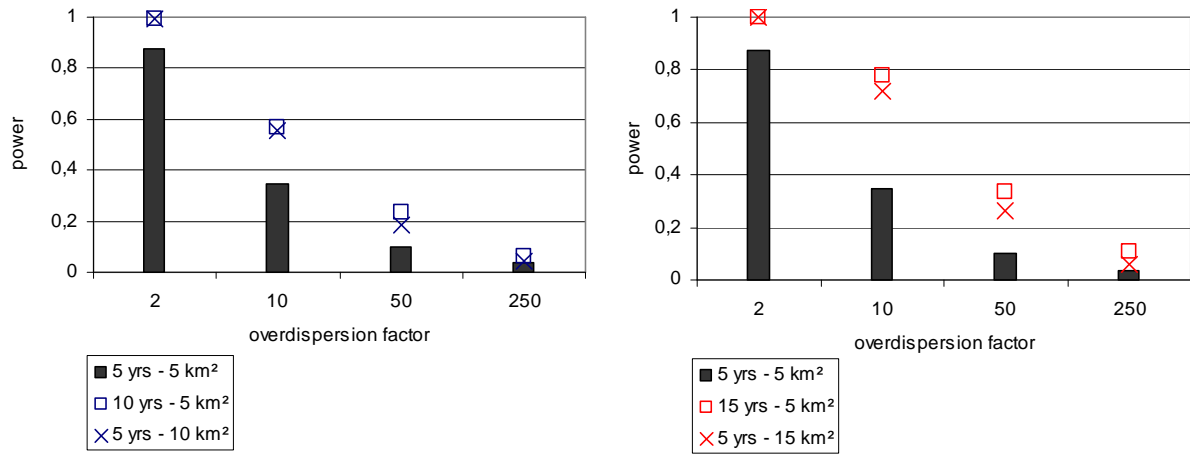


Figure 15. Power level when **doubling** (left) of **tripling** (right) the total survey effort, either by increasing the length of impact monitoring (□ : from 5 → 10 / 15 years) or by increasing the monitoring intensity (X : from 5 → 10 / 15 km<sup>2</sup>) assuming a decrease in numbers of 50% (max. abundance 1 bird/km<sup>2</sup>).



## 3.2 Thorntonbank

### 3.2.1 Reference situation

We modelled seabird occurrence at the impact & control site at the Thorntonbank using quasi-likelihood estimation, resulting in species-specific reference models (test results are displayed in Table 3).

For most species, only 'Seasonality' contributed significantly to the models' performance, resulting in a reference model without an area effect. Mostly, seasonality was modelled using a sine curve with a period of 12 months. Except for both tern species, in which the models performed much better when combining a 12-month period curve with a 6-month period curve. For the terns, including interaction resulted in over-fitting and extremely high standard errors, and the interaction model was therefore not included in the selection process.

For the gull species Little gull, Common gull and Black-legged kittiwake, there was a significant effect of the interaction term, indicating that their occurrence differed strongly between impact and reference area. Reference modelling in Great black-backed resulted in a model including the area factor as well 'Seasonality', but without an interaction term.

**Table 3. Test results for the reference model selection (based on flowchart in Figure 10) for the Thorntonbank study area.**

	Test Interaction	Test CI	Test Seasonality (1)	Test Seasonality (2)
Northern gannet	0.26	0.37	0.00	
Northern fulmar	0.72	0.82	0.01	
Little gull	0.02			
Common gull	0.02			
Lesser black-backed gull	0.77	0.92	0.00	
Herring gull	0.07	0.72	0.00	
Great black-backed gull	0.23	0.01		0.00
Black-legged kittiwake	0.01			
Sandwich tern		0.62	0.00	
Common tern		0.96	0.00	
Common guillemot	0.31	0.56	0.00	
Razorbill	0.73	0.48	0.00	

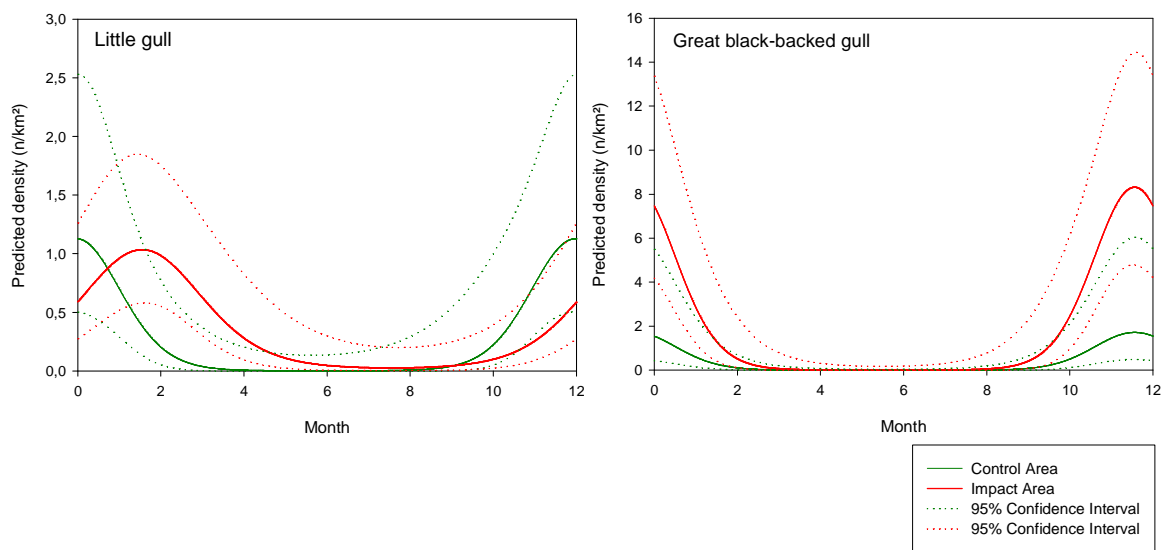
The resulting reference models, predicted maximum densities and the over-dispersion factors are summarised in Table 4. Count data of Lesser black-backed, Great black-backed gull and Black-legged

kittiwake exhibit extremely high over-dispersion, and these same species were recorded in very high densities. On the other extreme are the tern species, with low over-dispersion in the count data, and relatively low densities.

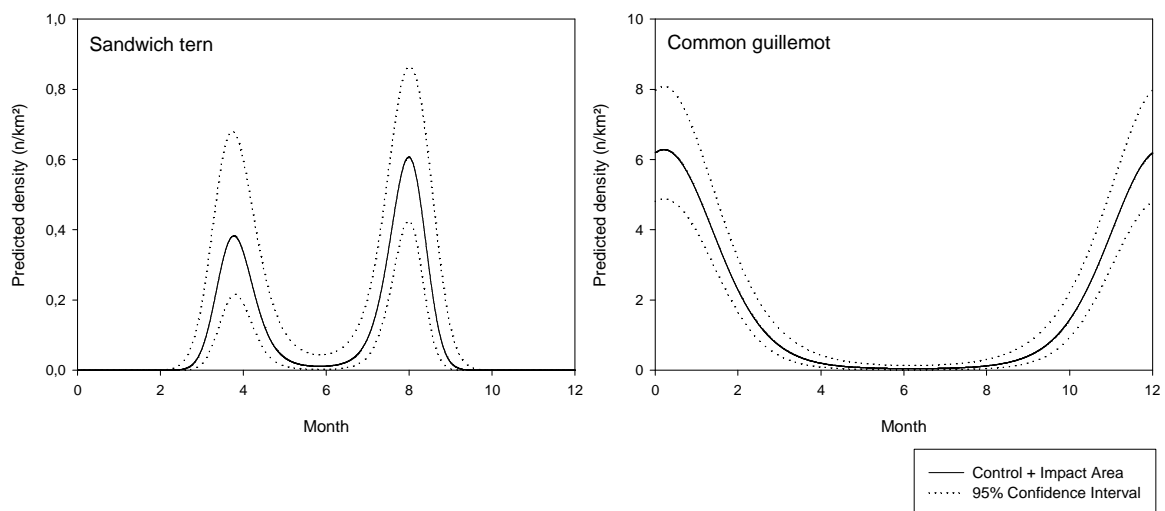
**Table 4. Predicted maximum abundances in the control and impact area, and the over-dispersion in the count data for twelve seabird species at the Thorntonbank study area during reference years.**

	Reference Model	Max Abundance (n/km <sup>2</sup> ) (Control Area)	Max Abundance (n/km <sup>2</sup> ) (Impact Area)	Overdispersion factor
Northern gannet	Seasonality	1.4	1.4	20.0
Northern fulmar	Seasonality	0.5	0.5	10.6
Little gull	CI * Seasonality	1.1	1.0	8.8
Common gull	CI * Seasonality	0.3	2.8	6.4
Lesser black-backed gull	Seasonality	16.6	16.6	88.6
Herring gull	Seasonality	0.4	0.4	7.2
Great black-backed gull	CI + Seasonality	1.7	8.3	44.3
Black-legged kittiwake	CI * Seasonality	1.9	10.6	33.9
Sandwich tern	Seasonality	0.6	0.6	1.3
Common tern	Seasonality	0.5	0.5	1.1
Common guillemot	Seasonality	6.3	6.3	13.1
Razorbill	Seasonality	1.0	1.0	9.7

While Little gull fits in the Interaction-effect scenario (§2.7.1) due to a clear phase shift in the seasonality pattern, the occurrence of Great black-backed gull illustrates the 'CI'-effect scenario (§2.7.1), with higher numbers in the impact area compared to the reference area (Figure 16). For Sandwich tern and Common guillemot, the reference model did not reveal any 'CI'-related effect, and predicted values are the same in both areas (Figure 17).



