Chapter 9. Monitoring seabird displacement effects by offshore wind farms: a modeling approach

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Photo INBO
Abstract

In 2009, we refined the statistical set-up for the assessment of displacement effects on seabirds by wind farms in the Belgian part of the North Sea, more precisely at the Thorntonbank and Bligh Bank. The observed seabird densities were modelled through quasi-likelihood estimation. The resulting models allowed to test for the difference in seabird occurrence between control and impact areas during the reference period.

In case of Northern gannet, Sandwich tern, Common guillemot and Razorbill at the Thorntonbank, as well as for Northern gannet, Black-legged kittiwake and Common guillemot at the Bligh Bank, the delineated control area held highly similar densities compared to the impact area. This of course makes a good base for future BACI-comparison. Moreover, this modelling process is the first crucial step towards a power analysis, which will give insight in the probability of being able to statistically detect specified changes in bird numbers.

In 2008, the first six turbines were installed at the Thorntonbank wind farm site. As expected, we were not yet able to discern any displacement effects. However, there are still about two hundred turbines to be installed at the Thorntonbank (C-Power), Bligh Bank (Belwind) and Bank Zonder naam (Eldepasco), and as such it is too soon to draw any conclusions.

9.1. 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: during autumn and spring, an estimated number of no less than 1.0 to 1.3 million seabirds annually migrate through this ‘migration bottleneck’ (Stienen et al. 2007).

The near future will see large scale exploitation of offshore wind energy, and a large concession zone comprising almost 10% of the waters under Belgian jurisdiction is reserved for wind farming.
Inevitably, this will affect the local seabird community in a number of ways: 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; ...).

The goal of this monitoring study is 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 farm, while others may be attracted to it due to an increase in food availability and roosting possibilities. In April 2008, six wind turbines were installed at the Thorntonbank, and at the Bligh Bank, construction works commenced in September 2009.

9.2. Material & Methods

9.2.1. Reference areas

The study is based on a Before-After Control-Impact comparison. Vanermen et al. (2006) and Vanermen & Stienen (2009) delineated control areas for both future wind farms based on the comparability of numbers and seasonality of seabirds occurring. This set-up however was slightly changed, and in case of the Thorntonbank this was based on the following considerations (see Figure 1):

- equal size & shape of control and impact area
- control area fully located within the former control area (Vanermen et al. 2006)
- maximum overlap with the monitoring routes sailed during the period 2005-2007 (see Figure 2)
- distance of 0.8 nautical miles between reference and control area, equalling half the mean distance sailed per ten-minute count (the geographical error)

These same considerations were taken into account for the delineation of the control area at the Bligh Bank (see Figure 1). However, since a large part of the impact area is situated on the Dutch part of the North Sea (where no counts of seabirds are available nor planned), the control area there is smaller than the impact area. The surface of the control area does equal that of the part of the impact area lying within the BPNS (see Figure 1).
9.2.2. Ship-based seabird counts

From 2005 onwards, intensive monitoring took place through ship-based seabird counts. 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’). The results of these observations are grouped in periods of ten minutes, resulting in so-called ‘ten-minute counts’, defined by a unique ‘position key’. Taking the travelled distance into account, the count results can be transformed to seabird densities with specified X- and Y-coordinates (at the geographical middle point of the track sailed during the ten-minute count).

The resulting database is characterised by huge variation in counted numbers, with far more zero than positive counts, and proportionally very high numbers at few locations. Hence, to increase the statistical power of the data, the variance should be lowered. This can be done by grouping and averaging the measured densities in space or in time, at a scale at which important ecological information does not get lost.

In close dialogue with the team ‘Biometrics and Quality Assurance’ of the Research Institute for Nature & Forest (INBO), a new approach was worked out, in which our count results were lumped per area (control/impact) and per month per year. Furthermore, only those ten-minute counts performed during days on which both the impact and reference area were visited are included in the analysis. This way, we tried to minimize variations due to short-term temporal changes in seabird abundance and due to strong day-to-day changes in weather and observation conditions.

