Development of offshore wind farms at Hesselø and Ringkøbing (Thor)

Assessment of the sensitivity of sites in relation to birds

Energistyrelsen/Danish Energy Agency

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0 Executive summary

As part of the Danish Energy Agency's decision regarding the final delineation of suitable areas for development of two offshore wind farms in the Danish part of the North Sea and Kattegat the suitability of these sites in relation to seabirds has been assessed. This report contains the results of this assessment, which aims to update the available seabird distribution models developed on the basis of historic survey data with survey data from 2018-2019 collected by DCE, Århus University. The assessment of the suitability of designated areas at Ringkøbing and Hesselø was based on an evaluation of the sensitivity of birds to wind farms in the two areas and an assessment of the statistical certainty related to documented distribution patterns.

The seabird distribution models are based on multivariate statistical methods (Generalised Additive Mixed Models), and hence the inherent statistical uncertainty of predicted densities of seabirds was quantified and mapped. Hence, zones where model results are less robust due to lower survey intensity could be identified and given less weight in the final delineation of suitable areas.

Offshore wind farms mainly impact seabirds in terms of habitat displacement and collision. Seabirds show highly variable levels of sensitivity to displacement and collision risk, and typically the two types of sensitivity are inverse with species showing low sensitivity to displacement having high sensitivity to collision and vice versa. Therefore, the final delineation of suitable areas was also based on an assessment of the sensitivity of the characteristic species of seabirds in the two target regions using the best available information available from post-construction monitoring programs.

The results of the bird distribution models using historic data showed that for the two sites the key species as measured by the number of birds which regularly use the sites are Red-/Black-throated Diver in the Thor area and Razorbill and Common Guillemot in the Hesselø area. Hence, the model update has focused on these three species. Other species for which updated distribution patterns were mapped in the two areas were Northern Gannet (both areas), Common Guillemot (Thor) and Razorbill (both areas).

The updated model of the distribution of Red-throated and Black-throated Divers in the North Sea indicate that the western part of the Thor site is generally characterised by low densities of divers, while the eastern part houses medium densities. Highest densities at the Thor site occur in April when densities above 0.75 birds/km^2 are predicted in a coherent zone just east of the planned wind farm. The estimated area of high habitat suitability within the wind farm and in a 5.5 km displacement zone reaches its maximum of 263 km^2 during the same month. The modelled densities of divers predicted at Thor have high confidence, and there is mounting evidence that divers show a stronger displacement response to offshore wind farms than other species of seabirds. Consequently, the potential for displacing divers from Thor is highest in April, when the estimated mean number of displaced divers is 123 birds or just less than 1% of the total number of divers occurring in the Danish part of the North Sea. In comparison, 346 divers are estimated to be displaced from the southern part of the Ringkøbing site representing 2.16% of the divers in the Danish part of the North Sea. Accordingly, assessed on its own the potential displacement of divers from the proposed Thor site is not likely to represent a showstopper for the development of the project, and will be significantly less than the potential displacement from developing the southern part of the Ringkøbing site. The displacement of divers from other sites located in the region of high habitat suitability in the North Sea without a doubt involves a sizeable proportion of the Danish North Sea population of divers. As the displacement in Thor is primarily related to the easternmost part of the wind farm the potential displacement impact will be significantly reduced if focusing the development on the westernmost part of the wind farm area.

The distribution model for Razorbill and Common Guillemot wintering in the Kattegat clearly indicated large concentrations of wintering Razorbill east of Anholt, over Lille Middelgrund and northeast of Djursland and large concentrations of Common Guillemot in the northern part of Kattegat and over Lille Middelgrund. Higher densities and suitable habitat for Razorbill and Common Guillemot occur at the minimum distance of 12 km and 19 km, respectively from the Hesselø site. Medium densities of both species of auks occur between the wind farm site and the island of Hesselø. The evidence for displacement of Razorbills and Common Guillemots from offshore wind farms is uncertain, yet indicative and precautionary displacement rates for a 2 km zone around the Hesselø site were applied. The estimated potential displacement of Razorbills from the site indicates that a mean number of 3,925 Razorbills are displaced, representing 1.8% of the total estimated number of Razorbills wintering in the Kattegat. The estimated mean number of displaced Common Guillemots is 1,227 birds representing 0.7% of the estimated total number of the species wintering in Kattegat. Accordingly, assessed on its own the potential displacement of Razorbills and Common Guillemots from the proposed Hesselø site is not likely to represent a showstopper for the development of the project. However, the cumulative displacement from the site with other existing and planned sites located in the areas of high habitat suitability to Razorbills in the Kattegat may involve a sizeable proportion of the Kattegat population of this species.

Although Northern Gannets should be expected to occur regularly at the Thor and Hesselø sites throughout the year the observations at hand do not indicate the presence of any coherent zone of higher densities neither in the North Sea nor in the Kattegat. Instead, Gannets occur widespread in deeper areas with ephemeral patches of higher densities. Due to their strong avoidance behaviour Gannets have low risk of collision with offshore wind farms, and do not represent key issues in relation to any of the two projects.

The occurrence of Common Guillemot at the Thor site can be characterised as widespread in low-medium densities during the non-breeding season. No concentrations of the species have been recorded at or near the site. The Razorbill occurs in lower densities than Guillemots at the site.

1 Introduction

DHI has been commissioned by the Danish Energy Agency to undertake the final delineation of suitable areas for development of two offshore wind farms in the Danish part of the North Sea and Kattegat in relation to seabirds. The final delineation follows the finalisation of the data basis on the occurrence of birds in four gross areas for offshore wind turbines (Skov et al. 2019). It aims to update the information on birds with survey data from 2018-2019 and determine the suitability of the designated areas at Ringkøbing and Hesselø based on an evaluation of the sensitivity of birds to wind farms in the two areas and an assessment of the statistical certainty related to documented distribution patterns.

The data basis in Skov et al. (2019) was established using fine-scale species distribution models in which the distribution of key seabird species in the North Sea and Baltic Sea was modelled using dynamic oceanographic parameters as predictors. In addition, the distribution of other less important species of seabirds was mapped by aggregating available data. The data collected by DCE in the target areas in 2018-2019 used aerial line transect methods (Petersen & Sterup 2019a, Petersen & Sterup 2019b). Although the findings from these surveys do not seem to deviate significantly from the documentation in Skov et al. (2019) the new data will undoubtedly strengthen the evidence for the current situation regarding densities of seabirds in the two areas.

As the seabird distribution models for key species are based on multivariate statistical methods the inherent statistical uncertainty of predicted densities can be readily quantified and mapped. Hence, zones where model results are less robust due to lower survey intensity can be identified and given less weight in the final delineation of suitable areas.

Offshore wind farms mainly impact seabirds in terms of habitat displacement and collision (Krijgsveld 2014, Dirschke et al. 2016). Seabirds show highly variable levels of sensitivity to displacement and collision risk, and typically the two types of sensitivity are inverse with species showing low sensitivity to displacement having high sensitivity to collision and vice versa. Therefore, the final delineation of suitable areas will also be based on an assessment of the sensitivity of the characteristic species of seabirds in the two target regions.

Skov et al. (2019) modelled the distribution of the following species which had been identified during the pre-screening process by the Danish Energy Agency as the most important in the gross areas: Ringkøbing/Thor and Jammerbugt: Red-/Black-throated Diver and Common Scoter; Hesselø: Red-/Black-throated Diver, Common Eider, Common Scoter, Velvet Scoter, Black-legged Kittiwake and Razorbill. Subsequently, the sites at Ringkøbing and Hesselø have been designated by the Agency as the target areas for development. The results of the bird models showed that for these two sites the key species as measured by the number of birds which regularly use the sites are Red-/Black-throated Diver in the Ringkøbing area and Razorbill in the Hesselø area. Due to recent observations of relatively large numbers of Common Guillemot in the southern Kattegat this species has also been added as a focus species for the model update in this report.

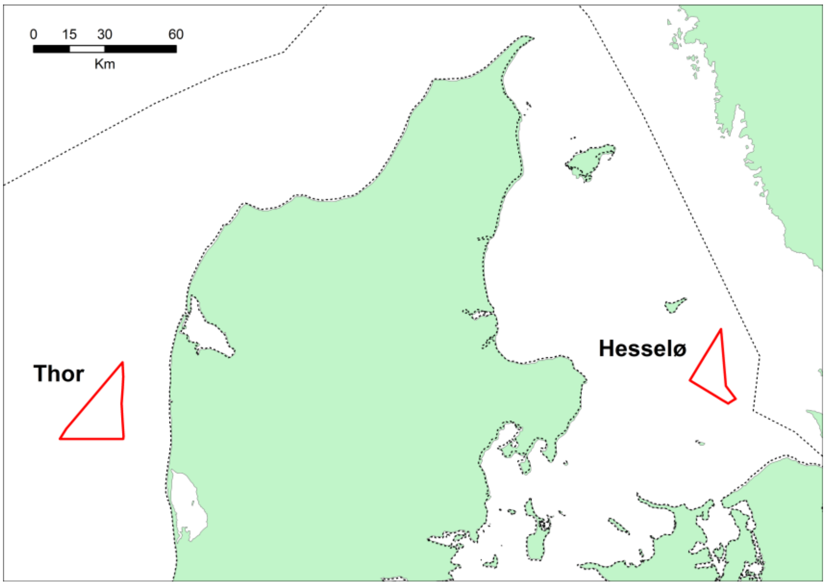


Figure 1 Overview of the Thor and Hesselø areas designated for offshore wind farm development. Danish Exclusive Economic Zone is indicated

2 Methodology

2.1 Seabird survey data

2.1.1 North Sea

A total of 84 data sets from visual aerial transect surveys of seabirds were received and processed:

- Two NOVANA surveys
- 49 surveys related to Horns Rev I and II offshore wind farms
- 10 surveys related to Horns Rev III offshore wind farm
- Three dedicated surveys for divers
- Surveys related to EIAs for the North Sea South and the North Sea North Offshore Wind Farms
- Seven dedicated surveys related to the screening for suitable areas for wind farm development at Ringkøbing: January 2019, February 2019, March 2019, April 2019, September 2019 and December 2019

In addition, there is a very large set of historical material with ship-based survey data from 1986-1993, which have been used to map the distribution of auk species in the North Sea. Ship-based data were preferred to data from aerial surveys as these species are difficult to identify from aircraft.

An overview of the spatial seasonal coverage of surveys included in this investigation is given in Figure 2. In the North Sea intensive coverage has only been achieved in the Horns Rev region due to baseline and monitoring programmes related to Horns Rev 1 and 2. The region off the Danish west coast, including the proposed gross areas for the

Ringkøbing site has been surveyed intensively during the spring season, moderately during winter and autumn and not at all during summer.

It is concluded that a very large amount of survey data exists on the occurrence of seabirds in the Danish parts of the North Sea. Gaps in survey coverage along the west coast are minimal and confined to the summer season, when densities of seabirds are low. This means that lack of knowledge of seabird distribution and abundance during certain periods can easily be compensated for by predictive modelling using couplings between seabird distribution and the marine biological conditions found along the west coast. Further surveys are not expected to provide greater certainty in the assessment of the importance of the areas to seabirds.

2.1.2 Southern Kattegat

The region was covered by NOVANA surveys in 2004 (not full coverage of the Hesselø area), 2008, 2012, 2013 and 2016. Eleven dedicated surveys related to the screening for suitable areas for wind farm development at Hesselø were undertaken December 2018, January 2019, February 2019, March 2019, April 2019, September 2019 and December 2019.

In addition, for waterbirds, from the Swedish side, data from aerial waterbird surveys in 2017-2019 were also made available by Lund University. In order to cover pelagic seabirds and species which are difficult to identify to species from airplane historic standardised ship-based line transect survey data kept in the European Seabirds at Sea Database (ESASD) were also included.

In the southern Kattegat the best coverage of the region around the proposed Hesselø site has been obtained during winter (Figure 3). During spring and autumn, only moderate coverage has been achieved, and almost no coverage during summer.

It is concluded that a large amount of data exists on the occurrence of seabirds in the region around the Hesselø site, particularly during the winter season when densities of most species of seabirds are highest.

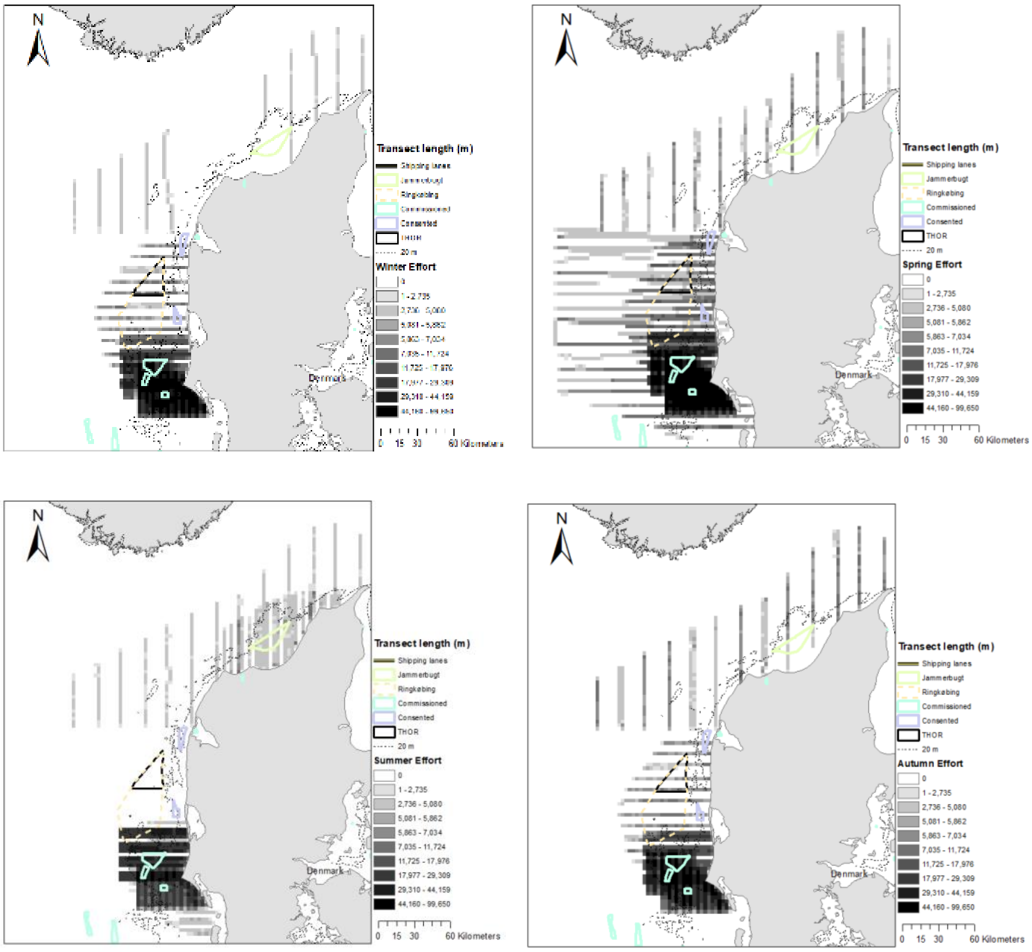


Figure 2 Seasonal coverage of aerial seabird survey data collected in the North Sea since 2000 and included in the investigation. Distance of surveyed transects (m) is summarized per 5 km^2. The 20 m depth contour is indicated.