**Figure 16. Predicted densities of Little gull and Great black-backed gull for the control and impact area at the Thorntonbank, with indication of the 95% point-wise confidence interval.**

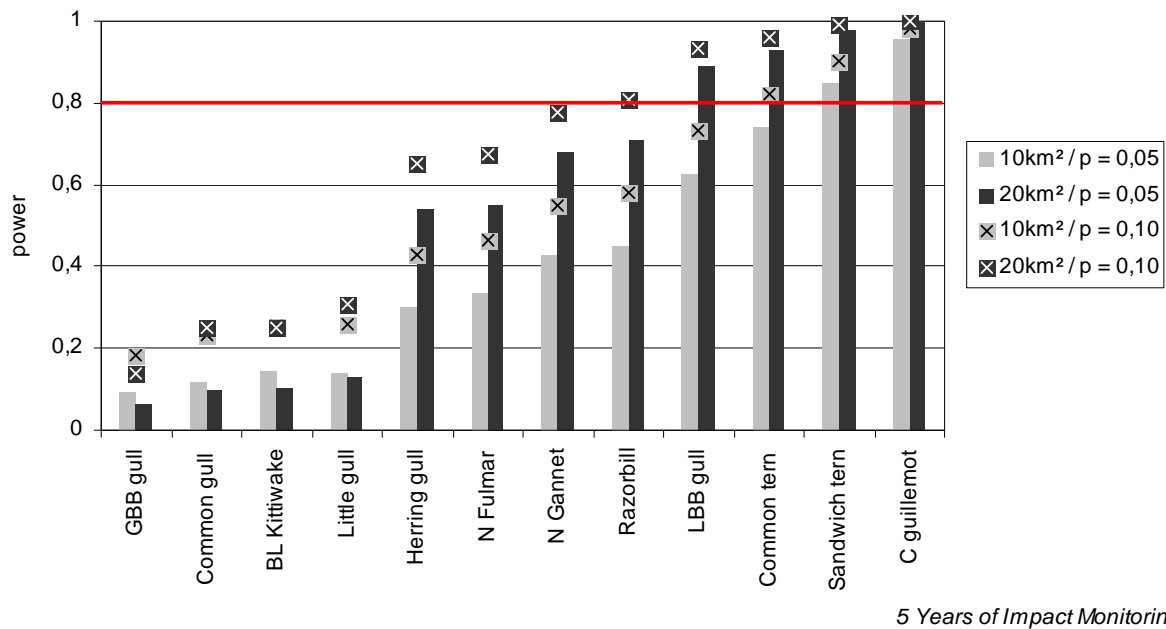


**Figure 17. Predicted densities of Sandwich tern and Common guillemot for the control and impact area at the Thorntonbank, with indication of the 95% point-wise confidence interval.**

### 3.2.2 Results Power analysis

Figure 18 displays the calculated powers based on the available reference data gathered at the Thorntonbank, assuming a 50% decrease and a monitoring period of five years after impact. The effect of increasing monitoring intensity from 10 to 20 km<sup>2</sup> appears to be highly relevant, as within 5 years a 50% decrease can be detected in 4 instead of 2 species. Power results can also be increased by pulling up the significance level from 5 to 10%, which is justified based on the need for the monitoring program to function as an early warning system (see §4.1).

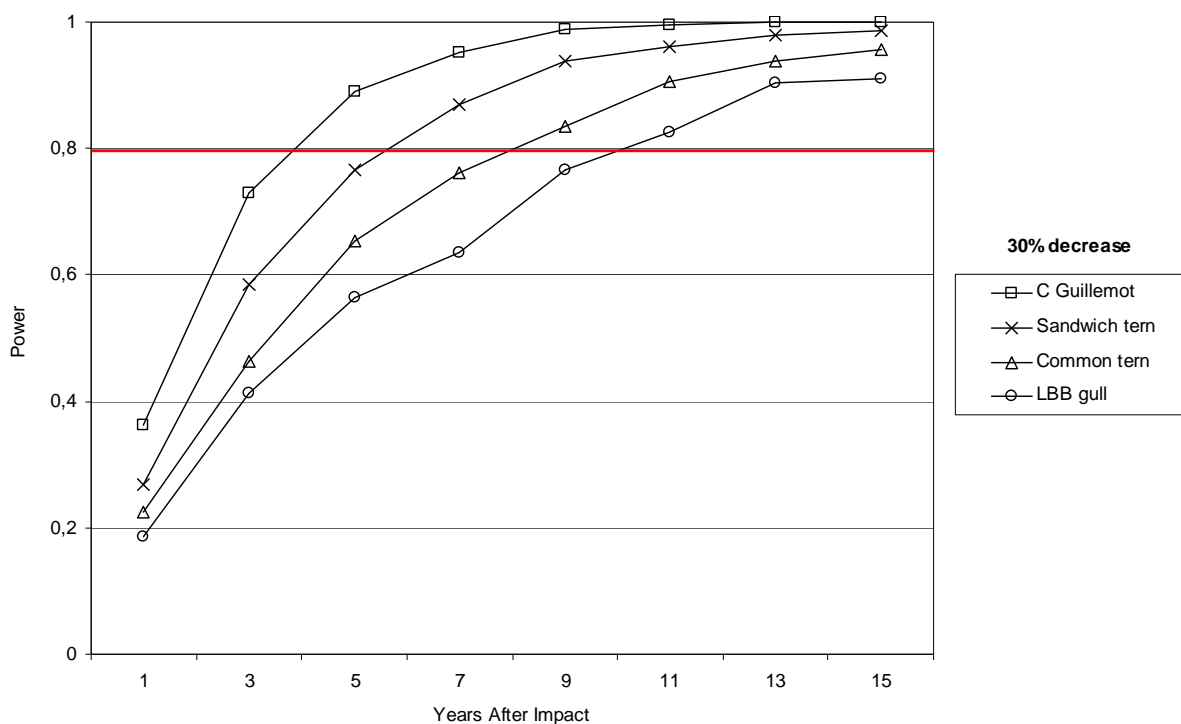
Concluding, for four species, being Common guillemot, Sandwich tern, Common tern and Lesser black-backed gull, we will be able to detect a 50% change in numbers after 5 years, with a chance of more than 80%, given a monitoring intensity of 20 km<sup>2</sup>. Presently, monitoring intensity at the Thorntonbank study area ranges from 10.9 km<sup>2</sup> in the control area to 17.5 km<sup>2</sup> in the impact area, averaging 14.2 km<sup>2</sup>. By applying a significance level of 0.10 instead of 0.05, we can also include Razorbill in this selection.



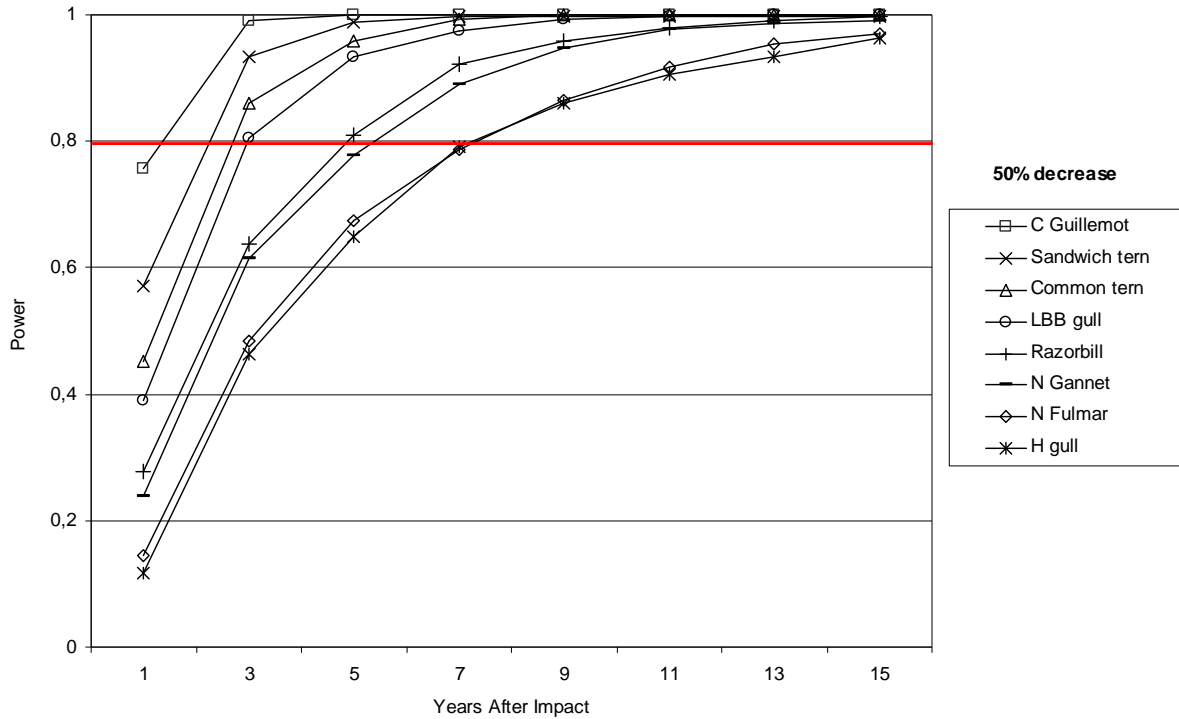
**Figure 18. Calculated powers (1 000 simulations) for twelve species of seabird 5 years after the impact and a change in numbers of 50%, for varying monitoring intensities (10 versus 20 km<sup>2</sup>/month) and significance levels (0.05 versus 0.10), based on data gathered at the Thorntonbank.**

To gain insight in how long monitoring should hold on, we calculated time series of power. This was done for three levels of decrease (30, 50 and 70%), assuming a monitoring intensity of 20 km<sup>2</sup> and applying a significance level of 0.10.

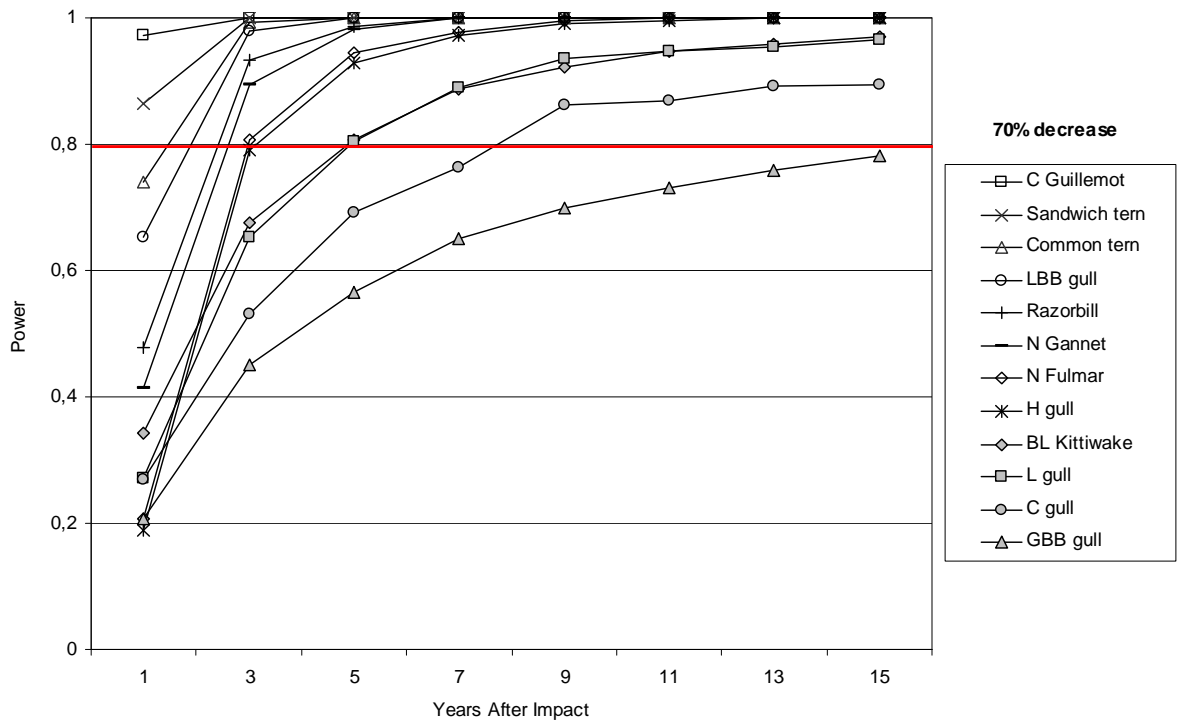
For a decrease of 30%, we reach a sufficient power (80%) after ten years for four seabird species, i.e. Common guillemot, Sandwich tern, Common tern and Lesser black-backed gull (Figure 19). Within the same period, it should be possible to detect a 50% change in four more species, namely Razorbill, Northern gannet, Northern fulmar and Herring gull. When a 70% decrease in numbers is simulated we may add Little gull, Common gull and Black-legged kittiwake to this selection, while for Great black-backed gull, the power does not reach 80% even after 15 years of impact monitoring.