9.2.3. Monitoring species

For the Thorntonbank study area, six species were selected for future monitoring by Vanermen & Stienen (2009). Northern gannet (Morus bassanus), Common guillemot (Uria aalge) and Razorbill (Alca torda) are widely distributed on the BPNS and occur commonly in the study area. The impact area is not of particular importance to these birds, but their common occurrence does make them rewarding species to monitor. In contrast, Little gull (Larus minutus), Sandwich tern (Sterna sandvicensis) & Common tern (Sterna hirundo) are rather scarce but highly protected species, aggregating in the impact area during at least part of the year. Importantly, all six species show negligible association with fishing vessels, so distribution patterns reflect natural preferences rather than distribution of fishing activity.

An analysis of the bird community at the Bligh Bank revealed that Northern gannet, Lesser black-backed gull (Larus fuscus), Black-legged kittiwake (Rissa tridactyla) and Common guillemot all occur in relatively high densities (Vanermen & Stienen, 2009). Unfortunately, the Lesser black-backed gull shows strong association with fishing vessels, making this a highly unreliable monitoring species within a BACI-framework. Analogous to the selection procedure of monitoring species for the Thorntonbank wind farm area (see also Vanermen & Stienen, 2009), the Lesser black-backed gull is therefore not included in the analysis. Instead we take Razorbill in consideration, despite its fairly low densities during the reference period.

Apart from these common species, there were indications that the area holds important concentrations of Great skua (Stercorarius skua) and Little gull during at least part of the year. High proportions of their relatively small populations migrate annually through the BPNS and therefore receive extra attention.

9.2.4. Monitoring scheme and count effort

Since 1993, the INBO carries out standardised seabird counts at the BPNS. From 2002 onwards, this was performed on a monthly basis 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 a true 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, Bligh Bank and Bank zonder Naam (Figure 2).

Figure 2. Monitoring routes sailed during the periods 2005-2007 (left) and 2008-2009 (right), with indication of the (future) location of wind turbines of C-Power and Belwind.

Figure 3 and Figure 4 display the count effort per year in the impact and control areas at both wind farm sites. Hereby, count effort is expressed as the number of square kilometres of transect that was counted (number of kilometres sailed multiplied by the width of the transect, equalling 0.3 km).

Only in 2005, the Thorntonbank study area was visited in all 12 months, but monitoring was also very intensive in the impact period 2008-2009. Outside those years, visits were quite irregular. The reference dataset holds 110 count records, and 38 records were collected after installation of the first six turbines.

Figure 3. Count effort in the Thorntonbank study area, expressed as the number of km² of transect monitored (the labels refer to the number of months during which monitoring took place).
The Bligh Bank wind farm area was monitored intensively from April 2008 to September 2009, while before that, visits were irregular (Figure 4). The reference dataset holds 116 count records (58 per area), with 4 more counts after the first foundations were installed in September 2009.

Figure 4. Count effort in the Bligh Bank study area, expressed as the number of km\(^2\) of transect monitored (the labels refer to the number of months during which monitoring took place).

9.2.5. Data-analysis: modelling

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 \( g(.) \) is the ‘link-function’, \( E(y) \) the expected value of the response variable \( y \) (also noted as \( \mu \)), \( \alpha \) 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 generally respond to a poisson-distribution. Seabirds however often show aggregated distribution, and we corrected for over-dispersion by applying a quasi-poisson model (quasi-likelihood estimation with a logarithmic link-function) (McCullagh & Nelder 1989, McDonald et al. 2000).

Whether counts were performed in the control / impact area or before / after the impact, is defined in the models by the factor variables ‘CT’ (Control-Impact) & ‘BA’ (Before-After). Since seabird occurrence is subject to large seasonal fluctuations, we included ‘month’ as a continuous variable. An elegant method to describe seasonal density patterns with a continuous variable is to use a sinusoidal curve, which can be written as the linear sum of a sine and a cosine term (Onkelinx et al. 2008):

\[ \text{Int. density} = a_1 \times \sin \left( 2 \times \pi \times \frac{\text{month}}{p} \right) + a_2 \times \cos \left( 2 \times \pi \times \frac{\text{month}}{p} \right) \]

In the above equation, \( p \) is the period of the sinusoidal curve, expressed as the number of months. Coefficients \( a_1 \) & \( a_2 \) determine the amplitude \( A \) and phase shift \( S \) of the sinusoidal curve as follows:

\[ A = \sqrt{a_1^2 + a_2^2} \quad S = \arctan \frac{a_1}{a_2} \]
Figure 5. Example of a sine curve in logarithmic scale (left) and the same curve transformed into the linear scale.