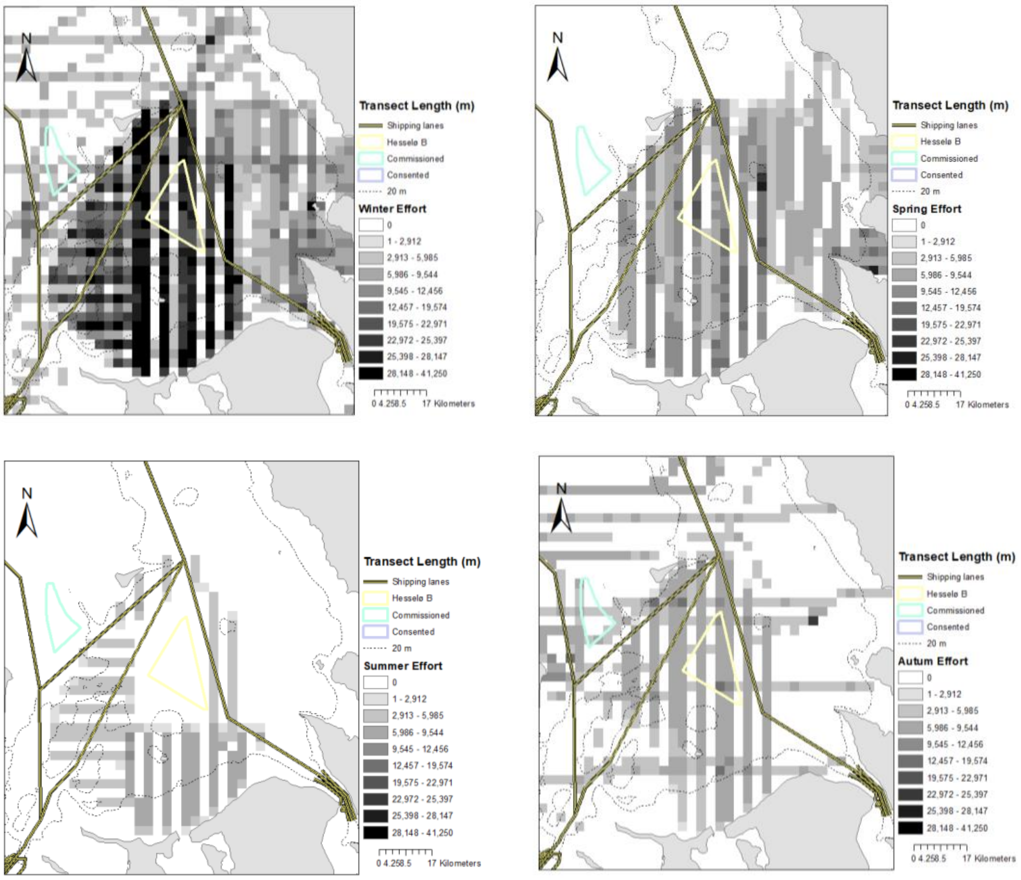


Figure 3 Seasonal coverage of aerial seabird survey data collected in the southern part of Kattegat since 2000 and included in the investigation. Distance of surveyed transects (m) is summarized per 5 km^2. The 30 m depth contour is indicated.

Table 1 Seabird survey data included in the investigation

Area	Period	Method	Source
North Sea	Aug 2012 and winter 2013	Aerial line transect survey	AU/DEC – Novana
North Sea	Five surveys 2006-2008 Apr 2008, Apr 2009, Apr/May 2016, Aug 2011, Aug 2012, Aug 2013	Aerial line transect survey	AU/DEC – dedicated surveys for divers and seaducks
Horns Rev	Aug 1999, Sep 1999, Nov 1999, Feb 2000, Mar 2000, Apr 2000, Aug 2000, Oct 2000, Dec 2000, Feb 2001, Mar 2001, Apr 2001, Aug 2001, Sep 2001, Jan 2002, Mar 2002, Apr 2002, Aug 2002, Feb 2003, Mar 2003, Apr 2003, Sep 2003, Dec 2003, Feb 2004, Mar 2004, May 2004, Sep 2004, Nov 2005, Feb 2006, Apr 2006, May 2006, Jan 2007, Feb 2007, Mar 2007, Apr 2007, Mar 2011, Mar 2011, Apr 2011, Oct 2011, Nov 2011, Jan 2012 , Feb 2012, Mar 2012, Mar 2012, Apr 2012	Aerial line transect survey	AU/DCE – surveys undertaken for Vattenfall (Horns Rev 1) and Ørsted (Horns Rev 2)
North Sea	Jan 2013, Feb 2013, Mar 2013, Apr 2013, May 2013, Jun 2013, Jul 2013, Aug 2013, Sep 2013, Nov 2013	Aerial line transect survey	Orbicon – surveys undertaken for ENDK in relation to baseline connected to EIA assessment for the Horns Rev 3 offshore wind farm
North Sea	Nov 2013, Feb 2014, Mar 2014, Apr 2014	Aerial line transect survey	Niras – surveys undertaken for ENDK in relation to baseline connected to EIA assessment for the Vestkysten N + S offshore wind farm

Area	Period	Method	Source
North Sea	January 2019, February 2019, March 2019, April 2019, September 2019 and December 2019	Aerial line transect survey	AU/DEC – dedicated surveys in relation to planning of Ringkøbing wind farm
Central Kattegat	Winter 2004, Winter 2008, Aug 2012, Winter 2013, Winter 2016	Aerial line transect survey	AU/DEC – Novana
Central Kattegat	Autumn and winter 1987-1993	Ship-based line transect survey	European Seabirds at Sea Database
Central Kattegat	Spring 2017, Winter 2018, Spring 2018, Winter 2019	Aerial line transect survey	Lund University – National waterbird survey
Central Kattegat	December 2018, January 2019, February 2019, March 2019, April 2019, September 2019 and December 2019	Aerial line transect survey	AU/DEC – dedicated surveys in relation to planning of Hesselø wind farm

2.1.3 Distance analysis

The raw survey data in the compiled data base was distance corrected following standard distance sampling techniques (Buckland et al. 2001) conducted using the Distance package in R (https://cran.r-project.org/web/packages/Distance). The analyses were conducted in line with Winiarski et al. (2014). As the behaviour of seabirds, i.e. whether sitting or flying cannot be safely assessed during aerial surveys distance detection functions were calculated for all birds. In the distance analysis all birds are assumed to be detected in the distance band closest to the airplane/ship, further away detectability decreases with increasing distance from the airplane/ship. A set of different detection function models were fitted. Half normal, hazard rate and uniform detection functions were fitted, and Cosine adjustment terms were added to the models as well as Hermite polynomials (for Half-normal detection function) and simple polynomial (for the hazard rate detection function). Bird abundance and sea state were available as covariates in the models. Finally, the best fitting function was chosen on the basis of the smallest Akaike Information Criterion (AIC) values (Burnham and Anderson 2002).

Detection functions were calculated separately for each species, survey platform and data provider for the North Sea and Kattegat. Estimated detection functions were used to estimate species-specific detection probability and effective strip widths (ESW), which represent the width within which the expected number of detected seabirds would be the same as the numbers actually detected within the full width of 432 m (airplane) or 300 m (ship). The abundance of each species in each segment was thereafter corrected using the correction factors listed in Table 2.

Table 2 Distance corrections applied for the aerial survey data for the North Sea and Kattegat for each species and data provider in data from 2004 to 2016.

	AU/DCE			Niras			Orbicon			Lund Univ.		
	Detect. Probabil.	**SE**	**ESW**	**Detect. Probabil.**	**SE**	**ESW**	**Detect. Probabil.**	**SE**	**ESW**	**Detect. Probabil.**	**SE**	**ESW**
NORTH SEA												
Red-throated/Black-throated Diver	0.44/0.39	0.31/0.01	424/374	X	X	X	0.33	0.02	315	X	X	X
Northern Gannet	0.65/-	0.07/-	623/-	X	X	X	0.34	0.06	503	X	X	X
Razorbill	0.17/-	0.02/-	251/-	X	X	X	NA	NA	NA	X	X	X
Common Guillmot	0.96/-	0.08/-	372/-	X	X	X	NA	NA	NA	X	X	X
KATTEGAT												
Red-throated/Black-throated Diver	0.24	0.02	404	X	X	X	X	X	X	0.58	0.37	288
Northern Gannet	NA	NA	NA	X	X	X	X	X	X	0.83	0.42	415
Razorbill	0.52	0.11	202	X	X	X	X	X	X	0.48	0.05	242
Common Guillemot	NA	NA	NA	X	X	X	X	X	X	1.00	0.13	200

Table 3 Distance corrections applied for the aerial survey data for the North Sea and Kattegat for each species and data provider in data from 2018-2019

	AU/DCE		
	Detect. Probabil.	**SE**	**ESW**
NORTH SEA			
Red-throated/Black-throated Diver	0.31	0.05	293
Northern Gannet	0.66	0.03	999
Razorbill	-	-	-
Common Guillmot	0.74	0.05	286
KATTEGAT			
Red-throated/Black-throated Diver	0.30	0.05	295
Northern Gannet	0.67	0.03	1000
Razorbill	0.69	0.08	269
Common Guillemot	0.69	0.06	268

2.1.4 Updating of geo-database on seabird survey data in the North Sea and Kattegat

The corrected abundance was merged with the effort data and species-specific densities (birds/km^2) were calculated. The data were finally re-segmented (mean density) into approximately 500 m segments, by adding up segments until 500 m was reached. Data with a resolution coarser than 1.5 km (survey segments) or highly variable original resolution were not included in further analyses and simulations. The hydrodynamic variables described below were extracted to the corrected survey data based on position and time.

2.2 Seabird distribution modelling

2.2.1 Introduction

The use of distribution models for interpolating fragmented survey data into useful maps of mean densities of seabirds is well established, yet the majority of marine distribution models are made at a relatively coarse resolution and covering relatively large extents (Bailey & Thompson 2009, Maxwell et al. 2009). Terrestrial applications of distribution models typically assume that the physical environment exerts a dominant control over the natural distribution of a species. Obviously, the transfer of distribution models from land to sea means that the validity of model assumptions and predictive performance will be affected by the unique physical properties of marine habitats (Robinson et al. 2011). As a consequence the detailed resolution of the distribution of marine species requires that the dynamic coupling to their physical environment is determined.

However, synoptic dynamic data on driving habitat parameters such as currents and hydrographic structures are often very difficult to obtain; the descriptions of key habitat features typically stem from correlations with static parameters such as water depth and distance to land (Skov et al. 2003, MacLeod & Zuur 2005, Cama et al. 2012). The fine-scale distribution of marine top predators like seabirds has been shown to correlate with physical oceanographic properties such as fronts, upwellings and eddies, which enhance the probability of predators encountering prey (Schneider & Duffy 1985, Skov & Prins 2001, Fauchald et al. 2011) and which exhibit spatial dynamics and oscillations at different frequencies.

To accurately describe the distribution of seabirds over time, one needs to be able to take account of the actual habitat components realised during each observation. In the absence of these dynamic characteristics of seabird habitats, static distribution models of seabirds are unlikely to resolve the true variation in the distribution of the birds. In other words, if high resolution distribution models are based on static factors or mean values rather than in situ values for dynamic factors, predicted densities will rarely match the observed densities. Thus, accurate assessment of habitat use by seabirds requires highly dynamic, fine-resolution data both for species and the environment. Likewise, the application of static rather than dynamic distribution models in studies like this aiming at identifying potential conflicts between developing areas for offshore wind and conservation interests in terms of high densities of sensitive species of seabirds may result in an overestimate of densities in the periphery of species aggregations and an underestimate of densities within aggregations, leading to less accurate assessments.

2.2.2 Extraction of dynamic oceanographic co-variables

The dynamic oceanographic co-variables were extracted from validated, regional oceanographic models covering the North Sea and Kattegat respectively (see chapter 3.3.4. and Appendices A and B in Skov et al. 2019 for a description of the variables). These regional models are developed and maintained by DHI and are part of DHI´s operational Water Forecast service. The modelled co-variables cover the full analysis area and all observations in both time and space. The stored temporal resolution of the variables is 1 hour and the spatial resolution within the analysis area is about 3-5 km for the North Sea and 1-3 km for Kattegat. The co-variables consist of modelled state variables such as current velocitycomponents, salinity and water temperature as well as post-processed variables such as current gradient and vorticity.

The dynamic oceanographic co-variables are extracted for each observation at the relevant location and time. For the North Sea analysis, hourly values of the oceanographic co-variables were applied. For the Kattegat analysis however, seasonal means were applied due to the historic ship-based data on Razorbill. The extraction of these co-variables from the large binary model files and the merging of the observations and the extracted co-variables was done using Python script whilst taking into account the different data formats and map projections.

2.2.3 Model fitting

Models were made for the Red-throated/Black-throated Diver in the North Sea and for Razorbill in the Kattegat. The dynamic predictors included: current gradient, current speed, absolute vorticity, salinity gradient and water depth (Table 4). Due to the large difference in observed densities of Razorbill between the historic data collected by ship-based line transects and the recent aerial line transects two different models were developed for Razorbill.

