LONG-TERM IMPACTS ON LONG-TAILED DUCK DISTRIBUTIONS RESULTING FROM THE CONSTRUCTION OF THE RØDSAND II AND NYSTED OFFSHORE WIND FARMS, DENMARK

Technical Report from DCE – Danish Centre for Environment and Energy No. 120 2018

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Abstract: The spatial distribution of Long-tailed Ducks around the Nysted and Rødsand II offshore wind farms in Danish Baltic was resurveyed during February to April 2018. These surveys were a follow up on a series of surveys, started in 2000, prior to the construction of the two wind farms to enable pre-construction bird distributions to be compared between different development phases of the two wind farms. In this report we compare bird distribution between four phases. Decreases in the density of Long-tailed Duck within and in the near vicinity of the wind farms post-construction at both sites has been documented in earlier reports. In this report we document that the present density of Long-tailed Duck within the wind farms remains significantly lower than it was prior to the construction of the wind farms. Comparing bird densities between the two latest phases (2011 and 2018) showed modest increase in Long-tailed Duck densities in and around the wind farm areas. The increase, however, involve less than an estimated 30 birds (compared to 3,000-4,000 estimated in the survey area) and are biologically trivial when compared to densities in unaffected areas.

Keywords: Long-tailed Duck, *Clangula hyemalis,* habituation, wind farm, displacement, spatial model

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Front page photo: Flying Long-tailed Ducks in a snow shower at Gedser Rev on 6th February 2018. Photo: Rasmus Due Nielsen

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Contents

1 Introduction

This document reports on the distribution of non-breeding Long-tailed Ducks *Clangula hyemalis* in and around two (Nysted and Rødsand II) offshore wind farms in southern Denmark, the statistical analyses used to assess the potential impacts of the two wind farms and complements the previous analyses of these data (Petersen et al. 2011, 2013).

The Nysted / Rødsand II offshore wind farms were initiated amongst the earliest in a series of offshore wind farm constructions carried out under a government-initiated demonstration project. Environmental investigations, including surveys of birds, were initiated in the area in 2000 as a baseline. The Nysted offshore wind farm was constructed throughout 2003. The analyses of distribution of Long-tailed Ducks was carried out comparing the baseline phase with the situations following the construction of both wind farms (Kahlert et al. 2005, Petersen et al, 2006, 2008). In a final phase, three surveys were carried out in February to April 2018 to determine levels of habituation to wind farm presence, given identical conditions to those in 2011, but seven years later in time. The survey phases in relation to the wind farm construction is as follows:

- Phase A: Pre-construction of both Nysted and Rødsand II offshore wind farms, 2000 – 2002
- Phase B: Post-construction of Nysted and pre-construction of Rødsand II, 2003-2007
- Phase C: Post-construction of both Nysted and Rødsand II offshore wind farms, 2011
- Phase D: Present study. Post-construction of both Nysted and Rødsand II offshore wind farms, 2018.

The surveys were conducted using the same transect lines and the same method throughout the study period, although the number of surveys undertaken differed between each phase.

This report includes new analyses of survey data from phase D, several years after the construction of the Rødsand II wind farm. Previous data from Phase A constitute information on the pre-construction baseline phase for both wind farms, phase B constitutes post-construction of the Nysted wind farm and pre-construction of the Rødsand II wind farm, while phase C constitutes post-construction of both wind farms. The main aim here is to establish if, and to what degree, the Long-tailed Duck show any habituation to the presence of the turbines in the years following construction. The three aerial surveys conducted during February, March and April 2018 used the same survey methods as used during the previous surveys of the study area. The statistical methods employed include distance sampling, to account for imperfect detection of birds in the sampling process, and spatially adaptive Generalised Additive Models with robust standard errors to model the spatially and temporally correlated geo-referenced data.

2 Survey data

The three aerial surveys were conducted on 21st February, 19th March and 4th April 2018, performed covering the same study area as was previously used to describe bird distributions and abundances in the wind farm areas, using the same defined transect lines. For each of the three surveys, totals of 774, 1,041 and 1,185 Long-tailed Ducks were observed on the transect lines respectively.

Table 1. Number of observed Long-tailed Duck for each of the three surveys conducted in winter/spring of 2018.

Date	Total number of observed Long-tailed ducks	Number of Long-tailed ducks inside NYSTED or within 500 m of the outermost turbines	Number of Long-tailed ducks inside RØSAND II or within 500 m of the outermost turbines
21st February	774	50	58
19th March	1,041	20	71
4th April	1,185	52	74

The majority of the birds occurred south of Gedser. On 21st February, numbers of Long-tailed Ducks was also observed on Gedser Rev (an area of shallow water extending approximately 15 km SE of the southernmost point of the island of Falster).

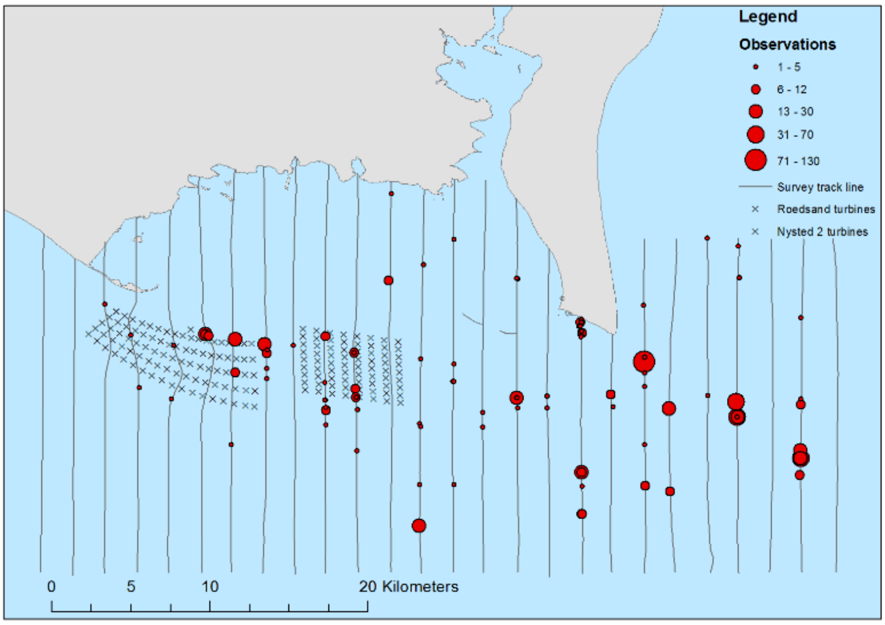


Figure 1. The spatial distribution of 774 observed Long-tailed Ducks in the Rødsand/Nysted study area on 21st February 2018.

