POST-CONSTRUCTION EVALUATION OF BIRD ABUNDANCES AND DISTRIBUTIONS IN THE HORNS REV 2 OFFSHORE WIND FARM AREA, 2011 AND 2012

Report commissioned by DONG Energy

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Executive summary

The Horns Rev 2 offshore wind farm comprises 91 turbines covering a total area of 34 km^2 ca. 14 km northwest of the Horns Rev 1 offshore wind farm and started its operational phase in September 2009.

DONG Energy contracted Aarhus University, DCE (Danish Centre for Environment and Energy) to undertake a total of 10 aerial surveys of birds throughout the Horns Rev study area during the winters and springs of 2011 and 2012. These surveys were conducted using the same survey methods as used during the Horns Rev 2 pre-construction surveys to offer a before/after comparison of bird distribution within and around the impacted area.

The single most abundant bird species in the study area was Common Scoter, which utilized the shallower waters of the surveyed area. Up to 187,000 individuals were observed during a single survey in March 2011 making the area internationally importance for this species. Divers were also present in the study area in significant numbers, of which Red-throated Diver comprised more than 90% of all diver observations. The most abundant gull species was Herring Gull, but Kittiwake and Little Gull were also frequently recorded within the area. Razorbills and Guillemots were mostly recorded in the western parts of the study area.

In this report, particular emphasis has been placed upon analyses of potential changes in the abundance and distribution of Common Scoters and diver species (i.e. Red-throated Diver/Black-throated Diver observations combined) before and after construction of turbines. In collaboration with DMP Statistical Solutions UK Ltd. in St. Andrews we used distance sampling tools and spatial adaptive modelling to estimate densities and predict distribution surfaces for the two species/species groups.

For the purpose of the pre- and post-construction comparisons, 10 surveys conducted in the survey area between November 2005 and April 2007 were selected. Abundance and distribution data from these 10 surveys were compared to data from the 10 post-construction surveys presented in this report. Aerial surveys conducted in relation to Horns Rev 1 between 2000 and 2004 covered an area that only included parts of the Horns Rev 2 wind farm site, and were thus not included. A series of six surveys performed during the winter of 2007/2008 were delivered for this analysis with a data structure that was not compatible with the selected surveys, and were thus omitted.

Although the overall abundance of divers was similar during the pre- and post-construction periods, marked distributional changes within the survey area were found. While densities significantly increased in the westernmost parts of the study area, significant decreases were found in and around the Horns Rev 2 offshore wind farm. While the cause for decreased densities at distances of 10 km from the Horns Rev wind farm are unclear, there are clear indications of a wind farm related displacement in areas closer to the wind farm. The distance from the wind farm towards the post-construction high density area for divers west of the wind farm was the best indication of a wind farm related disturbance effect. This distance was 5-6 km. The mean reduction in diver numbers within the area of the turbines of the Horns Rev 2 wind farm was estimated to be 17 individuals, and 48 birds when calculating reductions in the wind farm plus a buffer zone of 2 km around the outermost turbines. Taking the total area around the wind farm in which post-construction abundance was significantly lower than the pre-construction abundance, there was a mean of 173 fewer individuals. Significant reductions in density in the north eastern parts of the study area are unlikely to be related to the presence of the wind farm.

Overall Common Scoter abundance was also similar comparing the pre- and post-construction periods, but again marked distributional changes were found. Most notably Common Scoter abundances decreased in the area of approximately 100 km^2 around the Horns Rev 2 offshore wind farm and in the coastal area west of Skallingen post-construction. Densities increased in areas south of the Horns Rev 1 offshore wind farm, east of the Horns Rev 2 wind farm and in the western and northwestern parts of the survey area post-construction. Although there is no obvious explanation for reductions in scoter density in the eastern parts of the study area, decreases in density that correspond to the area in which the Horns Rev 2 offshore wind farm was constructed are likely to be associated to the presence of the wind farm. The abundance of Common Scoter decreased by a mean of 5,901 birds within the Horns Rev 2 wind farm, equivalent to 1.1% of the flyway population. Mean abundance post-construction was 13,193 birds less than pre-construction within the wind farms and a buffer zone of 2 km around the outer turbines. The mean difference in abundance pre- and post-construction in the ca. 50 km^2 area around the wind farm in which significant reductions were found amounted to 10,996 birds fewer, equivalent to 2.0% of the flyway population.

There were no significant changes in bird densities within the Horns Rev 1 offshore wind farm area across the 20 surveys. Horns Rev 1 was already operational during both the pre- and post-construction surveys conducted in relation to this work, and thus no change in utilization of the Horns Rev 1 wind farm site was expected or found over this period.

1 Methods

1.1 The line transect sampling method

The survey area covered the Horns Rev and its surroundings west of Blåvandshuk in the Danish part of the North Sea, including both the Horns Rev 1 and the Horns Rev 2 offshore wind farms (Fig. 1). Ten aerial surveys were conducted in the period between the early spring of 2011 and the spring of 2012. Each survey consisted of a total of 21 transects with a total length of 644 km. All transects were placed parallel to each other, though with some minor deviations in the wind farm areas due to the presence of individual wind turbines. The spacing between transects was 2 km in areas covering the two wind farm areas and 4 km elsewhere. The transects are shown in Fig. 1 and their lengths specified in Table 1).

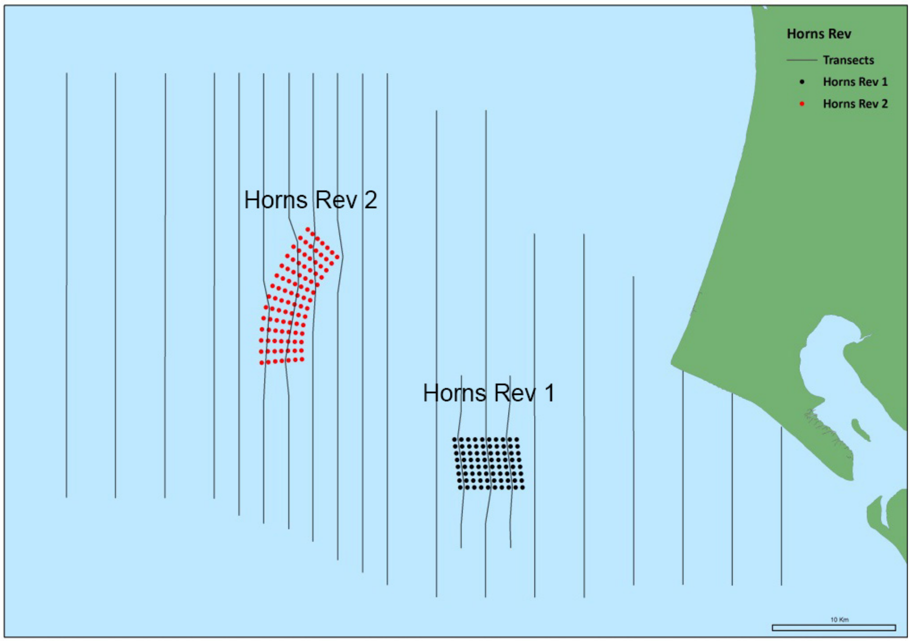


Figure 1. The survey area west of Blåvands Huk. The two existing Wind Farms (Horns Rev 1+2) are shown as are the 21 transects used during the aerial surveys.

A twin-engined, high-wing Partenavia P68 Observer aircraft was used in nine of the ten surveys, the last one conducted from a Cessna 337. Two observers, one on each side of the plane, counted all birds and marine mammals observed while on transect. Bubble windows installed in the airplanes ensured optimal viewing conditions for the observers.

Birds were counted in three transect bands (Table 2, Fig. 2). An inclinometer was used to allocate birds to the appropriate transect bands and to measure the precise vertical angle to all observed marine mammals. Each observer recorded the exact time of each observation, species, transect distance band, behavior and if possible age and sex of birds onto a dictaphone. In order to provide precise geographic coordinates to all observations the times of the observations were later converted to positions by relating to the positions continuously recorded by a GPS (Trimble, GeoXT) in the plane.

Table 1. The length of the individual transects used in the aerial surveys conducted in the Horns Rev Area in 2011 and 2012.

Transect #	Length (Km)
1	12.9
2	15.6
3	17.4
4	25.1
5	29.5
6	29.5
7	14.0
8	39.6
9	14.1
10	39.5
11	41.5
12	40.5
13	39.6
14	38.0
15	37.2
16	36.6
17	35.9
18	34.5
19	34.4
20	34.5
21	34.5

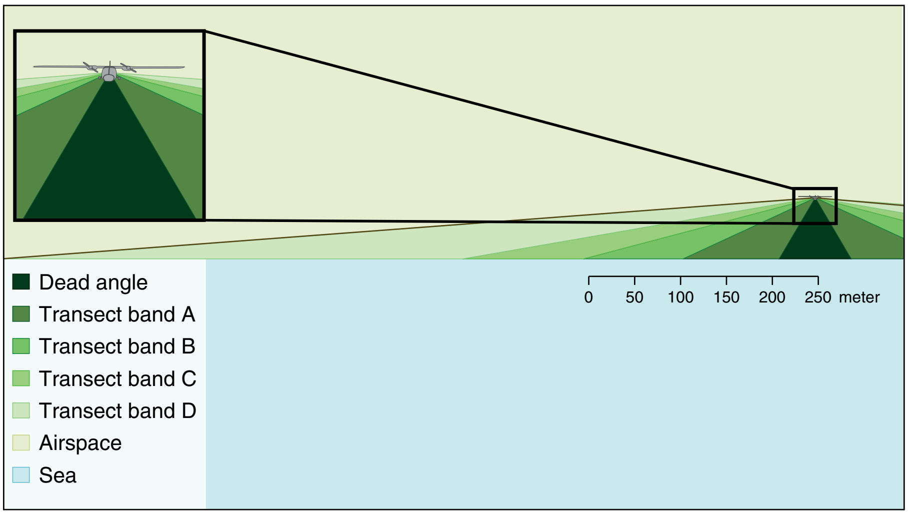


Figure 2. The spatial extent of the line transect distance bands perpendicular to the flight direction of the aircraft. A blind or “dead” 44 m wide band on each side of the track line was excluded from the survey area.

Table 2. The transect band delimitation used during aerial surveys conducted in the Horns Rev Area in 2011 and 2012. The distances/angles listed below are defined as the perpendicular distances/angles from the count route (90˚ being vertical and 0˚ being horizontal).

Transect band	Delimitation (meters). Measured perpendicular on the flying route	Delimitation (degrees). Measured perpendicular on the flying route
A	44-163	60˚-25˚
B	164-432	25˚-10˚
C	433-1500	10˚-3˚

The surveys were conducted from a flight altitude of 250 feet (75m) and with a ground speed of approximately 90 knots (160km/h). The combination of low flying speed and altitude is designed to increase the ability of the observers to detect animals on the transect line and to positively identify them to species level (Fig. 3).

Birds were identified to species levels when possible. For some similar species, differentiating plumage and appearance to enable identification to species level requires very good survey conditions. For this reason, in this report, Razorbills and Guillemots are aggregated to "Razorbill/Guillemot" and Red-throated and Black-throated Divers to "divers".

Sea state (wind), sun intensity and precipitation were recorded at the beginning of each individual transect and again along the transect if the conditions changed. Heavy precipitation and high wind speeds can influence the observers' possibility of detecting birds.

All human activities (e.g. fishing vessels, gill nets and hunters) were also recorded.

Figure 3. Common Scoters and a few Velvet Scoters 1 March 2011, the species are often seen in mixed groups. Common Scoters often take off at some distance. Photo: Kent Olsen/Naturhistorisk Museum, Aarhus.

1.2 Estimating densities and spatial distributions for divers and Common Scoter

The observed counts from the aerial line transect surveys were inflated for imperfect detection from the survey track lines and spatially explicit statistical models built to quantify species distribution and identify any overall or spatially explicit changes pre- and post-construction of the recently installed Horns Rev 2 wind farm. This process comprised two main parts – correction for imperfect detection and spatially explicit modelling.

In order to correct for imperfect detection the distance sampling method was used to fit a detection function. This function describes the reduced probability of detecting a bird or group of bird with increased distance from the transect line. Using this method overall numbers of birds within the survey area could be estimated.

In a second analysis step spatial modelling was used to describe the distribution of the birds within the study area at a fine geographical scale. Relationships between estimated bird densities and environmental covariates, such as for instance water depth, was established. Bird densities could thereafter be predicted to a surface covering prediction grid with grid cells of 500 x 500 meters size. Generalized Estimating Equations (GEEs) was used to estimate confidence intervals for the density estimations. Both spatial and temporal autocorrelation was taken into consideration using this method. The process is described in more details below.

1.2.1 Correcting for imperfect detection using Distance sampling analysis

In order to enable density and abundance estimates the survey data was established describing the survey track line and the bird observations, respectively. Data describing the survey transect track lines was established as GIS line themes, divided into segments of 500 meters. Observation data was established in a GIS theme, with information about species, numbers, distance band and observation conditions. Additionally, for the diver data set, two observations were omitted from the analysis, both with errors in the distance band allocation, since these values lay outside of the range of the distance bands.

Detection function model selection

Half-normal and hazard-rate key functions were compared for each species, using a comprehensive set of candidate models constructed from the available covariates: log of group size, observer initials, behaviour and sea state. The preferred model for each species was chosen on the basis of AIC (Akaike Information Criterion, Fig. 4). The figure shows plots of the fitted average detection function across individuals for the chosen models and summary information for each model is given in Table 3.

For each species/species group the chosen detection function model was used to estimate the abundance of individuals in each segment.

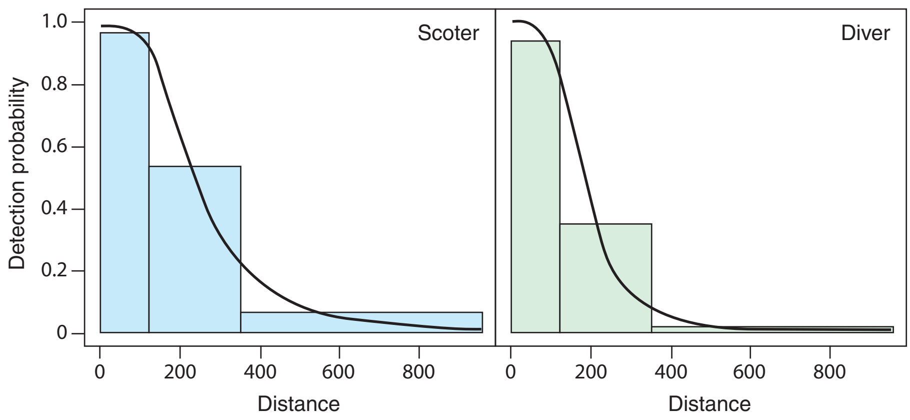


Figure 4. Fitted detection functions for the Common Scoter and diver data sets. The detection function indicates the fitted average detection probability across individuals.

Table 3. Summary information for the chosen detection functions for each group. In both cases, too few degrees of freedom were available to carry out a Chi-squared goodness-of-fit test.

	Number of detected groups	Detection function key	COvariates In chosen model
Scoter	22771	Hazard rate	Log group size, initials, behaviour, sea state
Diver	1536	Hazard rate	Initials, behaviour

1.2.2 Spatially explicit modelling

The corrected counts for imperfect detection for each segment served as inputs for the statistical models in order to produce distribution maps for each species/species group. Uncertainties were quantified for all of these outputs and abundances calculated for each species/species group, with associated 95% confidence intervals (Mackenzie et al. 2013a).

We present here a technical description of the statistical models used to generate the species density maps and abundance estimates. This pre-supposes knowledge of Generalized Linear Models (GLMs) and smoothing methods.

To accommodate local surface features in species distribution and potentially patchy numbers of animals across the survey area, a range of candidate models were considered for the species-specific density surfaces. The scope of the models considered was chosen to adequately capture surfaces with both local surface features (e.g. patchy surfaces with locally acting hotspots) and global surface features (e.g. flat surfaces or far-reaching trends). A recently developed Complex Region Spatial Smoother (Scot-Hayward et al. in press) was used to fit the density surfaces, the details of which are described here.

Model details

The count data were assumed to be (potentially over-dispersed) Poisson counts with spatio-temporal autocorrelation. Flexible surfaces were implemented for each species/species group and these surfaces were allowed to change substantially before and after construction/impact (via an interaction effect with the spatial smooth).

Main (factor variable) terms for pre-post construction/impact (determined using the installation date of the wind farm) and calendar month were included, along with a smooth function for water depth were fitted in models for each species. A smoother-based term for a spatial surface was also included in each model and this surface was permitted to change substantially pre- and post-construction/impact, should this be justified using objective fit criteria.

In all cases, a log link and over-dispersed Poisson errors were assumed for each model.

The Complex Region Spatial Smoother (Scot-Hayward et al. in press) was used to fit the density surfaces. For this approach, model flexibility is determined by both the number of 'knots' used (i.e. anchor points) for the model and the effective range (*r*) of the basis associated with each knot. Here *r* controls the spatial extent to which each knot/basis influences the fitted surface. Since the optimal choices for both of these features are always unknown, these details were considered as a part of the model selection process governed by objective fit criteria.

For a given knot number, the initial knot locations on the spatial surface were chosen to maximize the coverage across the spatial area, via a space filling algorithm (Johnson et al. 1990), and these locations were permitted to move according to the Spatially Adaptive Local Smoothing Algorithm (Walker et al. 2011) model selection method. The local exponential basis function (($\exp(-d/r^2)$ with d=Euclidean distance) was implemented and was permitted to have variable *r*-values across the surface, which were dictated by the data. A variable number of knot numbers were used for the candidate models and an objective fit criterion (below) was used to choose the best model(s).

The degree of flexibility permitted for the spatial models was determined using Cross-Validation (CV). This 10-fold CV score balances fit to the data with model complexity and is based on evaluating model predictions to data unseen by the model (validation data). The data are randomly split into 10 mutually exclusive sets and while 9 of the 10 sets are used to train the model, the remaining set is used to evaluate these trained model predictions to the validation set. This is repeated until all 10 sets have acted as validation sets and effectively repeatedly simulates model predictions on unseen data (Hastie et al. 2009). The sum of the squared differences between the observed data in the validation sets and the predictions based on the training data are then found in each case, and the average of these 10 values used to give a CV score.