Generalized additive (mixed) models (GA(M)Ms) were fitted using the “mgcv” and “MuMIn” package in R statistics (Wood 2004, Burnham 2002) for each of the two modelled seabird species. The model that provided the best fit was used. Due to zero-inflation a two-step GA(M)M model was fitted. This consisted of a presence absence binomial model and a positive gamma model. Initially all predictors, both static and dynamic, were included as smooth terms in the ´full´ model as listed in Table 4. Predictors which were deemed uninfluential or resulted in unrealistic ecological responses were excluded in a stepwise manner based on expert judgement and AIC scores. The allowed degree of freedom was restricted to a maximum of 5 degrees of freedom (k = 5). Finally, the prediction from both the absence presence and positive model were combined to yield the final distribution. A correlogram was used to assess potential residual autocorrelation.

2.2.4 Model evaluation

Predictive accuracy of the North Sea models was evaluated using observed data from NIRAS (Vesterhav North and South baseline data) which was not included in the model´s dataset. The predictive accuracy of the distribution models was evaluated by fitting the model on 70% of the randomly selected data and predicting on 30% of the remaining data.

2.2.5 Hydrodynamic modelling

To be able to describe the dynamic distribution of the key species the observed distribution patterns were related to the dynamic environment by statistical models as described above. Information of the dynamic environment was extracted from DHI’s hydrodynamic models for the Inner Danish Waters (DKBS Ver. 2) and the North Sea (HDUKNS Ver. 3). The different hydrodynamic model outputs and validation are described in Appendix A in Skov et al. (2019).

2.2.6 Prediction of dynamic distributions of seabirds

Final models fitted were used to predict and map the distributions and densities of all modelled bird species in the North Sea and Kattegat study area in a spatial resolution of 500 m.

Table 4 Model overview indicating the bird species modelled, databases used and both dynamic and static predictors used for the North Sea and Kattegat investigated areas.

Study area	Modelled Species	Database Source	Predictors	
			Dynamic	**Static**
North Sea	Divers (*Gaviidae*)	DCE-Århus University aerial surveys Orbicon aerial surveys for calibration, Niras aerial surveys for validation	Current gradient, current speed, chlorophyll, absolute vorticity, salinity and salinity gradient	Water depth, Sea bottom Slope
Kattegat	Razorbill (*Alca torda*)	ESAS ship-based surveys and Århus University aerial surveys and Lund aerial surveys		Water depth, Sea bottom Slope
Kattegat	Common Guillemot (Uria aalge)	ESAS ship-based surveys and Århus University aerial surveys and Lund aerial surveys	Salinity, current speed,	Water depth

2.3 Assessment of uncertainty in modelled distributions of seabirds

2.3.1 Mapping of levels of uncertainty

The uncertainty about the predicted seabird distributions was assessed using point-wise standard errors for the function estimate of the models. The relative standard error (proportional error) was calculated by dividing the combined model standard errors (default outputs from the predict.gam function in the mgcv package in R) by the model predictions. The relative standard error was mapped to define areas of higher uncertainty (based on the function estimates of the models).

2.4 Assessment of importance of areas to seabirds

2.4.1 Percentile contours

In order to outline the areas of highest habitat suitability we used the 90th percentile in the predicted densities, as it is generally considered a robust and transparent method, and as it is widely established as a useful upper threshold. The use of the 90th percentile is in line with Embling *et al*. (2010) and Heinänen & Skov (2015), who investigated the use of a range of percentiles for selection of candidate areas for protection of harbour porpoises in British waters.

2.5 Assessment of the sensitivity of seabirds to offshore wind farms

2.5.1 Habitat displacement

The assessment of the sensitivity of areas of higher densities marked by the 90th percentiles of modelled distributions of Red-throated/Black-throated Diver (Ringkøbing) and Razorbill (Hesselø) to displacement from offshore wind farms was made using the best available data from monitoring programmes in the North Sea. The displacement of divers was assessed spatially using a displacement range of 5.5 km around the perimeter of the planned Thor wind farm. Within this distance a 99% displacement was assessed within the offshore wind farm and 50% displacement from the perimeter to 5.5 km distance following the findings from Petersen et al. (2014) and Garthe et al. (2018) from the post-construction monitoring at Horns Rev 2 in the Danish part of the North Sea and at offshore wind farms in the German Bight. It should be stressed that the maximum range of the displacement (set here to 5.5 km following Garthe et al. 2018) is still rather uncertain. For the Razorbill and Common Guillemot displacement levels and ranges at the planned wind farm at Hesselø were 75% displacement within the wind farm and 50% in a 2 km distance based on the findings of Heinänen & Skov (2018) from the post-construction monitoring at offshore wind farms in the Dutch sector of the North Sea.

2.5.2 Collision

The assessment of the sensitivity of areas of higher densities marked by the 90th percentiles of modelled distributions of Red-throated/Black-throated Diver (Ringkøbing) and Razorbill (Hesselø) to collision risk due to offshore wind farms was made using the updated information available from post-construction monitoring programs in the North Sea, in particular from the reviews of Krijgsveld et al. (2014) and Cook et al. (2018) and the study of Skov et al. (2018).

3 Results

3.1 Distribution models

3.1.1 North Sea

3.1.1.1 Red-throated/Black-throated Diver

The results for the updated distribution models for Red-throated and Black-throated Diver are shown in Table 5, Figure 4 and Figure 5. The presence/absence part of the models indicate that the species prefer areas away from shipping lanes and wind farms characterised by a combination of a water depth lower than 40m, high productivity and surface salinity above 25 psu. These features are typically found in the interface between the estuarine Jutland Current with low saline riverine water and the high saline North Sea water mass. The validation results indicate that the presence-absence part of the model describes the input densities reasonably well with an AUC value of 0.69, while the predicted densities due to the high resolution only describes a small proportion of the variation in observed densities. The validation of the ability of the model to predict densities independently from the input data indicates that the model predictions provide a reliable generalisation of the densities over the modelled region with a Sperman’s correlation coefficient of 0.11. The validation of the model’s predictive power is illustrated in Figure 6 which shows that the predicted numbers of divers along the aerial transect lines in the North Sea are comparable to the observed numbers.

The positive part of the model stresses the importance of the intermediate depth areas with 10m – 30m water depth located at the interface between high surface salinity and high productivity. The predicted mean monthly densities in Figure 7 show zones of persistent higher densities centred along the 20 m depth contour which is consistent with the mean position of the interface between the Jutland Current and the North Sea water mass. The western part of the Thor site is generally characterised by low densities of divers (0.01-0.2 birds/km^2), while the eastern part houses medium densities of 0.2-0.5 birds/km^2. The densities in the Thor site are highest during the months of January and April, - during the latter month densities above 0.75 birds/km^2 are predicted just east of the planned wind farm.

The uncertainty associated with the predicted densities of divers are illustrated in Figure 8, which documents that the densities predicted for the areas inside and around Thor are bounded by relatively low levels of uncertainty. The densities predicted just north of Horns Rev and south of Thor have relatively high levels of uncertainty due to variability in observed densities.

The estimated potential displacement of divers from the Thor site is shown in Figure 9 and Table 6, and compared with similar level of displacement from the southern part of the Ringkøbing site. The mapped areas of high habitat suitability to divers show a coherent zone of suitable habitat extending from south to north at the eastern edge of the Thor wind farm and penetrating areas of good habitat in the displacement zone east of Thor and in the southern part of the Ringkøbing site. The updated model results underline that the abundance of divers at Thor and Ringkøbing sites varies significantly between months with the estimated area of high habitat suitability within the Thor wind farm and in the displacement zone of 5.5 km ranging between 7 km2 and 263 km2. The potential for displacing divers Is lowest in March and highest in April. The estimated mean number of displaced divers from Thor in April is 123 birds, and 346 from the southern part of the Ringkøbing site. At no time during the year does the estimated number of displaced divers from Thor represent more than 1% of the total number of divers occurring in the Danish part of the North Sea, while the number of displaced birds from the southern part of the Ringkøbing site represent 2.16%. However, the displaced numbers only represent small proportions of the total bio-geographic populations of Red-/Black-throated Divers (Table 6).

Table 5 Smooth terms, adjusted R-squared and evaluation statistics for the updated distribution models for Red-throated/Black-throated Diver *Gavia stellate/arctica* in the North Sea. F statistics and the approximate significance for the smooth terms and t-statistic and the significance for the parametric terms are shown.

	Presence/absence			**Positive density**		
	Estimate	t	p-value	Estimate	t	p-value
Parametric terms						
January	-4.344	-11.249	0	2.019	19.097	0
February	0.821	1.694	0.09	-0.075	-0.614	0.539
March	0.792	1.639	0.101	-0.105	-0.847	0.397
April	1.111	2.278	0.023	-0.047	-0.384	0.701
May	0.772	1.584	0.113	-0.128	-1.03	0.303
October	0.158	0.323	0.746	-0.112	-0.872	0.383
November	-0.924	-9.666	0	0.197	4.21	0
December	-0.073	-0.658	0.511	-0.057	-1.045	0.296
		F	p-value		F	p-value
Salinity (surface)		3.933	0		3.432	0
Current speed (surface)			0			
Distance shipping lane		3.927	0			
Depth		3.79	0		2.920	0
Distance HR1		3.169	0		1.003	0.844
Chlorophyll *a*		3.696	0		1.418	0.711
R-sq.(adj)	0.014			0.02		
AUC	0.688					
Spearman´s corr.						
Sample (n)	142450			4435		

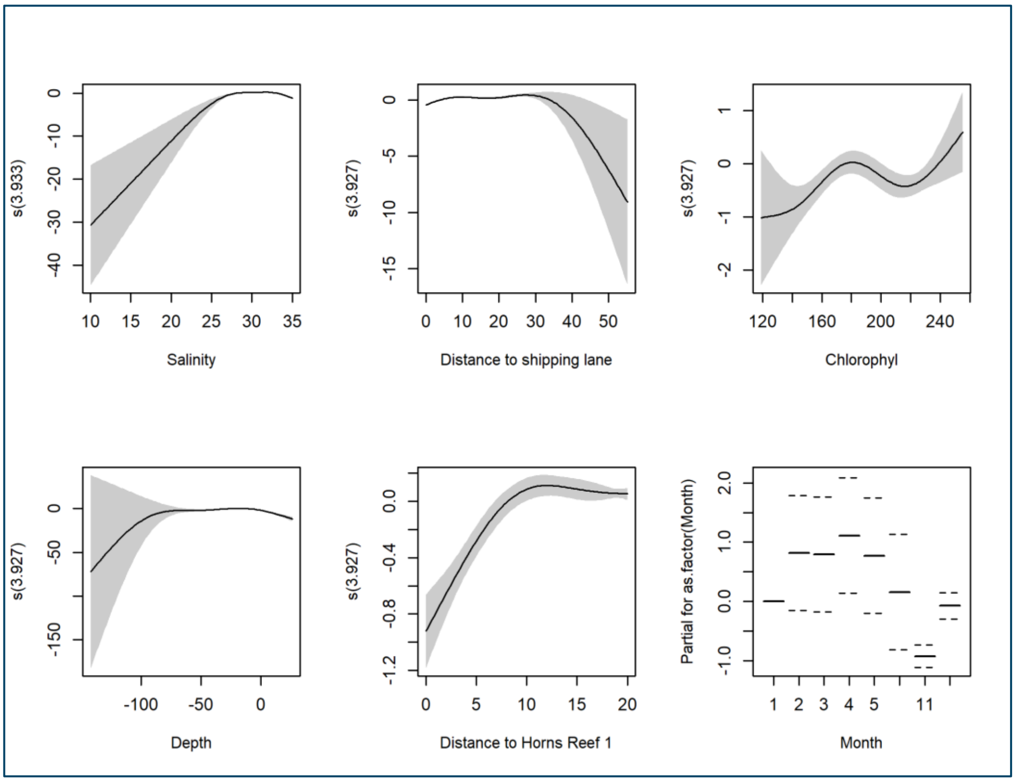


Figure 4 Response curves for presence absence model part for Red-throated/Black-throated Diver *Gavia stellate/arctica* in the North Sea.

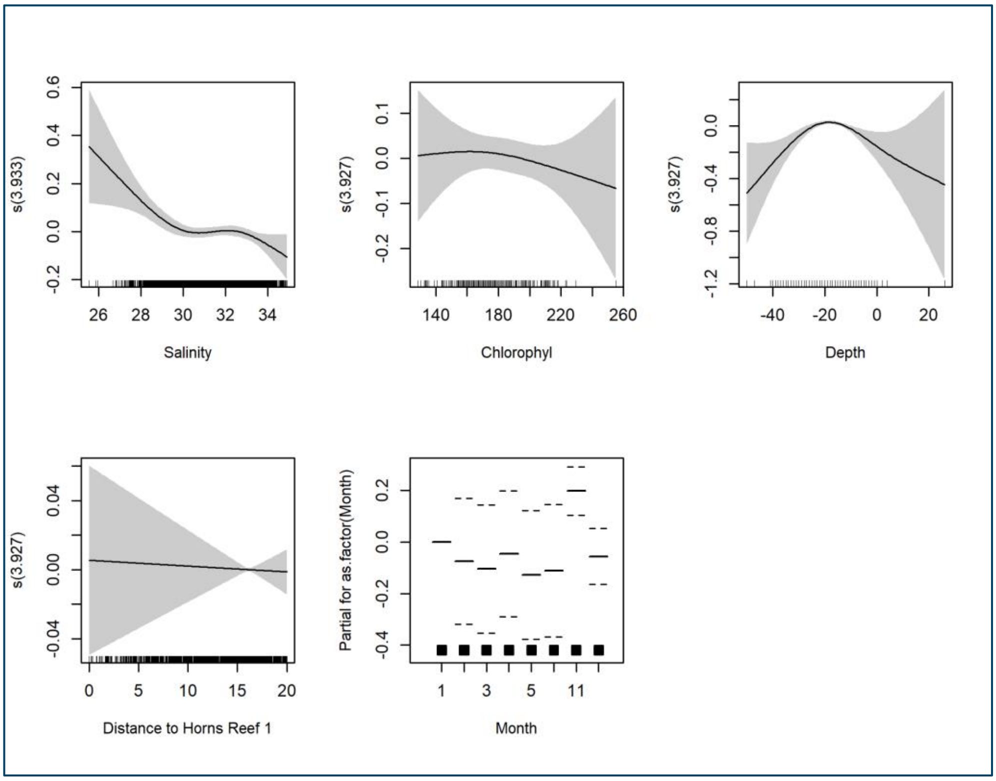


Figure 5 Response curves for positive model part for Red-throated/Black-throated Diver *Gavia stellate/arctica* in the North Sea.