Figure 2. The spatial distribution of 1,041 observed Long-tailed Ducks in the Rødsand/Nysted study area on 19th March 2018.

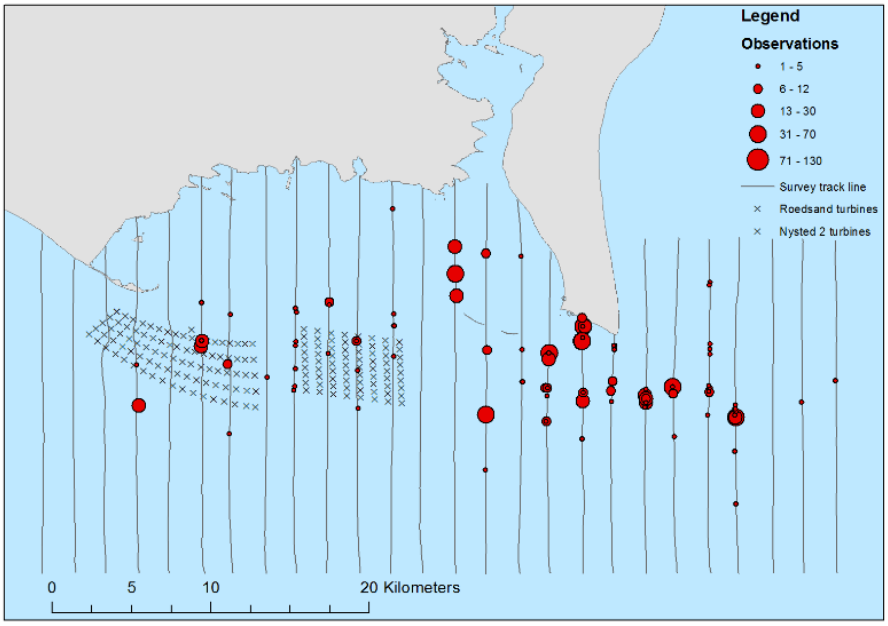
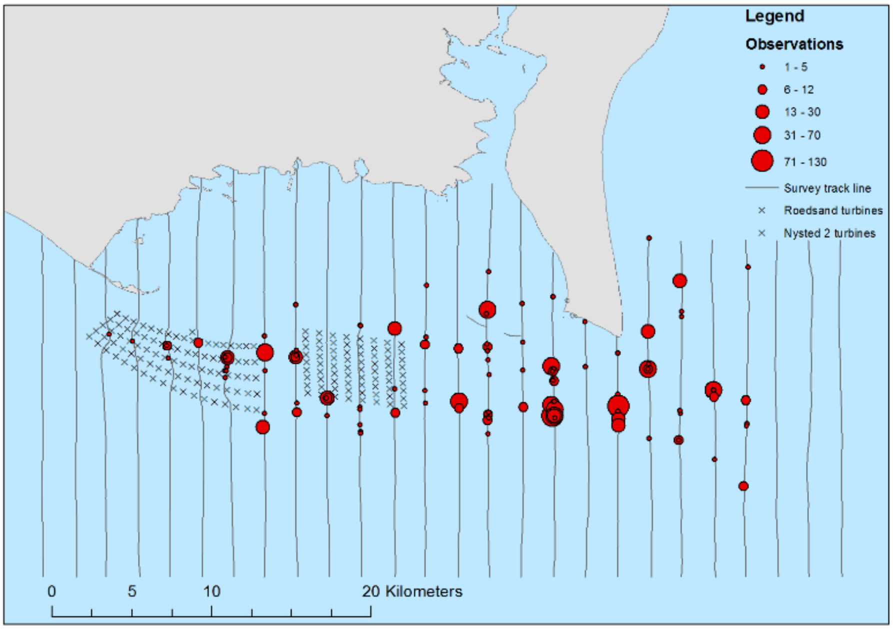


Figure 3. The spatial distribution of 1,185 observed Long-tailed Ducks in the Rødsand/Nysted study area on 6th April 2018.



3 Correcting the observed counts for imperfect detection

In the previous report, the data from phases A-C were corrected using a hazard rate detection function with log(cluster size), survey data, observer and bird behaviour included in the model. For phase D, a forwards selection procedure using AIC, was used to assess both hazard rate and half-normal detection functions with a variety of covariates (those already used during A-C, but adding sea state and sun intensity). The best selected model was a half normal with log(cluster size) and observer as covariates. As for the previous phases, the data were aggregated into three distance class bins out from the observer (with breaks at 0, 119, 388 and 956 m distance, excluding a band of 44 m between the survey track line and the start of the innermost transect band, comprising a dead angle directly under the aircraft). The detection functions were fitted using the R package mrds (Lakke et al. 2017, R Core Team 2017). The resulting detection function is shown in Figure 4.

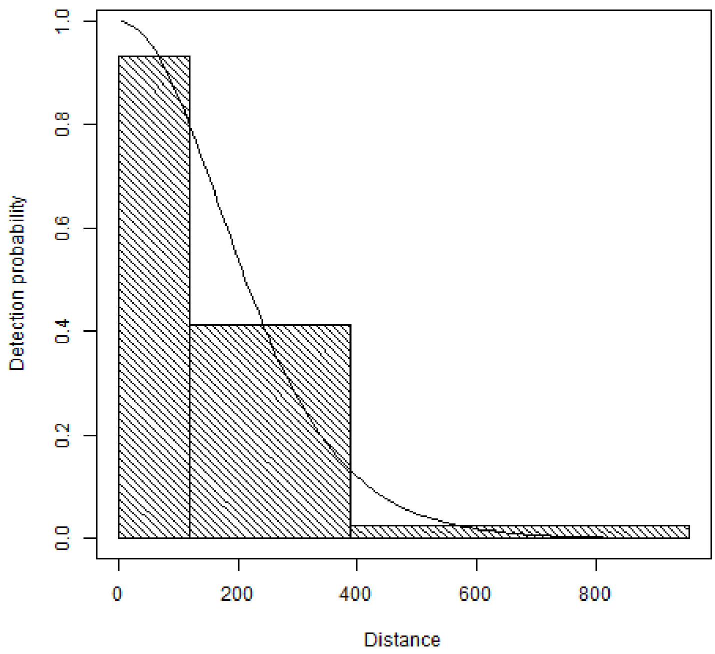


Figure 4. Fitted average detection probability as a function of perpendicular distance (m) from the flight line with the fitted half normal detection function overlaid.