Spatially explicit Inference

Spatially explicit inference in the predictions and associated estimates of abundance involved combining parameter uncertainty in the detection function fitting process with parameter uncertainty in the parameters for the spatially explicit models. The details of this two part process are described in this section.

1.2.3 Parameter uncertainty in the detection functions

To assist this combined inference process, 500 bootstrap resamples of the detection functions were also produced by resampling lines (with replacement) from each survey. As a part of this process, the preferred detection functions were refitted using the observations from the bootstrap replicates and individual abundance estimates obtained for each segment, in each case. This gave rise to 500 sets of abundance estimates per segment for input to the combined inference process.

1.2.4 Parameter uncertainty in the spatially explicit models

The count data are collected along transects and consecutive measurements on these transects are closely linked in space and time. Additionally, due to environmental or prey conditions which may be unknown to us, the abundance of animals at any particular location is likely to be more similar for points close together in time compared with points distant in time. Models fitted to the count data attempt to explain animal abundance at any particular location, but the covariate information that describes why animals are found in high/low numbers at particular locations is often missing from the model. This leaves a pattern in the noise component – as represented by model residuals. Further, these patterns are likely to be similar along the track lines. This correlation in model residuals along the track lines violates a critical assumption for standard statistical models (such as GLMs/GAMs) which require independence of errors. Further, ignoring this violation can invalidate all model-based estimates of precision (e.g. standard errors, confidence intervals and *p*-values). Further to this, if the incorrect inference is used in model selection, the selected model may not be justified, meaning even point estimates may be poor. Given positive correlation is typical, the models will tend to be over-complicated and statistical significance tends to be attributed to random fluctuations in the data.

For this reason, a modelling framework which incorporates this autocorrelation was used to obtain realistic model-based estimates of precision in this analysis (Generalized Estimating Equations (GEEs); Hardin and Hilbe 2002). GEEs are designed to explicitly estimate and incorporate residual autocorrelation within the transects. To ensure this extra complexity was required, a runs-test (Mendenhall 1982) was employed in each case to test for statistically significant levels of spatio-temporal autocorrelation in model residuals along the transects. In the case that statistically significant levels of autocorrelation were found, transect-days were used to define the panel/blocking structure. In a GEE setting, correlation is permitted within survey lines but independence between these is assumed.

The GEE method adjusts model-based estimates of precision (e.g. 95% confidence intervals) for the autocorrelation observed in the model residuals, via empirical sandwich estimates of variance, to give robust results and realistic model inference.

1.2.5 Combining the uncertainty from the detection function and spatial modelling processes

A non-parametric bootstrap process was used to provide 500 sets of estimated abundances for each transect segment across the surface, based on the parameter uncertainty at the detection function stage. These bootstrap replicates were then used as inputs into the CReSS model fitted using GEEs which was refitted for each bootstrap realisation. The GEE-based standard errors from each model refit were then used to generate a parametric bootstrap replicate from each of these 500 realisations. These provided empirical confidence intervals across the surface. Note that these geo-referenced confidence intervals include the uncertainty in model parameters at the detection function and spatial modelling stage, spatio-temporal autocorrelation and over-dispersion.

2 Results

2.1 Species account for the ten surveys conducted in 2011 and 2012

A total of 30 species of water birds, 5 species groups and 3 species of marine mammals were registered on 10 aerial surveys conducted in the survey area in 2011 and 2012 (Table 4).

Of these 35 species or species groups of birds 16 were recorded in numbers less than 50 individuals. Only a few bird species or species groups were recorded with more than 500 individuals. Common Scoter was the most abundant bird species in the survey area (Fig. 3), followed by Herring Gulls, Unidentified gulls, Razorbills/Guillemots and divers, all of which were recorded in excess of 500 individuals (Table 4).

Distribution maps for selected species and species groups, including Red-throated Diver/Black-throated Diver, Common Scoter, Little Gull and Razorbill/Guillemot are given in this section.

Table 4. The number of observed individuals by survey date and bird or mammal species/species group for ten aerial line transect surveys at Horns Rev in winter and spring of 2011 and 2012.

Species	**1 MAR 2011**	**26 MAR 2011**	**11 APR 2011**	**13 OCT 2011**	**17 NOV 2011**	**15 JAN 2012**	**8 FEB 2012**	**2 MAR 2012**	**22 MAR 2012**	**11 APR 2012**	**Total**
Red-throated Diver	28	60	409	50	3	14	17	80	199	76	936
Red-throated/Black-throated Diver	1	2	24	47	3			1	13	2	93
Red-necked Grebe								2			2
Northern Fulmar		1		1	1	1			1	1	6
Northern Gannet	3	13	14	10	8				2	8	58
Great Cormorant	2	3				3			1		9
Greylag Goose			27							29	56
Brent Goose							25				25
Eurasian Wigeon	5		21								26
Eurasian Teal			79								79
Mallard							5				5
Common Eider	126	33	5	5	11	3	192	67	1	32	475
Long-tailed Duck	7				3						10
Common Scoter	187,726	80,950	29,146	9,037	16,500	115,516	29,478	34,127	22,315	8,216	533,011
Velvet Scoter	65	150	104	3	9	12	41	56	5	27	472
Common Goldeneye							115				115
Red-breasted Merganser							1		1		2
Oystercatcher							4				4
Bar-tailed Godwit	2										2
Great Skua				1							1
Black-legged Kittiwake	3	8	117	17	58	59	3	5	2		272
Black-headed Gull			1	2				2	19		24
Little Gull	18	2	74		28	18	2	17	65	72	296
Mew Gull				17	2	3	36	33	2	2	95
Lesser Black-backed Gull		1	18						2	21	42
Herring Gull	907	160	451	557	506	607	109	133	27	306	3,763
Great Black-backed Gull	6	3	36	5	3	16	2	6	5	52	134
Unidentified Gull	1	6	102	1,344	24	417	18	18	19	47	1,996

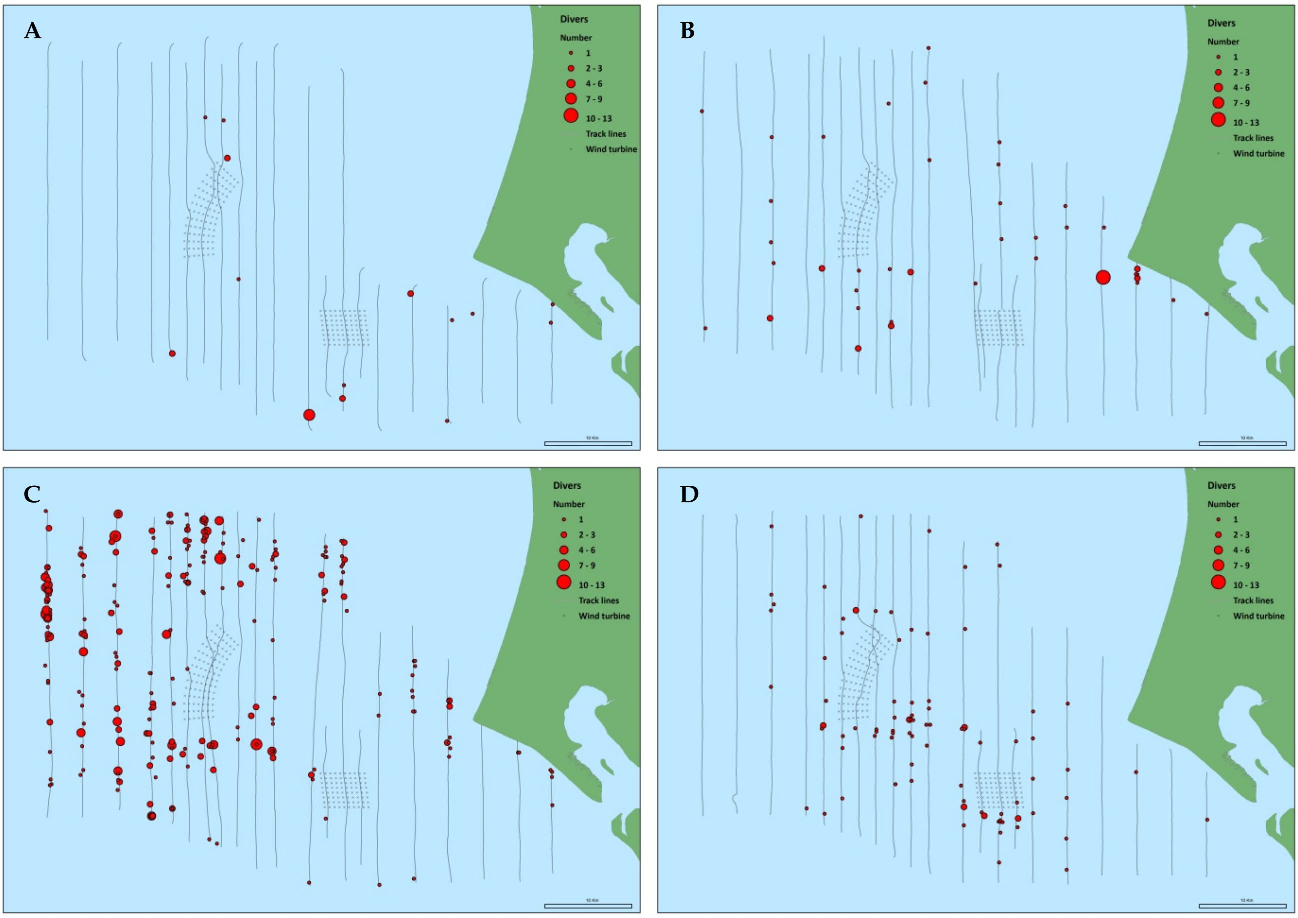
Sandwich Tern		1	68					1	2	58	130
Arctic Tern			32							16	48
Common/Arctic Tern			1	1	1						3
Unidentified Tern			95	2	1					5	103
Razorbill						6			2		8
Guillemot			2	45	3	35		1	6	5	97
Guillemot/Razorbill		2	7	356	27	37		5	19	3	456
Harbour Porpoise	14	10	64	76	5	13	4	20	41	2	249
Harbour Seal	11	2	14	4	1	8	14		17	1	72
Grey Seal						1					1
Unidentified Seal			3	5				1			9
Unidentified Shark				1							1

2.1.1 Red-throated Diver/Black-throated Diver *Gavia stellata/Gaiva arctica*

A total of 1,029 divers were counted on the 10 surveys. Most birds (91%) could be identified as Red-throated Diver *Gavia stellata*. The rest of the observed divers were not identified to species, but no Black-throated Divers were specifically identified. Birds were recorded during all survey flights in numbers from 6 to 433 birds (Table 4).

Most birds were registered in the diver spring migration period (March/April). The highest numbers of divers were recorded in the western part of the survey area. The spatial distribution of the observed birds is shown for each survey (Figure 5A-J).

Horns Rev and the eastern parts of Danish North Sea from the German border northwards to a line west of the entrance to Limfjorden are important for Red-throated Diver/Black-throated Diver. Both species are included under the Appendix 1 of the EU Birds Directive.



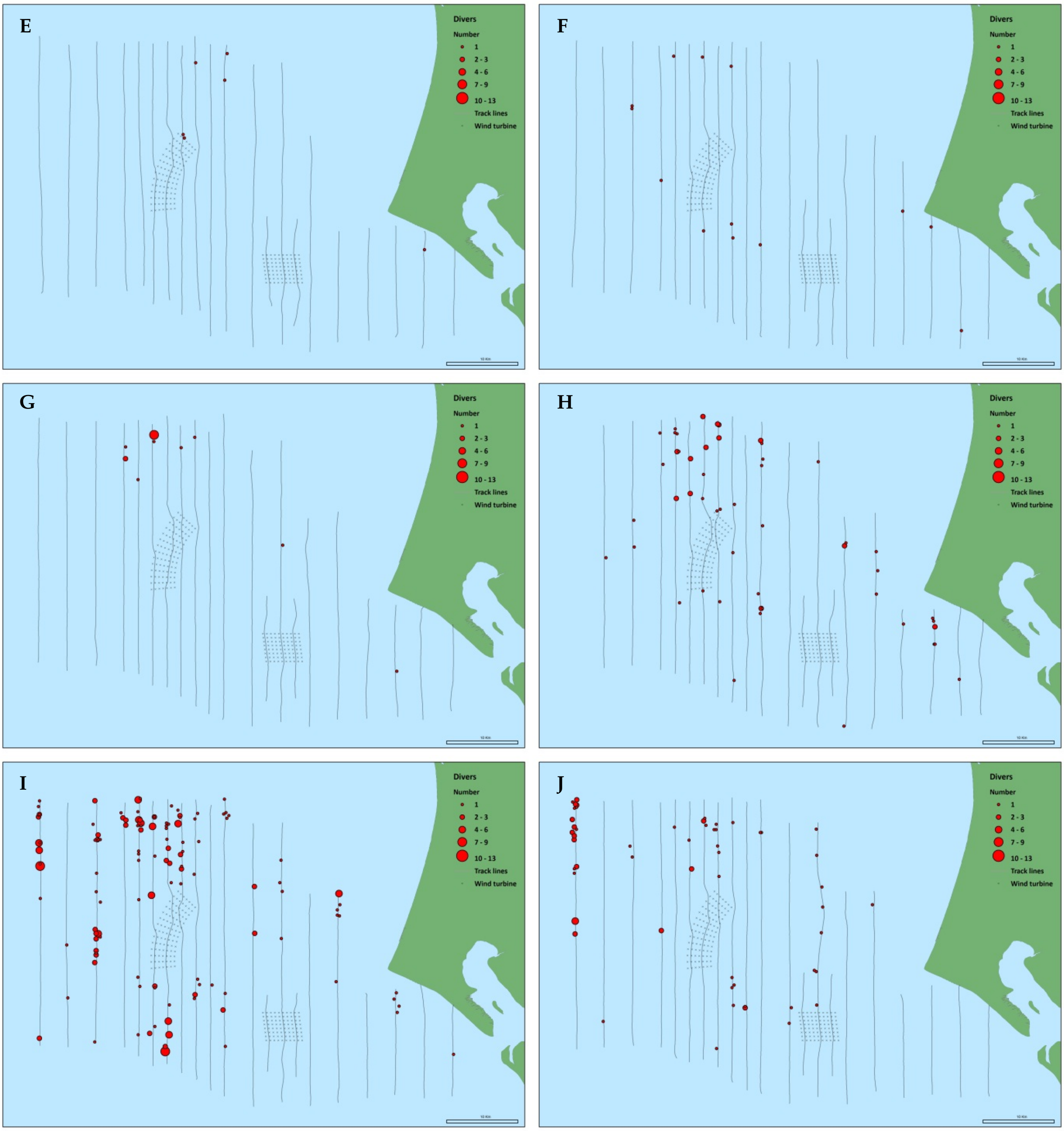


Figure 5. The spatial distribution of Divers recorded during 10 aerial surveys conducted in Horns Rev survey area west of Blåvand in 2011 and 2012. The spatial distribution is shown for each survey. A: 1 March 2011, B: 26 March 2011, C: 11 April 2011, D: 13 October 2011, E: 17 November 2011, F: 15 January 2012, G: 8 February 2012, H: 2 March 2012, I: 22 March 2012 and J: 11 April 2012.

2.1.2 Red-necked Grebe *Podiceps grisegena*

A single observation of two birds was made on 2 March 2012 (Table 4).

2.1.3 Northern Fulmar *Fulmarus glacialis*

Single birds were recorded during six of the 10 surveys (Table 4). This species is more common in the northern part of the Danish North Sea.

2.1.4 Northern Gannet *Morus bassanus*

A total of 58 birds was registered on seven of the 10 survey flights. Birds were recorded throughout the survey area with the majority in the western part. No birds were recorded in winter with highest numbers recorded in spring, 11 April 2011 14 birds and 26 March 13 birds (Table 4). The spatial distribution of all birds is shown (Fig. 6).

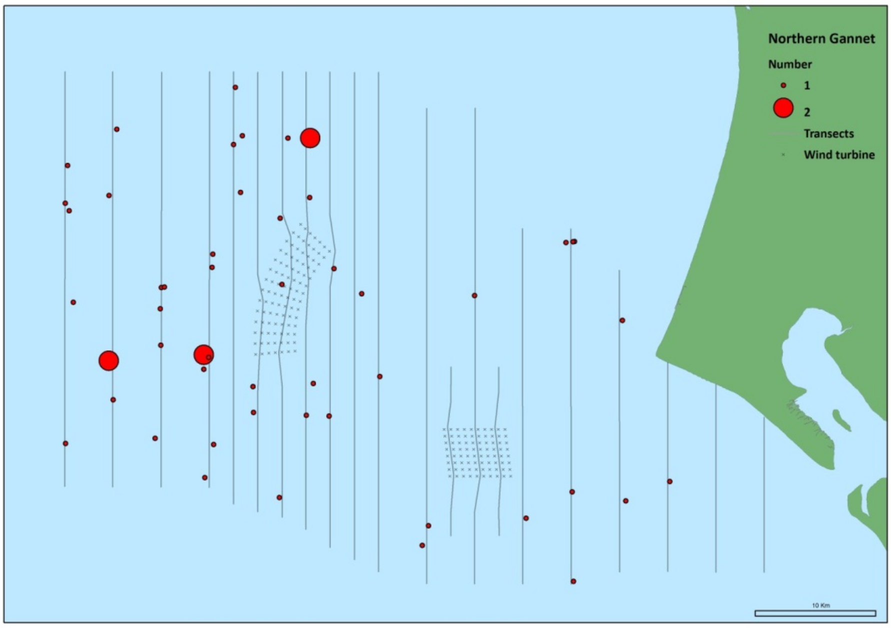


Figure 6. The spatial distribution of all Northern Gannets recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012.

2.1.5 Geese

Two species of geese were recorded, with two observations of Greylag Goose *Anser anser* (56 birds) and one observation of Brent Goose *Branta bernicla* (25 birds, Table 4). The survey area is not a staging area for any species of geese but several species pass through in their migration periods.

2.1.6 Common Eider *Somateria mollissima*

A total of 475 Common Eiders were recorded with birds present on all surveys (Table 4). Nearly all birds were recorded close to shore south and east of Horns Rev (Fig. 7). Highest numbers were recorded in winter and early spring.