**Figure 19. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Thorntonbank wind farm area for four seabird species assuming a monitoring intensity of 20 km<sup>2</sup> per area per month, and a decrease in numbers of 30%.**



**Figure 20.** Time series of power results (significance level = 0.10 / 1 000 simulations) at the Thorntonbank wind farm area for eight seabird species assuming a monitoring intensity of 20 km<sup>2</sup> per area per month, and a decrease in numbers of 50%.



**Figure 21.** Time series of power results (significance level = 0.10 / 1 000 simulations) at the Thorntonbank wind farm area for twelve seabird species assuming a monitoring intensity of 20 km<sup>2</sup> per area per month, and a decrease in numbers of 70%.

### 3.2.3 Results impact analysis

Table 5 summarizes the test results of our impact analysis, while Figure 24 & Figure 25 offer a graphical view of the BACI results.

The only effects of turbine presence on bird densities that we have found are attraction effects in Sandwich and Common tern (Table 5). Numbers in the impact area increased with respectively 30 and 77%, while they dropped in the control area. For both species, we also detected a significant interaction between 'BA' and 'Seasonality', indicating a shift in seasonality pattern. After the impact, Sandwich tern was observed comparatively less during spring migration, while spring numbers of Common tern increased compared to the reference period (Figure 22).

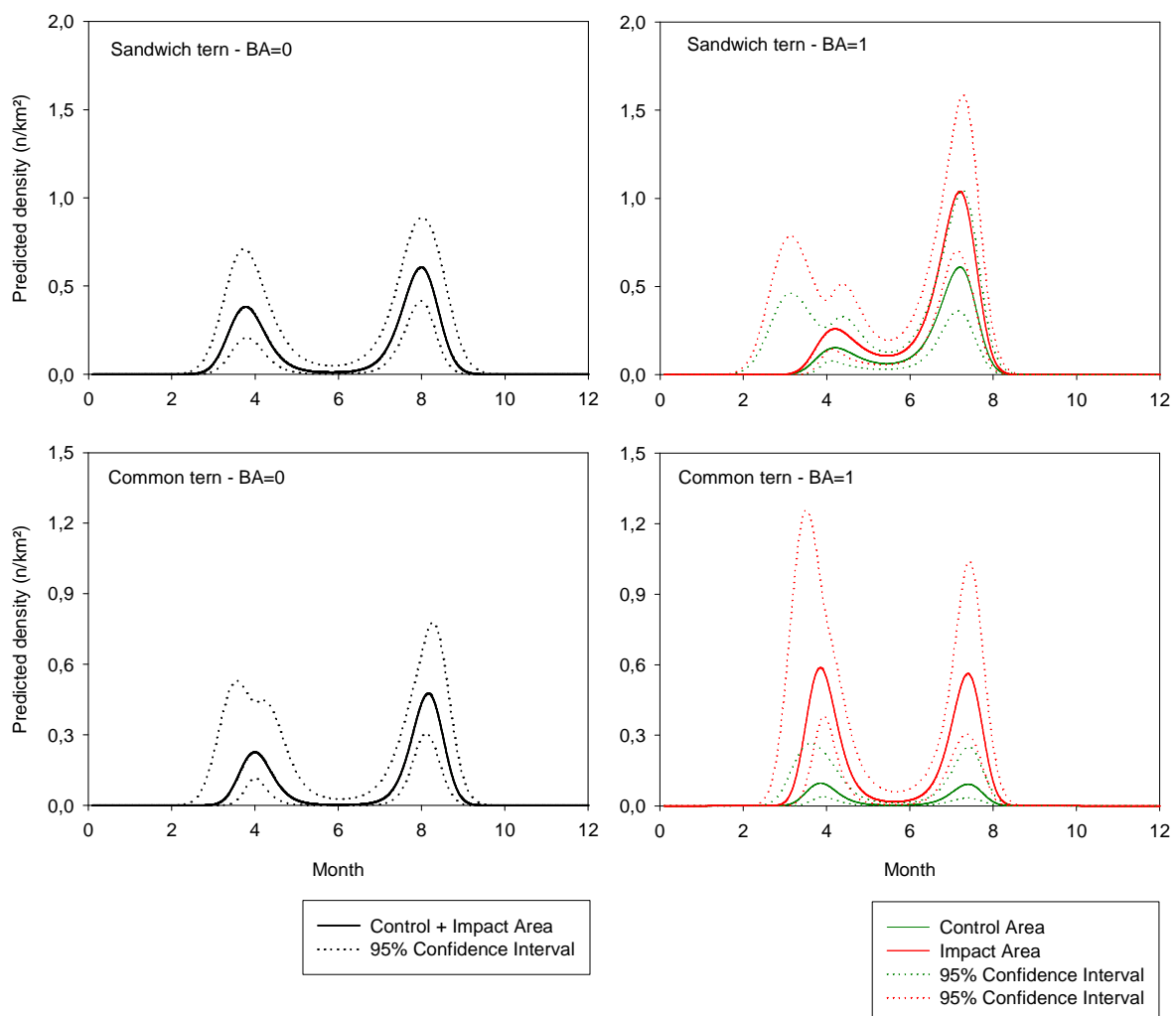
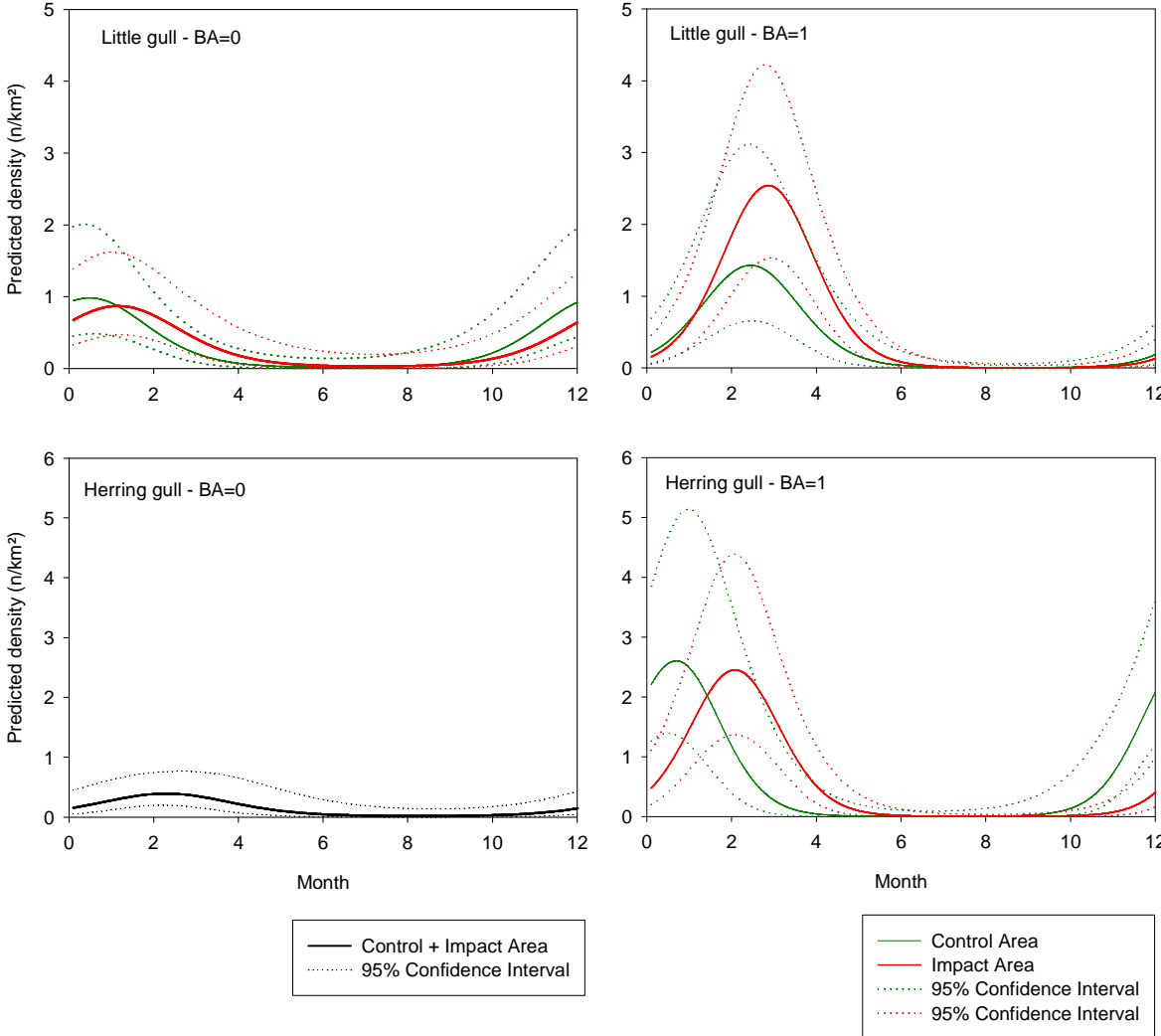


Figure 22. Predicted numbers for Sandwich and Common tern at the Thorntonbank study area according to the impact model.

Interaction effects were also detected in Little gull and Herring gull (Table 5). Peak numbers of Little gull have shifted from January/February to March/April. For Herring gull, numbers in the both areas have increased strongly, with a slight shift in seasonality between impact and reference area after impact (Figure 23). However, none of these effects can be addressed to the turbines' presence.