Figure 5 presents a fictitious example of a summer visitor, in which the period of the seasonality 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 sine/cosine terms, as for example in:

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

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 6).

Figure 6. Example of combining two sine curves with different periods, in the logarithmic scale (left) and after transformation into the linear scale (right).
9.2.6. Data-analysis: statistical testing

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

Figure 7 presents the flowchart for the selection of the reference model. When going through the whole flowchart, we end up with one of the following five reference models:

- **reference model 1** “Seasonality+CI+Seasonality:CI”: the full ‘reference model’ including ‘seasonality’ (sum of sine and cosine terms) and the factor variable ‘CI’ (control-impact area), as well as the interaction between both;
- **reference model 2** “Seasonality+CI”: the same model as the previous, but without interaction;
- **reference model 3** “Seasonality”;  
- **reference model 4** “CI”;
- **reference model 5** “Intercept”

We start from the most complex model, including an interaction term. By dropping this latter, we may test if there is a difference in seasonality pattern between both areas (test 1). Logically, seasonal fluctuations occur on a broader scale that the study area itself, and therefore we do not expect this test to reveal significance. For the same reason, seasonality forms the base of our model and is tested for last. Anyhow, if the p-value of the first test exceeds 0.05, we may drop the interaction and continue with model 2. If not, model 1 is the selected reference model.

Next, we want to know if there is an additive effect of ‘CI’ (test 2), which would indicate a difference between the two areas. The resulting p-value of test 2 will stipulate whether to continue with test 4, or alternatively, to drop ‘CI’ and to continue with test 3. Eventually we end up with one of the five aforementioned reference models.

![Flowchart of tests performed to select a reference model](image-url)

Figure 7. Flowchart of tests performed to select a reference model (the terms indicated in red are successively left out of the model – e.g. test 1 compares a model with the interaction term ‘Seasonality:CI’ included with a model without interaction).
Chapter 9. Seabirds

The impact analysis depends on the selected reference model. If we observed an interaction- or area-effect during the reference years, the factor variables ‘BA’ & ‘CI’ are included in the model (4 unique combinations). However, in case we did not observe any difference between impact and control area, we opt to include the factor variable ‘T’ (0=no turbines present; 1=turbines present) instead of ‘CI’, resulting in only 3 unique combinations (Table 1).

Table 1. Overview of the unique combinations of factor variables used in the impact analysis (green=reference period / red=impact period).

<table>
<thead>
<tr>
<th>‘BA’-‘CI’</th>
<th>Control-Impact</th>
<th>Before-After</th>
<th>Turbine presence</th>
<th>‘BA’-‘T’</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0</td>
<td>Control Area</td>
<td>Before</td>
<td>No turbines</td>
<td>0 – 0</td>
</tr>
<tr>
<td>0 – 1</td>
<td>Impact Area</td>
<td>Before</td>
<td>No turbines</td>
<td>0 – 0</td>
</tr>
<tr>
<td>1 – 0</td>
<td>Control Area</td>
<td>After</td>
<td>No turbines</td>
<td>1 – 0</td>
</tr>
<tr>
<td>1 – 1</td>
<td>Impact Area</td>
<td>After</td>
<td>Turbines</td>
<td>1 – 1</td>
</tr>
</tbody>
</table>

Depending on the selected reference model, there are five different scenarios (the green terms represent the reference model):

- **reference model 1**: \((\text{Seasonality}+\text{CI}+\text{Seasonality} \cdot \text{CI}) \cdot \text{BA} = \) Seasonality + CI + BA + Seasonality:CI + Seasonality:BA + Seasonality:BA:CI
- **reference model 2**: \((\text{Seasonality}+\text{CI}) \cdot \text{BA} = \) Seasonality + CI + BA + Seasonality:BA + BA:CI
- **reference model 3**: \((\text{Seasonality}) \cdot (\text{BA} + \text{T}) = \) Seasonality + BA + T + Seasonality:BA + Seasonality:T
- **reference model 4**: \((\text{CI}) \cdot \text{BA} = \) CI + BA + BA:CI
- **reference model 5**: \((\text{Intercept}) \cdot (\text{BA} + \text{T}) = \) BA + T

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 effects of the ‘BA:CI’- or ‘T’-term (tests 2’ & 2” - Figure 8 & Figure 9). However, when these terms are included in an interaction term of a higher degree, these need to be dropped first (tests 1’ and 1”).