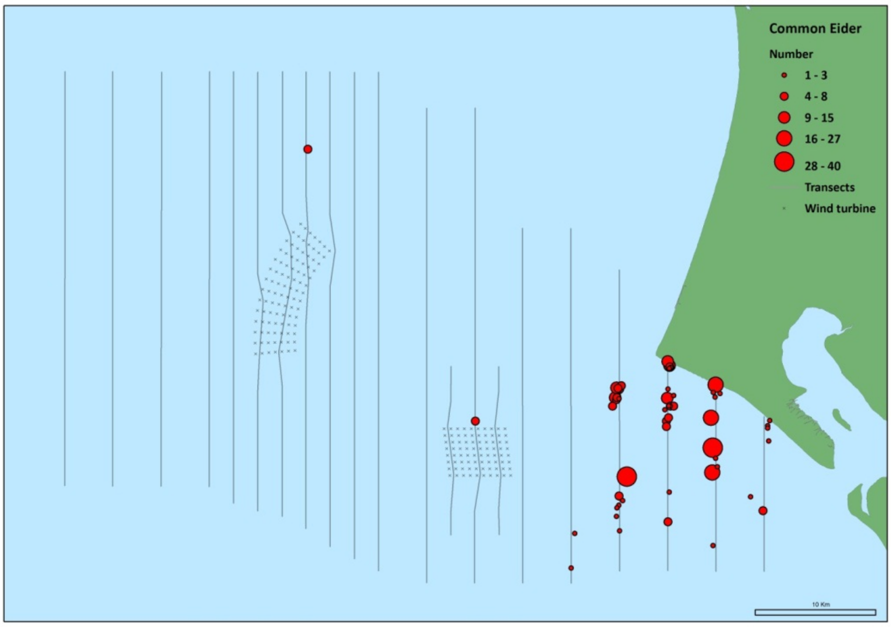


Figure 7. The spatial distribution of all Common Eiders recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012.

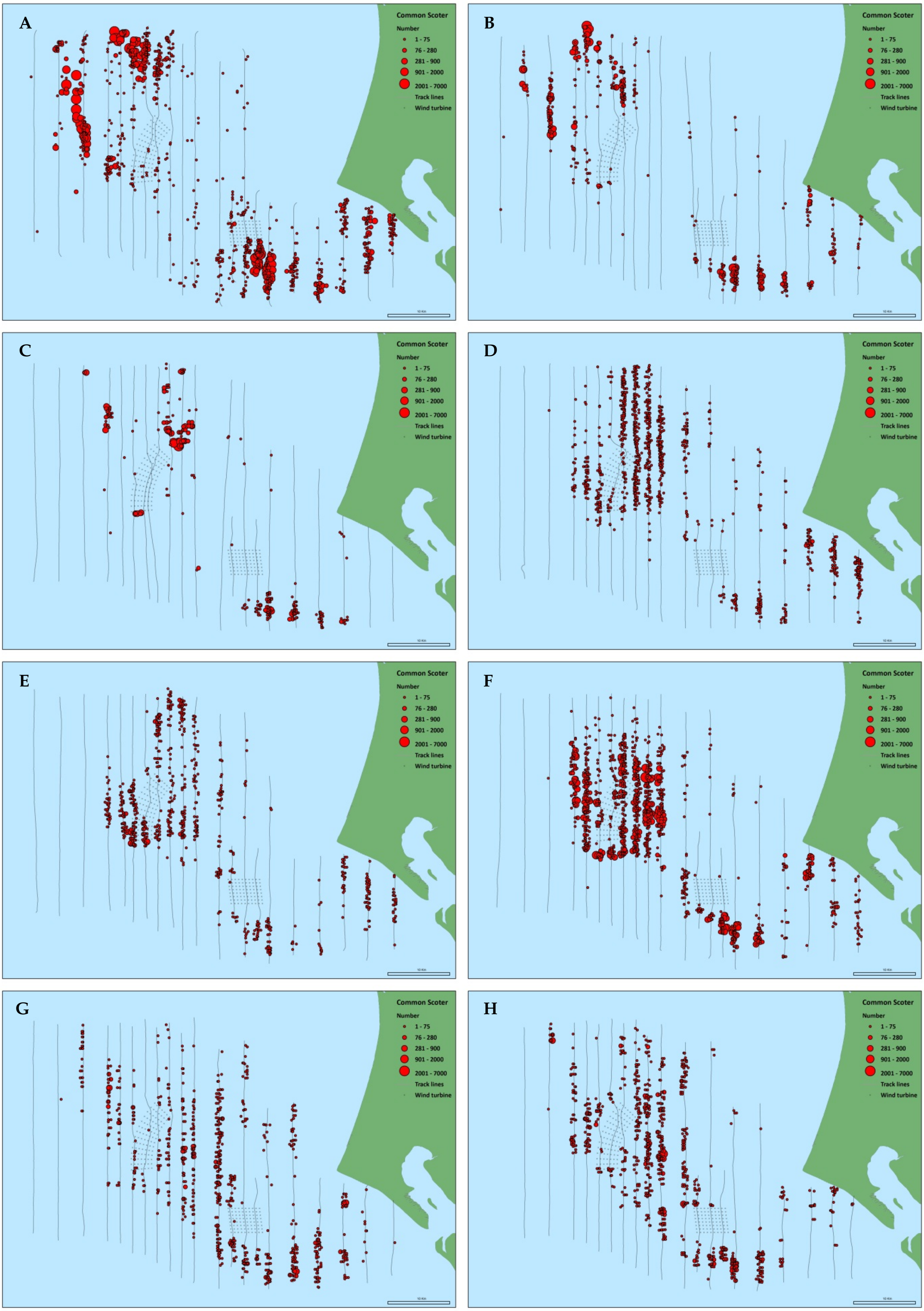
2.1.7 Common Scoter *Melanitta nigra*

Common Scoter was the most abundant species in the survey area. They were present in the area during all survey days. A total of 533,011 birds were recorded, most on 1 March 2011 with 187,726 birds and 15 January of 2012 with 115,516 birds (Table 4).

Common Scoters were distributed over most of the survey area though absent from the southern part of the central and western-most areas. The spatial distribution is shown for each survey (Figure 8A-J).

Most birds were registered in winter but the species is numerous throughout the year as the area also serves as a moulting/staging area during late summer (Petersen & Nielsen 2011).

Horns Rev is of international importance to Common Scoter as a result of the vast numbers of birds present in the area, particularly in winter and spring.


A
B
C
D
E
F
G
H
Common Scoter
Number
1 - 75
76 - 280
281 - 900
901 - 2000
2001 - 7000
Track lines
Wind turbine

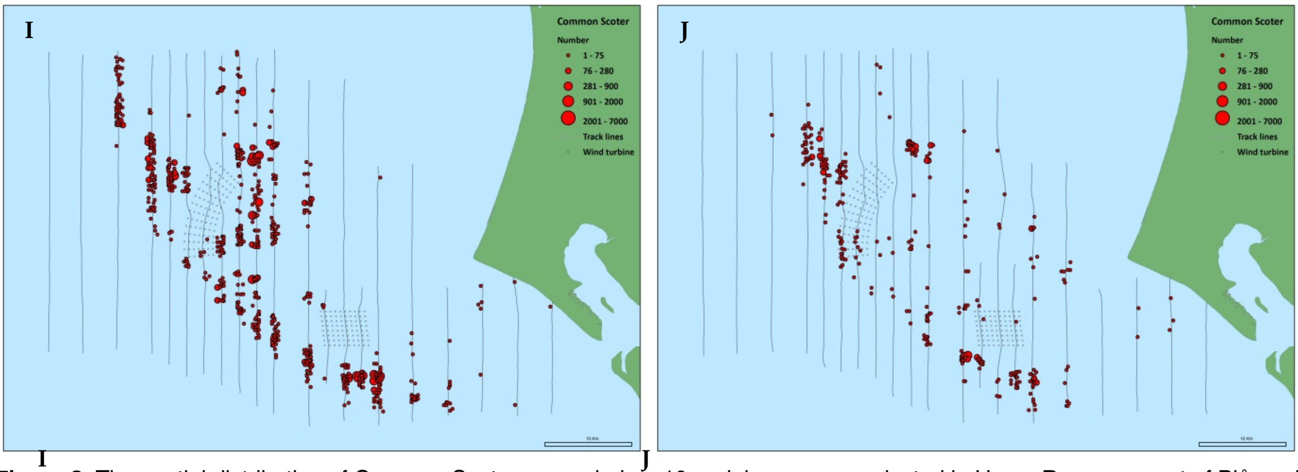


Figure 8. The spatial distribution of Common Scoters recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012. The spatial distribution is shown for each individual survey. A: 1 March 2011, B: 26 March 2011, C: 11 April 2011, D: 13 October 2011, E: 17 November 2011, F: 15 January 2012, G: 8 February 2012, H: 2 March 2012, I: 22 March 2012 and J: 11 April 2012.

2.1.8 Velvet Scoter *Melanitta fusca*

A total of 472 birds was registered with birds present on all survey flights. The majority of birds were recorded in spring with 150 birds 26 March 2011 and 104 birds 11 April 2011 (Table 4).

Birds were recorded in most of the survey area except for the western most part. The spatial distribution of all observed birds is shown (Fig. 9).

Velvet Scoters are very similar to the more common Common Scoters when they are resting on the water. Some birds are therefore probably overlooked in large flocks of Common Scoters and therefor Velvet Scoter numbers may be underestimated.

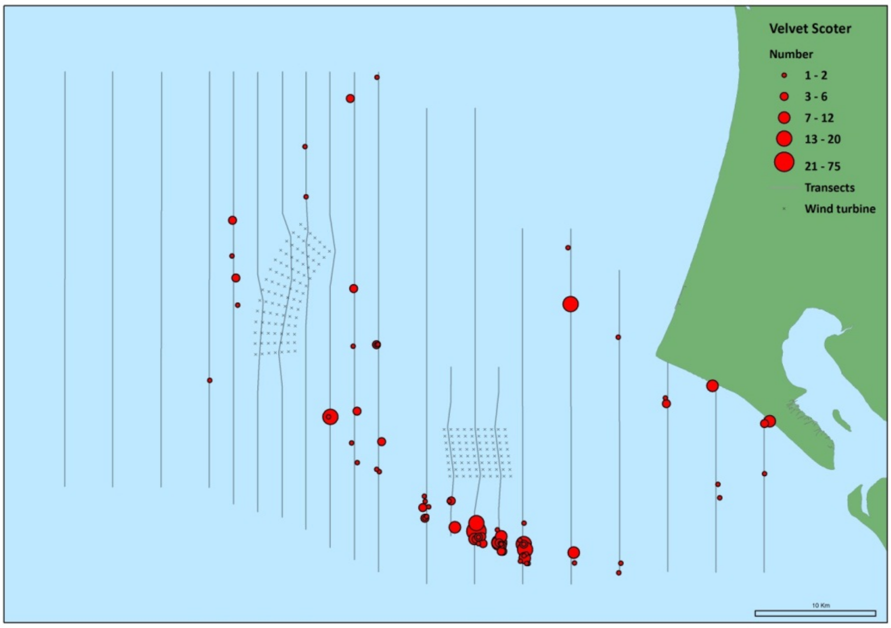


Figure 9. The spatial distribution of all Velvet Scoters recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012.

2.1.9 Other Ducks

An additional six species of ducks were recorded, Common Goldeneye *Bucephala clangula* (115 birds) Eurasian Teal *Anas crecca* (79 birds), Wigeon *Anas penelope* (26 birds), Long-tailed Duck *Clangula hyemalis* (10 birds), Mallard *Anas platyrhynchos* (5 birds) and Red-breasted Merganser *Mergus serrator* (2 birds, Table 4). Only Common Goldeneye, Long-tailed Duck and Red-breasted Merganser use the survey area as a staging area. The dabbling duck species only use the area for passage during migration.

2.1.10 Waders

Two species of waders were recorded, namely four Eurasian Oystercatcher *Haematopus ostragelus* and two Bar-tailed Godwit *Limosa lapponica* (Table 4).

2.1.11 Black-legged Kittiwake *Rissa tridactyla*

This species was observed on nine of the 10 surveys, with a total of 272 birds recorded (Table 4). Most birds were registered on 11 April 2011 where a group of birds were seen resting on a wind turbine and the surrounding water in the northern part of the Horns Rev 2 Wind Farm.

No apparent temporal seasonal peak in numbers was recorded.

Birds were mainly recorded in the central and western part of the survey area. The spatial distribution is only shown for surveys with >50 birds recorded (Figure 10A-C).

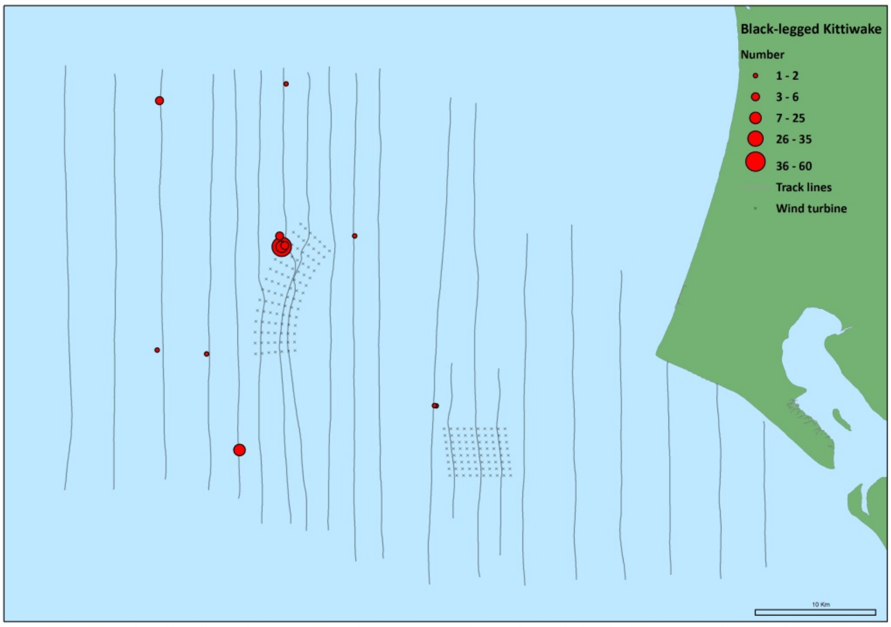


Figure 10A. The spatial distribution of Black-legged Kittiwakes recorded on an aerial survey conducted on the 11 April 2011 in the Horns Rev area west of Blåvand.

Figure 10B. The spatial distribution of Black-legged Kittiwakes recorded on an aerial survey conducted on the 17 November 2011 in the Horns Rev area west of Blåvand.

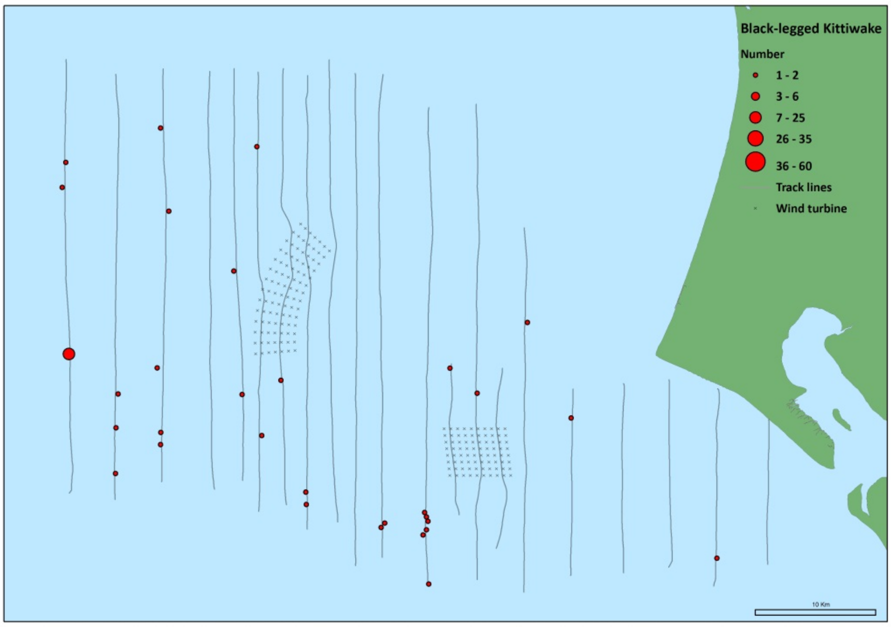
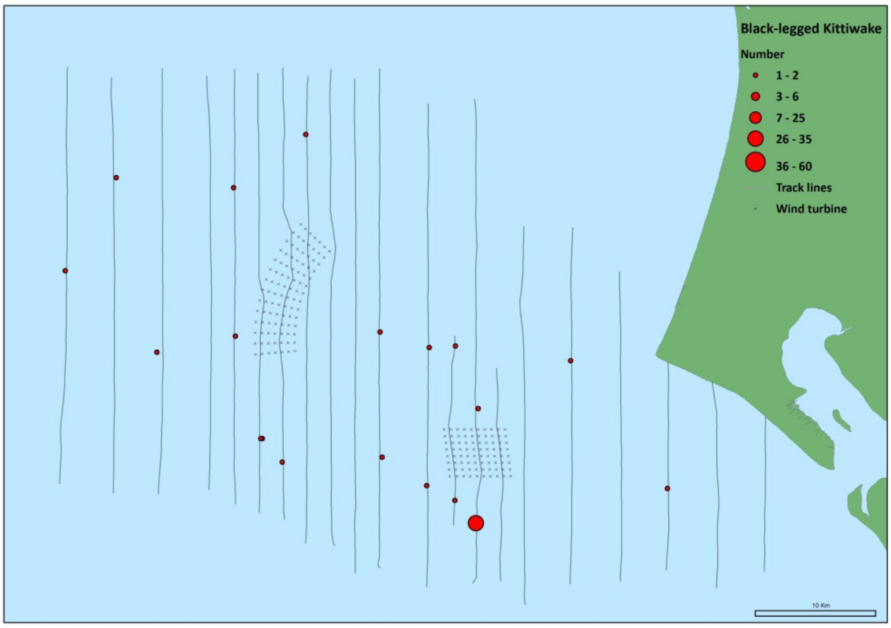


Figure 10C. The spatial distribution of Black-legged Kittiwakes recorded on an aerial survey conducted on the 15 January 2012 in the Horns Rev area west of Blåvand.