**Figure 23. Predicted numbers for Little and Herring gull at the Thorntonbank study area according to the impact model.**

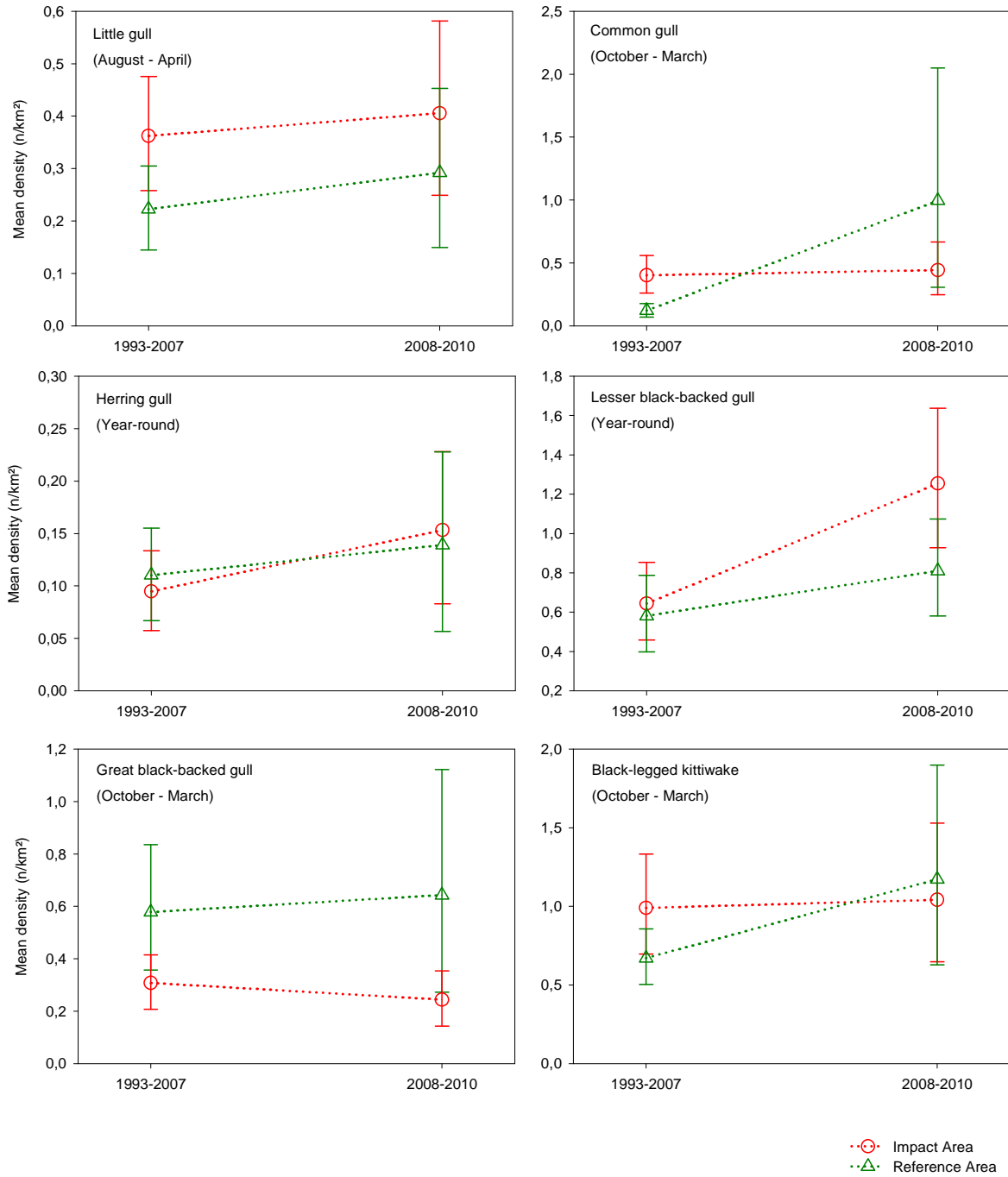
In four other seabird species, numbers in the wind farm area have dropped significantly since the turbines' construction, but a comparable decrease was observed in the control area ('BA'-effect, see Table 5). This was the case for the 'true' seabirds, i.e. Northern fulmar, Northern gannet and both auk-species (Figure 25).

For Lesser and Great black-backed gull as well as Black-legged kittiwake, the models were not able to discern any effect (Table 5). This is more or less confirmed by the parallel BACI-graphs in Figure 24 in case of Great black-backed gull & Black-legged kittiwake, while a positive turbine effect could be suspected in Lesser black-backed gull.

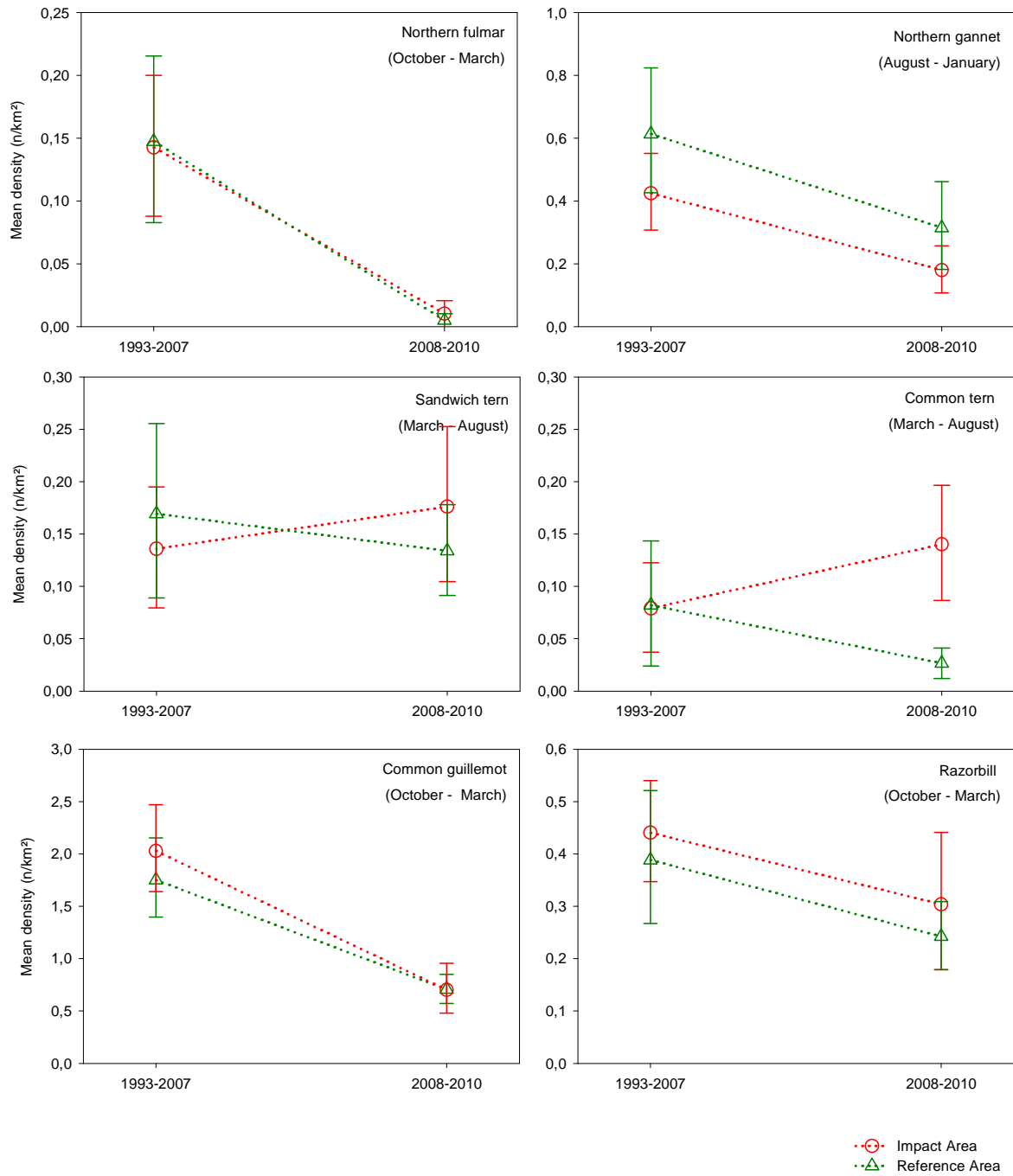
In Common gull, the impact modelling resulted in highly unreliable predictions. Despite this, the geometric mean densities displayed in the BACI graph (Figure 24) suggest a possible avoidance effect.

**Table 5. Overview of the impact analysis results for the Thorntonbank wind farm area, including a hypothesis concerning displacement effect based on the preliminary impact dataset.**

Species	Turbine effects	p - value	Other effects	p - value	Hypothesis
Sandwich tern	T	0.038	BA:Seasonality	0.000	Attraction
Common tern	T	0.000	BA:Seasonality	0.000	Attraction
Herring gull	T:Seasonality	0.001	BA:Seasonality	0.014	No effect
Little gull	-	-	BA:Seasonality	0.000	No effect
Northern Gannet	-	-	BA	0.014	No effect
Northern Fulmar	-	-	BA	0.011	No effect
Common guillemot	-	-	BA	0.000	No effect
Razorbill	-	-	BA	0.016	No effect
Lesser Black-backed gull	-	-	-	-	No effect
Great Black-backed gull	-	-	-	-	No effect
Black-Legged kittiwake	-	-	-	-	No effect
Common gull	/	/	/	/	?Avoidance?



**Figure 24. Geometric mean gull densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Thorntonbank.**



**Figure 25. Geometric mean seabird densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Thorntonbank.**



### 3.3 Blighbank

#### 3.3.1 Reference situation

A significant seasonal pattern was found in four species, i.e. Northern gannet, Common gull, Black-legged kittiwake and Common guillemot. In the count results of Razorbill we detected an interaction effect (CI\*Seasonality), while for Little gull there appears to be a 'CI'- as well as a 'Seasonality'-effect. For the five remaining study species, i.e. Northern fulmar, Great skua, Lesser black-backed, Herring and Great black-backed gull, the reference model is limited to the intercept (Table 7).