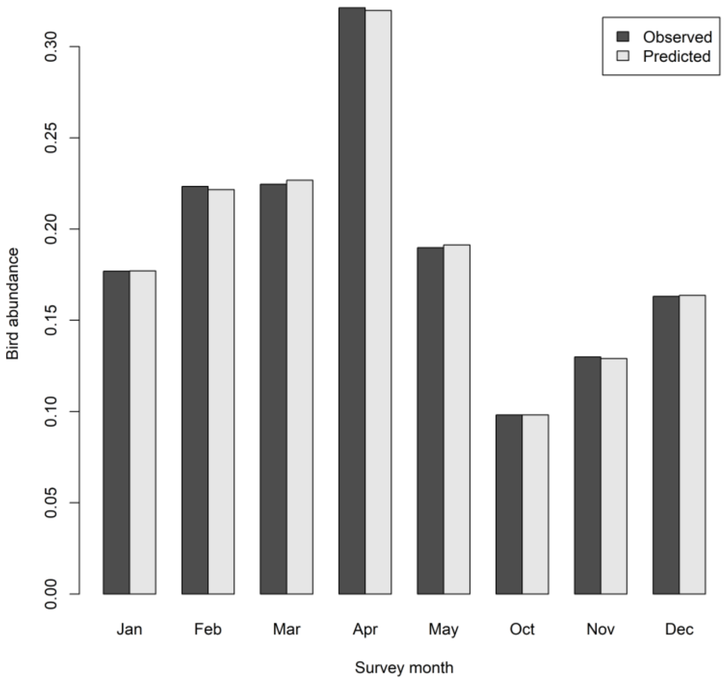
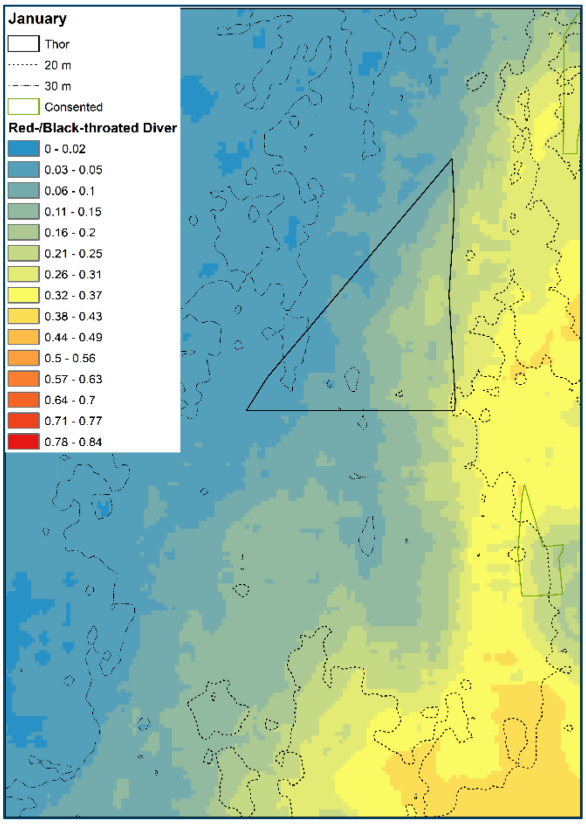
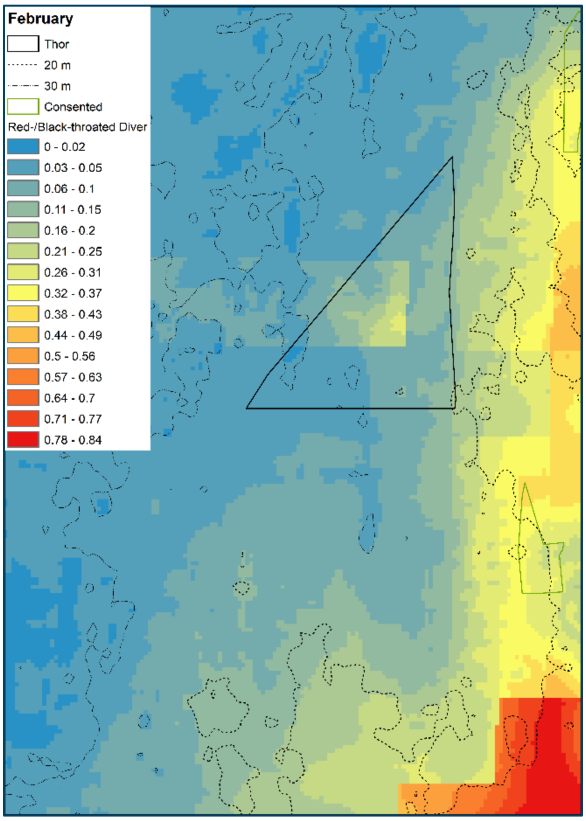
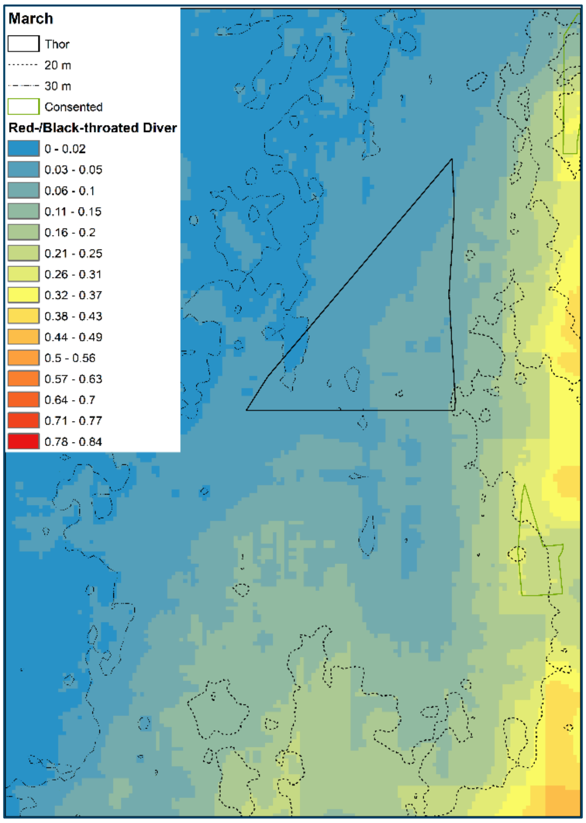
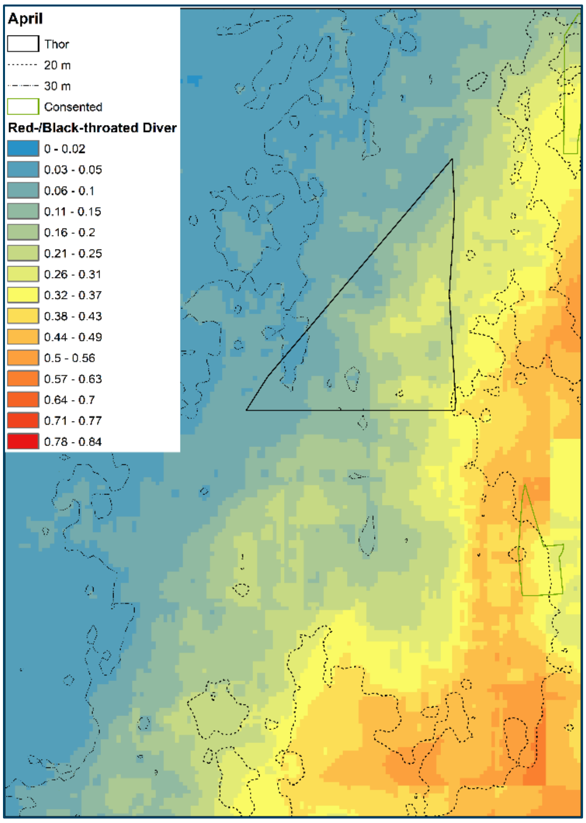


Figure 6 Comparison of predicted versus observed numbers of Red-throated/Black-throated Diver *Gavia stellate/arctica* along the aerial transect lines in the North Sea.


January
Thor
20 m
30 m
Consented
Red-/Black-throated Diver
0 - 0.02
0.03 - 0.05
0.06 - 0.1
0.11 - 0.15
0.16 - 0.2
0.21 - 0.25
0.26 - 0.31
0.32 - 0.37
0.38 - 0.43
0.44 - 0.49
0.5 - 0.56
0.57 - 0.63
0.64 - 0.7
0.71 - 0.77
0.78 - 0.84


February
Thor
20 m
30 m
Consented
Red-/Black-throated Diver
0 - 0.02
0.03 - 0.05
0.06 - 0.1
0.11 - 0.15
0.16 - 0.2
0.21 - 0.25
0.26 - 0.31
0.32 - 0.37
0.38 - 0.43
0.44 - 0.49
0.5 - 0.56
0.57 - 0.63
0.64 - 0.7
0.71 - 0.77
0.78 - 0.84


March
Thor
20 m
30 m
Consented
Red-/Black-throated Diver
0 - 0.02
0.03 - 0.05
0.06 - 0.1
0.11 - 0.15
0.16 - 0.2
0.21 - 0.25
0.26 - 0.31
0.32 - 0.37
0.38 - 0.43
0.44 - 0.49
0.5 - 0.56
0.57 - 0.63
0.64 - 0.7
0.71 - 0.77
0.78 - 0.84


April
Thor
20 m
30 m
Consented
Red-/Black-throated Diver
0 - 0.02
0.03 - 0.05
0.06 - 0.1
0.11 - 0.15
0.16 - 0.2
0.21 - 0.25
0.26 - 0.31
0.32 - 0.37
0.38 - 0.43
0.44 - 0.49
0.5 - 0.56
0.57 - 0.63
0.64 - 0.7
0.71 - 0.77
0.78 - 0.84

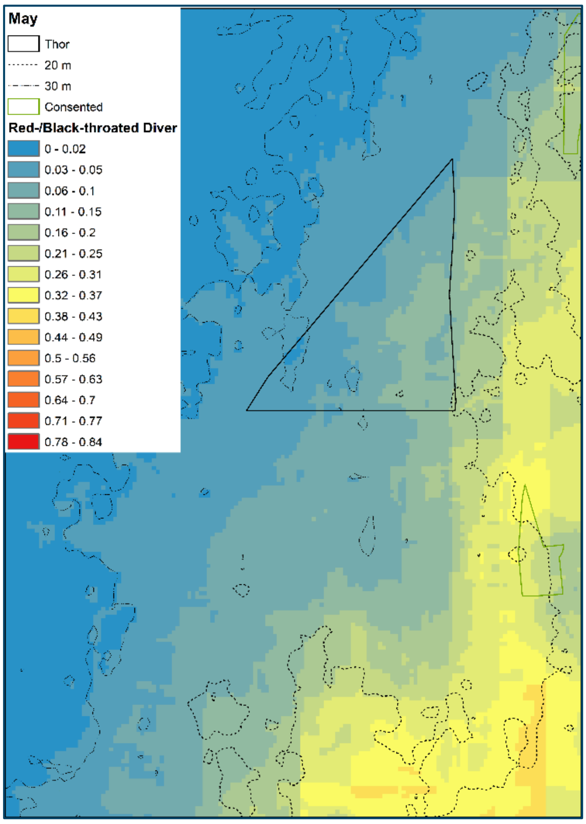
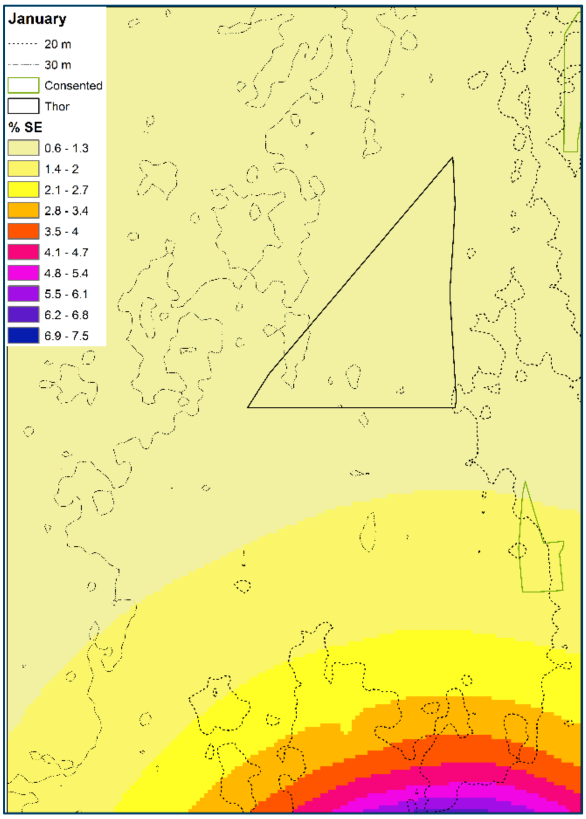
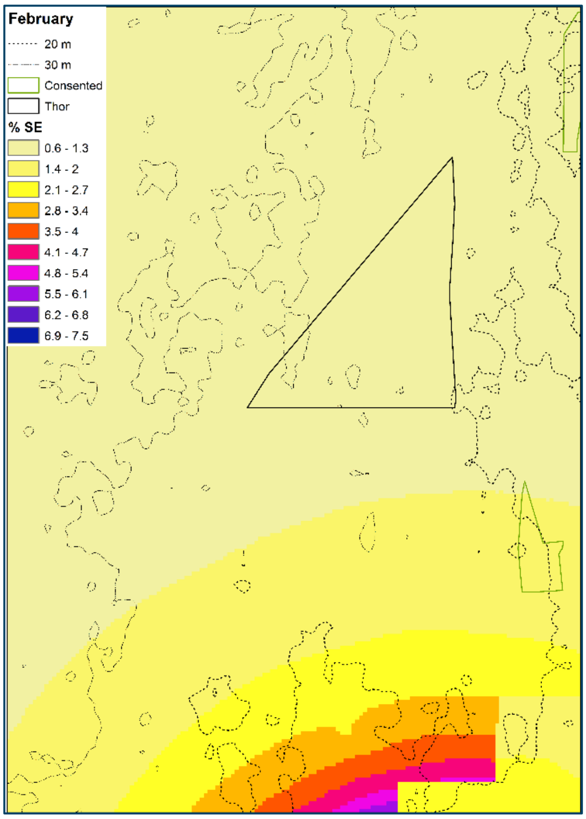
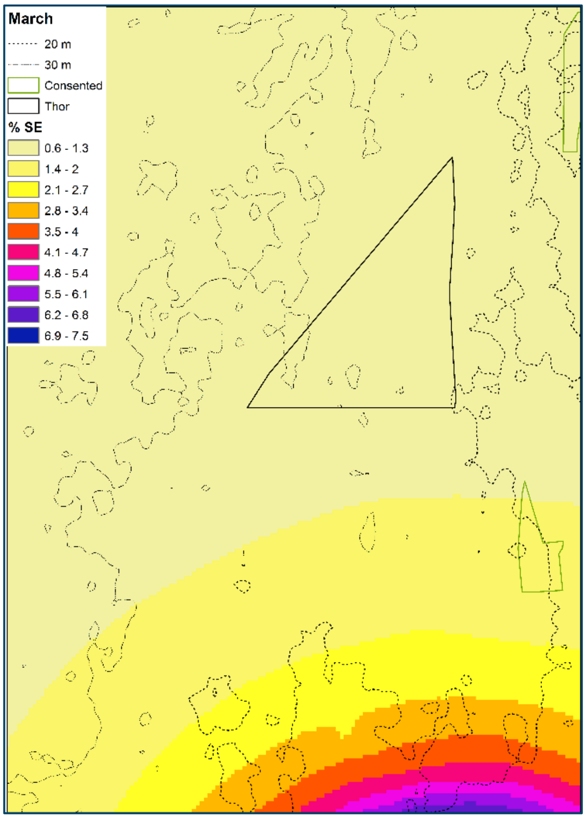
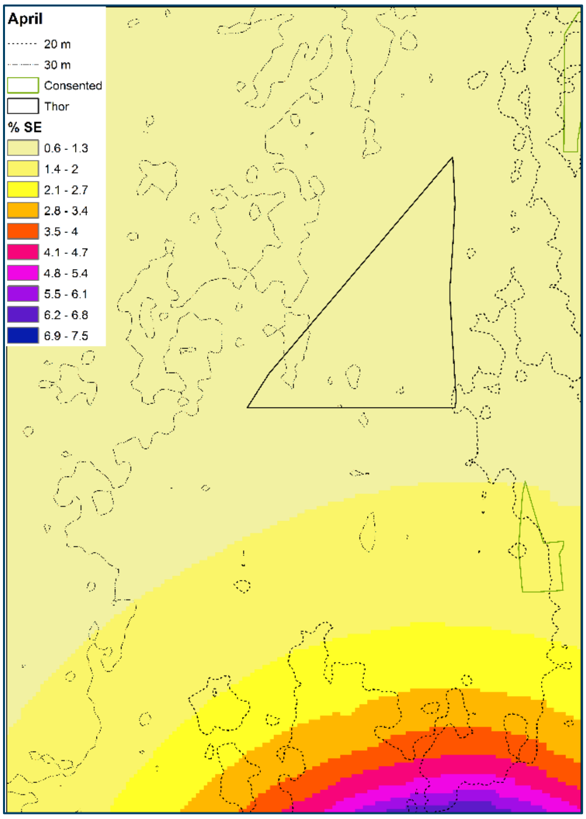