2.1.12 Little Gull Hydrocoloeus minutus

A total of 296 birds were recorded on nine survey dates. Highest numbers were recorded in the migration period for Little Gull, with maxima of 74 birds on 11 April 2011 and 72 birds on 11 April 2012 (Table 4).

Birds were mainly recorded in the western and central part of the survey area. The spatial distribution is only shown for surveys with >50 birds recorded (Fig. 11A-C).

Little Gull is listed under Appendix 1 of the EU Birds Directive. During the surveys performed in this area Little Gull has not been found in numbers that indicate that the area is of particular importance to the species.

Figure 11A. The spatial distribution of Little Gulls recorded on an aerial survey conducted on the 11 April 2011 in the Horns Rev area west of Blåvand.

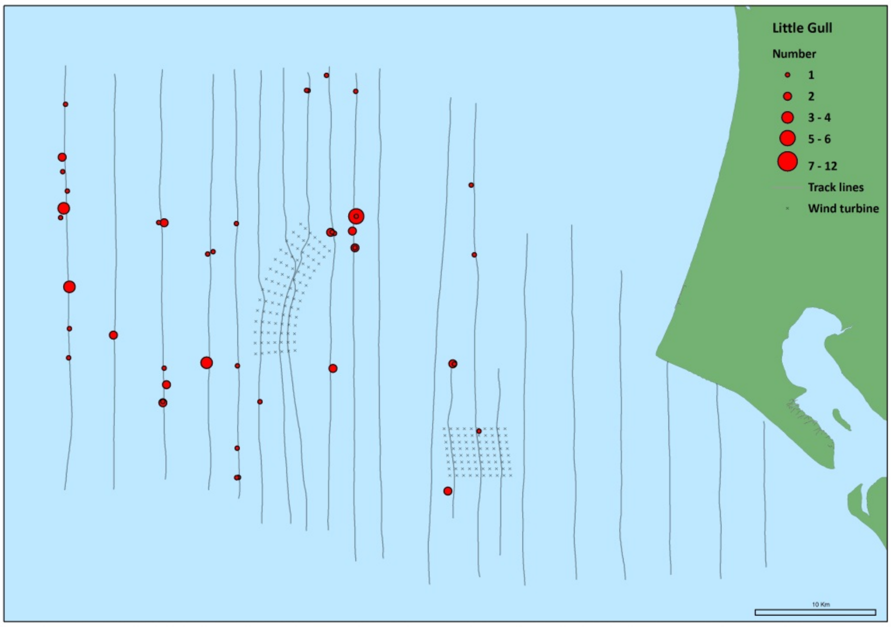
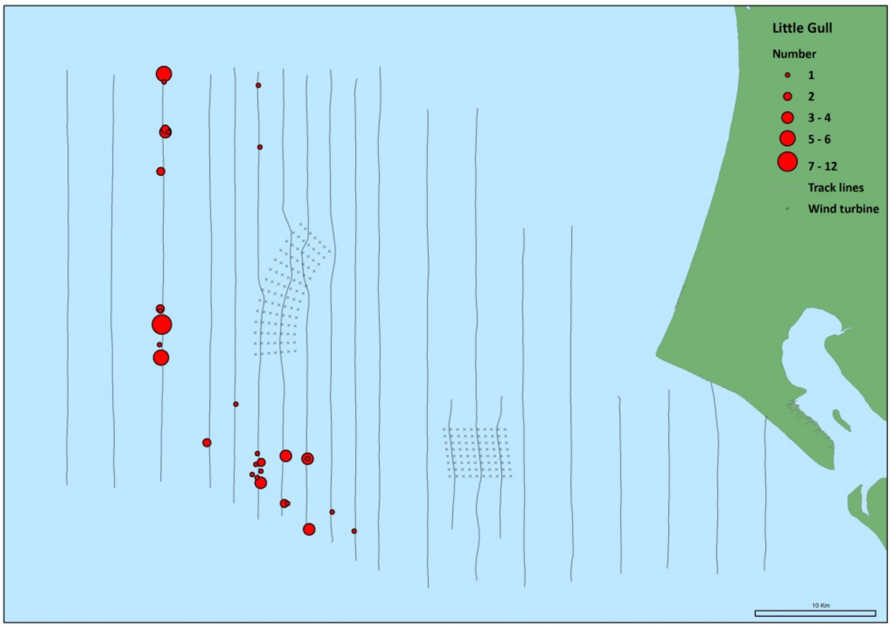


Figure 11B. The spatial distribution of Little Gulls recorded on an aerial survey conducted on the 22 March 2012 in the Horns Rev area west of Blåvand.



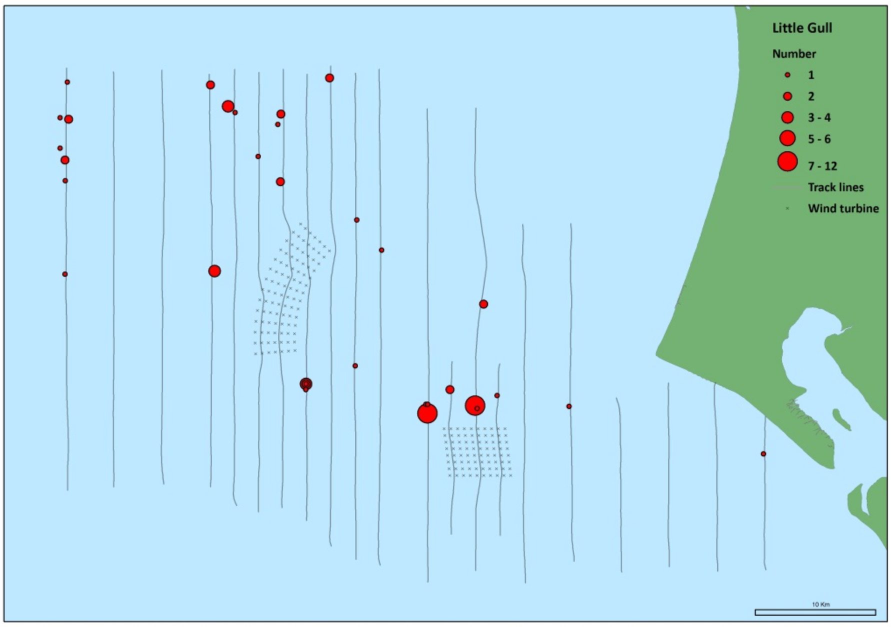


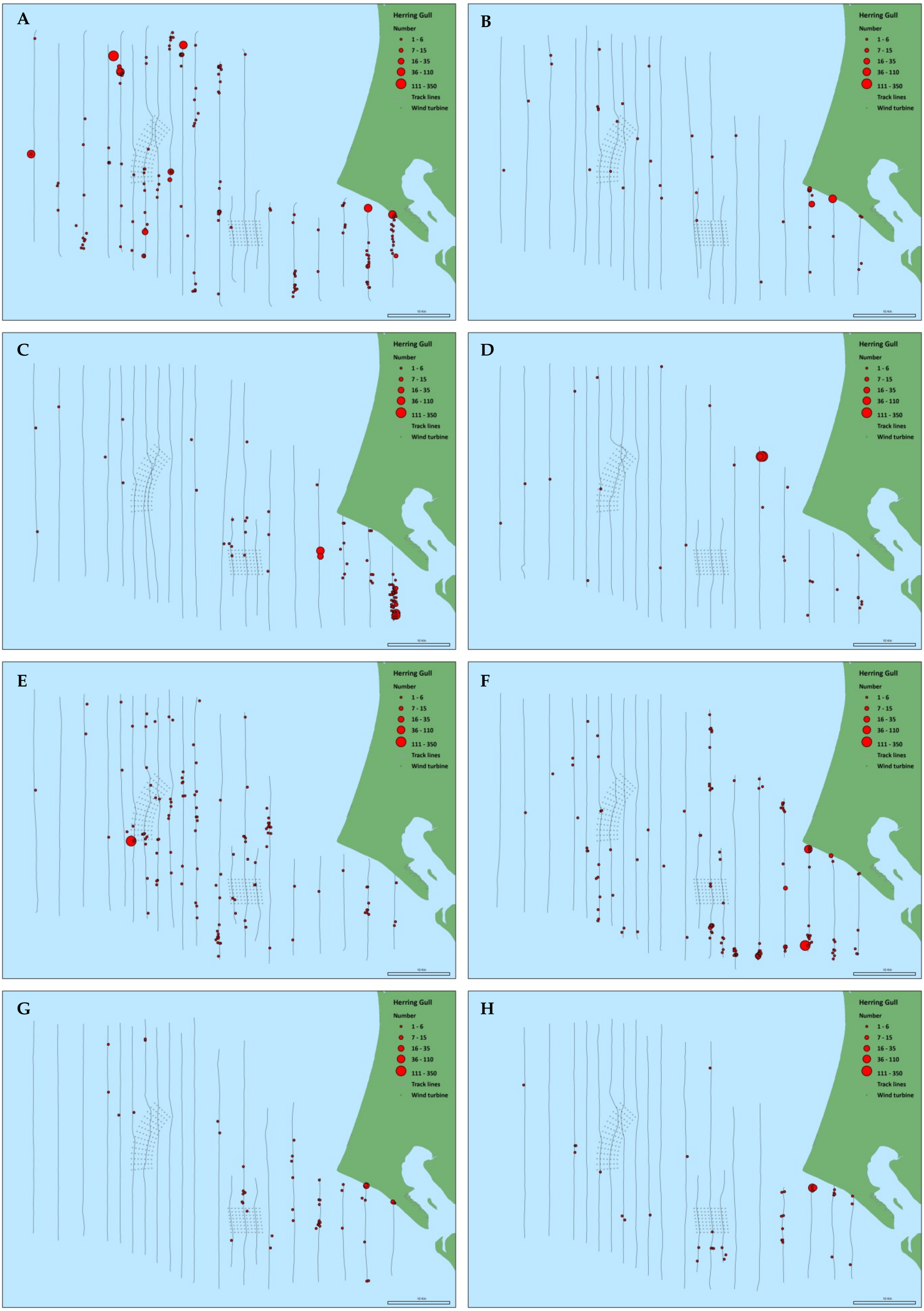
Figure 11C. The spatial distribution of Little Gulls recorded on an aerial survey conducted on the 11 April 2012 in the Horns Rev area west of Blåvand.

2.1.13 Herring Gull *Larus argentatus*

Herring Gull was the most abundantly observed gull species in the survey area, with a total of 3,763 birds seen across 10 surveys dates (Table 4).

Birds were recorded throughout the survey area with the highest densities in the central and eastern part of the area. The spatial distribution is shown for all survey dates (Fig. 12A-J).

No seasonal trend was observed. Large aggregations of gulls at sea are mainly recorded near fishing vessel or near hydrographical fronts. Large concentrations of gulls can be seen during the winter at Blåvandshuk where Razor Shells *Ensis sp* sometimes wash ashore in large numbers on which the gulls can forage.


A
B
C
D
E
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G
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Herring Gull
Number
1 - 6
7 - 15
16 - 35
36 - 110
111 - 350
Track lines
Wind turbine

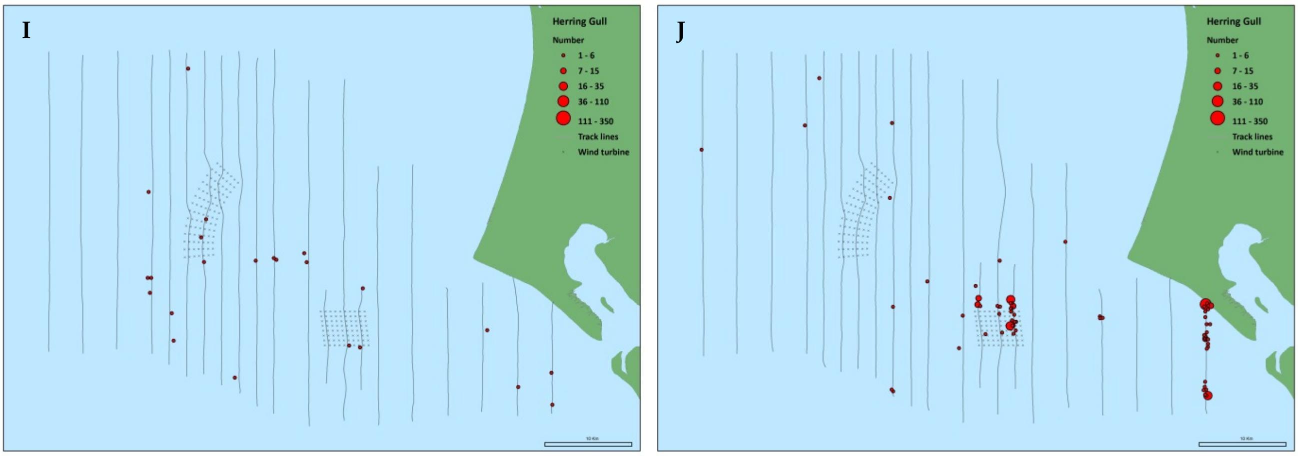


Figure 12. The spatial distribution of Herring gulls recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012. The spatial distribution is shown for each individual survey. A: 1 March 2011, B: 26 March 2011, C: 11 April 2011, D: 13 October 2011, E: 17 November 2011, F: 15 January 2012, G: 8 February 2012, H: 2 March 2012, I: 22 March 2012 and J: 11 April 2012.

2.1.14 Great Black-backed Gull *Larus marinus*

Great Black-backed Gulls were recorded on all survey dates, though never in high numbers. In total 134 birds were recorded. Most birds (52 individuals) were recorded on the 11 April 2012. Highest numbers were recorded in spring with peak numbers on the April surveys in both 2011 and 2012 (Table 4).

Birds were recorded throughout the survey area. The distributions of the observed birds from all surveys in combination are shown in a single map (Fig. 13).

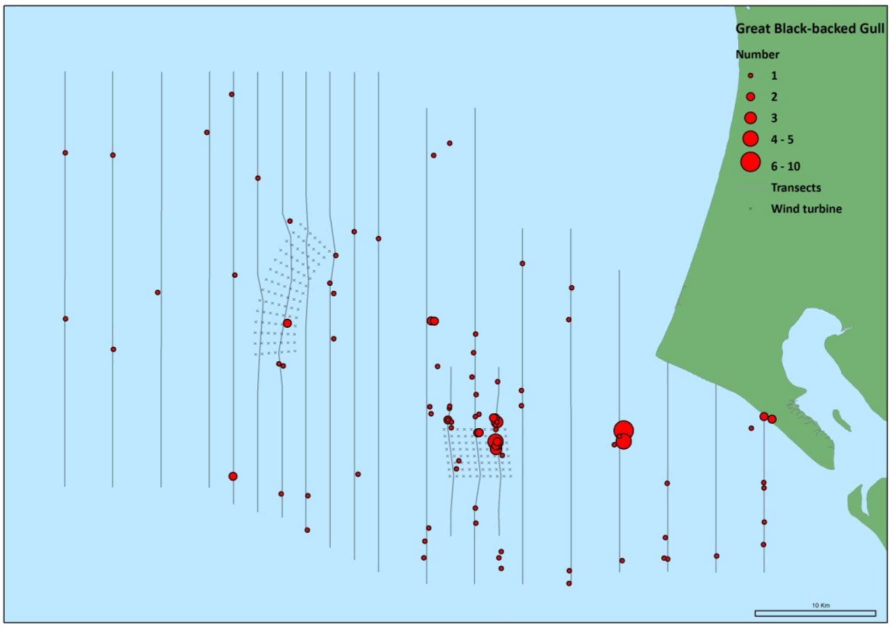


Figure 13. The spatial distribution of all Great Black-backed Gulls recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012.

2.1.15 Other Gulls and Terns *Laridae*

The following species or species groups of gulls were recorded in the survey area: Mew Gull *Larus canus* (95 birds), Lesser Black-backed Gull *Larus fuscus* (42 birds), Black-headed Gull *Chroicocephalus ridibundus* (24 birds) and Great

Skua *Stercorarius skua* (1 bird). and an Unidentified Gull *Larus sp.* (1,996 birds, Table 4).

2.1.16 Razorbill/Guillemot *Alca torda/Uria aalge*

A total of 561 Razorbills/Guillemots were recorded, including 97 Guillemots and 8 Razorbills (the rest being unidentified Razorbill/Guillemot). Razorbills *Alca torda* and Guillemots *Uria aalge* are very similar in plumage and appearance and hence difficult to separate under certain survey conditions. Most birds were recorded on the 13 October 2012, with a total of 401 birds recorded (Table 4).

Most birds were recorded in the deeper parts of the survey area, particularly in the western part. The spatial distribution of all observed birds is shown in a combined map (Fig. 14).

No apparent seasonal trend was observed. 71.5% of all observed birds were recorded on a single survey on the 13 October 2012.