**Table 6. Test results for the reference model selection (based on the flowchart in Figure 10) for the Blighbank study area.**

	Test Interaction	Test CI	Test Seasonality (1)	Test Seasonality (2)
Northern gannet	0.60	0.52	0.02	
Northern fulmar	0.68	0.81	0.08	
Great skua	0.25	0.67	0.16	
Little gull		0.00		0.00
Common gull	0.57	0.97	0.00	
Lesser black-backed gull	0.39	0.69	0.18	
Herring gull	0.79	0.85	0.29	
Great black-backed gull	0.98	0.23	0.67	
Black-legged kittiwake	0.31	0.31	0.04	
Common guillemot	0.63	0.19	0.00	
Razorbill	0.02			

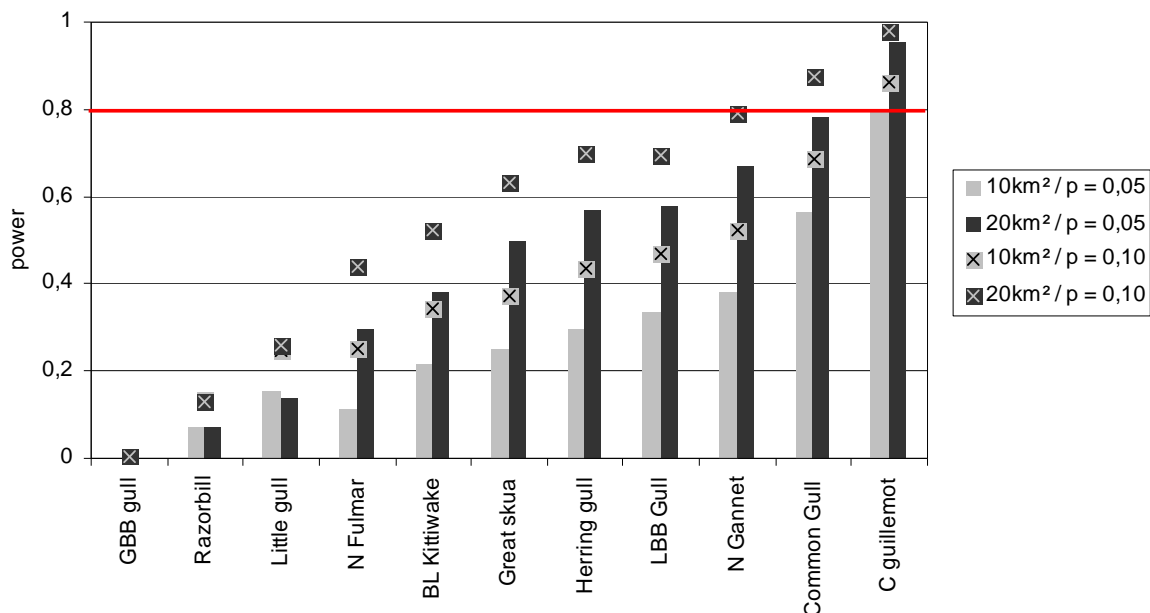
As was the case at the Thorntonbank, we observed very high over-dispersion in some gull species (Great black-backed gull & Black-legged kittiwake), whereas Great skua and Herring gull were observed in very low densities ( $<0.1$  birds/km<sup>2</sup>).

**Table 7. Predicted maximum abundances in the control and impact area, and the over-dispersion in the count data for eleven species of seabird at the Blighbank study area during reference years.**

	Reference Model	Max Abundance (n/km <sup>2</sup> ) (Control Area)	Max Abundance (n/km <sup>2</sup> ) (Impact Area)	Overdispersion factor
Northern fulmar	Intercept	0.20	0.20	18.5
Northern gannet	Seasonality	0.84	0.84	13.5
Great skua	Intercept	0.04	0.04	2.0
Little gull	CI + Seasonality	0.10	0.97	1.35
Common gull	Seasonality	0.25	0.25	1.6
Lesser black-backed gull	Intercept	0.32	0.32	13.5
Herring gull	Intercept	0.08	0.08	3.6
Great black-backed gull	Intercept	0.30	0.30	224.0
Black-legged kittiwake	Seasonality	1.76	1.76	50.9
Common guillemot	Seasonality	3.60	3.60	13.4
Razorbill	CI * Seasonality	1.11	0.35	5.3

### 3.3.2 Results Power analysis

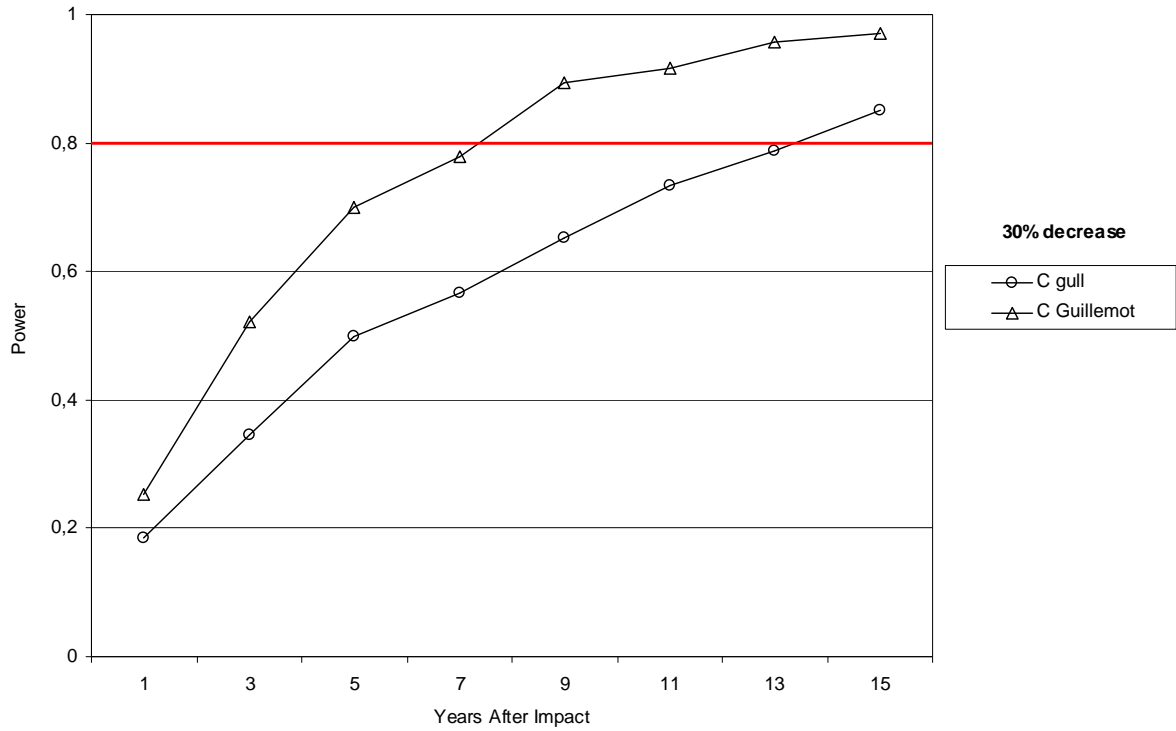
Figure 26 displays the calculated powers based on the available reference data gathered at the Blighbank, assuming a 50% decrease and a monitoring period of five years after impact. The results are less favourable than at the Thorntonbank (Figure 26). Again Common guillemot shows the best outcome, as this species occurs in moderately high densities with moderate over-dispersion. When monitoring intensity is increased to 20 km<sup>2</sup> per month, and the applied significance level is 0.10, power in Common gull and Northern gannet also reaches 80%. On the other extreme is Great black-backed gull with extremely low power due to low densities and extremely high over-dispersion. Surprisingly, Razorbill too shows poor power.



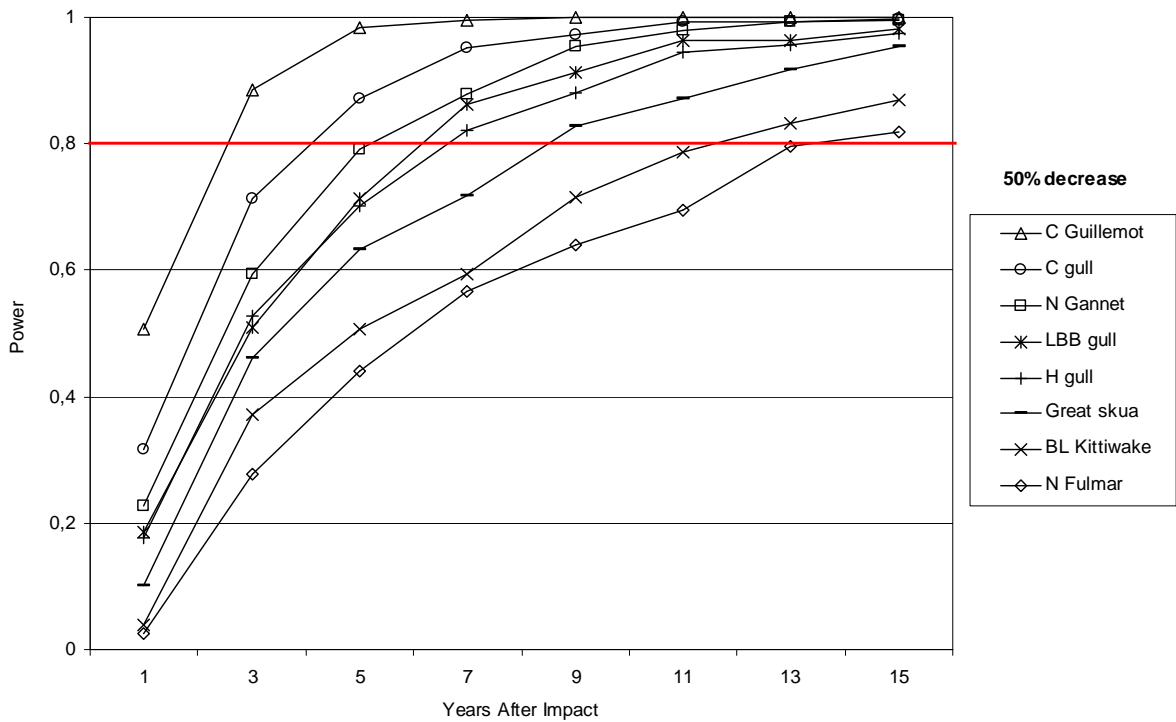
**Figure 26. Calculated powers (1 000 simulations) for eleven species of seabird 5 years after the impact and a change in numbers of 50%, for varying monitoring intensities (10 versus 20 km<sup>2</sup>/month) and significance levels (0.05 versus 0.10), based on data gathered at the Blighbank.**

When simulating a decrease in numbers of 50%, and given a monitoring intensity of 20 km<sup>2</sup> and a significance level of 0.10, our results show that only after ten years of monitoring, sufficient power (80%) is reached for six seabird species, being Common guillemot, Northern gannet, Great skua, Common, Lesser black-backed and Herring gull (Figure 28). To reach an 80% power level, we need 3 more years for Black-legged kittiwake and 5 more for Northern fulmar.