Figure 7 Predicted mean monthly density (n/km^2) of Red-throated/Black-throated Diver *Gavia stellate/arctica* at the Thor site. Depth contours and consented wind farms are indicated.


January
20 m
30 m
Consented
Thor
% SE
0.6 - 1.3
1.4 - 2
2.1 - 2.7
2.8 - 3.4
3.5 - 4
4.1 - 4.7
4.8 - 5.4
5.5 - 6.1
6.2 - 6.8
6.9 - 7.5


February
20 m
30 m
Consented
Thor
% SE
0.6 - 1.3
1.4 - 2
2.1 - 2.7
2.8 - 3.4
3.5 - 4
4.1 - 4.7
4.8 - 5.4
5.5 - 6.1
6.2 - 6.8
6.9 - 7.5


March
20 m
30 m
Consented
Thor
% SE
0.6 - 1.3
1.4 - 2
2.1 - 2.7
2.8 - 3.4
3.5 - 4
4.1 - 4.7
4.8 - 5.4
5.5 - 6.1
6.2 - 6.8
6.9 - 7.5


April
20 m
30 m
Consented
Thor
% SE
0.6 - 1.3
1.4 - 2
2.1 - 2.7
2.8 - 3.4
3.5 - 4
4.1 - 4.7
4.8 - 5.4
5.5 - 6.1
6.2 - 6.8
6.9 - 7.5

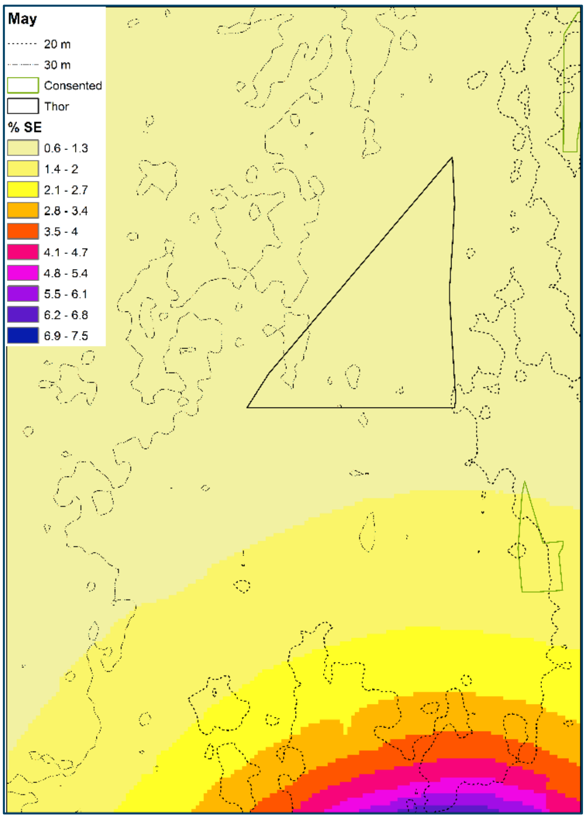
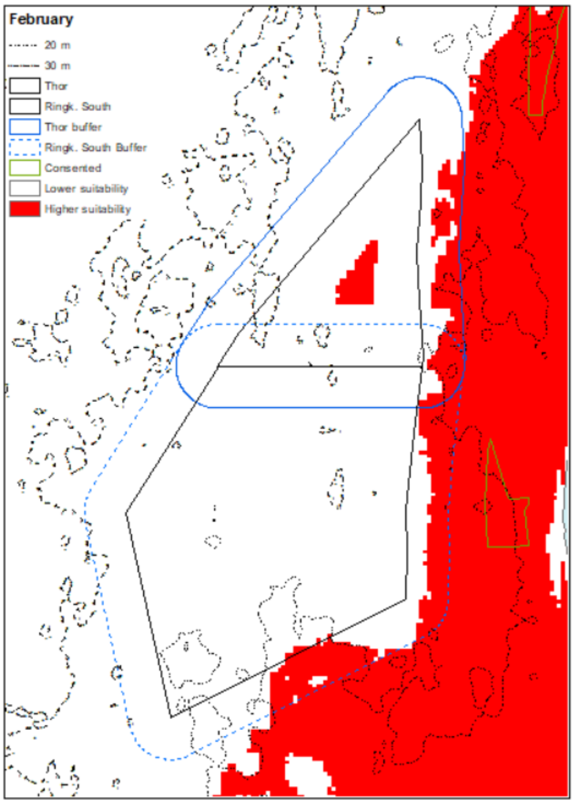
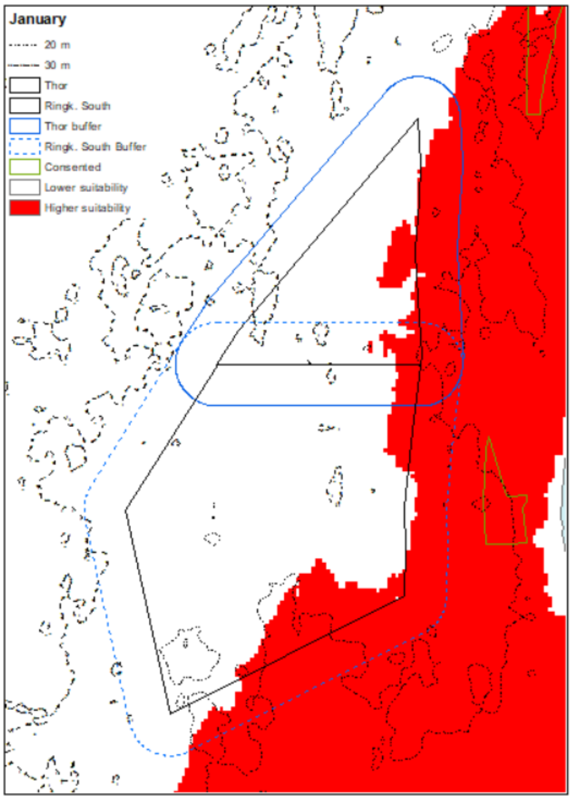
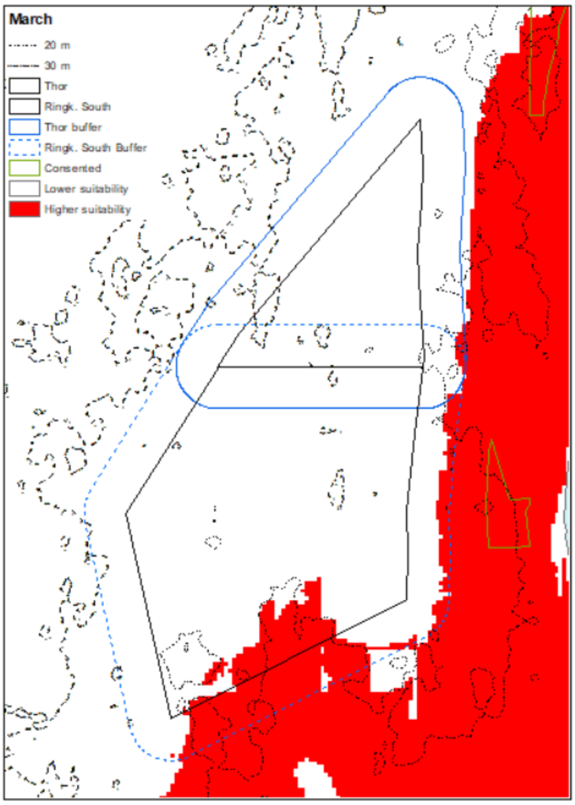
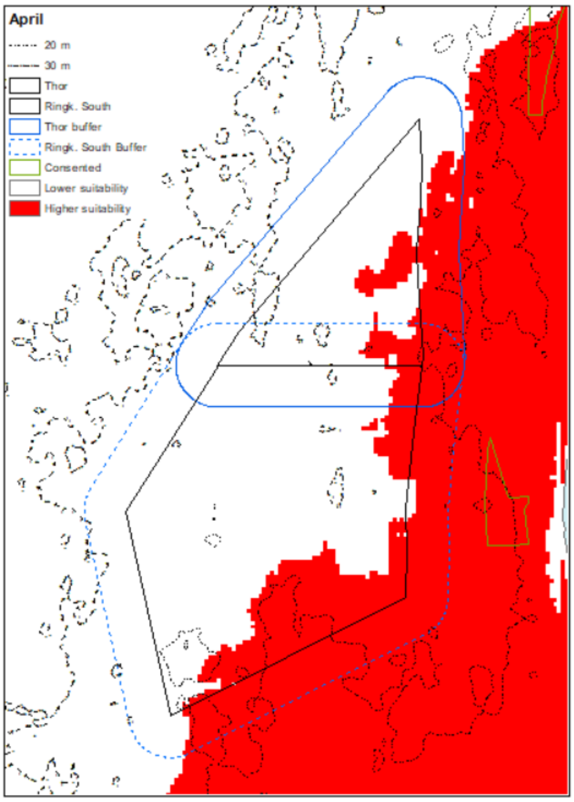


Figure 8 Uncertainty of predicted mean monthly density (n/km^2) of Red-throated/Black-throated Diver *Gavia stellate/arctica* at the Thor site expressed as proportion standard error (SE) of mean density. Depth contours and consented wind farms are indicated.


February
20 m
30 m
Thor
Ringk. South
Thor buffer
Ringk. South Buffer
Consented
Lower suitability
Higher suitability


January
20 m
30 m
Thor
Ringk. South
Thor buffer
Ringk. South Buffer
Consented
Lower suitability
Higher suitability


March
20 m
30 m
Thor
Ringk. South
Thor buffer
Ringk. South Buffer
Consented
Lower suitability
Higher suitability


April
20 m
30 m
Thor
Ringk. South
Thor buffer
Ringk. South Buffer
Consented
Lower suitability
Higher suitability

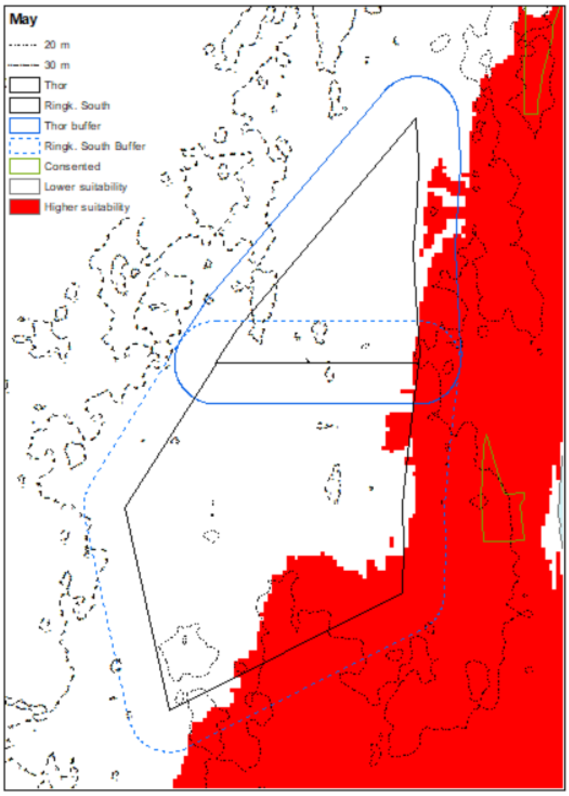


Figure 9 Areas of high habitat suitability to Red-throated/Black-throated Diver *Gavia stellate/arctica* predicted during the main months of occurrence at the Thor and Southern part of Ringkøbing sites and displacement zones. Depth contours and consented wind farms are indicated.