4 Modelling Methods

4.1 Modelling framework

The data available for analysis consist of distance corrected transect / segment data over a number of survey days, which are likely to be spatially and temporally auto-correlated. Covariate data may explain why bird numbers at locations or time points close together are more similar to each other than at locations / time points far apart. However, if this information is missing from the model, there will be pattern left in the noise component of the model (model residuals), which could lead to improper model conclusions.

We use a modelling framework that allows for count data, smooth terms for covariates and residual correlation, comprising Generalised Additive Models (GAMs, Hastie & Tibshirani 1989, Wood 2006) which generate robust (or empirical) standard errors (Hilbe 2014). The GAMs allow for smooth covariate relationships and, rather than assuming a model for the correlation seen in the model residuals, we use these residuals to drive the correction for the standard errors of the parameter estimates (robust standard errors). Since the response data are counts of birds, we used a Poisson distribution with extra dispersion (Quasi-Poisson) for the noise component and a log link function to ensure predictions are positive. The extra dispersion allows more variability in the noise component than is assumed under a strict Poisson model.

4.2 Covariate SPEcification

The covariates available for modelling were phase (A-D), water depth, distance to coast and the spatial coordinates (in UTM grid coordinates). The distance to coast covariate repeated the information provided by the spatial coordinates and so was not considered for modelling. The phase term was modelled as a factor variable; one level for each phase. Depth was modelled using a B-spline with smoothness selected by the Spatially Adaptive Local Smoothing Algorithm (SALSA, Walker et al. 2011). The spatial smooth was undertaken using a flexible surface fitting approach (CReSS, Scott-Hayward et al. 2014) with targeted smoothness using SALSA2D. The knot locations allowed for selection in the spatial smooth term were specific to each phase. This enabled the spatial surface to vary depending on the phase. The SALSA algorithms allow for targeted flexibility to ensure important local features are not missed and 'smoothed-out', such as areas in and around a potentially impacted site, and to ensure the spatial range of any local effects that do exist are not exaggerated. For instance, 'smoothing-out' local features will result in under-reporting of any impacts in and around the site(s) of interest and may result in extending the range of the impact into areas, which are, in reality, unaffected. All modelling was analysed using the MRSea package in R (R Core Team 2017, Scott-Hayward et al. 2017).

The equation for the mean element of the model was:

$$
\begin{aligned}
counts = g(\mu) = \log(\mu) \\
&= \beta_0 + \beta_1 PhaseB + \beta_2 PhaseC + \beta_3 PhaseD \\
&+ \sum_{j=4}^{J} \beta_j s(depth) + \sum_{k=J+1}^{K} \beta_k\, s(x, y, phase)
\end{aligned}
$$

Where J and K were chosen using the one and two dimensional SALSA algorithms and $s()$ represents a B-spline smooth for depth and a local radial smooth (Gaussian) for the covariates.

4.3 Model selection

The SALSA algorithms used a quasi-likelihood version of the BIC information criterion to determine the best number and location of knots from a given start point. The SALSA algorithm for the depth term was initialised with one knot at the mean, but was subsequently allowed to choose 1-3 internal knots (generating 3-5 degrees of freedom). The spatial term was initialised with either 10, 20, 30 or 40 knot locations evenly spaced across the study region (four separate models) with a minimum of 2 knots and a maximum of 45 knots allowed in the search. 10-fold cross-validation was used to choose the best of the different start knot models.

4.4 Uncertainty estimation

For the two-stage analysis approach, detection function fitting and surface fitting, the key objective is to ensure that the final result incorporates uncertainty from both of the estimation processes.

To capture the uncertainty in the detection function process, transect-days were re-sampled with replacement and the chosen detection function re-fitted to the set of bootstrap transects. This returned 500 sets of non-parametric bootstrap-based adjusted counts to use as input to the surface fitting process. The best surface model was then fitted to each bootstrap based input and a parametric bootstrap realisation (based on the GAM results using the robust estimator for the variance) obtained for each, giving 500 bootstrap-replicate based fitted surfaces with which to harvest percentile geo-referenced confidence intervals.

4.5 Outputs

The outputs in the results section show the distance corrected survey data across the four phases, and the spatial model predictions for each. We also present 'difference-maps' illustrating where statistically significant changes/redistribution of Long-tailed Ducks across a surveyed area can be supplied with reference to the two wind farm sites. This allows any differences over time to be geo-referenced, to assist with judgement about whether differences are both significant and related to the speculative impact.

5 Results

The distribution of the distance corrected counts across the four phases is shown in Figure 5. In each of the phases, the majority of sightings were in the central and south eastern parts of the study region. Each of the four phases had varying amounts of survey effort, shown in Table 2. Phase B was subject to most effort and Phase D the least.