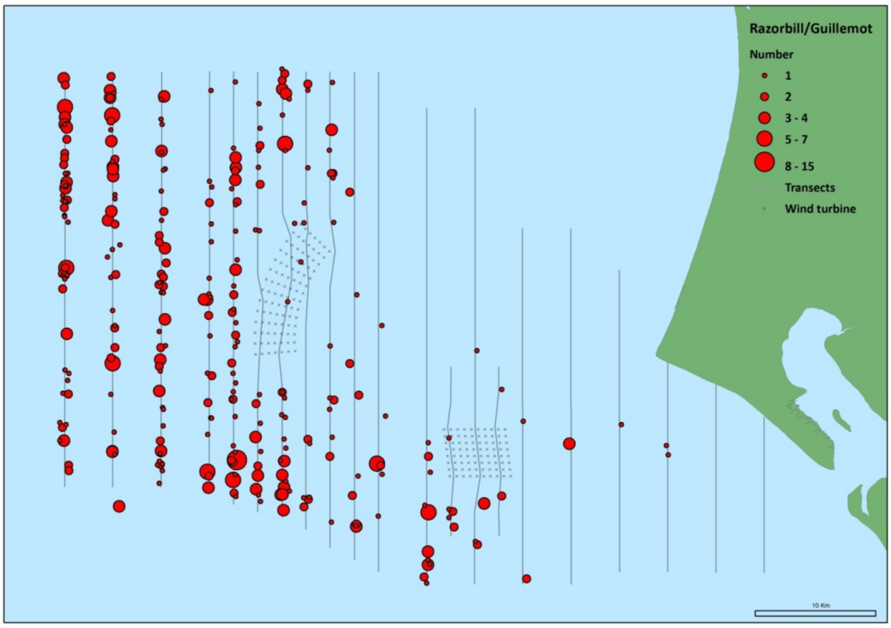


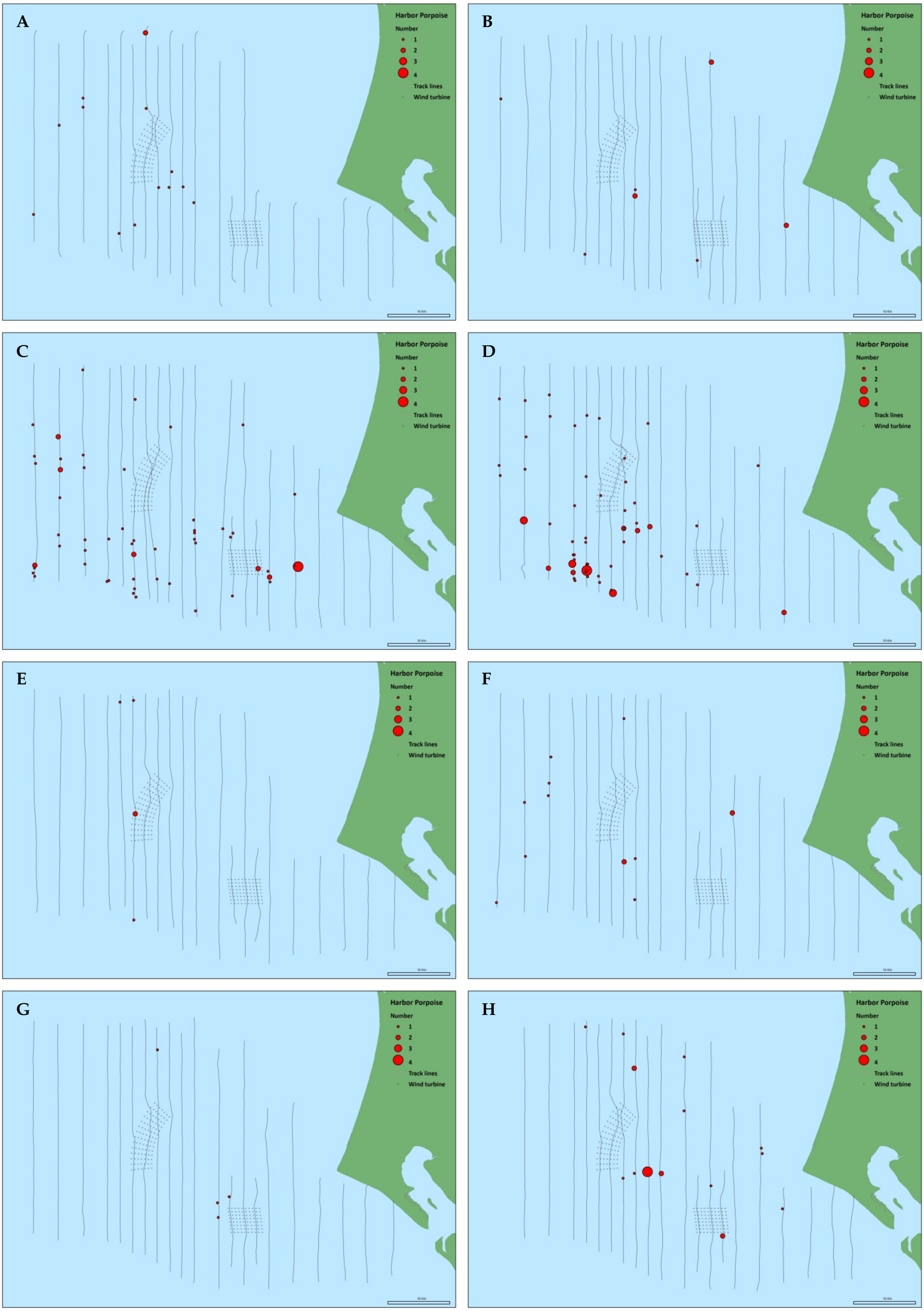
Figure 14. The spatial distribution of all Razorbill/Guillemot recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012.

2.1.17 Marine Mammals

Three species of marine mammals were registered, Harbour Porpoise *Phocoena phocoena* (249), Harbour Seal *Phoca vitulina* (72) and Grey Seal *Halichoerus gryptus* (1, Table 4). Harbour Seal is common in the Wadden Sea whereas Grey Seal is scarcer and only regularly recorded on a few sand banks within the Wadden Sea.

Harbour Porpoises were observed on all survey dates, with a maximum of 76 animals recorded on 13 October 2011 (Table 4).

Harbour Porpoises were recorded throughout the survey area with the highest numbers in the southern part of the survey area, and particularly on the southern edge of the Horns Rev sand bar (Fig. 15A-J).


A
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Harbor Porpoise
Number
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Track lines
Wind turbine

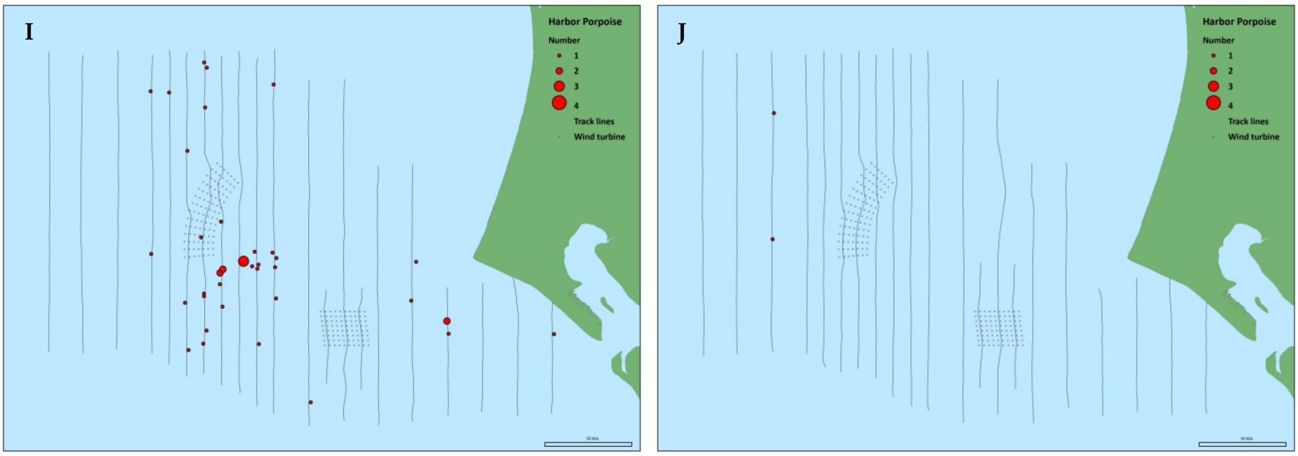


Figure 15. The spatial distribution of Harbour Porpoises recorded on 10 aerial surveys conducted in Horns Rev area west of Blåvand in 2011 and 2012. The spatial distribution is shown for each individual survey. A: 1 March 2011, B: 26 March 2011, C: 11 April 2011, D: 13 October 2011, E: 17 November 2011, F: 15 January 2012, G: 8 February 2012, H: 2 March 2012, I: 22 March 2012 and J: 11 April 2012.

2.2 Comparison between pre- and post-construction abundances and distributions of divers and Common Scoters

In this section we analyze the potential changes in abundances and distributions of divers and Common Scoter before and after the installation of the Horns Rev 2 offshore wind farm. These two species were selected for analysis because Common Scoter was the single most abundant bird species in the study area, and Red-throated Diver/Black-throated Diver was selected because of the high conservation status of these species and the fact that they were found in numbers adequate for the statistical analyses involved.

Results from the 10 post-construction surveys conducted in 2011 and 2012 in the study area were compared to 6 pre-construction surveys performed in relation to the EIA process of the Horns Rev 2 offshore wind farm, conducted between November 2005 and May 2006 (Christensen et al. 2006) and another four surveys conducted in the same area from January to April 2007 as post-construction surveys in relation to the Horns Rev 1 offshore wind farm (Petersen & Fox 2007). These 10 pre-construction surveys were conducted on the following dates: 19 November 2005, 2 February 2006, 25 February 2006, 12 March 2006, 15 April 2006, 11 May 2006, 25 January 2007, 15 February 2007, 3 March 2007 and 1 April 2007. Surveys conducted in relation to the Horns Rev 1 wind farm area between 2000 and 2005 did not cover the entire area of the Horns Rev 2 wind farm, and were thus omitted. Six surveys conducted as part of the Horns Rev 2 pre-construction investigation program between the autumn of 2007 and the spring of 2008 were delivered in a data format that prevented inclusion in the analyses conducted here, and were thus omitted. Thus, results from 10 Horns Rev 2 pre-construction surveys could be compared to results from 10 Horns Rev 2 post-construction surveys.

Average densities across the 10 surveys from the pre- and the 10 surveys from the post-construction periods were included in the comparison between the two periods. Since seasonal variations in bird abundances were detected for both Red-throated Diver/Black-throated Diver and for Common Scoter the average density and distribution of each species, for the pre- and the post-construction situation respectively, are given for months in which data are available for the same month both pre- and post-construction

(Fig. 18 A-E and 24 A-E). But for the comparison between pre- and post-construction distributions data from all 20 surveys were included.

Distance sampling principles was used to fit a detection function from the line transect survey data. Estimation of densities and distributions was conducted using spatial modelling. Thus, a surface covering density and distribution estimation to grid cells of 500 by 500 m was established for the situation before and after the installation of the Horns Rev 2 wind farm.

The Horns Rev 1 offshore wind farm was in operation already before the first Horns Rev 2 related pre-construction survey was conducted.

2.2.1 Red-throated Diver/Black-throated Diver

Diver densities of up to 1.4 individuals per grid cell (0.25 km^2) were found.

Diver numbers changed significantly across months (Fig. 16), with water depth (Fig. 17) and across the spatial surface. However, there was no evidence for an overall change in bird numbers before and after impact (Table 5). The divers redistributed away from the central and northeastern parts of the survey area after impact (Fig. 18 A-E). There is compelling and significant evidence for redistribution away from the impact site and into northwestern areas (Fig. 19).

Table 5. GEE-based *p*-values for the terms in the average model.

Model term	*p*-value
Month	0.0000
s(depth)	0.0000
s(spatial surface)	0.0000
Impact	0.9528
s(spatial surface)*Impact	0.0000

Figure 16. Estimated (link-scale) month relationship with upper and lower GEE-based 95% confidence intervals.

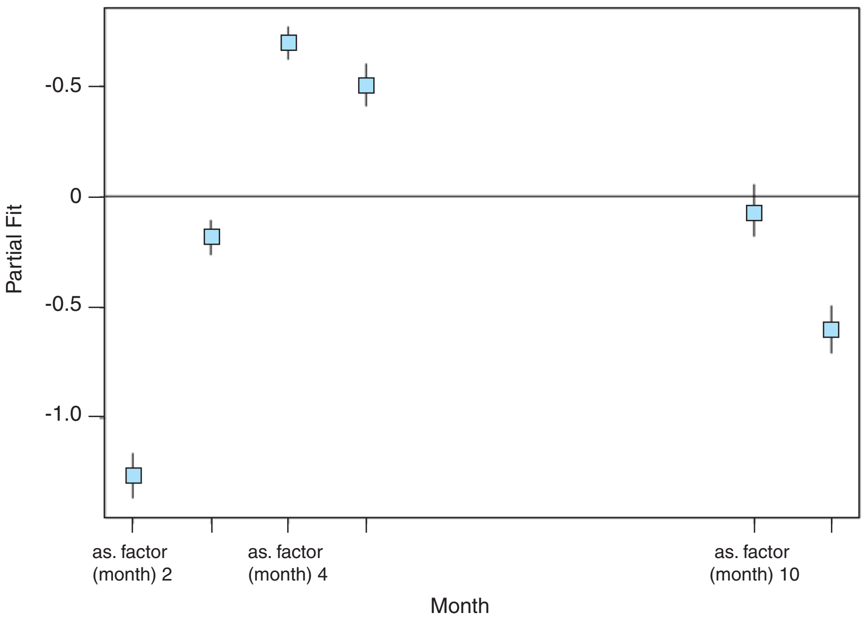
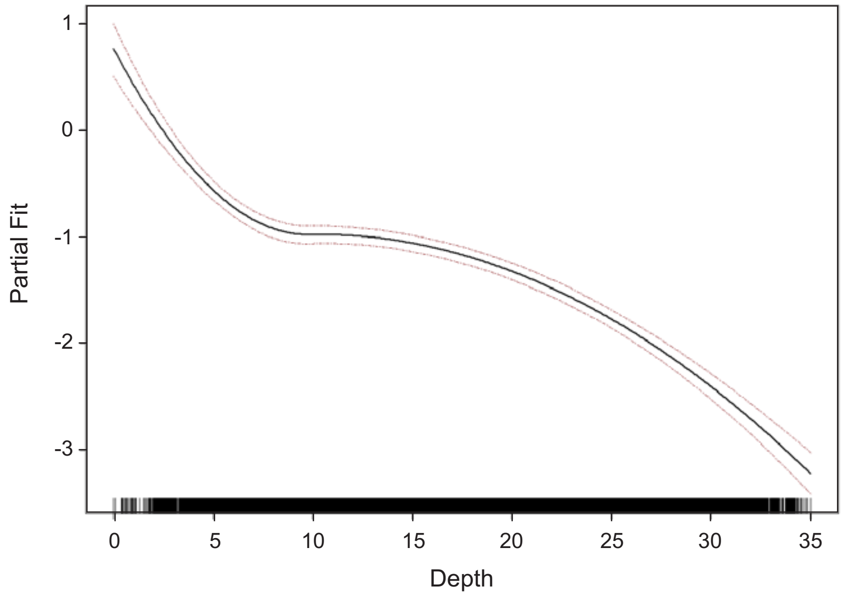
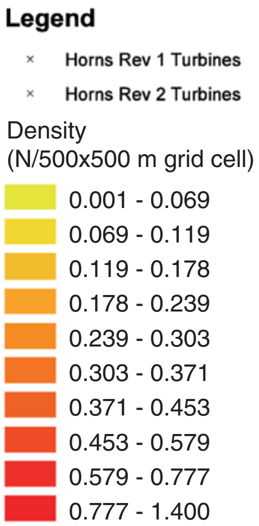


Figure 17. Estimated (link-scale) water depth relationship with upper and lower GEE-based 95% confidence intervals.





The modeled abundance and distribution of divers in the study area by month for the pre- and post-construction periods respectively are given (Fig. 18 A-F).

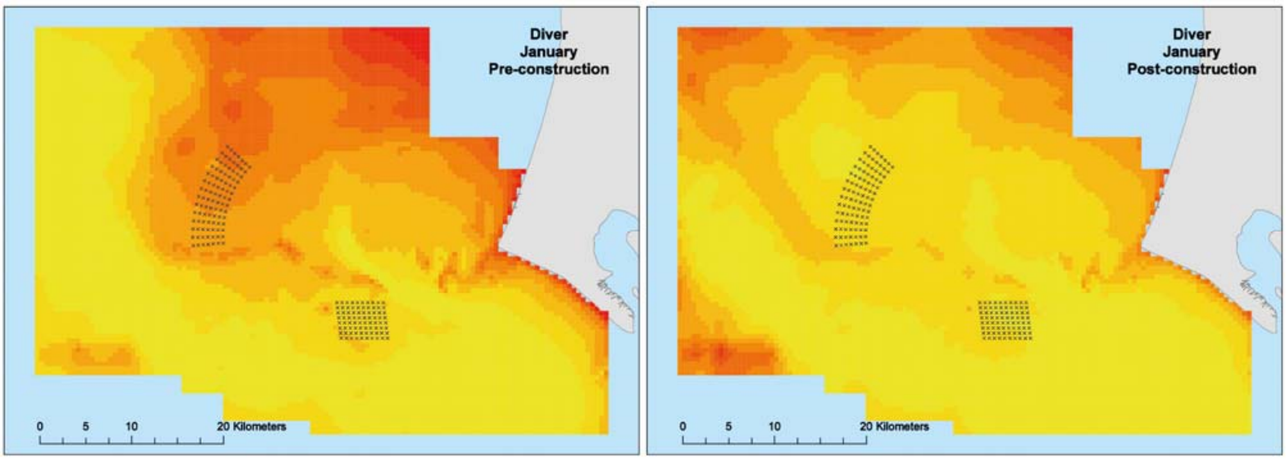


Figure 18A. Estimated densities of Red-throated Diver/Black-throated Diver in the Horns Rev 2 survey area in January for the pre-construction period (left map) and for the post-construction period (right map).

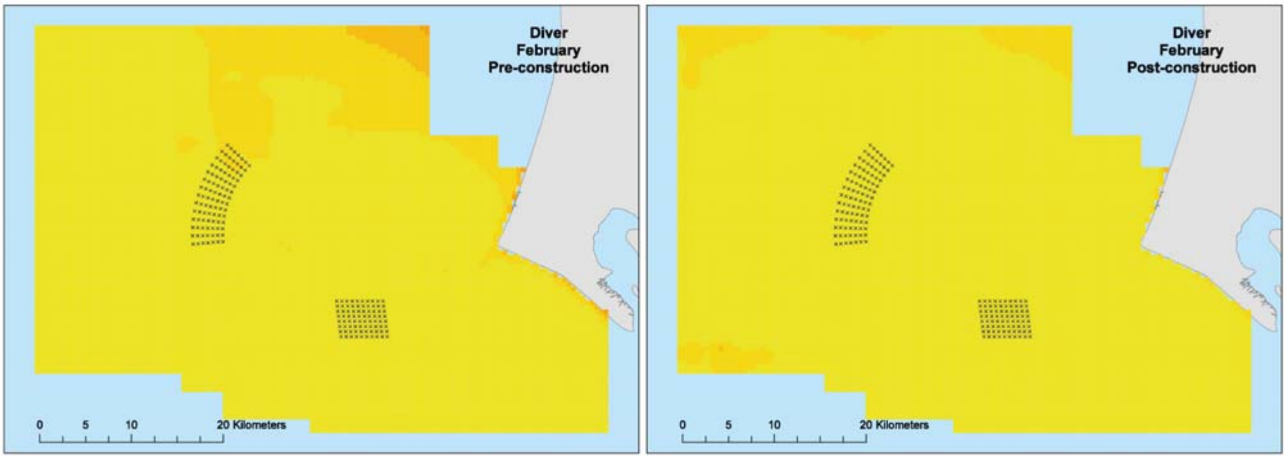


Figure 18B. Estimated densities of Red-throated Diver/Black-throated Diver in the Horns Rev 2 survey area in February for the pre-construction period (left map) and for the post-construction period (right map).