Table 6 Statistics on the estimated displacement of Red-throated/Black-throated Diver *Gavia stellate/arctica* from the Thor and southern part of Ringkøbing sites

Area	Jan	Feb	Mar	Apr	May
Thor area (km^2)	440				
Area of high habitat suitability in Thor and displacement range (km^2)	263	152	7	243	129
Number of displaced birds	88	68	37	123	56
% displaced birds of total in Danish part of the North Sea	0.72	0.54	0.38	0.77	0.61
% displaced birds of total bio-geographic population*	0.014	0.011	0.006	0.020	0.009

Area	Jan	Feb	Mar	Apr	May
Ringøbing south area (km^2)	1267				
Area of high habitat suitability in Ringkøbing south and displacement range (km^2)	533	237	271	691	534
Number of displaced birds	218	153	144	346	172
% displaced birds of total in Danish part of the North Sea	1.79	1.21	1.47	2.16	1.87
% displaced birds of total bio-geographic population*	0.035	0.025	0.023	0.056	0.028

* wpe.wetlands.org

3.1.2 Southern Kattegat

3.1.2.1 Razorbill

One distribution model was developed for the Razorbill covering the historic (pre-2000) ship-based line transect surveys and the aerial surveys undertaken after 2000. This model included only topographic predictors as well as XY coordinates. The results for the model are shown in Table 7, Figure 10, Figure 11 and Figure 12. The distribution of the Razorbill is characterised by large concentrations in areas of between 15 and 35 m water depth and bottom slopes with a peak around 0.5.

The validation results for the model indicate that the presence-absence part of the model describes the observations reasonably well with an AUC value of 0.68, while the predicted densities due to the high resolution only describe a small proportion of the variation in the observed densities. The validation of the ability of the model to predict densities independently from the input data indicated that the model predictions provide a reliable generalisation of the densities over the modelled region with a Spearman´s correlation coefficient of 0.3. The validation of the models´ predictive power is illustrated in Figure 12, which shows that the predicted number of Razorbills along the ship-based transect lines and aerial surveys transects in the Kattegat are comparable to, yet slightly lower than the observed numbers. According to Figure 14 uncertainty of model predictions as expressed by the relative model standard errors are associated with the shallowest areas, while the predicted densities in the open waters including the wind farm site have high levels of confidence.

The estimated potential displacement of Razorbills from the Hesselø site is shown in Figure 15 and Table 8. The mapped areas of high habitat suitability to Razorbill show zones of suitable habitat located east of Anholt, over Lille Middelgrund and northeast of Djursland. Medium densities of 1-5 birds per km^2 are predicted between Hesselø and the wind farm area. The closest distance from the wind farm and 2 km displacement zone to the areas of high habitat suitability is 12 km. The estimated mean number of displaced Razorbills is 3,925. This represent 1.79% of the total estimated number of Razorbills wintering in the Kattegat and 0.39% of the bio-geographic population (Table 9).

Table 7 Smooth terms, adjusted R-squared and evaluation statistics for the distribution models for Razorbill *Alca torda* in the southern Kattegat based on the aerial and ship-based line transect data. F statistics and the approximate significance for the smooth terms and t-statistic and the significance for the parametric terms are shown.

	Presence/absence			**Positive density**		
		Chi-Sq	p-value		F	p-value
Depth		71.209	0		4.163	0.003
Slope		24.483	0		2.642	0.087
te(x.res, y.res)		458.741	0		12.147	0
R-sq.(adj)	0.089			0.126		
AUC	0.679					
Spearman´s corr.				0.296		
Sample (n)	8462			2391		

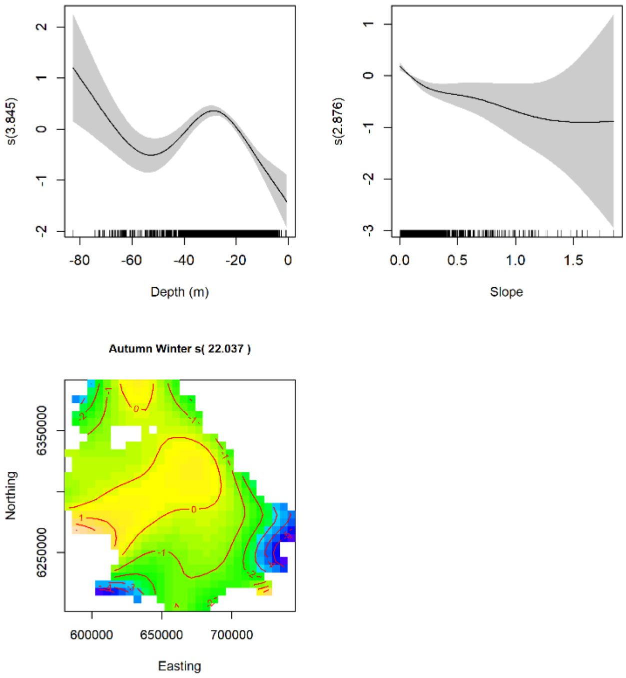


Figure 10 Response curves for presence absence model parts for Razorbill *Alca torda* based on the aerial ship-based line transect data

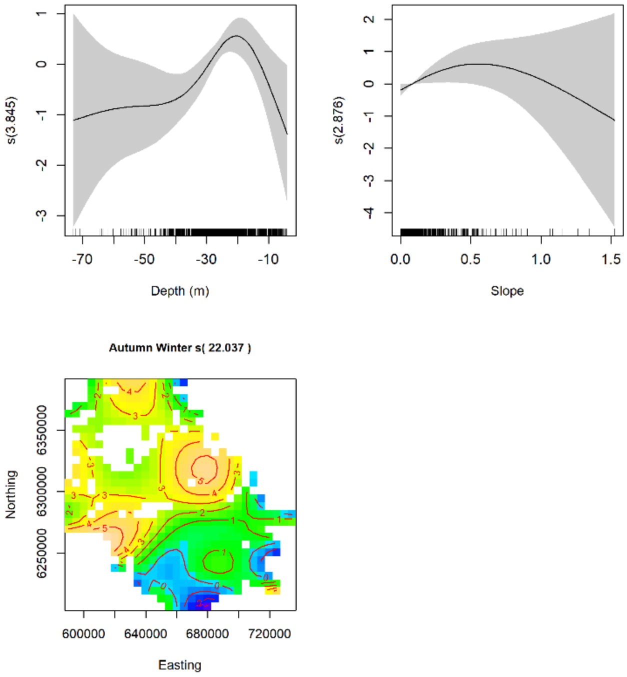


Figure 11 Response curves for positive model parts for Razorbill *Alca torda* based on the aerial and ship-based line transect data

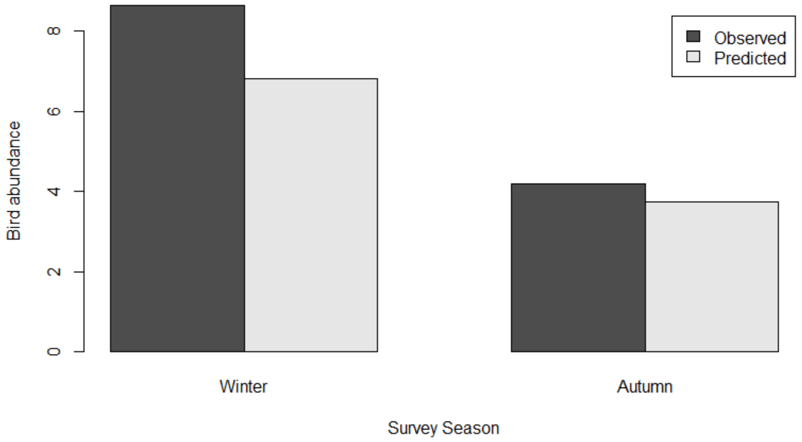


Figure 12 Comparison of predicted versus observed numbers of Razorbill *Alca torda* along the aerial and ship-based transect lines in the southern Kattegat.

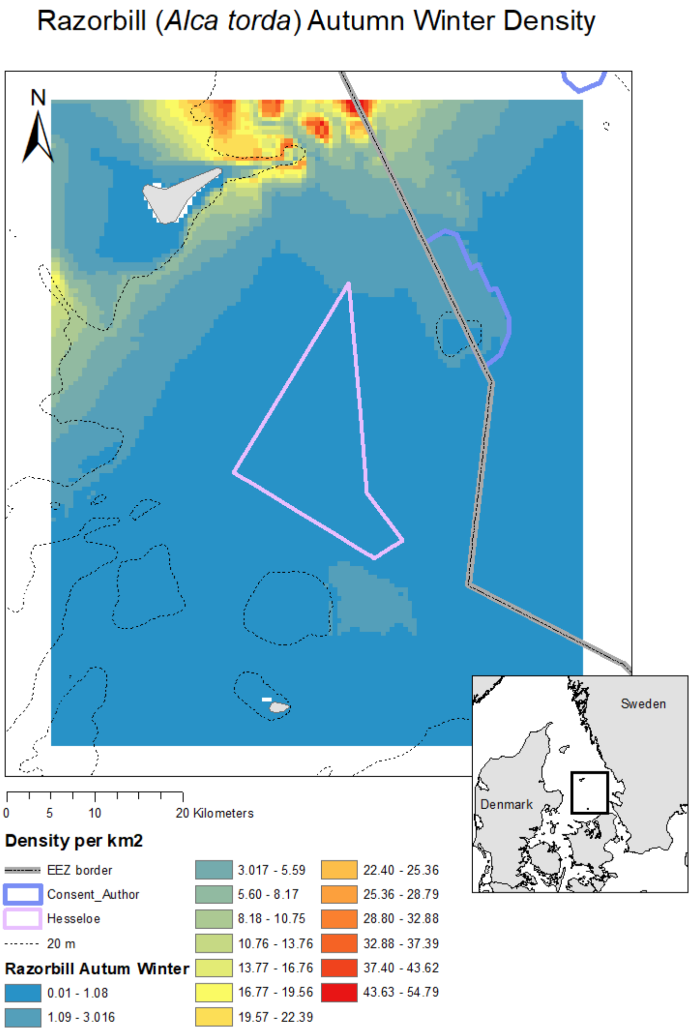


Figure 13 Predicted mean monthly density (n/km^2) of Razorbill *Alca torda* from the aerial and ship-based transect lines at the Hesselø site. Depth contours, EEZ boundary and consented wind farms are indicated

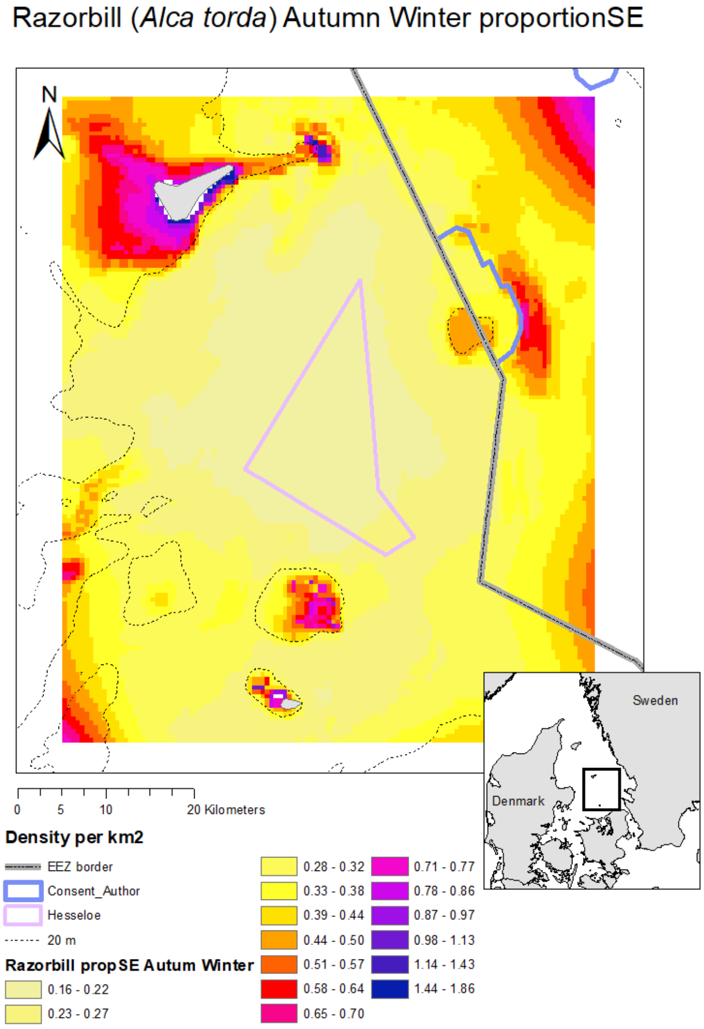


Figure 14 Uncertainty of predicted mean monthly density (n/km^2) of Razorbill *Alca torda* from the aerial and ship-based transect lines at the Hesselø site expressed as proportion standard error (SE) of mean density. Depth contours, EEZ boundary and consented wind farms are indicated