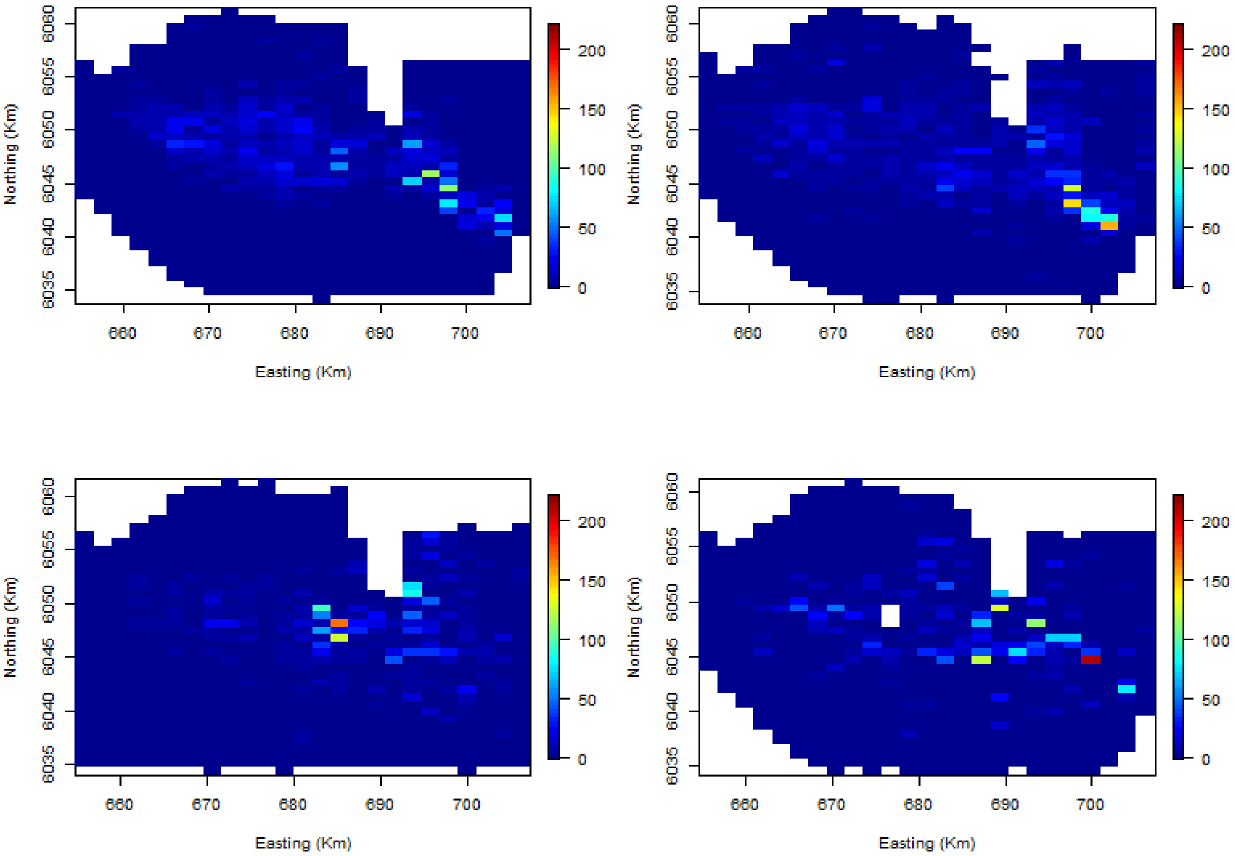


Figure 5. Duck distribution based on the corrected counts (input data for the surface fitting models) for each phase (A: Upper left, B: upper right, C: lower left, D: lower right).

Table 2. Table showing the total number of observations (segments) in each phase and the number of non-zero observations.

Phase	Number of data points	Percentage of non-zero Observations
A	11478	10.0%
B	14128	11.6%
C	5896	7.8%
D	3364	6.7%

The final model (Model 1) selected the depth relationship to have one internal knot at approximately -14m with a peak in abundance at around -10m deep waters. Figure 6 shows this partial relationship along with 95% confidence intervals. The spatial term selected 19 knot locations, 10 in phase A, 2 in phase B, 6 in phase C and one in phase D. The dispersion parameter estimate was 90 (indicating the residuals are 90 times more variable than assumed under a strict Poisson model) and the empirical runs test returned a *p*-value of <0.001 indicating that the use of robust standard errors was appropriate. Thus the final selected model was;

$$\begin{aligned} counts = g(\mu) = \log(\mu) \\ &= \beta_0 + \beta_1 PhaseB + \beta_2 PhaseC + \beta_3 PhaseD \\ &+ \sum_{j=4}^{6} \beta_j s(depth) + \sum_{k=7}^{16} \beta_k\, s(x, y, phaseA) \\ &+ \sum_{m=17}^{18} \beta_m s\,(x, y, phaseB) + \sum_{p=19}^{24} \beta_p\, s(x, y, phaseC) \\ &+ \beta_{25} s(x, y, phaseD) \end{aligned}$$

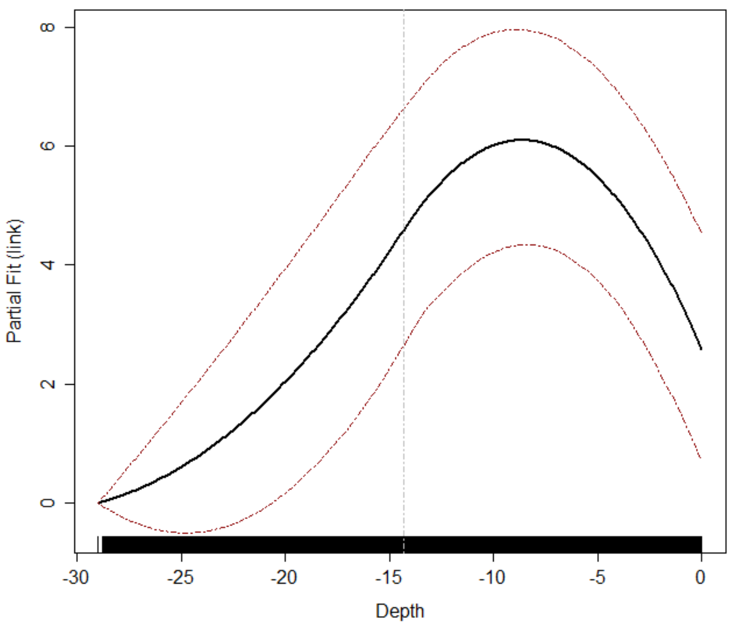


Figure 6. Partial relationship for depth (df=3) with 95% confidence intervals (red dashed lines). The grey dashed line is the location of the only internal knot chosen by SALSA.

Model predictions for each phase are shown in Figure 7 along with the locations of any wind farms that were present at the time. Figure 8 shows the spatially referenced scaled Pearsons residuals in each phase, which are used to determine if there is any systematic bias in the model estimation. These images show good scatter of residuals with no clusters of positive or negative residuals which would indicate systematic bias.