So the first two tests in both flowcharts are crucial, while the following are rather facultative, testing the significance of the terms ‘BA:Seasonality’ and/or ‘BA’. These latter indicate the difference between the periods before and after the impact, due to a change in numbers or seasonality at a broader scale, apart from any turbine effect.
Figure 8. Graphic scheme of models & tests carried out within the framework of the impact study based on reference model 1 (the terms indicated in red are successively left out of the model).

Figure 9. Graphic scheme of models & tests carried out within the framework of the impact study based on reference model 3 (the terms indicated in red are successively left out of the model).
9.3. Results

9.3.1. Seabird presence during the reference period at the Thorntonbank

Figure 10. Geometric mean densities (+/-std.error) per two-month period in the Thorntonbank study area during the reference years 1993-2007.

Visual interpretation of mean seabird densities in the Thorntonbank reference and impact area suggests that there are only minor differences in the presence of Sandwich tern, Common guillemot and Razorbill between reference and impact area (Figure 10). Comparability between the two areas is however less for the other species, but except for Northern gannet densities in September-October and Common tern densities in March-April, the ranges of standard errors overlap. In the case of the
Common tern, we are faced with the more worrying fact that the database holds no more than 7 positive (non-zero) counts (2 in the control area & 5 in the impact area).

Modelling the observed densities allows for a statistical analysis of the reference data. Based on the seasonal patterns displayed in Figure 10, we decided to model the tern species with a two-fold seasonality pattern (a curve with period p=12 months added with a curve with p=4 months), while the other species were modelled based on a single sine curve with a period of one year (Table 2). The drop in deviance induced by the resulting reference models varies from 19.4 to 59.4%, for Northern gannet and Common tern respectively.

In the case of Little gull and Common tern, the interaction term contributes significantly to the model (a drop in deviance of 32.6% and 59.4% respectively), proving a different seasonality pattern between both areas. According to the model, peak abundance of Little gull in the reference area occurs in midwinter, while in the impact area, highest numbers are predicted to occur two months later, in early spring. For Little gull, model 1 was thus the final reference model. This could also be the case for Common tern, however, this species’ model is characterised by large standard errors on the predicted densities (Figure 11). It can therefore not be used as a base for impact assessment, let alone for a power analysis.

In the other four seabird species, statistical testing revealed that there are no differences between control and impact area. Only seasonality was able to explain a significant deal of the variance in densities, resulting in model 3 as a reference model. Peak numbers of both auk species are predicted to occur in midwinter, while Northern gannet is predicted to be most abundant during autumn migration. A different pattern is observed in Sandwich tern. At the BPNS, this species is present from April to September, with numbers peaking in June. At the study area however, Sandwich tern is quite common during migration in April and August, but fully absent during the breeding season (May-June). Some years, high numbers of Sandwich tern breed in the colony of Zeebrugge, but apparently the Thorntonbank is outside the foraging range of these birds (averaging 16km according to Brenninkmeijer & Stienen, 1994).

Concluding, the reference area is well suited for future monitoring of all species except for Common tern. This is mainly due to the very low number of only 7 positive counts in the reference period.

Table 2. P-values resulting from ANOVA-tests (see Figure 7) and drop in deviance based on the selected reference model (* indicates significance).

<table>
<thead>
<tr>
<th>Species</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Model</th>
<th>Δ Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern gannet</td>
<td>0.263</td>
<td>0.366</td>
<td>0.003*</td>
<td>-</td>
<td>3</td>
<td>19.4%</td>
</tr>
<tr>
<td>Little gull</td>
<td>0.019*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>32.6%</td>
</tr>
<tr>
<td>Sandwich tern</td>
<td>0.688</td>
<td>0.650</td>
<td>0.000*</td>
<td>-</td>
<td>3</td>
<td>55.4%</td>
</tr>
<tr>
<td>Common tern</td>
<td>0.048*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>59.4%</td>
</tr>
<tr>
<td>Common guillemot</td>
<td>0.308</td>
<td>0.558</td>
<td>0.000*</td>
<td>-</td>
<td>3</td>
<td>55.1%</td>
</tr>
<tr>
<td>Razorbill</td>
<td>0.729</td>
<td>0.481</td>
<td>0.000*</td>
<td>-</td>
<td>3</td>
<td>32.4%</td>
</tr>
</tbody>
</table>
Figure 11. Predicted seabird densities (with 95% point wise confidence intervals) according to the selected reference models for the Thorntonbank wind farm area (the break in the vertical axis in the Common tern graph is at 1 bird/km²).
9.3.2. Seabird presence during the reference period at the Bligh Bank

Figure 12. Geometric mean densities (+/-std.error) per two-month period in the Bligh Bank study area during the reference years 1993-2009.