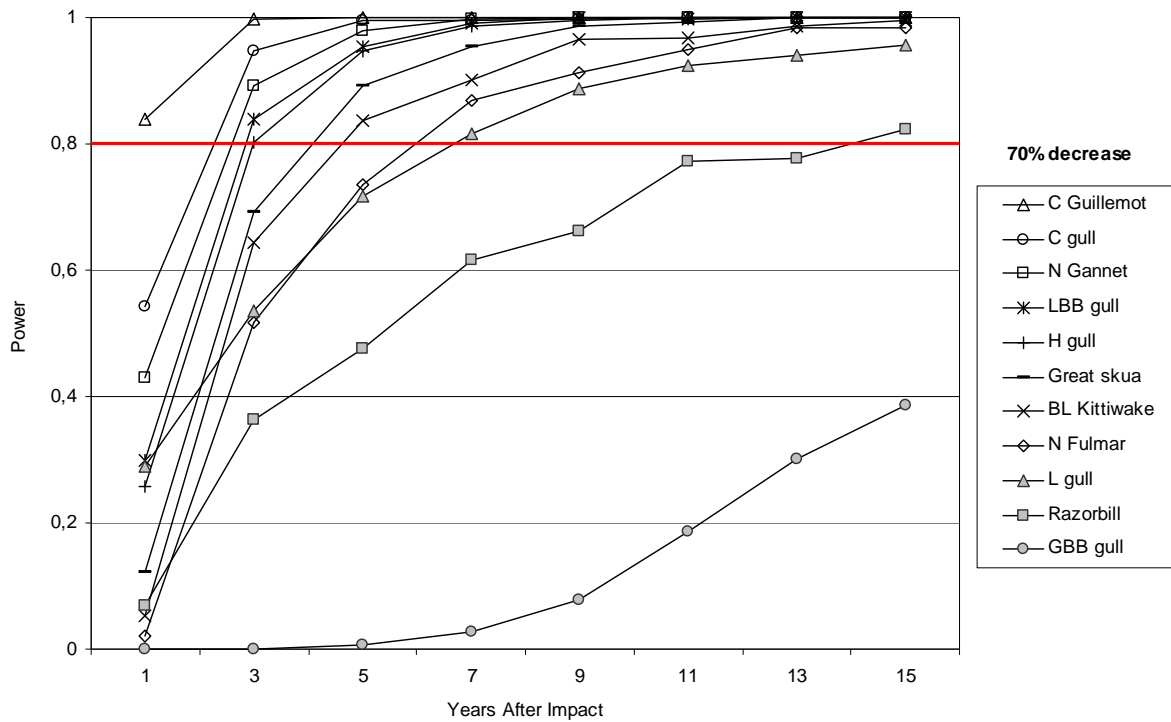
For Little gull, we observe a power of 80% after 7 years, assuming a drop in numbers of 70%, while for Razorbill this limit is reached only after fifteen years (Figure 29). Again, Great black-backed gull proves to be the worst monitoring species.



**Figure 27. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Blighbank wind farm area for two seabird species assuming a monitoring intensity of 20km<sup>2</sup> per area per month, and a decrease in numbers of 30%.**



**Figure 28. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Blighbank wind farm area for eight seabird species assuming a monitoring intensity of 20km<sup>2</sup> per area per month, and a decrease in numbers of 50%.**



**Figure 29. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Blighbank wind farm area for eleven seabird species assuming a monitoring intensity of 20km<sup>2</sup> per area per month, and a decrease in numbers of 70%.**

### 3.3.3 Results Impact analysis

Since we do not dispose of year-round data since the beginning of the impact period (see Figure 7), we could not perform reliable impact modelling for two species, i.e. Little gull and Razorbill. The BACI-graphs in Figure 31 & Figure 32 do suggest avoidance of Little gull and no effect in Razorbill.

Analysis of the impact data of the remaining species does show significant turbine effects in three species, being Common gull, Herring gull & Lesser black-backed gull. The BACI-graphs (Figure 31) learn that in case of Common and Herring gull this is due to a very high increase in numbers (with a factor 22 and 6 respectively) in the impact area as opposed to the reference area, indicating attraction to the wind farm. This pattern is mainly due to the results of the December campaign in 2010, when numbers of both species in the wind farm were extremely high, not only compared to the control area but compared to all other areas at the BPNS visited during three days of seabird monitoring (Figure 30).

In contrast, numbers of Lesser black-backed gull in the impact area remained more or less the same while they increased strongly in the control area, suggesting avoidance (explaining a negative 'T'-effect combined with a positive 'BA'-effect) (Figure 31).

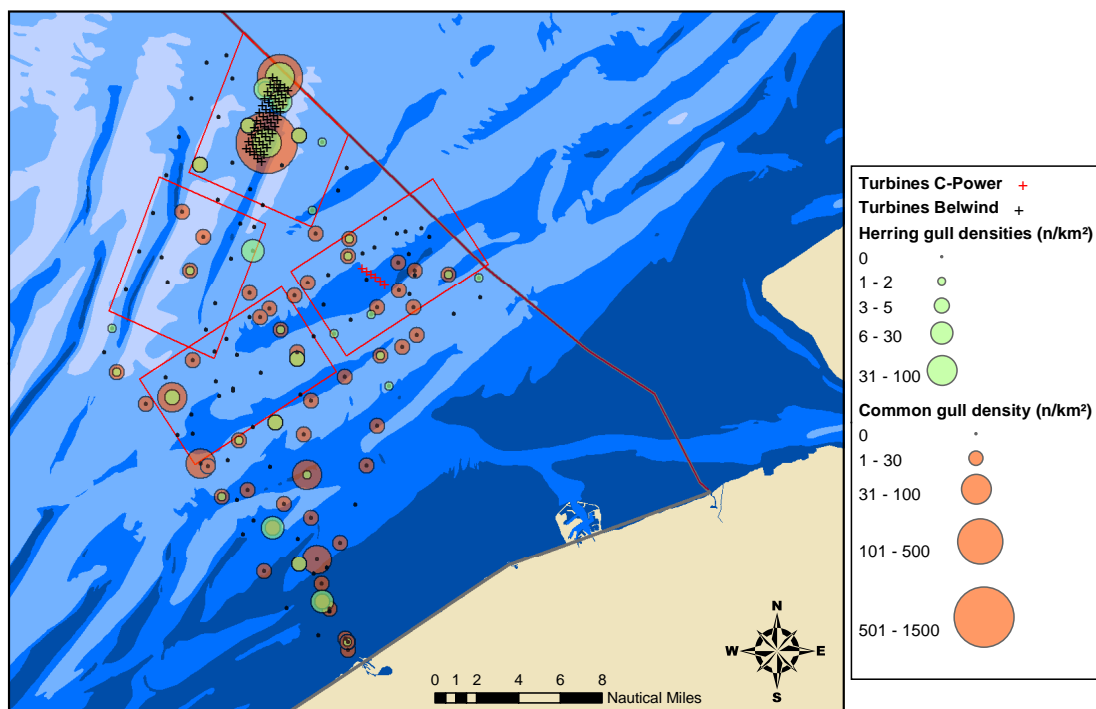


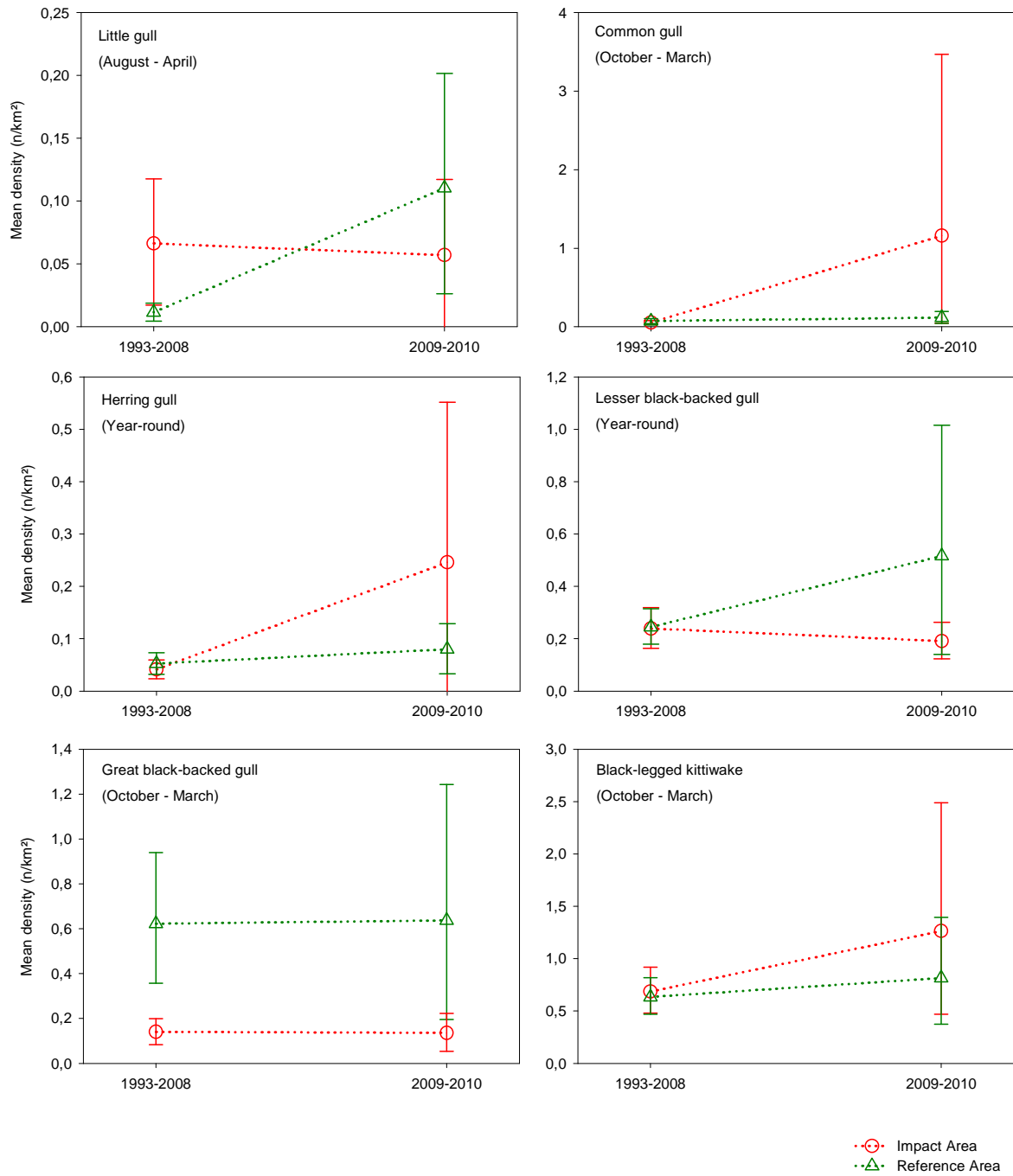
Figure 30. Distribution of Herring and Common gull during three monitoring days in December 2010.

Count results of Northern fulmar, Great skua, and Common guillemot only revealed a 'BA'-effect. As expected based on this result, the BACI-graphs of these species (Figure 32) display a general drop in observed numbers after construction, with a parallel trend in the impact and control area.