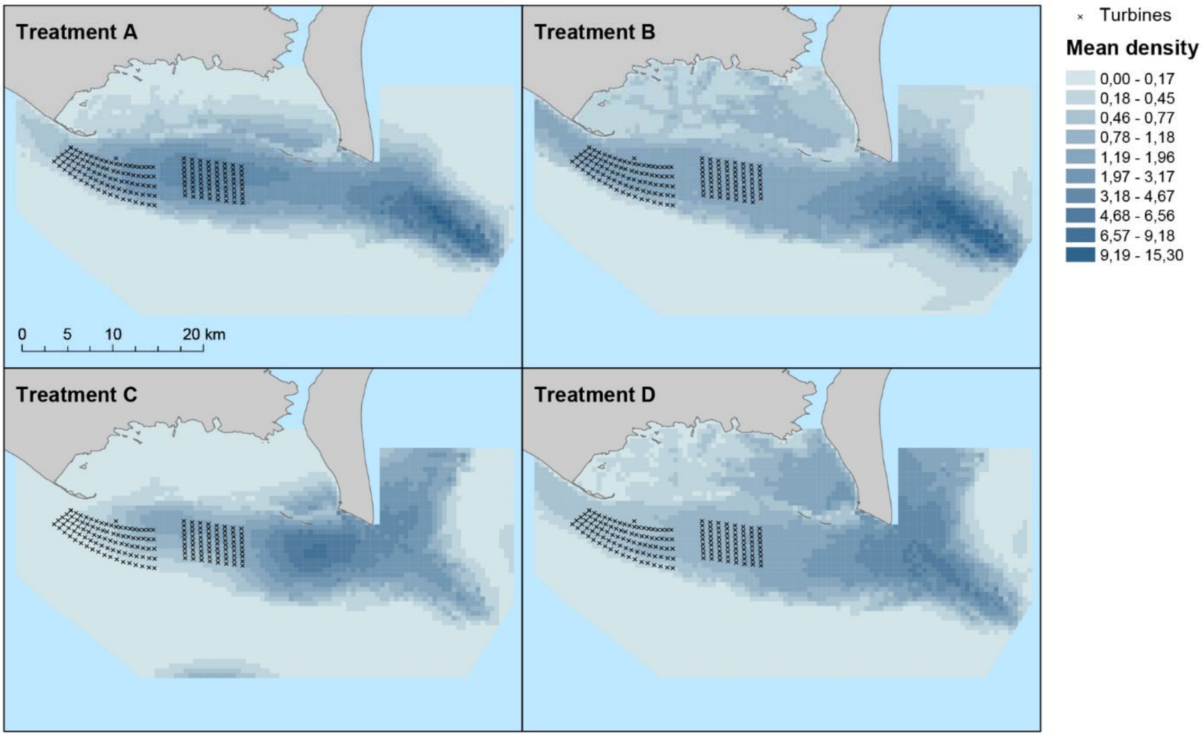


Figure 7. Predicted duck distribution for each of the four phases. The black crosses indicate the locations and extent of the windfarms either under construction or constructed in each phase.

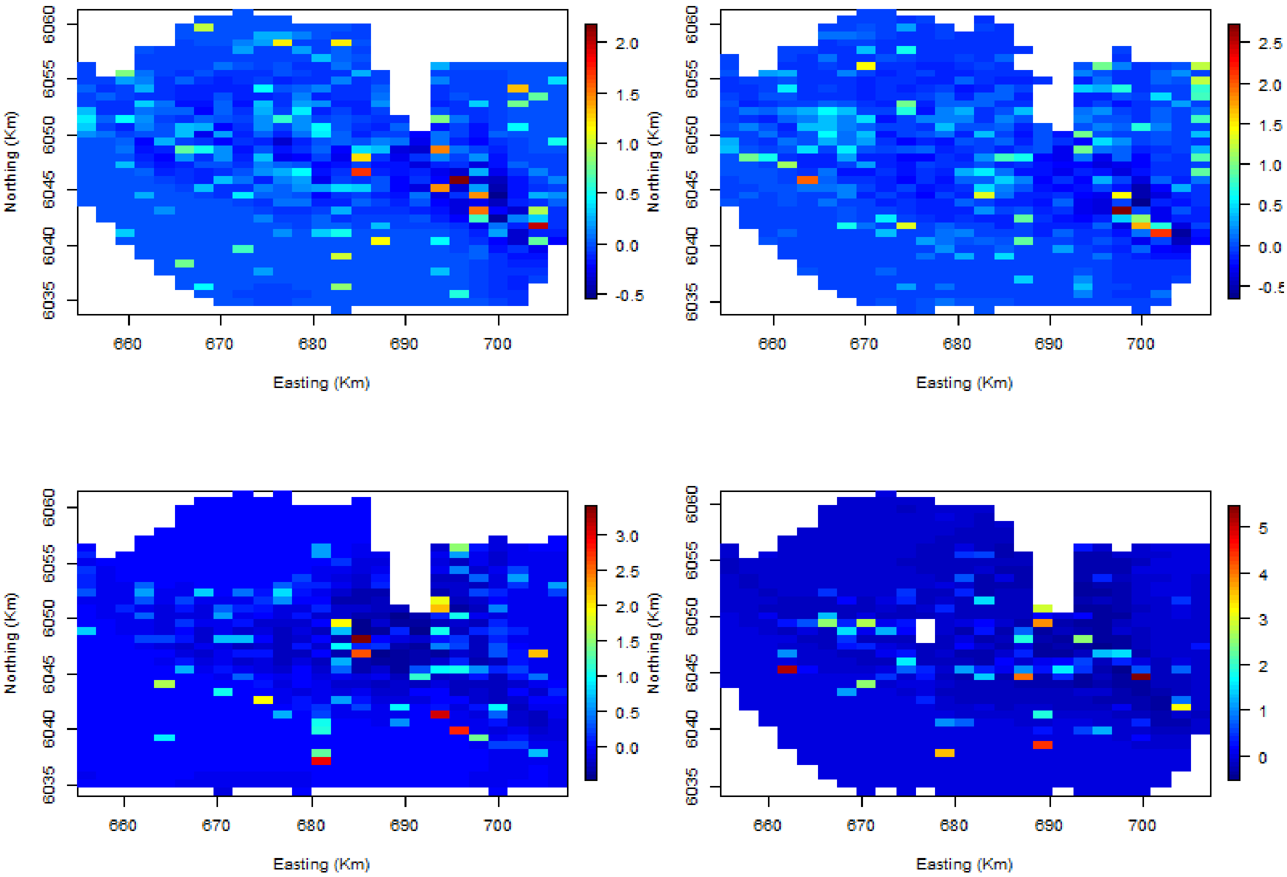


Figure 8. Scaled Pearson residual plots (residuals adjusted for the variance assumed under the model) for the model fitted to the duck data in each phase. Well fitted models exhibit good mixing of negative and positive residuals, while ill-fitting models would be evidenced by clusters of negative or positive residuals.