When seabird densities in the impact and reference area at the Bligh Bank are compared, we see that only for Common guillemot, there is very good accordance (Figure 12). In fact, this would also be the case for Black-legged kittiwake if it was not for one record of a very high density observed in October 2008, strongly skewing the seasonal pattern. For the other species, comparability in densities is less striking but due to high variability in the data, differences generally fall within the standard error ranges.

Modelling gives an objective insight in our reference data. Seasonal fluctuations in all six species were modelled using a single sine curve with a period equalling one year (Table 3).
Unfortunately, for Great skua, none of the tested models was able to explain a significant part of the deviance. This species is quite rare and seldomly observed, and even in the BPNS as a whole it does not show a clear seasonal pattern. The resulting model is limited to the intercept.

In the Razorbill and Little gull model, the interaction term appeared to be significant. Razorbill densities in the impact area are predicted to be lower than in the control area, and to peak one month earlier. Unfortunately, the Little gull model is based on very few data (only 5 positive counts), resulting in highly unreliable predicted densities (Figure 13). This is the same scenario as encountered for Common tern at the Thorntonbank. This model too is useless and we will therefore not include this species in future monitoring at the Blighbank wind farm.

Lastly, no differences between the two areas could be discerned for the remaining three species, Northern gannet, Black-legged kittiwake and Common guillemot, and seasonality was the only variable contributing significantly to the density models. Predicted densities of these three species all peak during winter months.

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Model</th>
<th>Δ Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern gannet</td>
<td>0.599</td>
<td>0.492</td>
<td>0.020*</td>
<td>-</td>
<td>Model 3</td>
<td>15.4%</td>
</tr>
<tr>
<td>Great skua</td>
<td>0.249</td>
<td>0.725</td>
<td>0.186</td>
<td>-</td>
<td>Model 5</td>
<td>0%</td>
</tr>
<tr>
<td>Little gull</td>
<td>0.000*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Model 1</td>
<td>71.3%</td>
</tr>
<tr>
<td>BL kittiwake</td>
<td>0.360</td>
<td>0.319</td>
<td>0.042*</td>
<td>-</td>
<td>Model 3</td>
<td>20.9%</td>
</tr>
<tr>
<td>Common guillemot</td>
<td>0.607</td>
<td>0.187</td>
<td>0.000*</td>
<td>-</td>
<td>Model 3</td>
<td>56.5%</td>
</tr>
<tr>
<td>Razorbill</td>
<td>0.018*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Model 1</td>
<td>65.3%</td>
</tr>
</tbody>
</table>
Figure 13. Predicted seabird densities (with 95% point wise confidence intervals) according to the selected reference models for the Bligh Bank wind farm area (the break in the vertical axis in the Little gull graph is at 5 birds/km²).
9.3.3. Impact analysis Thorntonbank

Figure 14. Geometric mean densities (+/- std.error) during periods of peak abundance in the reference and impact area before and after the first turbines were built.

Figure 14 compares geometric mean densities of seabirds before and after the six turbines were built. The means are based on the period of peak occurrence:

- Northern gannet: August-January
- Little gull: November-April
- Sandwich tern: March-April / July-August
- Common guillemot: October-March
- Razorbill: October-March

Little gull densities remained more or less the same in both the impact and the control area. Accordingly, there was no displacement effect indicated by the ‘BA.CT’ term (test 2’). Due to a shift
in peak numbers from winter to spring months, there was only a significant effect of the interaction between ‘BA’ and seasonality (test 3').

A clear drop in densities of Northern gannet and Common guillemot occurred in the impact area, and a strikingly parallel decrease took place in the reference area. Accordingly, tests 1' & 2' did not reveal any turbine effect (‘T:Seasonality’ & ‘T’), while the drop in densities after 2007 indicated by ‘BA’ was significant. This is most probably due to a general decrease in numbers rather than a displacement effect of the turbines.