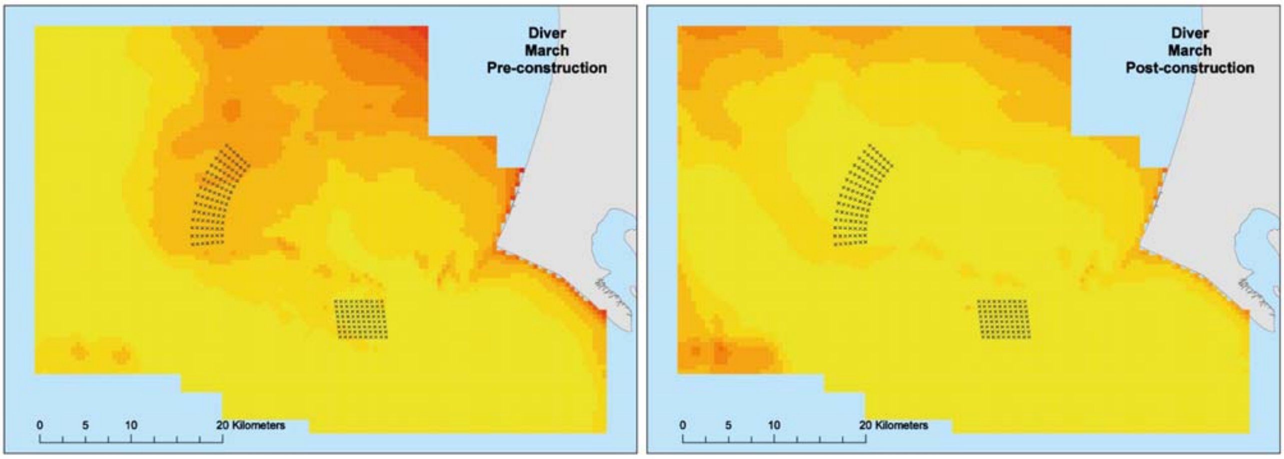


Figure 18C. Estimated densities of Red-throated Diver/Black-throated Diver in the Horns Rev 2 survey area in March for the pre-construction period (left map) and for the post-construction period (right map).

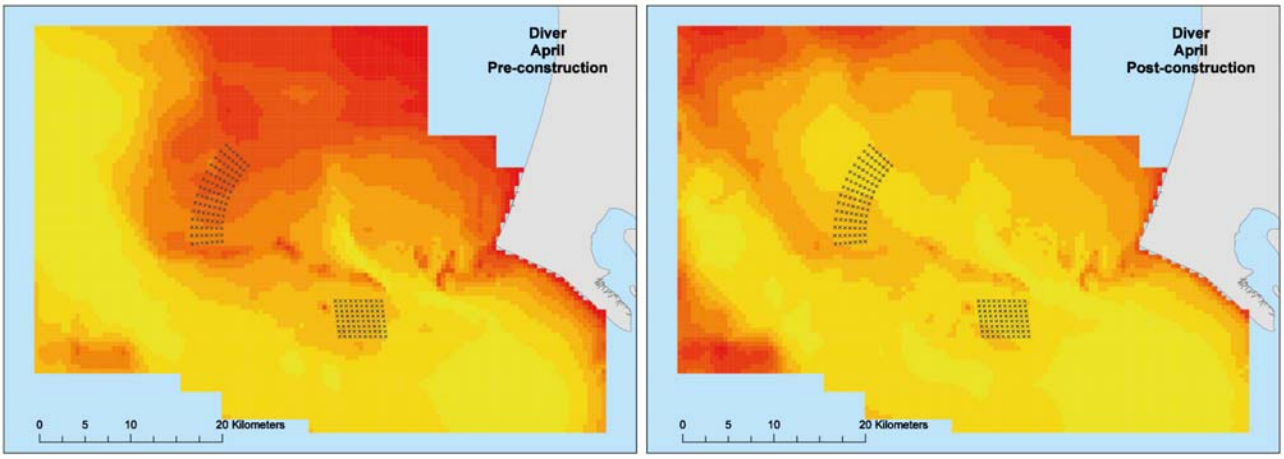


Figure 18D. Estimated densities of Red-throated Diver/Black-throated Diver in the Horns Rev 2 survey area in April for the pre-construction period (left map) and for the post-construction period (right map).

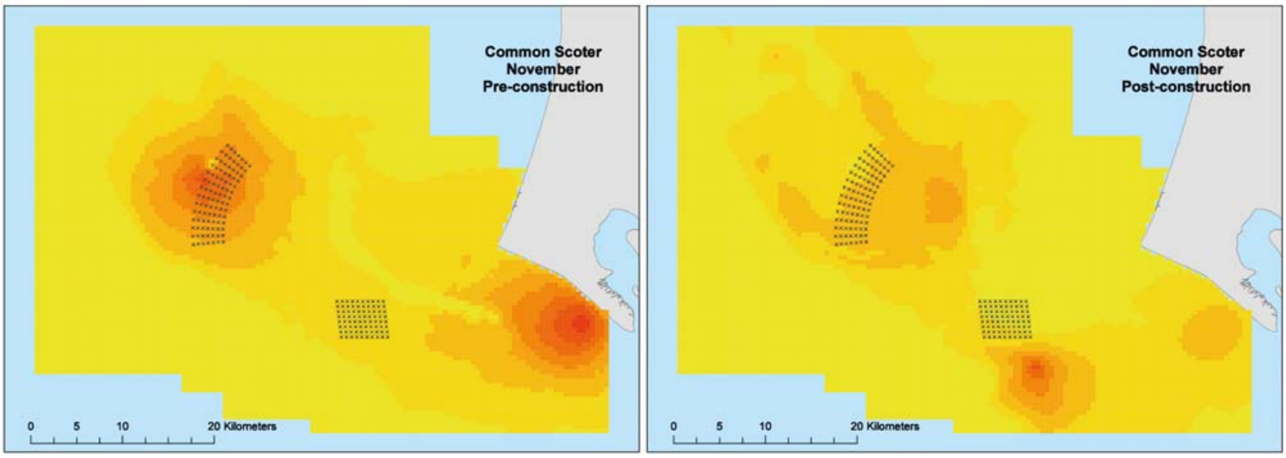


Figure 18E. Estimated densities of Red-throated Diver/Black-throated Diver in the Horns Rev 2 survey area in November for the pre-construction period (left map) and for the post-construction period (right map).

The average pre-construction abundances per 0.25 km² grid square were combined and compared to the corresponding value for the post-construction situation. Both areas of increased densities and reduced densities were detected (Fig. 19). In the western parts of the study area diver densities increased markedly and significantly, while diver densities in the central areas around the Horns Rev 2 offshore wind farm and to the north east decreased. This decrease in abundances was significant within a ca. 400 km² area, centred upon, and including the majority of, the Horns Rev 2 wind farm that represents approximately 10% of this area (Fig. 19).

Every grid square in the survey area was binned into distance bands of 500 meters from the periphery of the Horns Rev 2 offshore wind farm. Cells were assigned to distance bands by the position of their grid square centroid. Thus, mean abundance per grid square could be calculated. Plotting these abundance values against distance category showed that there was a post-construction reduction of ca. 0.12 individuals per grid square within the distance category from 0 to 500 m from the periphery of the Horns Rev 2 wind farm as compared to the pre-construction situation (Fig. 20). This is equivalent to 0.48 divers per km² in the first 500 m distance band around the Horns Rev 2 wind farm. Only at distances more than 13 km from the Horns Rev 2 wind farm are post-construction diver abundances higher than during the pre-construction surveys.

The reduction in overall mean diver abundances within the Horns Rev 2 wind farm was 16.8 birds. The corresponding number for the wind farm site and a surrounding buffer of 2 km was 48.1 birds, while within a distance of 4 km from the wind farm site a reduction of 86.4 birds was calculated (Table 6). Within the area around the Horns Rev 2 wind farm and northeast of there, in which changes in abundance was significant, representing an area of almost 400 km², there was a reduction of 173.0 divers.

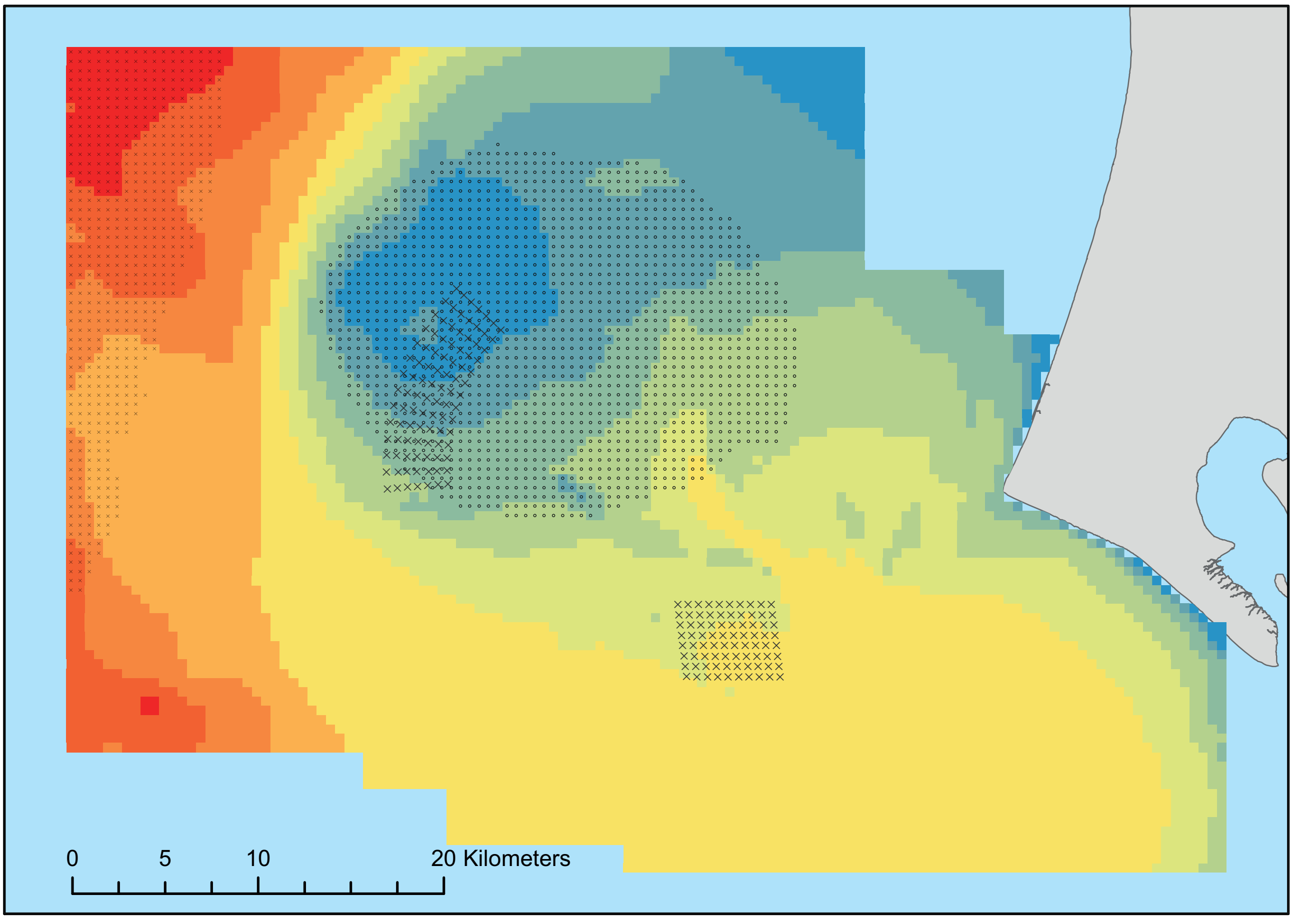


Figure 19. Estimated pre- and post-construction difference in Red-throated Diver/Black-throated Diver numbers per 0.25km^2 in each grid cell averaged over the survey period. Grid cells which show statistically significant increases are indicated by + signs, those with significantly lower densities are represented by 0 signs.

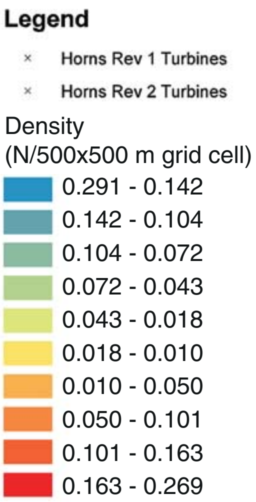
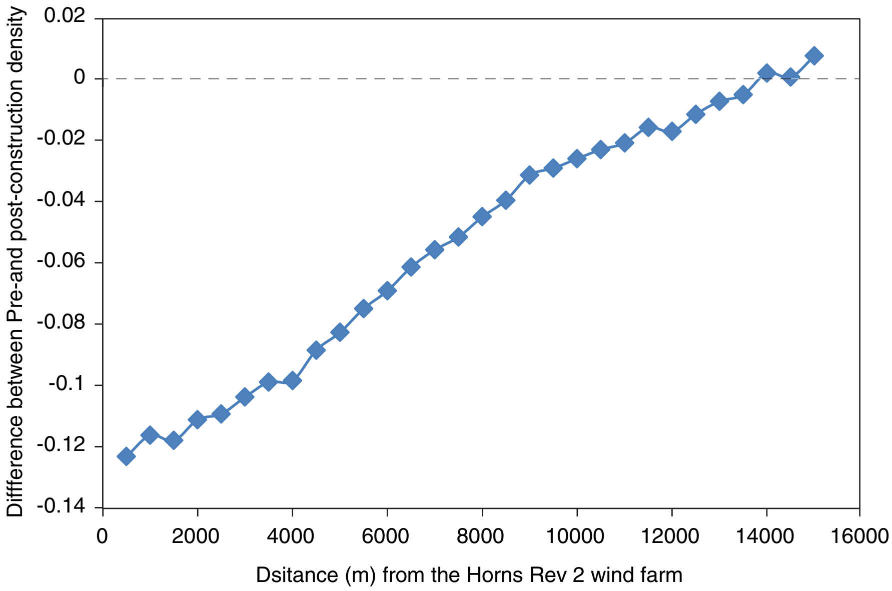


Table 6. The pre- to post-construction change in diver abundance in and around the Horns Rev 2 offshore wind farm. Negative values indicate reduced abundance.

Area	**Change in diver abundance**	**Percentage of the eastern Palearctic flyway population**
Horns Rev 2 offshore wind farm	-16.8	0.006
Horns Rev 2 offshore wind farm + 2 km buffer	-48.1	0.016
Horns Rev 2 offshore wind farm + 4 km buffer	-86.4	0.033
Area with significant reductions around HR2	-173.0	0.067

Figure 20. Differences between pre- and post-construction densities (y-axis) of divers in the Horns Rev 2 survey area in relation to 500 meters distance intervals (x-axis) from the periphery of the Horns Rev 2 offshore wind farm. Negative values indicate lower densities after the construction of the Horns Rev 2 offshore wind farm.



2.2.2 Common Scoter

Very high densities of Common Scoters were recorded in the survey area

The model indicates a (statistically significant) cyclic pattern across months (Fig. 21) and a statistically significant relationship with water depth which predicts fewer birds in deeper waters (Fig. 22).

The raw data indicates higher bird numbers in the center of the survey area and in the eastern region, pre-construction. These data also show the birds relocated away from these areas (both in and around the Horns Rev 2 wind farm and eastern, coastal areas) and into northern areas post-construction. The same pattern of change is found in the modelled distributions of the Common Scoters (Fig 24 A-E).

Additionally, the spatial element in the model suggests two hotspots in bird numbers pre-construction, one near the location of the Horns Rev 2 wind farm site pre-installation and one near the coastal eastern side of the survey area (Fig 24 A-E, left hand side figures, 25). In the post-construction situation the Common Scoters appear to have shifted into the center of the study area, east of the Horns Rev 2 wind farm site and to a smaller extent to the north and west of the Horns Rev 2 wind farm. However, the increased numbers in the centre of the area are not compelling when considering the uncertainty in these predictions (Figure 25). In the coastal, eastern parts of the survey area the birds shifted toward the southwest to the south of the Horns Rev 1 wind farm (Figure 24 A-E, right hand side, 25).

Table 7. GEE-based *p*-values for the CReSS model terms.

Model term	*p*-value
Month	0.0000
s(depth)	0.0000
s(spatial surface)	0.0000
Impact	0.0711
s(spatial surface):Impact	0.0000

There was no evidence for any change in average Common Scoter number pre- and post-construction/impact (p=0.16545 for the impact term when the interaction effect was omitted), however there was a significant redistribution post-impact relevant to the wind farm location. Specifically, significantly fewer Common Scoters were seen in and around the Horns Rev 2 wind farm post-construction than before (evidenced by the blue colouration located near the turbines, Fig. 25). There were also significantly fewer birds near the coastal parts of the survey area post-impact, which is likely to be unrelated to the wind farm installation. These declines were balanced by small but significant increases in the northern and southern parts of the survey area.

There were no significant changes in Common Scoter numbers near the location of the Horns Rev 1 wind farm which existed prior to this survey (Fig. 25).

Figure 21. Estimated (link-scale) month relationship with upper and lower GEE-based 95% confidence intervals.