The main purpose of this report was to determine any significant differences in spatial distribution and abundance between the four phases, in particular, to investigate if there has been any habituation of birds to the windfarms. Table 3 shows the percentage of cells with positive and negative differences in each of the two wind farm regions along with the percentage of significant positive and negative differences.

The differences between each consecutive phase (A to B, B to C and C to D) along with the difference between phase D and the baseline phase, A (pre-construction) are shown in Figure 9. In all phases, there are some regions of the study area that experienced increases in bird densities (red) and others where they decreased (blue/purple). Lastly, by way of comparison to the previous report and as an indication of overall uncertainty in each phase, Figure 10 shows the overall abundance in each phase along with 95 percentile based confidence intervals.

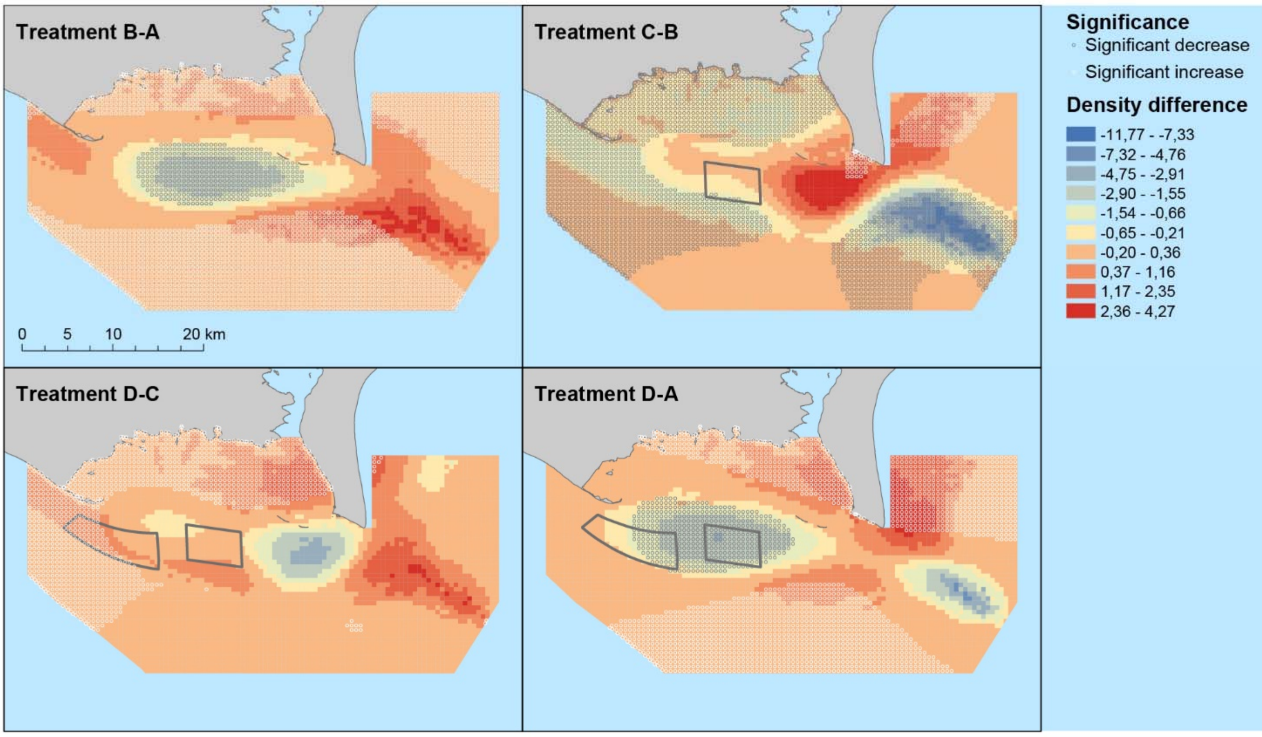
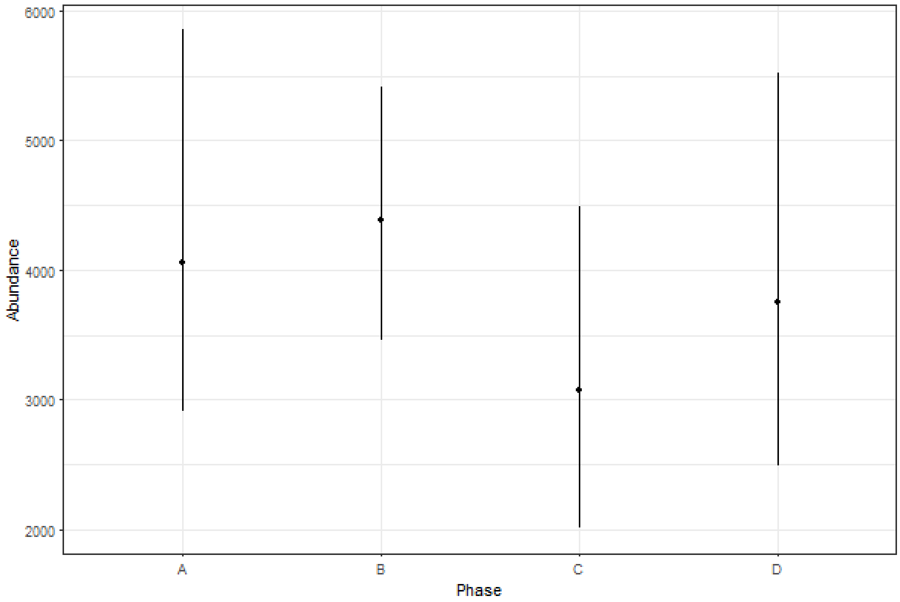


Figure 9. Predicted differences in estimated duck counts (colour scale indicates numbers/grid cell of 0.25 km2) between phases A and B, B and C, C and D and lastly A and D. The grid of open grey circles represent grids with a significant decline in average numbers between the two phases and the grid of open white circles represent those areas with a significant increase in average numbers between the two phases. The black polygons indicate the location and extent of the windfarms, either under construction or constructed in each phase.