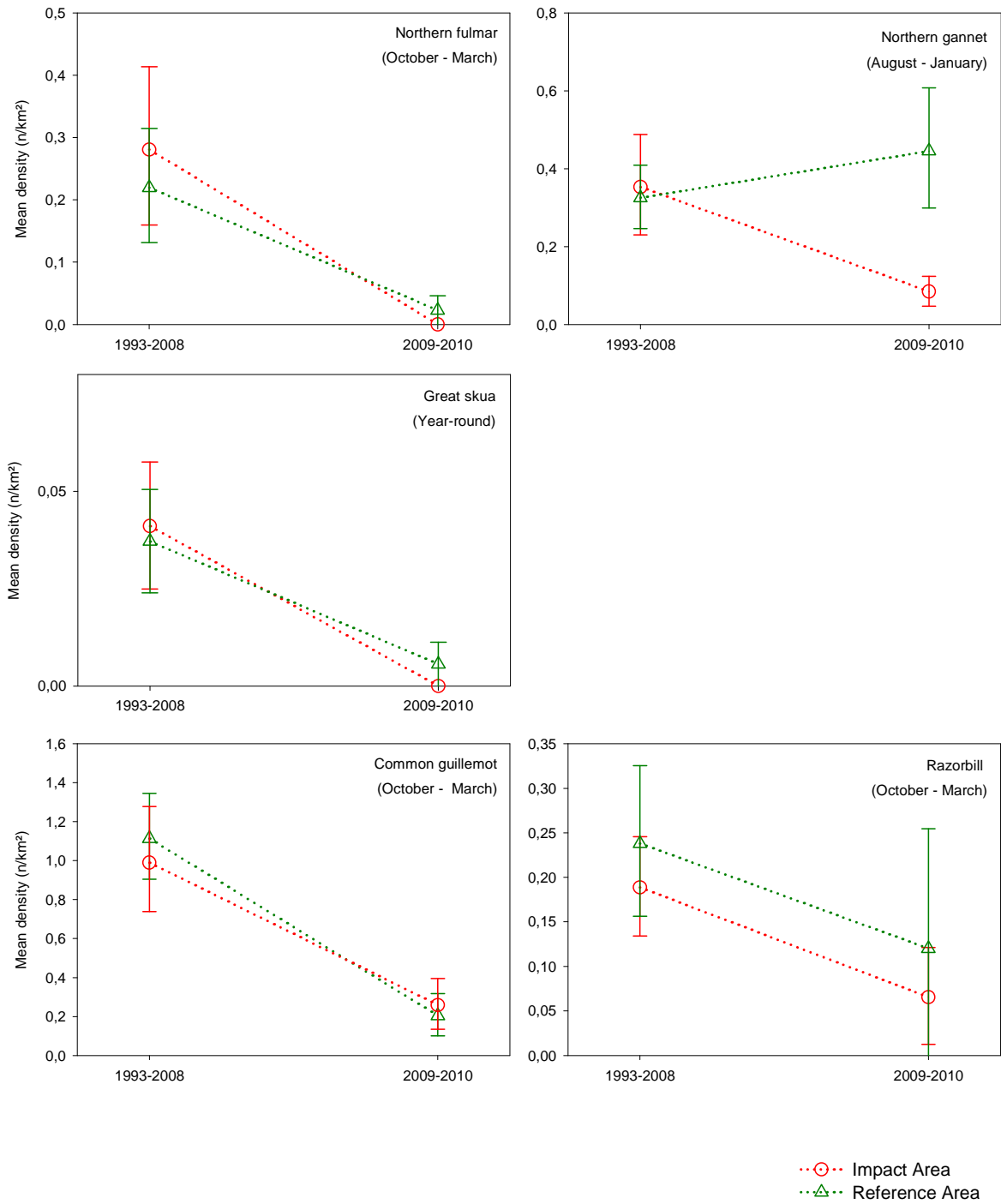
For the remaining three species no effects could be discerned, which seems plausible based on the BACI-graphs in case of Great black-backed gull and Black-legged kittiwake. In case of Northern gannet however, we observed a clear drop in numbers in the impact area, opposed to a slight increase in the control area (Figure 32), suggesting avoidance of the wind farm area.

**Table 8. Overview of the impact analysis results for the Blighbank wind farm area, including a hypothesis concerning displacement effect based on the preliminary impact dataset**

Species	Turbine Effect	p-value	Other Effect	p-value	Hypothesis
Common gull	T	0.000			Attraction
Herring gull	T	0.001	-	-	Attraction
Lesser Black-backed gull	T	0.001	BA	0.000	Avoidance
Northern Fulmar	-	-	BA	0.021	No effect
Great skua			BA	0.010	No effect
Common guillemot	-	-	BA	0.001	No effect
Great Black-backed gull	-	-	-	-	No effect
Northern Gannet	-	-	-	-	?Avoidance?
Black-legged kittiwake	-	-	-	-	No effect
Little gull	/	/	/	/	?Avoidance?
Razorbill	/	/	/	/	?No effect?



**Figure 31. Geometric mean gull densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Blighbank.**



**Figure 32. Geometric mean seabird densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Blighbank.**



### 3.4 Synthesis of Impact modelling

Three years after the first construction works at the Thorntonbank wind farm area, we detected a significant increase in numbers of Sandwich and Common terns in the impact area as opposed to the reference area. Impact modelling was due to high unreliability not possible in Common gull, but the BACI-graph suggests an avoidance effect (indicated by question marks in Table 9).

For none of the other species a turbine effect could be discerned, neither by the impact modelling, nor by visual interpretation of the geometric mean densities as displayed in the BACI-graphs (Figure 24 & Figure 25).

At the Blighbank study area, impact modelling showed a significantly positive effect in Common gull and Herring gull, while the opposite accounts for Lesser black-backed gull. Impact modelling did not detect any effect in Northern gannet, despite a clear drop in numbers in the impact area as opposed to the control area (see BACI-graph in Figure 32), which is why we do hypothesise avoidance by this species.

While impact modelling was not possible for Little gull and Razorbill due to lack of data, BACI-graphs suggest avoidance by Little gull and no effect in Razorbill (indicated by the question marks in Table 9).

**Table 9. Hypotheses on the displacement effects based on the preliminary impact datasets for the Thorntonbank and Blighbank wind farm areas.**

Species	Thorntonbank	Blighbank
Northern Fulmar	No effect	No effect
Northern Gannet	No effect	?Avoidance?
Great skua		No effect
Little gull	No effect	?Avoidance?
Common gull	?Avoidance?	Attraction
Herring gull	No effect	Attraction
Lesser Black-backed gull	No effect	Avoidance
Great Black-backed gull	No effect	No effect
Black-legged kittiwake	No effect	No effect
Sandwich tern	Attraction	
Common tern	Attraction	
Common guillemot	No effect	No effect
Razorbill	No effect	?No effect?



## 4 Discussion

### 4.1 Power analysis

Underwood & Chapman (2003) state that the power in impact studies is affected by:

- the variability in the measurements
- the probability of a type I error
- the amount of sampling
- the effect size

In the scenario-based analysis we investigated the effect of the variability in the data by varying the over-dispersion factor. Also we tested how bird abundance and type of reference model affects the resulting power.

Next we calculated powers based on our actual observed reference data. Here, the variability is determined by the data records themselves, but we varied the effect size, the amount of sampling (number of years) and we calculated the power based on two levels of significance (0.05 & 0.10).

Indeed, our power results are negatively influenced by the over-dispersion factor ( $\Phi$ ), which expresses the way the data variance is related to the expected response value ( $E(y)=\Phi * \sigma$ ). Since we spatially aggregated our count results per area, the over-dispersion will be largely due to the year-to-year variation, rather than a reflection of the clustering behaviour of the bird species involved. Also, when the model leaves a great deal of variance unexplained, this is inevitably reflected in the factor of over-dispersion. Therefore, it might not always be the best solution to 'force' a simple sine curve to the data. While for some species it is probably a true reflection of the actual field situation this does not necessarily hold true for *all* species. It might be interesting to additionally perform GAM modelling, since GAM's are data-driven rather than model-driven (Yee & Mitchell, 1991). This way, an asymmetric seasonal pattern for example, will be fitted better and far more easily than with an a priori defined sine curve. Preliminary tests already showed that GAM modelling in a quasi-poisson context resulted in consistently lower over-dispersion factors.

The more birds present per monitoring month, the higher the power. Hence there is a strong positive correlation between species abundance and the resulting power. But, more importantly, the same effect is obtained when monitoring intensity is increased, also resulting in more birds observed per monitoring month. Thus, counting more will result in better power, despite the fact that in our methodology, the data are condensed to only one record per area per month. By increasing monitoring intensity we may include more species of which we desire to detect certain changes within a certain time frame.

It is also possible to extend this time frame to increase the power. For equal total survey efforts, we found that prolonging the impact monitoring period (for example 5 km<sup>2</sup> / 10 years ) gives slightly better results, as compared to intensifying the counts (10 km<sup>2</sup> / 5 years). Since time is of crucial importance

in impact studies aiming to function as early warning systems, intensifying the counts should nevertheless be preferred over prolonging the survey.

Finally, we tested how the power of our impact analysis reacted on different types of seabird occurrence during the reference years, resulting in three different reference models ('Seasonality', 'CI+Seasonality' & 'CI\*Seasonality').

The model without an area effect performed best, while the other two models resulted in much lower powers. This finding shows the importance of delineating a control area which is highly comparable to the impact area regarding seabird numbers and seasonality. Underwood & Chapman (2003) state that to detect 'press' impacts it requires a maximum number of control locations. Within the BPNS however, each area hosts its own characteristic seabird community, varying throughout the year, and delineating other suitable control areas is therefore very difficult.

For both wind farms, we calculated powers based on the characteristics of the true reference data. At the Thorntonbank, a monitoring period of 5 years after impact should be enough (power  $\geq 80\%$ ) to detect a 50% change in numbers of 3 species, being Common guillemot, Sandwich tern and Common tern, given a monitoring intensity of 10 km<sup>2</sup> and a significance level of 0.05. Common guillemot is a common species occurring in predictable and high numbers throughout the winter season, and was expected to perform best as a monitoring species. We are happy to also be able to include Annex I species Common and Sandwich tern, for both of which the area was found to be of particular importance during the reference study (Vanermen & Stienen 2009). Both species occur in relatively low numbers, but since the data exhibit low over-dispersion, power scores high.

Doubling the monitoring intensity from 10 to 20 km<sup>2</sup>, adds only one more species to this selection, being Lesser black-backed gull. This species often shows extremely high spatial over-dispersion, and may therefore not be the promising monitoring bird it appears to be based on the power results presented here.