Razorbill densities slightly decreased in the impact area, with a more pronounced decrease in the control area. This difference however did not appear to be significant. In both areas, densities of Sandwich tern slightly increased, but again, no turbine effects could be detected.

Table 4. P-values resulting from ANOVA-tests for the impact analysis based on reference model 1 (see also Figure 8) (* indicates significance).

<table>
<thead>
<tr>
<th></th>
<th>Test 1'</th>
<th>Test 2’</th>
<th>Test 3’</th>
<th>Test 4’</th>
<th>Test 5’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little gull</td>
<td>0.184</td>
<td>0.302</td>
<td>0.002*</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5. P-values resulting from ANOVA-tests for the impact analysis based on reference model 3 (see also Figure 9) (* indicates significance).

<table>
<thead>
<tr>
<th></th>
<th>Test 1”</th>
<th>Test 2”</th>
<th>Test 3”</th>
<th>Test 4”</th>
<th>Test 5”</th>
<th>Test 6”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern gannet</td>
<td>0.183</td>
<td>0.635</td>
<td>0.580</td>
<td>0.045*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sandwich tern</td>
<td>0.057</td>
<td>0.340</td>
<td>0.258</td>
<td>0.782</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Common guillemot</td>
<td>0.566</td>
<td>0.528</td>
<td>0.624</td>
<td>0.000*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Razorbill</td>
<td>0.874</td>
<td>0.394</td>
<td>0.705</td>
<td>0.114</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

9.4. Discussion

Compared to the previous monitoring report (Vanermen & Stienen, 2009), we introduced two new developments in our approach. Instead of using the ten-minute count results as the traditional base for seabird data processing, we now grouped these count data per area and per month per year, in order to decrease variability. Secondly, we modelled our data using quasi-likelihood estimation, and comparability of impact area and control area could be tested based on the resulting models.

When analysing the reference data, it appeared to be impossible to perform reliable statistical processing in case of Common tern at the Thorntonbank and Little gull at the Bligh Bank, due to a very low number of positive count records. For Great skua the proposed modelling set-up failed to explain a significant deal of the deviance due to an unclear seasonal pattern in the species’ occurrence at the Bligh Bank study site.

On the other hand, control and impact areas held highly comparable densities of most other studied species, as in Northern gannet and Common guillemot at both sites, as well as Razorbill and Sandwich tern at the Thorntonbank site and Black-legged kittiwake at the Bligh Bank site.

We did observe a significantly different seasonality pattern in Little gull at the Thorntonbank, and in Razorbill at the Bligh Bank. We regard seasonal occurrence of seabirds as a broad scale phenomenon, and therefore we do not expect differences in seasonal patterns to occur at such a small scale. This might suggest that observed densities of these species do not reflect a truthful situation, and we should be careful towards conclusions in future impact assessments concerning these species.

The selected reference models will be used as a base for a power analysis. This will make it possible to determine the survey effort necessary to detect specified changes in bird numbers with a certain significance level (for example a 25% change in bird numbers with a 5% significance level) (McLean et al., 2006).

Finally, we presented our approach for future impact assessments. We already tested for displacement effects by the six turbines at the Thorntonbank, and none could be detected. Clearly, it is far too soon to draw any conclusions because of two reasons. First of all, this assessment is based on the numbers within the full impact area (future wind farm location plus buffer zone), where presently only 6 out of 54 turbines are present. Furthermore, until the year 2010, seabird counts were restricted...
to the buffer zone, since it was prohibited for the research vessel to enter the area in between the turbines.

9.5. Acknowledgements

We first want to thank n.v. C-Power, n.v. Belwind and the Management Unit of the North Sea Mathematical Models (MUMM) for their financial input and assigning this research to us. MUMM staff members Robin Brabant, Steven Degraer, Bob Rumes & Thierry Jacques are thanked for their guidance and critical comments on this report, and the same accounts for my colleagues Dirk Bauwens and Paul Quataert of the “Biometrics and Quality Assurance” team. We would also like to thank all volunteers who assisted during the seabird counts (especially Walter Wackenier & Kevin Lambeets), as well as the crew of the research vessel “Zeeleeuw”, and not in the least the Flanders Marine Institute (VLIZ), without who’s logistic support this research would not be possible.

9.6. Reference list