Table 3. Table showing the percentage of cells in each windfarm polygon that show both a 'best guess' that is an increase or a decrease, and also the percentage of cells that significantly increase or decrease (calculated from the bootstrap predictions).

	Phase C to D		Phase A to D	
	Nysted	**Rødsand II**	**Nysted**	**Rødsand II**
Percentage of cells increasing	53%	95%	0	2%
Percentage of cells significantly increasing	0	40%	0	0
Percentage of cells decreasing	47%	5%	100%	98%
Percentage of cells significantly decreasing	0	0	100%	48%

Figure 10. Estimates of abundance by phase of the study. These estimates of abundance were made using the best surface fitting model to make predictions to each geo-referenced cell and summing the estimates across grid cells within phases. The vertical bars are 95 percentile based confidence intervals calculated from the 500 bootstraps.



Mean Long-tailed Duck abundance and densities for each of the phases along with 97.5% confidence intervals for both are shown in Table 4 and mean abundance and densities for each survey flight undertaken in 2018 in Table 5.

Table 4. Table showing the mean abundance and the mean density across the four phases and the lower and upper values for the 97,5% confidence intervals for each.

Phase	Mean Abundance	Lower 2.5%	Upper 97.5%	Mean Density (Birds/Km^2)	Lower 2.5%	Upper 97.5%
A	4010	2924	5723	3.49	2.54	4.98
B	4422	3458	5606	3.84	3.01	4.87
C	3178	2045	4639	2.76	1.78	4.03
D	3729	2482	5427	3.24	2.16	4.72

Table 5. Table of abundances and density estimates for the three phase D surveys.

Date Of Phase D Survey	Mean Abundance	Mean Density (Birds/Km^2)
21/2/2018	3365.15	3.222
19/3/2018	3379.93	3.249
4/9/2018	3367.93	3.233

It should be noted that there was some uncertainty in the model selection task and that there were several models with cross-validation scores that overlapping 95% confidence intervals. The next "best" model (Model 2) to the one described above had the same term for depth, but a spatial term with 13 knots (7 in phase A, 3 in phase B, one in phase C and two in phase D). The significant differences plots and table of differences are shown in Table 6. Mean abundance and densities of Long-tailed Duck for each of the phases along with 95% confidence intervals for both are shown in Table 7 and the overall statistical changes within the two wind farm areas are summarized in Tables 8 and 9.

Table 6. Table showing the percentage of cells in each windfarm polygon that show both a 'best guess' that is an increase or a decrease, and also the percentage of cells that significantly increase or decrease (calculated from the bootstrap predictions).

	Phase C To D		Phase A To D	
	Nysted	Rødsand II	Nysted	Rødsand II
Percentage of cells increasing	100%	100%	0%	11%
Percentage of cells significantly increasing	92%	53%	0%	0%
Percentage of cells decreasing	0%	0%	76%	70%
Percentage of cells significantly decreasing	0%	0%	100%	100%

Table 7. Table showing the mean abundance and the mean density across the four phases and the lower and upper values for the 95% confidence intervals for each.

Phase	Mean Abundance	Lower 2.5%	Upper 97.5%	Mean Density (Birds/Km^2)	Lower 2.5%	Upper 97.5%
A	4013	2866	5626	3.49	2.49	4.89
B	4408	3458	5461	3.83	3.01	4.75
C	2956	2020	4217	2.57	1.76	3.67
D	3661	2384	5478	3.18	2.07	4.76

Table 8. Table showing the overall statistically significant trends in numbers of Long-tailed Ducks within the two wind farm areas between the different phases of the investigations, based on the most favourably selected model. Grey shaded boxes indicate trends that fit with predictions of an impact from construction (i.e. significant declines) and yellow shaded boxes indicate trends that fit with predictions of habituation (i.e. significant increases).

Phase comparison	Nysted	Rødsand II
B-A	Decline	Moderate decline
C-B	No change	Decline, specially western part of wind farm area
D-C	No change	Medium increase, especially in the western and southern part of wind farm
D-A	Decline	Decline

Table 9. Table showing the overall statistically significant trends in numbers of Long-tailed Ducks within the two wind farm areas between the different phases of the investigations, based on the most second most favourably selected model. Shaded boxes indicate trends that fit with predictions of an impact from construction (i.e. significant declines) and habituation (i.e. significant increases).

Phase comparison	Nysted	Rødsand II
B-A	Decline	Moderate decline
C-B	Decline	Decline
D-C	Increase	Increase, especially in the eastern part of wind farm
D-A	Decline	Decline

6 Discussion

This project was initiated as a follow-up on previous investigations of Long-tailed Ducks distribution around the two offshore wind farms, Nysted and Rødsand II. Previous analyses demonstrated that the abundance of the species declined in the areas of the wind farms after their construction. It was expected that, with time, the Long-tailed Ducks would become familiar with the wind farms and gradually utilize the areas of the wind farms in abundances equivalent to the pre-construction levels.

The results from both models (Models 1 and 2) were consistent in showing statistically significantly lower numbers of Long-tailed Duck within both wind farm areas than were present during the baseline surveys (Tables 8 and 9). Hence, after 16-18 years, the species has not returned to levels of abundance that were present prior to their construction.

Analysis of changes in abundance from phases B to C using outputs from both models followed predictions of an impact from wind farm construction (Rødsand II) and no sign of habituation to the Nysted wind farm (Tables 8 and 9).

Overall abundance of Long-tailed Ducks in phase C was between a quarter and one third of those in phases A and B. Numbers also recovered subsequently by 25% from phase C to D, resulting increased numbers of birds throughout the entire study area. This was reflected in significant increases in birds within 40% of grid cells (amounting to just 25 birds in all) in the western and southern part of Rødsand II during this period under Model 1 (Figure 9). Under the less-favoured Model 2, there were stronger suggestions of habituation, since 92% of cells within the Nysted offshore wind farm showed significant increases in phase D compared with C, and 53% for the Rødsand II wind farm (in this case in the eastern section). Owing to the different initialised positions of the knots, two were retained in phase D allowing for a more detailed surface, but at the expense of model fit in the other phases (this model had a poorer QL-BIC score).