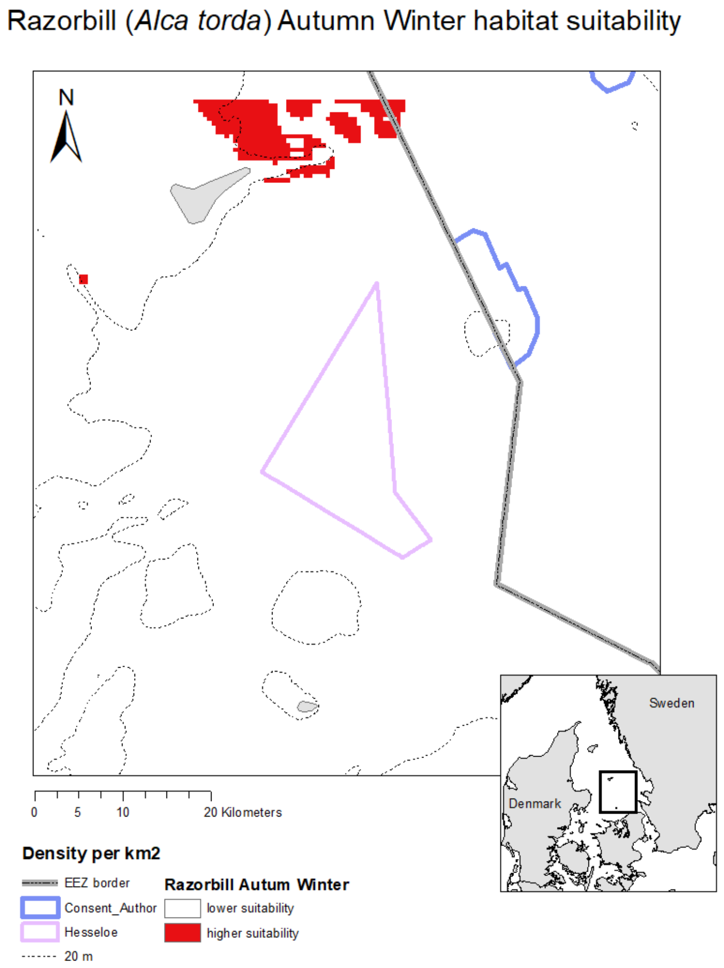


Figure 15 Areas of high habitat suitability to Razorbill *Alca torda* predicted from the aerial and ship-based transect lines during the main months of occurrence at the Hesselø site and displacement ranges from thee planned wind farm. Depth contours, EEZ boundary and consented wind farms are indicated

Table 8 Statistics on the estimated displacement of Razorbill *Alca torda* from the Hesselø site

Hesselø area (km^2)	247
Area of high habitat suitability in Hesselø site and displacement range (km^2)	0
Number of displaced birds	3,925
% displaced birds of total in the Kattegat	1.79
% displaced birds of total bio-geographic population*	0.39

*Birdlife International (2020a)

3.1.2.2 Common Guillemot

One distribution model was developed for the Common Guillemot covering the historic (pre-2000) ship-based line transect surveys and the aerial surveys undertaken after 2000. This model included topographic and hydrodynamic predictors as well as XY coordinates. The results for the model are shown in Table 9, Figure 16, Figure 17 and Figure 18. The distribution of the Common Guillemot is characterised by large concentrations in the northern and eastern part of the Kattegat with the closest concentrations being predicted over Lille Middelgrund in areas of between 20 and 60 m water depth and moderate current speeds.

The validation results for the model indicate that the presence-absence part of the model describes the observations well with an AUC value of 0.75, while the predicted densities due to the high resolution only describe a small proportion of the variation in the observed densities. The validation of the ability of the model to predict densities independently from the input data indicated that the model predictions provide a reasonable generalisation of the densities over the modelled region with a Spearman´s correlation coefficient of 0.16. The validation of the models´ predictive power is illustrated in Figure 18, which shows that the predicted number of Common Guillemots along the ship-based transect lines and aerial surveys transects in the Kattegat are comparable to the observed numbers.

The estimated potential displacement of Common Guillemots from the Hesselø site is shown in Figure 21 and Table 10. The mapped areas of high habitat suitability to Common Guillemot show zones of suitable habitat located over Lille Middelgrund. Medium densities of 1-8 birds per km^2 are predicted in a zone from Hesselø to and including the southern part of the wind farm area. The closest distance from the wind farm and 2 km displacement zone to the areas of high habitat suitability is 19 km. The estimated mean number of displaced Common Guillemot is 1,227. This represent 0.68% of the total estimated number of Razorbills wintering in the Kattegat and 0.03% of the bio-geographic population (Table 10).

Table 9 Smooth terms, adjusted R-squared and evaluation statistics for the distribution models for Common Guillemot *Uria aalge* in the southern Kattegat based on both aerial and ship-based line transect data. F statistics and the approximate significance for the smooth terms and t-statistic and the significance for the parametric terms are shown.

	Presence/absence			**Positive density**		
		Chi-Sq	p-value		F	p-value
Depth		112.569	0			
Salinity surface		492.085	0		11.747	0
Current speed surface		–	–		9.261	
te(x.res, y.res)		186.221	0		9.205	0
R-sq.(adj)	0.176			0.031		
AUC	0.751					
Spearman´s corr.				0.160		
Sample (n)	8442			2936		

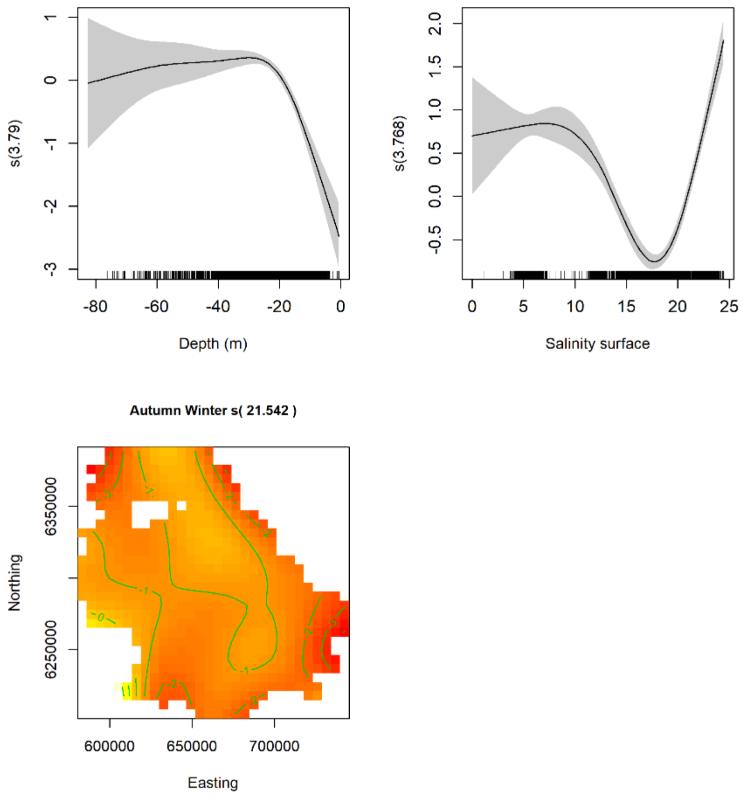


Figure 16 Response curves for presence absence model parts for Common Guillemot *Uria aalge* in the southern Kattegat based on both aerial and ship-based line transect data

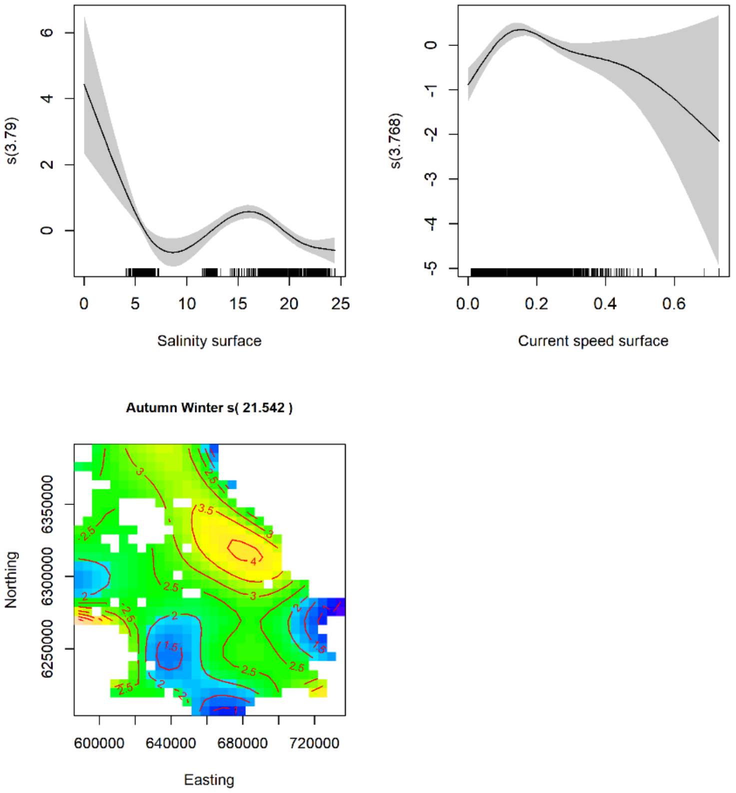


Figure 17 Response curves for positive model parts for Common Guillemot *Uria aalge* in the southern Kattegat based on both aerial and ship-based line transect data

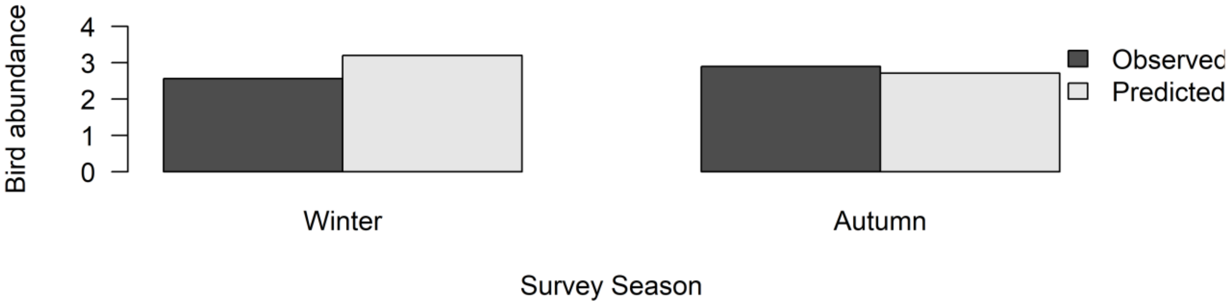


Figure 18 Comparison of predicted versus observed numbers of Common Guillemot *Uria aalge* in the southern Kattegat based on both aerial and ship-based line transect data

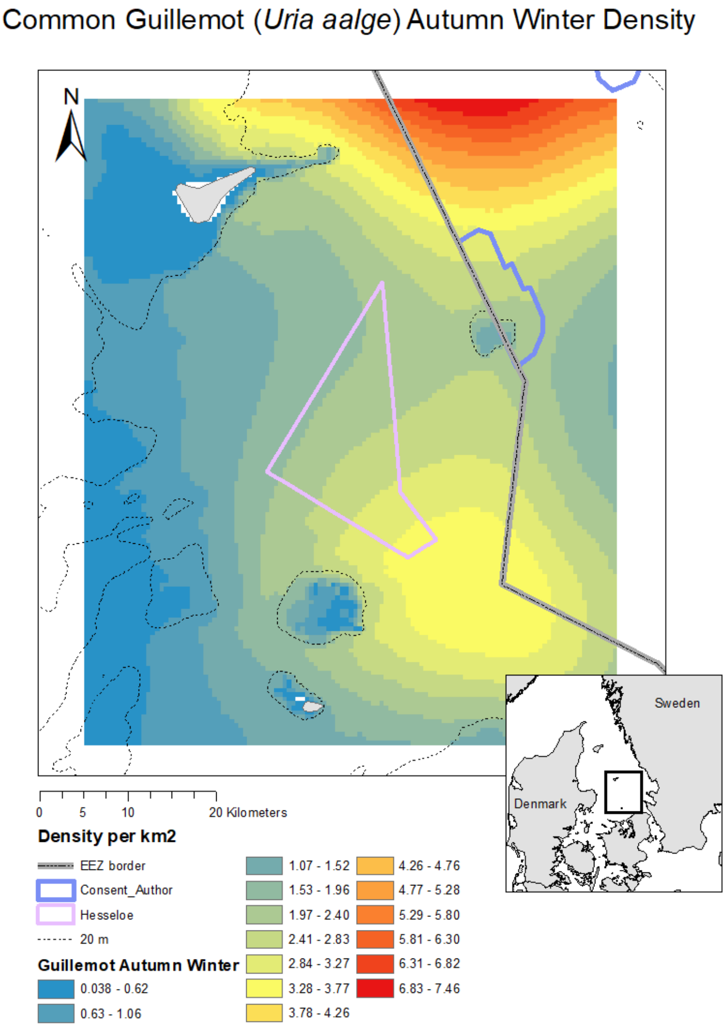


Figure 19 Predicted mean monthly density (n/km^2) of Common Guillemot *Uria aalge* in the southern Kattegat based on both aerial and ship-based line transect data. Depth contours, EEZ boundary and consented wind farms are indicated

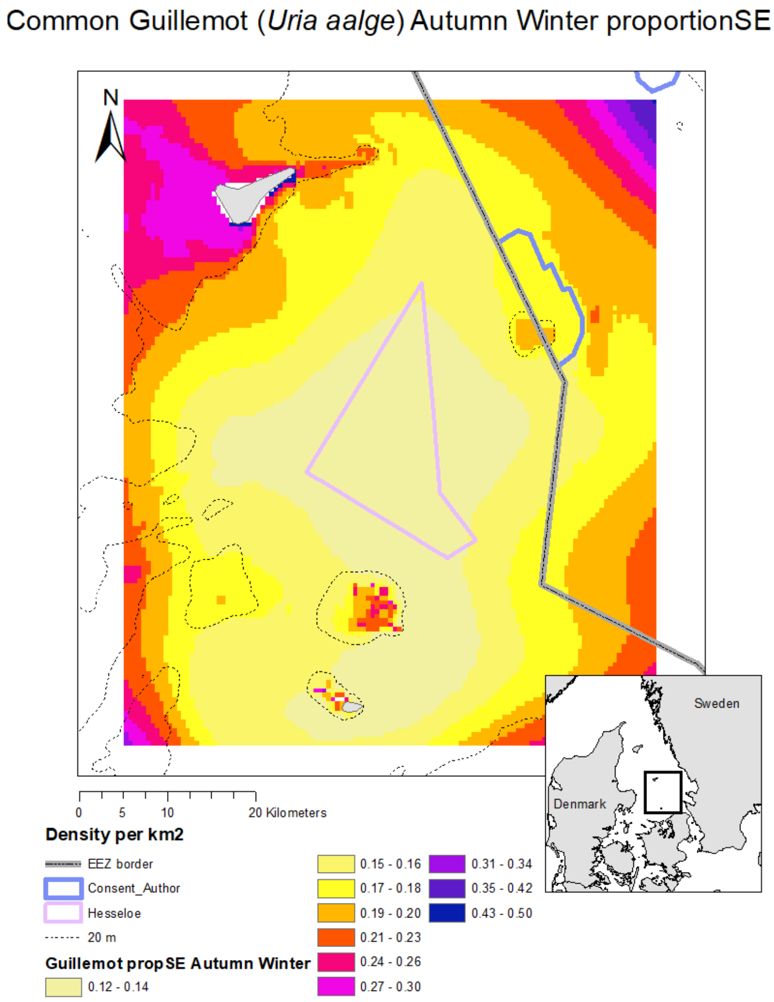


Figure 20 Uncertainty of predicted mean monthly density (n/km^2) of Common Guillemot *Uria aalge* in the southern Kattegat based on both aerial and ship-based line transect data expressed as proportion standard error (SE) of mean density. Depth contours, EEZ boundary and consented wind farms are indicated