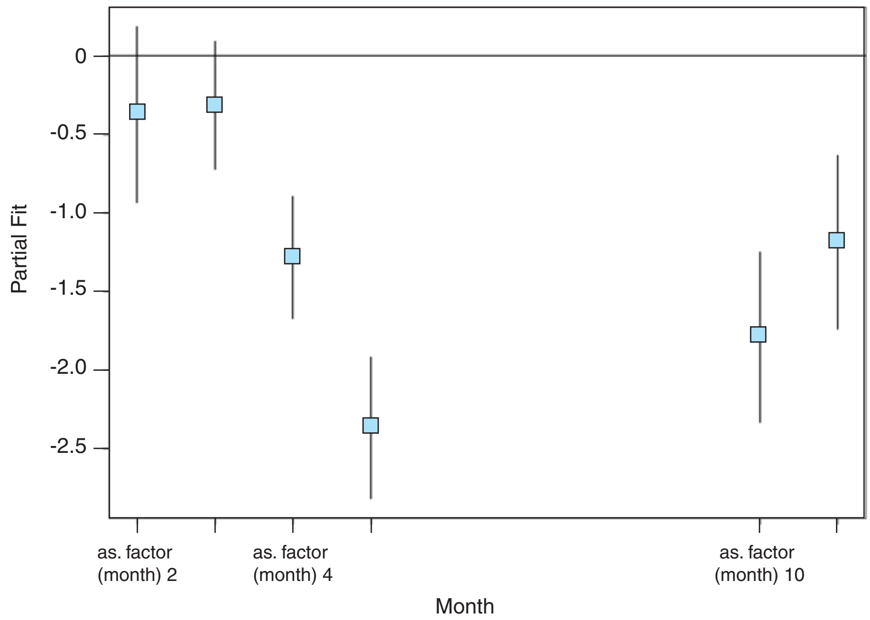


Figure 22. Estimated (link-scale) depth relationship with upper and lower GEE-based 95% confidence intervals.

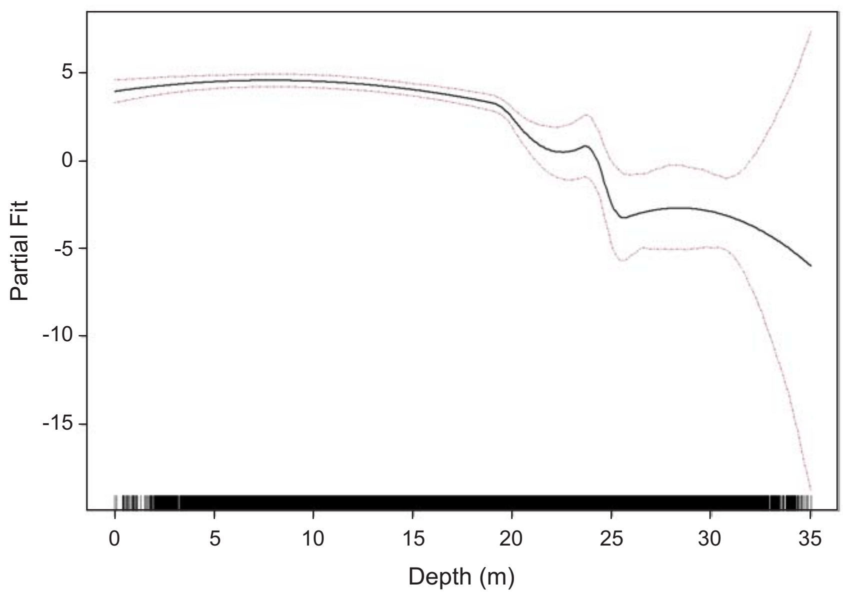
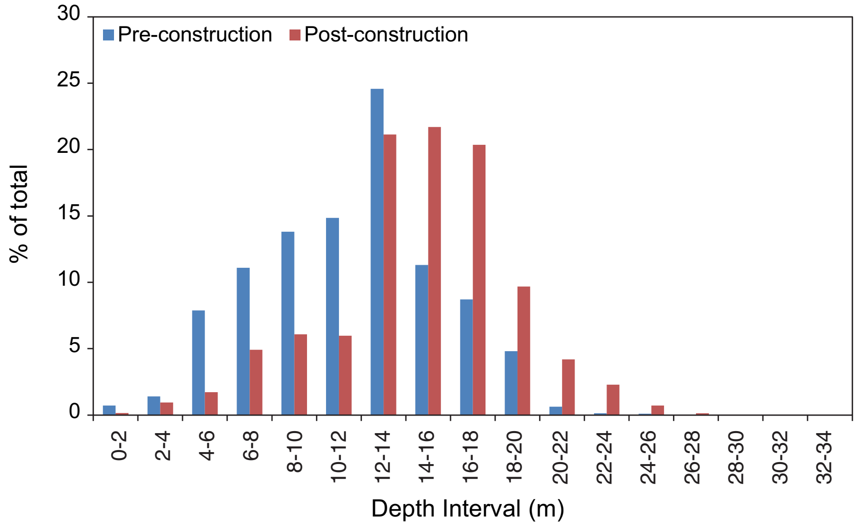
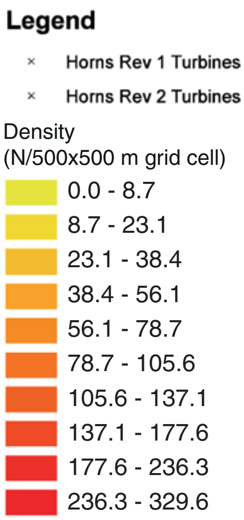


Figure 23. The depth frequency distribution of 344,380 pre-construction and 464,611 post-construction Common Scoters in the survey area. The values were weighted by number of individuals.



A depth frequency distribution change was observed between pre- and post-construction. Common Scoters were recorded on deeper water during the post-construction period than during the pre-construction surveys (Fig. 23). There was a marked shift away from water depth of 4 to 12 meters and an increased frequency in water depths from 14 meters outwards to beyond 20 m.

The observed shift in distribution between pre- and post-construction surveys exhibited very similar patterns between months. For all months with data from both pre- and post-construction the modeled distributions for the pre- and the post-construction surveys was modeled (Fig. 24 A-E).



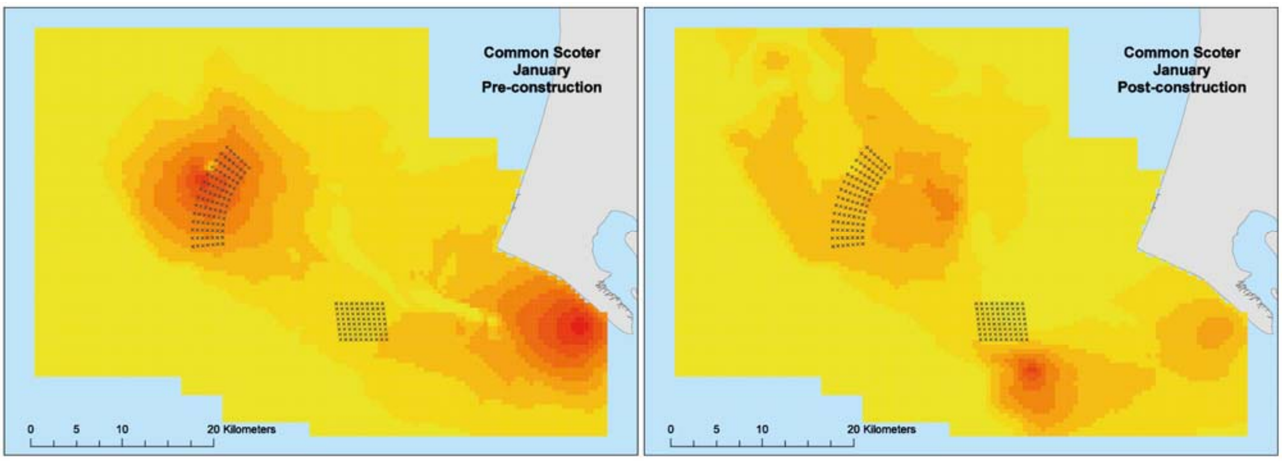


Figure 24A. Estimated densities of Common Scoters in the Horns Rev 2 survey area in January for the pre-construction period (left map) and for the post-construction period (right map).

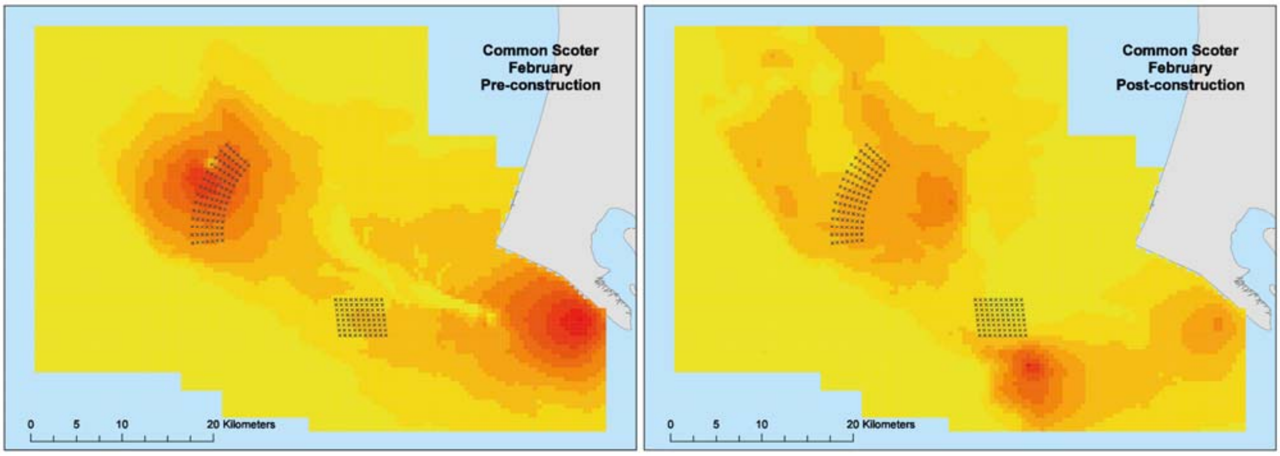


Figure 24B. Estimated densities of Common Scoters in the Horns Rev 2 survey area in February for the pre-construction period (left map) and for the post-construction period (right map).

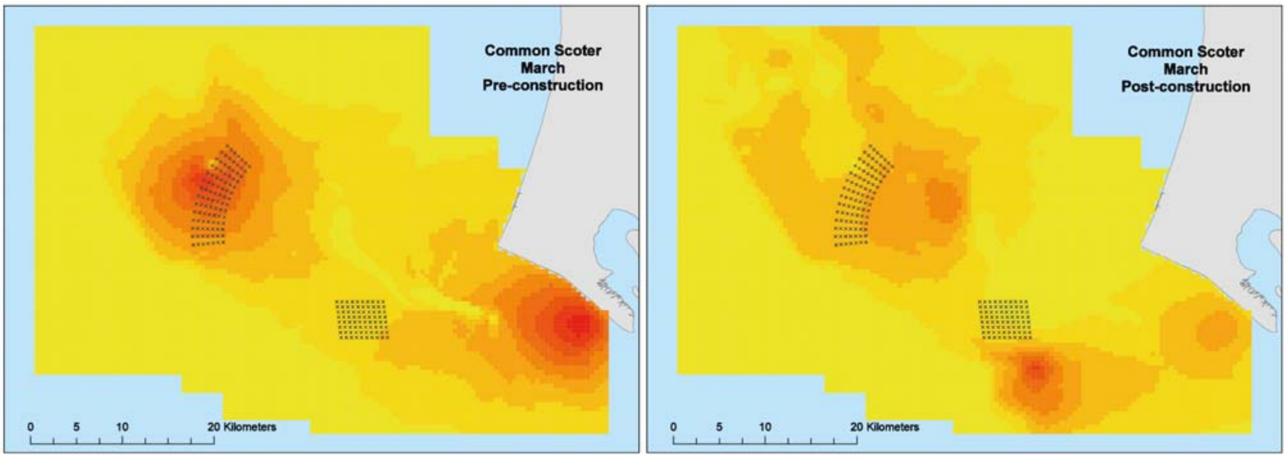


Figure 24C. Estimated densities of Common Scoters in the Horns Rev 2 survey area in March for the pre-construction period (left map) and for the post-construction period (right map).

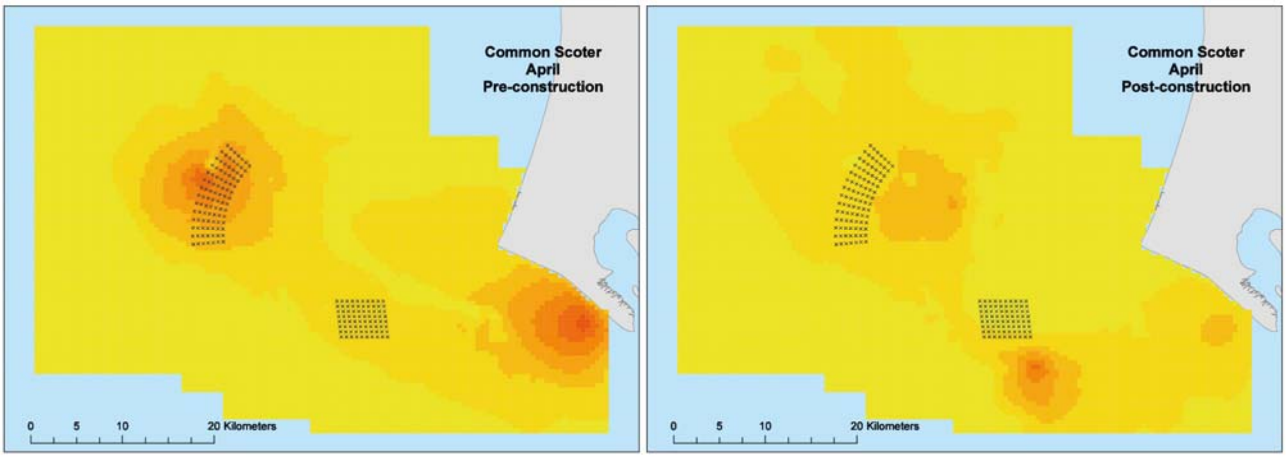


Figure 24D. Estimated densities of Common Scoters in the Horns Rev 2 survey area in April for the pre-construction period (left map) and for the post-construction period (right map).

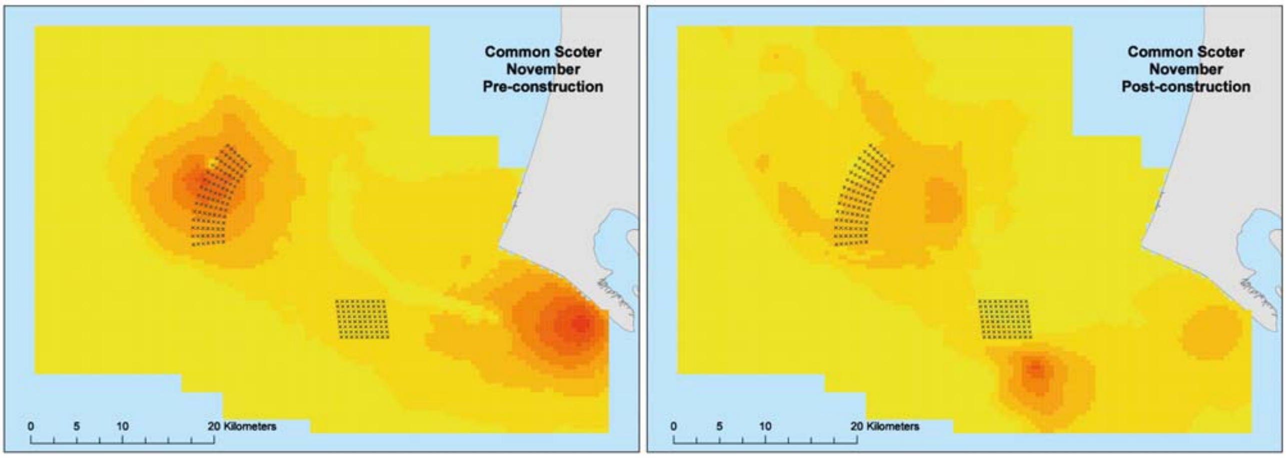


Figure 24E. Estimated densities of Common Scoters in the Horns Rev 2 survey area in November for the pre-construction period (left map) and for the post-construction period (right map).

The average pre-construction abundances per 0.25 km² grid square were combined and compared to the corresponding value for the post-construction situation. Both areas of increased densities and reduced densities were detected (Fig. 25). In the coastal areas west of Skallingen significant reductions in Common Scoter abundance was observed. In and around the Horns Rev 2 significant reductions in Common Scoter densities were also observed.

As well as significant decreases in the coastal areas west of Skallingen and in the Horns Rev 2 offshore wind farm area, significant increases in Common Scoter abundances were detected in the western and north-western parts of the study area, in an area 6 to 10 km east of the Horns Rev 2 site and in an area approximately 5 km south and southeast of the Horns Rev 1 site.

Every grid square in the survey area was binned into distance bands of 500 meters from the periphery of the Horns Rev 2 offshore wind farm. Cells were assigned to distance bands by the position of their grid square centroid. Thus, mean abundance per grid square could be calculated. Plotting these abundance values against distance category showed that there was a reduction of ca. 34 individuals per grid square. This is equivalent to 136 Common Scoters per km² in the first 500 m distance band around the Horns Rev 2 wind farm (Fig. 26). Only at distances more than 5 km from the Horns Rev 2 wind farm are post-construction Common Scoter abundances higher than during the pre-construction surveys.

The reduction in Common Scoter abundances within the Horns Rev 2 wind farm was 5,901 birds. The corresponding number for the wind farm site and a buffer of 2 km was 13,193 birds, while within a distance of 4 km from the wind farm site a reduction of 17,697 birds was calculated (Table 8). Within the approximately 52 km² area around the Horns Rev 2 wind farm in which changes in abundance was significant, there was a reduction of 10,996 Common Scoters.