When we want to add more species of which we desire to detect a 50% change, we should prolong the monitoring period to at least eight years and apply a significance level of 0.10, thus adding Razorbill, Northern gannet, Northern fulmar and Herring gull.

Power scores very low for the remaining four species, caused by the type of reference model (including an area and/or interaction effect) that is applied to simulate the random impact data sets. Interestingly, when we perform the simulations with a model *without* an area effect, powers score much higher, even when still applying the same complex impact model to test for the turbine effect (BA:CI). Hence the poor outcome results from 'extending' the area effect observed in the reference period into the impact period, which may not always be a true reflection of the field situation. Indeed, in case of a shift in seasonality as observed in Little gull (see Figure 16) one can wonder if this is in fact a true reflection of reality. Observed seasonality patterns result from the large scale migration phenomenon, and it seems unlikely that differences occur at such a small scale if not induced by coincidence. Still, care is needed, since within the scale of the BPNS, Little gull does show different

seasonality patterns offshore compared to onshore areas. We cannot change our reference data, but for the purpose of random impact data simulation, it may be better to use a more general reference model.

At the Blighbank, observed numbers of seabirds are generally lower than at the Thorntonbank, resulting in lower statistical power. Assuming a monitoring intensity of 10 km<sup>2</sup>, Common guillemot is the only species for which we will be able discern a decrease in numbers of 50% after 5 years. After 8 years, we may add 4 more species, being Common gull, Northern gannet, Lesser black-backed and Herring gull, provided that monitoring intensity equals 20 km<sup>2</sup> and that we apply a significance level of 0.10.

At first sight, the power results in this study seem to be rather low, and one can argue if we should be satisfied with these outcomes. Extremely important in this respect is to realise that not being able to detect a certain change *does not mean that there is no effect!*

McLean *et al.* (2006 & 2007) conducted a comparable study on long-time series of aerial survey counts of five seabird species (Red-throated diver, Common scoter, Sandwich tern, Lesser & Great black-backed gull). The (hypothetical) monitoring set-up in this study is quite different from the one presented here. The authors calculate the power of detecting changes within a study area of varying size (2x2 km<sup>2</sup>, 5x5 km<sup>2</sup> etc.), with the hypothetical wind farm located in the centre. The study investigates the effect of the gradient of decline (uniform, or gradually), spatial scale, survey intensity, survey duration, inclusion of spatial variables and inclusion of reference areas. McLean *et al.* (2007) concluded that “the statistical power to detect a 50% change in birds numbers remains low (<85%) for all species irrespective of the length of time over which monitoring is carried out”, for significance levels of 0.20.

Indeed, the cheapest and easiest way to pull up the power of any impact analysis is to apply a higher significance level than the conventional 0.05. Here, the significance level represents the chance wrongly concluding that the turbines are causing an impact, while in fact they are not ('type I error'). As is known, a stringent significance level goes at the expense of the power, resulting that potential impacts may go unnoticed (Underwood & Chapman, 2003). This of course is not advisable, as we wish our study to function as an early warning system, and slightly increasing the significance level from 0.05 to 0.10 is therefore perfectly justified.

Concluding, by maximizing monitoring intensity and monitoring period, we can increase the power of our impact study to an acceptable level for most seabird species. However, there are clear logistic limitations. During the intensive monitoring program of the last few years, monitoring intensity was about 14 km<sup>2</sup> per area per month at the Thorntonbank and 12 km<sup>2</sup> at the Blighbank. Unfortunately, regarding the use of research vessels we are now at the top of our possibilities. One possible solution is to focus all energy on one wind farm area, which however would be a pity since a monitoring set-up with two impact and two control sites is clearly more valuable. Otherwise it could be possible -

whenever visibility allows so - to increase the transect width, and to count along both sides of the ship. This way monitoring intensity could possibly be increased with 50%.

#### 4.2 Impact study Thorntonbank

The only two species in which we detected a significant turbine effect were Sandwich tern and Common tern. Since 2008, numbers of both species increased in the impact area, which was not the case in the control area, indicating attraction to the turbines. Presently, only 6 out of 54 turbines are in place, and it would be too easy and too soon to address this increase to the turbines' presence. On the other hand, clear positive effects on fish communities are already visible (Reubens *et al.*, 2010), possibly also affecting higher trophic levels.

For none of the other species a turbine effect could be proven, despite slight indications of avoidance in Common gull.

As mentioned, 48 more turbines still have to be built in the impact area, but ironically, 'impact' monitoring is already going on for three years. Continuing to apply a two-level factor variable simply indicating turbine presence or absence is therefore not feasible. In order to be able to compare the effect of 6 with that of 54 turbines, we may include the turbine effect as a continuous variable, representing the number of turbines actually in place.

#### 4.3 Impact study Blighbank

Significant turbine effects were detected in three species, being Common gull, Herring gull, Lesser black-backed gull. In case of Common and Herring gull this is a positive effect suggesting attraction to the wind farm. We need to say that this finding is mainly based on the results of one monitoring month (December 2010) when numbers of both species in the wind farm were extremely high, not only compared to the control area but compared to all other areas visited during three days of seabird monitoring. In January 2011, almost no birds were present in the wind farm, while in February, we again observed increased numbers of gulls. Considering the limited impact dataset, it is too soon to draw any firm conclusions, but the near future should reveal if these gulls are in fact attracted by the turbines' presence.

For Lesser black-backed and Little gull, the BACI graphs show that numbers in the impact area remained more or less the same while numbers in the control area increased strongly. Again, it is too soon to state that this is due to avoidance of the wind farm area. For none of the other species, the impact analysis detected a turbine effect, which is confirmed by the BACI graphs, displaying parallel trends in numbers in the impact and control area.

## 5 Summary

Seabird count results exhibit extremely high variation in counted numbers, a high proportion of zero counts, and strong auto-correlation effects. This inevitably results in low statistical power regarding the use of these data in impact assessment. Therefore, in our BACI monitoring set-up, count data are spatially aggregated per reference and impact area, thus minimizing variation, and avoiding autocorrelation. We studied the expected power of our monitoring study by performing power calculations for several scenarios of decrease in numbers, monitoring intensity and monitoring duration. We found that for most species we will be able to detect changes in numbers of 30-70% relatively easy for most seabird species within a period of 10 years after the impact. Species that combine common occurrence ( $>1$  bird/km<sup>2</sup>) with moderate over-dispersion (factor  $< 10$ ) are most suitable for monitoring. We cannot control local seabird occurrence, but by carefully delineating a control area and maximizing monitoring intensity, the power of our impact analysis is strongly enhanced. Ideally, the control area holds equal numbers of seabirds compared to the impact area.

Surprisingly, we already found some significant effects. More precisely, tern activity in the Thorntonbank wind farm area significantly increased since the first turbines were built, and the same holds true for Common and Herring gull densities at the Blighbank wind farm. Enhanced seabird activity inside the wind farms may be induced by mere attraction to artificial structures as a stepping stone, a resting place or a 'reference' in the wide open seascape, but also by enhanced foraging conditions. While this counters the worries of habitat loss due to avoidance or habitat deterioration, increased bird activity increases the risk of collision mortality.

The reference study already revealed increased activity of Common and Sandwich tern at the Thorntonbank study area during migration periods. Considering their high protection status and fragile populations, the area was therefore indicated to be of particular importance to these birds. While both tern species are already exposed to wind farm induced mortality at their breeding sites at Zeebrugge (Everaert & Stienen, 2006), they will now be exposed to the same threat during their migration far out at sea. The occurrence of terns at the Thorntonbank study area should therefore receive maximum attention in the coming monitoring years.

As mentioned, we found significant attraction effects in Common and Herring gull at the Blighbank. Again, these results are highly preliminary, especially considering the limited time frame in which impact data at the Blighbank could be collected. Future monitoring will inevitably result in more firm conclusions. Nevertheless, these early findings already indicate that attraction effects may be more apparent than avoidance effects, which stresses the need for proper radar research, to study flight activity inside the wind farms, and to model collision risks.



## 6 Samenvatting

Een typische zeevogeldataset wordt gekenmerkt door een hoge variatie in waargenomen aantallen, een hoog aantal nultellingen, en sterke autocorrelatie. Bij het gebruik van dit soort gegevens in impactanalyses valt de statistische 'power' daarom normaal gezien laag uit. In plaats van punttellingen te gebruiken, hebben wij daarom onze telresultaten gegroepeerd per gebied en per maand, om zo de variantie te drukken en negatieve effecten van autocorrelatie te vermijden. We bestudeerden de te verwachten power van onze impactstudie door verschillende scenario's na te gaan, en we varieerden de afname in aantallen, alsook de monitoringsintensiteit en monitoringsduur. Uit onze resultaten blijkt dat we voor de meeste soorten een afname van 30 tot 70% kunnen detecteren binnen een periode van 10 jaar na de impact. Sommige soorten presteren duidelijk beter dan andere, door toedoen van hun hogere abundantie, en/of lagere overdispersie.

Verrassend genoeg vonden we nu reeds significante effecten als gevolg van de aanwezigheid van offshore windturbines. Met name op de Thorntonbank blijken de aantallen Visdief en Grote stern binnen het impactgebied te zijn toegenomen sinds de eerste turbines er werden gebouwd. Hetzelfde geldt voor Stormmeeuw en Zilvermeeuw op de Blighbank. Terwijl we oorspronkelijk vooral vreesden voor habitatverlies, blijkt uit onze zeer voorlopige resultaten dat vogels eerder aangetrokken worden door de windparken dan dat ze ze vermijden. Aantrekking kan het gevolg zijn van de voorkeur voor artificiële objecten als pleisterplaats of als referentiebakken binnen het open zeegebied, maar kan evengoed het gevolg zijn van verbeterde voedselcondities. Hoedanook stelt dit de vogels voor een ander probleem, namelijk dat van verhoogde mortaliteit als gevolg van aanvaring.

Reeds tijdens de referentiejaren werd de verhoogde aanwezigheid van sterns in de omgeving van de Thorntonbank aangemerkt als aandachtspunt, gezien hun hoge beschermingsstatus en kwetsbare populaties. Terwijl beide soorten in hun broedgebieden al vaak bloot staat aan de risico's van windmolen gerelateerde mortaliteit, lijkt ditzelfde probleem zich nu ook op open zee te gaan stellen. De recente bevindingen onderstrepen ook het belang van degelijk radaronderzoek, om de aantallen vliegbewegingen binnen de windparken in kaart te kunnen brengen, als input voor aanvaringsmodellen. Anderzijds zijn nog steeds slechts 6 van de 54 geplande windmolens op de Thorntonbank aanwezig, en zijn de hier gepresenteerde resultaten hoedanook zeer voorlopig te noemen.



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