To summarise, while there is no evidence for any recovery of numbers of Long-tailed Duck within the Nysted and Rødsand II windfarms to former, pre-construction levels, there was some equivocal evidence of a medium level of increase in abundance within these areas in the last seven years. Whether this constitutes some form of habituation in the windfarm regions during the between phase C and phase D is open to question given the small absolute numbers of birds involved in the areas between turbines. The uncertainty is such that for large parts of the windfarm regions there is neither evidence of an increase or a decrease in abundance compared with phase C. Furthermore, if model selection were included in the bootstrap process it is possible that the increased variability would lead to fewer cells in the difference plots attaining statistical significance.

It has also been suggested that an additional three surveys should be conducted as part of phase D to inflate the sample size and therefore, hopefully, the confidence in the results. Without doing a dedicated power analysis, there is no way to tell whether three additional surveys would be sufficient to improve the clarity of definition of the difference to support the case for habituation. Unfortunately, this analysis is beyond the scope of this current report and would involve discussions regarding what the assumed spatial distribution is for those three additional surveys.

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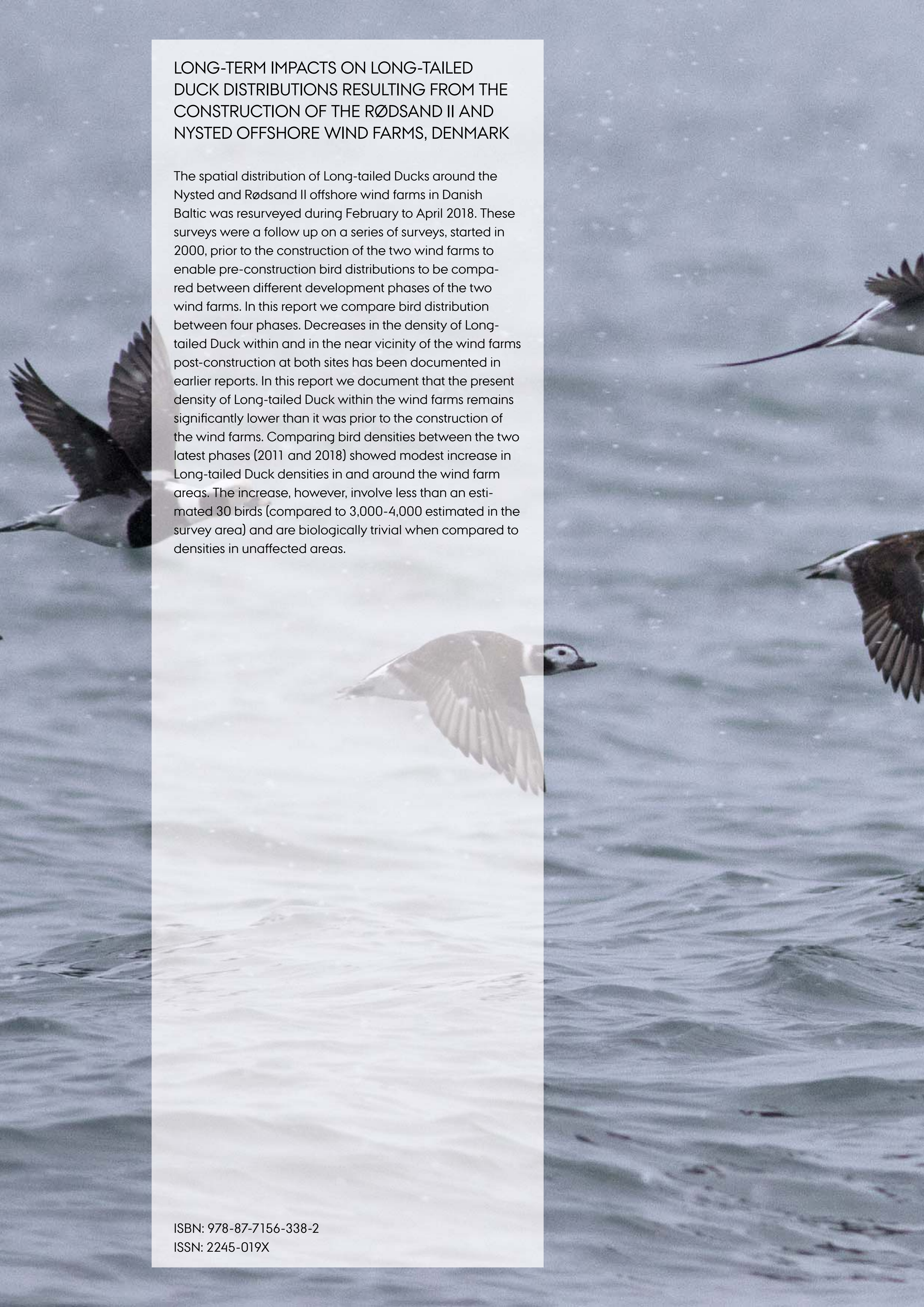

LONG-TERM IMPACTS ON LONG-TAILED DUCK DISTRIBUTIONS RESULTING FROM THE CONSTRUCTION OF THE RØDSAND II AND NYSTED OFFSHORE WIND FARMS, DENMARK

The spatial distribution of Long-tailed Ducks around the Nysted and Rødsand II offshore wind farms in Danish Baltic was resurveyed during February to April 2018. These surveys were a follow up on a series of surveys, started in 2000, prior to the construction of the two wind farms to enable pre-construction bird distributions to be compared between different development phases of the two wind farms. In this report we compare bird distribution between four phases. Decreases in the density of Long-tailed Duck within and in the near vicinity of the wind farms post-construction at both sites has been documented in earlier reports. In this report we document that the present density of Long-tailed Duck within the wind farms remains significantly lower than it was prior to the construction of the wind farms. Comparing bird densities between the two latest phases (2011 and 2018) showed modest increase in Long-tailed Duck densities in and around the wind farm areas. The increase, however, involve less than an estimated 30 birds (compared to 3,000-4,000 estimated in the survey area) and are biologically trivial when compared to densities in unaffected areas.

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