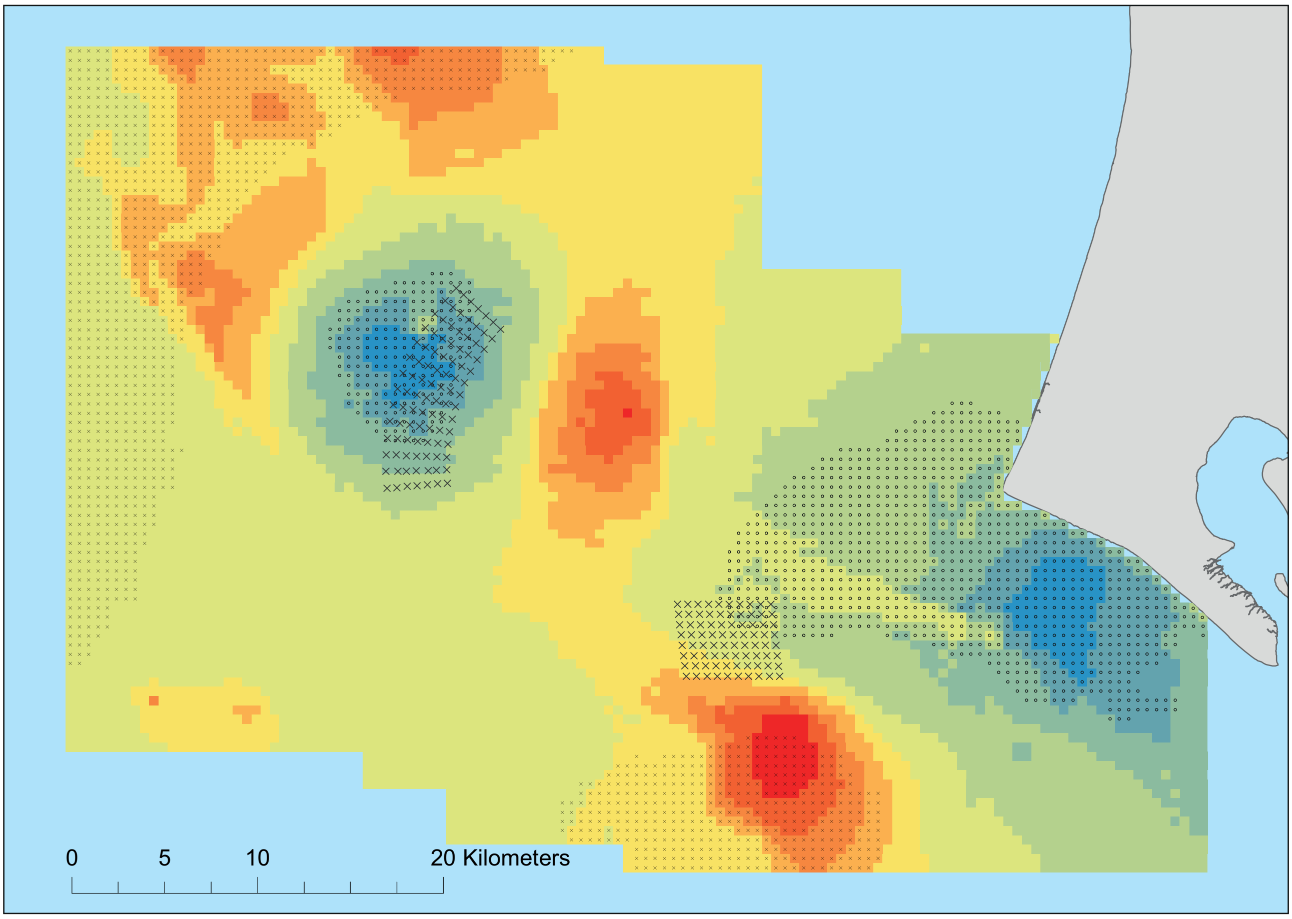


Figure 25. Estimated pre- and post-construction difference in Common Scoter numbers per 0.25km^2 in each grid cell averaged over the survey period. Grid cells which show statistically significant increases are indicated by + signs, those with significantly lower densities are represented by 0 signs.

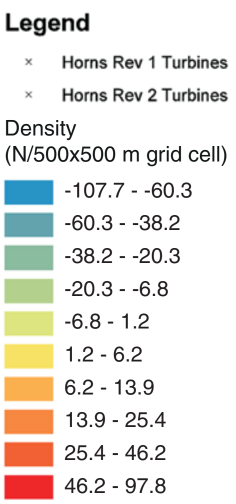
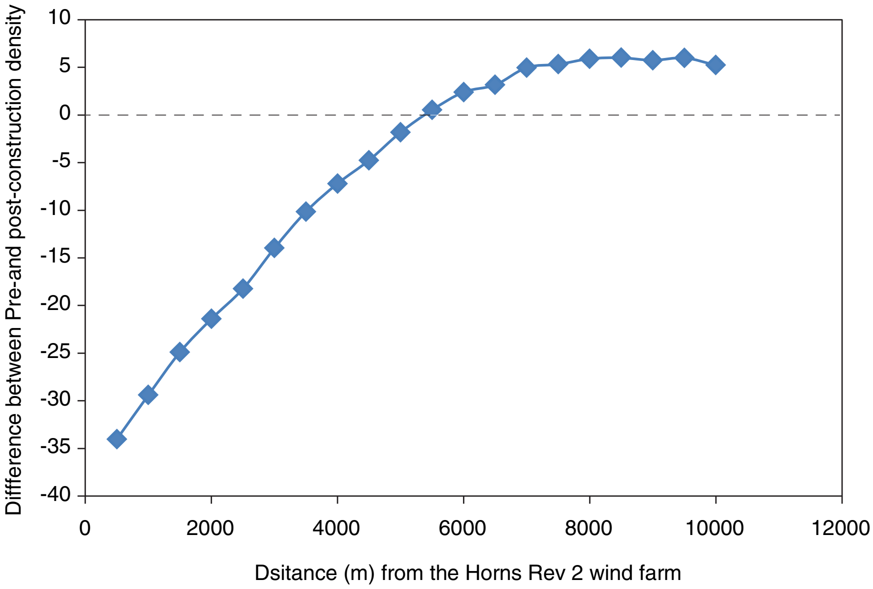


Table 8. The pre- to post-construction change in Common Scoter abundance in and around the Horns Rev 2 offshore wind farm. Negative values indicate reduced abundance.

Area	**Change in Common Scoter abundance**	**Percentage of the eastern Palearctic flyway population**
Horns Rev 2 offshore wind farm	-5,901	1.1
Horns Rev 2 offshore wind farm + 2 km buffer	-13,193	2.4
Horns Rev 2 offshore wind farm + 4 km buffer	-17,697	3.2
Area with significant reductions around HR2	-10,996	2.0

Figure 26. Differences between pre- and post-construction abundances by 0.25 km grid square (y-axis) of Common Scoters in the Horns Rev 2 survey area in relation to 500 meters distance intervals (x-axis) from the periphery of the Horns Rev 2 offshore wind farm. Negative values indicate lower abundances after the construction of the Horns Rev 2 offshore wind farm.



3 Discussion

The modelling approach used to analyse these data employs recently developed spatial modelling methods which have also been rigorously tested against alternative modelling approaches as part of commissioned work by the UK government (Mackenzie et al. 2013b). For this reason, these methods are now the recommended modelling methods for the analysis of baseline and environmental impact assessment in the UK.

The avian species composition at Horns Rev in 2011 and 2012 was similar to that of previous surveys in the area, performed from 2000 until 2007 (Petersen et al. 2006, Christensen et al. 2006, Petersen and Fox 2007). Most of the species recorded in the area were present in numbers too small for objective comparisons of differences in densities before and after construction of the Horns Rev 2 wind farm. In this report analysis of changes in distribution of only two species, namely Common Scoter and Red-throated Diver/Black-throated Diver have been carried out as they were present in high numbers and at the same time have high conservation value.

3.1 Red-throated Diver/Black-throated Diver

Divers are known to have been displaced from other areas with offshore wind farms (Percival 2009, 2010, Dierschke et al. 2012, Petersen et al. 2006).

Since the overall abundance of divers in the entire study area was similar during the pre- and post-construction periods, the observed changes in diver distributions across the study site cannot be related to changes in overall abundance. With a well defined area within witch differences between pre- and post-construction diver densities were significantly lower after the construction of the Horns Rev 2 wind farm, we regard this a strong indication that the wind farm causes displacement of divers. However, reduced abundances out to distances of more than 10 km are unlikely to be directly related to the presence of the Horns Rev 2 offshore wind farm. The distance from the Horns Rev 2 wind farm area to the area of increased diver density west of the wind farm in the post-construction phase is 5-6 kilometres. From a precautionary principle we do regard this the likely impact distance.

The divers are fish-eating species, in the Horns Rev area most likely feeding mainly on sand eel. No fine grained and large scale information are available on sand eel distribution and abundance across the study area and survey period are available, so whether changes in diver density across the area is partially caused by changes in food availability remains unknown.

The geographical extent of the decline in post-construction diver densities in the Horns Rev 2 offshore wind farm and the area immediately to the north and northwest does indicate an effect of the presence of the wind turbines and the associated activities. The distance from this part of the wind farm to the area of increased diver density in the post-construction phase is 5-6 km. With a pre- to post-construction reduction in diver abundances of 17 birds within the Horns Rev 2 wind farm turbines, the reduction represents 0.006% of the flyway population. When including the area in which significant declines in diver abundance was found around the Horns Rev 2 wind farm, the reduction will number 173 birds and cover an area of almost 400 km^2. Part of this area is more than 10 km away from the Horns Rev 2 wind farm. We believe that a direct wind farm related displacement effect out to this distance is unlikely to occur, and we regard the distance of 5-6 km between the wind farm and the area of increased diver density in the post-construction phase as a more reliable estimation of impact distance.

The reduced densities found east of the Horns Rev 2 wind farm could potentially be caused by a wind farm related barrier effect. Flying divers changed flight paths that could be related to the presence of the wind farm (Skov et al. 2012). If birds enter the area flying in from the west, a flight path avoidance of the wind farm, even if only partial, could potentially reduce diver utilization of areas east of the wind farm.

3.2 Common Scoters

Common Scoter was the single most abundant bird species in the Horns Rev 2 survey area and data from the 10 post-construction aerial surveys showed no exception in that respect. However, the spatial distribution of the species changed markedly between the pre- and post-construction survey periods. Both areas of increased densities and reduced densities were detected, suggesting a significant redistribution of the birds. In the coastal areas west of Skallingen, significant reductions in Common Scoter abundances were observed. This was also the case in and around the Horns Rev 2 wind farm. In contrast, significant increases in Common Scoter densities were detected in the western and north-western parts of the study area, in an area 6 to 10 km east of the Horns Rev 2 site and in an area approximately 5 km south and southeast of the Horns Rev 1 site. The magnitude of the reduction effect was consistently related to the distance from the turbines, which strongly suggested a behavioural response of birds to turbine presence post-construction.

During the first years of bird surveys around Horns Rev 1, from 1999 to 2001, few Common Scoters were recorded at the Horns Rev itself (Petersen et al. 2006). From 2002 onwards a rapid increase of Common Scoters on the Horns Rev itself was observed.

The East Palearctic flyway population of Common Scoters was estimated to be 550,000 individuals in winter, and with a 1% level of 5,500 individuals (latest Wetlands International WPE (World Population Estimates) on website http://wpe.wetlands.org/search?form%5Bspecies%5D=melanitta+nigra&form%5Bpopulation%5D=&form%5Bpublication%5D=5). This estimate needs reassessment, because the Danish wintering population in 2008 was estimated to be 600,000 birds (Petersen and Nielsen 2011) before considering wintering numbers anywhere else in the flyway. Nevertheless, the observed reductions in the density of Common Scoters within the Horns Rev 2 offshore wind farm amounts to more than the 1% criterion for this population of the species, and to 2% of the flyway population within the area within which a significant density reduction was shown.

The population level impact of such displacement on Common Scoters is unknown. For birds displaced from previously favoured feeding areas into adjacent feeding areas subject to higher densities, increased inter- or intra-specific competition may have adverse energetic effects on the displaced birds (foraging in unfamiliar areas) and those birds previously occupying such areas (experiencing greater competition). Likewise, altered predation or pseudo-predation pressure (such as for instance human disturbances from increased maintenance boat traffic in the area) may reduce the energetic conditions of the birds. The exact effect of these changes at the overall flyway population level is difficult to assess. In an assessment of species vulnerability towards offshore wind farms Common Scoters was described to be the fourth highest ranking Eurasian waterbird species, with only the diver species ranking higher (Furness et al. 2013).

Common Scoters were frequently seen fouraging between the turbines, particularly in the south western corner of the Horns Rev 2 offshore wind farm. Similar findings were found in the Horns Rev 1 wind farm during an earlier study (Petersen and Fox 2007). Studies of Common Scoter flight trajectories in and near the Horns Rev 2 wind farm in relation to the post-construction monitoring program found that these birds were reluctant to fly into the wind farm area, and horizontally avoided the wind farm area (Skov et al. 2012). Since the frequency of flight trajectories into the wind farm were reduced, the probability of Common Scoters settling there to forage will also be reduced. With a predominant northward current in the study area, the presence of more Common Scoters in the south western part of the wind farm could potentially be explained with birds drifting with current from concentrations of birds outside of the wind farm area into the area between the turbines.

Common Scoters were found to be present at on average greater water depths during the post-construction period, as compared to the pre-construction period. This change is mostly influenced by decreased abundances of Common Scoters in the eastern parts of the study area and increased numbers found in the western parts of the area. This change in depth distribution is not causing the reduced abundances in and around the Horns Rev 2 offshore wind farm as the core Common Scoter area in that area experienced marked abundance declines within the water depths preferred by the Common Scoters over the post-construction period. Displacement to greater water depths implies elevated energetic costs to the birds as the energetic cost related to diving for food at the bottom of the sea will increase.

3.2.1 Food availability

The observed shift in water depth distributions could be related to changes in food distribution. The razor clam, *Ensis directus*, is the predominant bivalve species at the Horns Rev sand bank while the though shell, *Spisula subtruncata*, dominated the bivalve community in the coastal areas off Skallingen. Both bivalve species are important food items for Common Scoters. Habitat suitability for these two bivalve species was modelled for parts of the study area (Leonhard et al. 2012).

In the coastal areas off Skallingen there was an improvement in habitat suitability during 2005-2007 until 2011 for *Spisula*. During the same time frame Common Scoter abundances were reduced markedly in the same area, which indicated that the modelled habitat utilisation for the bivalves was not reflected in the numbers of Common Scoters present in that area over the same time span.

Based on long term modelling, habitat suitability for *Ensis directus* was reduced in and around the Horns Rev 2 offshore wind farm, and more so than in areas elsewhere on the reef, both pre- and post-construction of the turbines (Leonhard et al. 2012). Notwithstanding this, in the pre-construction period, the area subsequently developed for the Horns Rev 2 wind farm was the area supporting the highest densities of Common Scoters in the area

(Christensen et al. 2006, Petersen and Fox 2007). Thus, for this area, the relationship between the bivalve habitat suitability model and the Common Scoter densities seemed to be poor.

Because there were no obvious geographical relationships between the outputs from the bivalve habitat suitability modelling and those from modelling of Common Scoter densities, before and after the construction of the turbines or from changes between these two periods bivalve habitat suitability parameters were not included as covariates in the modelling of bird distributions.

3.3 Horns Rev 2 effects as related to Horns Rev 1 effects

The Horns Rev 1 offshore wind farm area was already constructed and in the operational phase before the first of the 20 aerial surveys used in this analysis was undertaken. An analysis of the effect of the Horns Rev 1 offshore wind farm on the distribution of Common Scoter concluded that the birds were present within the wind farm site in as high densities as outside the wind farm during certain years following construction (Petersen & Fox 2007).

4 Conclusion

As part of the post-construction monitoring programme in relation to the Horns Rev 2 offshore wind farm off the west coast of Denmark, 10 aerial surveys of bird abundances and distributions were performed during the winter and spring period from March 2011 to April 2012. The most abundant bird species in the study area was the Common Scoter, numbering up to 187,000 individuals recorded during a single survey in March 2011. The study area is of international importance to the flyway population of Common Scoters.

Gull species were also abundant in the study area. Herring Gull was the most numerously occurring gull species identified. Kittiwakes and Little Gulls were also frequently recorded in the area.

Divers were frequent in the study area. The majority of the divers were Red-throated Diver.

Razorbills and Guillemots were abundant in the study area, particularly in the western parts of the area. Up to 400 Razorbills/Guillemots were observed during a single survey in October 2011.

Emphasis was placed on analysing potential changes in the abundance and distribution of divers and Common Scoter in the Horns Rev 2 wind farm area between pre- and post-construction of the wind farm. For that purpose, the 10 surveys presented in this report provided the post-construction data set. An additional 10 surveys, covering the same period of the year, conducted between November 2005 and April 2007, comprised the pre-construction data set.

The 10 pre-construction surveys and the 10 post-construction surveys were all performed after the start of the operational phase of the Horns Rev 1 offshore wind farm.

Divers showed no significant differences in overall abundances between the pre- and post-construction periods within the survey area. However, distributional changes were observed, particularly within and near the Horns Rev 2 offshore wind farm. This was interpreted as a displacement effect, caused by the presence of the Horns Rev 2 wind farm. With reduced abundances out to a distance of more than 10 km from the wind farm site we assume that other factors than the presence of the wind farm will have influenced the changes in the areas far from the wind farm. Increased densities were found in the western parts of the study area. The pre- to post-construction change in diver number was a reduction of 17 individuals for the turbine area of Horns Rev 2 wind farm, and a reduction of 173 birds in the area in which significant differences between pre- and post-construction abundances was found. The latter number represents 0.07% of the Red-throated Diver flyway population. The numbers involved are thus small as compared to the entire flyway population.

Common Scoters showed no significant differences in overall abundances between the pre- and post-construction periods within the survey area. However, distributional changes were observed, particularly in the coastal areas off Skallingen and in and around the Horns Rev 2 offshore wind farm. At the same time marked increases in densities were observed in areas south of Horns Rev 1 offshore wind farm as well as east, west and northwest of the Horns Rev 2 offshore wind farm. Reduced post-construction abundances were observed out to a distance of 5 km from the periphery of the Horns Rev 2 wind farm. Within the turbines of the wind farm the reduction between pre- and post-construction numbers amounted to 5,901 birds, equivalent to 1.1% of the flyway population. When including a buffer zone of 2 km around the wind farm the decrease amounted to 13,193 birds or 2.4% of the flyway population. If considering the area around the Horns Rev 2 wind farm in which reduction in abundance was significant the reduced number of birds was 10,996 or 2.0% of the flyway population.

5 Litterature

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