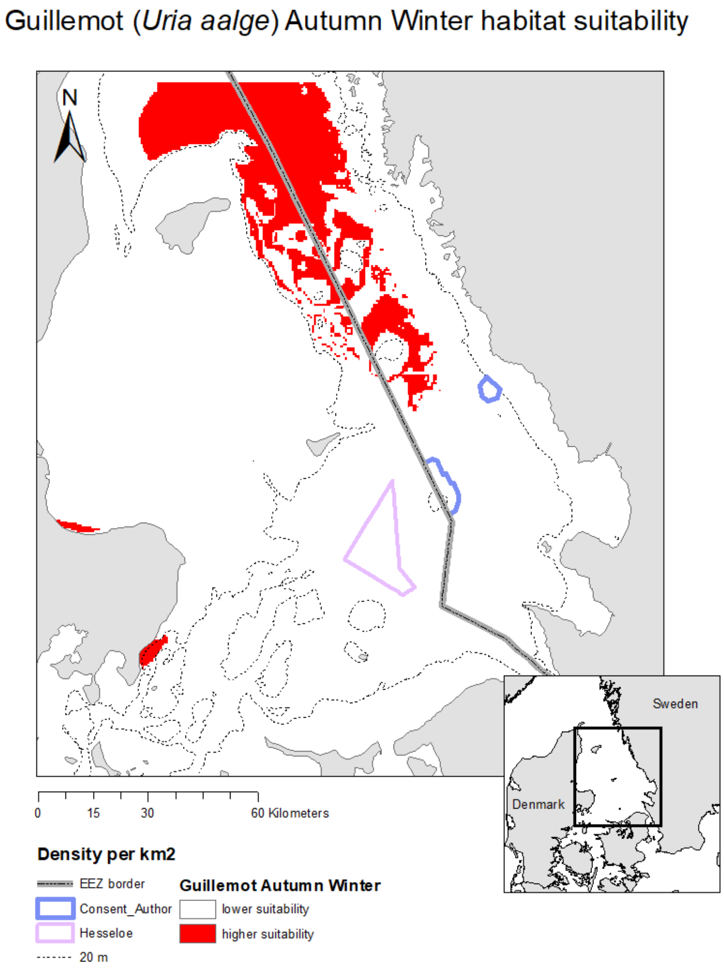


Figure 21 Areas of high habitat suitability to Common Guillemot *Uria aalge* predicted from the aerial and ship-based transect lines during the main months of occurrence at the Hesselø site and displacement ranges from thee planned wind farm. Depth contours, EEZ boundary and consented wind farms are indicated

Table 10 Statistics on the estimated displacement of Common Guillemot *Uria aalge* from the Hesselø site

Hesselø area (km^2)	247
Area of high habitat suitability in Hesselø site and displacement range (km^2)	0
Number of displaced birds	1,227
% displaced birds of total in the Kattegat	0.68
% displaced birds of total bio-geographic population*	0.03

*Birdlife International (2020a)

3.2 Observed seabird densities – Thor site

3.2.1 Red-throated/Black-throated Diver

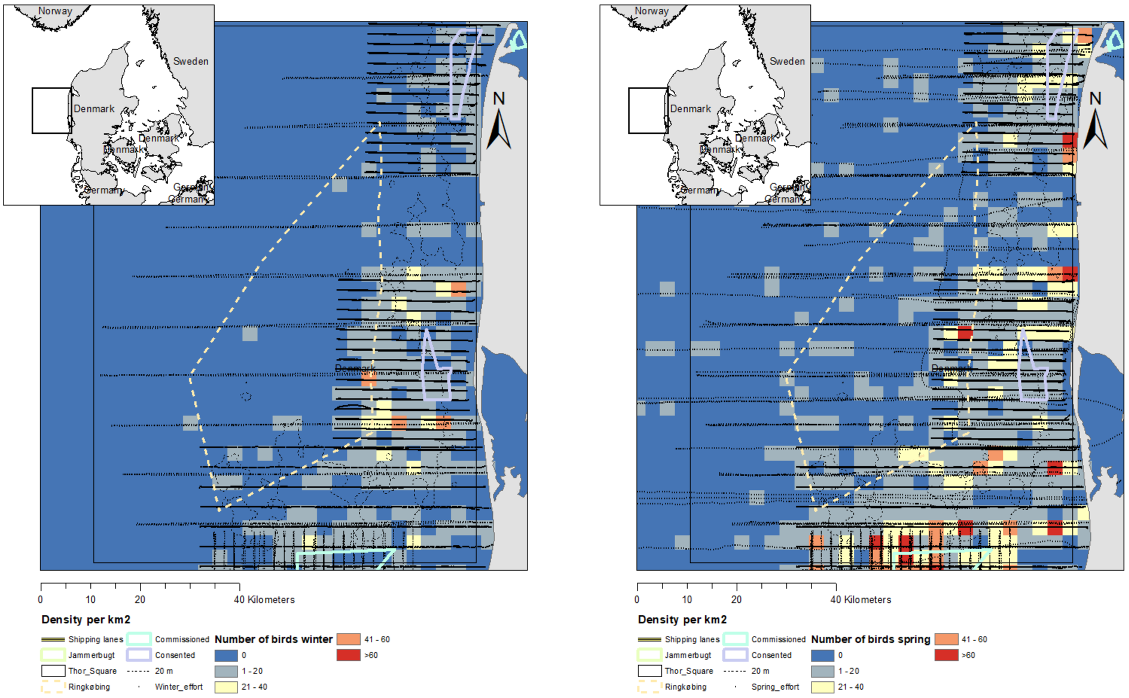
As seen from the distribution model results the Red-throated/Black-throated Divers concentrate in the interface between the Jutland Current and North Sea water mass. Although densities change between months, this pattern is persistent, and is also apparent in the observed densities collected during the various aerial surveys in the region after 2000, including the recent ones during 2018-2019 (Figure 22). The distribution pattern is mainly driven by the difference in salinity, yet productivity and water depth obviously also play a role as diver densities drop to low levels in areas with a water depth larger than 25 m.

The affinity to the interface or the salinity front in the modelled distribution of the two species in the Danish part of the North Sea is an extension of similar trends in the German Bight with the highest densities in the frontal zone along the 20 m curve off Sylt and at Amrum Bank (Skov & Prins 2001). Divers also displayed a relationship with areas of lower current speed which are consistent with the dominant conditions found in the northern part of the German Bight.

The interface between the Jutland Current and the North Sea water mass overlaps with the eastern part of the Thor site, which gives rise to relatively high densities and high habitat suitability in the eastern 1/3 of Thor. Despite the relatively high degree of spatial overlap between high habitat quality and the planned windfarm sites higher densities (> 1.0 birds/km^2) were only predicted during the month of April before the onset of spring migration. During the other months there is no evidence of larger areas of higher densities of divers overlapping the wind farm site.

Divers (*gavidae*) Winter Observations

Divers (*gavidae*) Spring Observations



Divers (*gavidae*) Summer Observations

Divers (*gavidae*) Autumn Observations

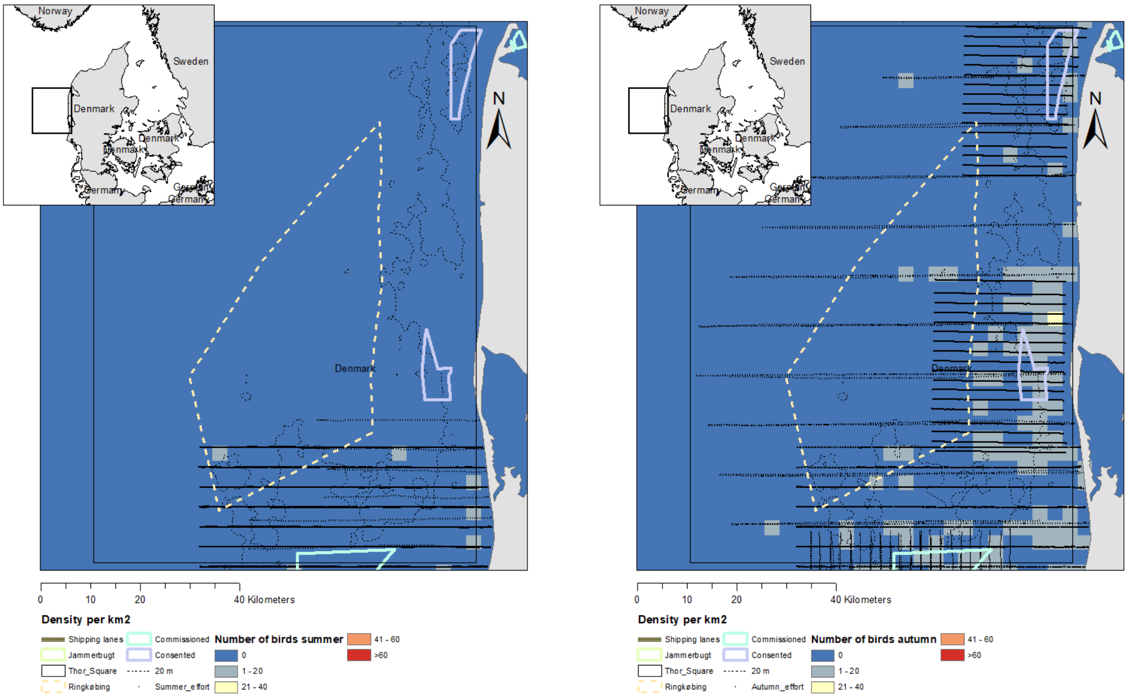


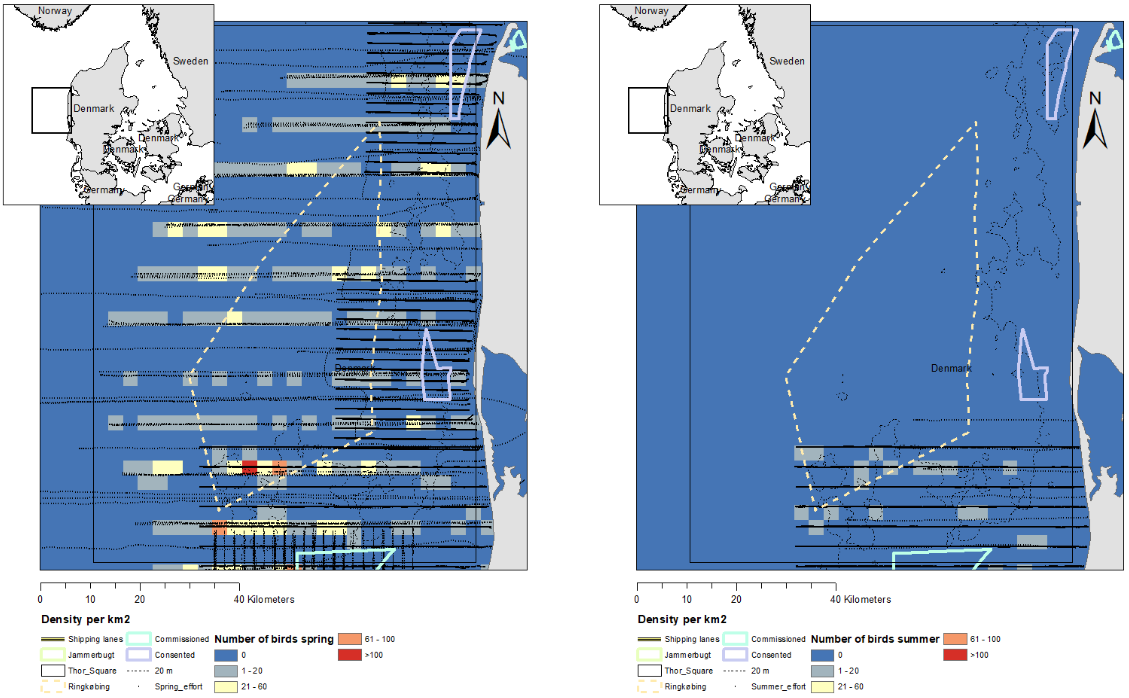
Figure 22 Observed densities of Red-throated/Black-throated Diver *Gavia stellate/arctica* split by season

3.2.2 Northern Gannet

As seen from the maps of observed densities during the aerial surveys in the North Sea (Figure 23) the distribution of the Northern Gannet is strongly related to the areas deeper than 20m with higher surface salinity. In the Danish part of the North Sea higher densities have historically been observed around the western edge of Horns Rev and along the southern slopes of the Norwegian Trench during the dispersal from the colonies in the autumn season (Skov et al. 1995). Recently, higher numbers of Gannets have turned up in other parts of the eastern North Sea and Kattegat, including offshore areas along the west coast of Jutland as recorded during the aerial surveys undertaken by DCE during 2018-2019 (Petersen et al. 2019a). As seen in Figure 23, the high densities do not occur in a coherent zone but appear as small patches dispersed across the entire regions. Accordingly, small patches of higher densities of this species should currently be expected to occur regularly at the Thor site. The dynamics of the species are most likely driven by the availability of the primary food source, large herring and mackerel, and hence patches may be ephemeral with Gannets spending a relatively small amount of time at a particular location.

Northen Gannet (*Morus bassanus*) Spring Observations

Northen Gannet (*Morus bassanus*) Summer Observations



Northen Gannet (*Morus bassanus*) Autumn Observations

Northen Gannet (*Morus bassanus*) Winter Observations

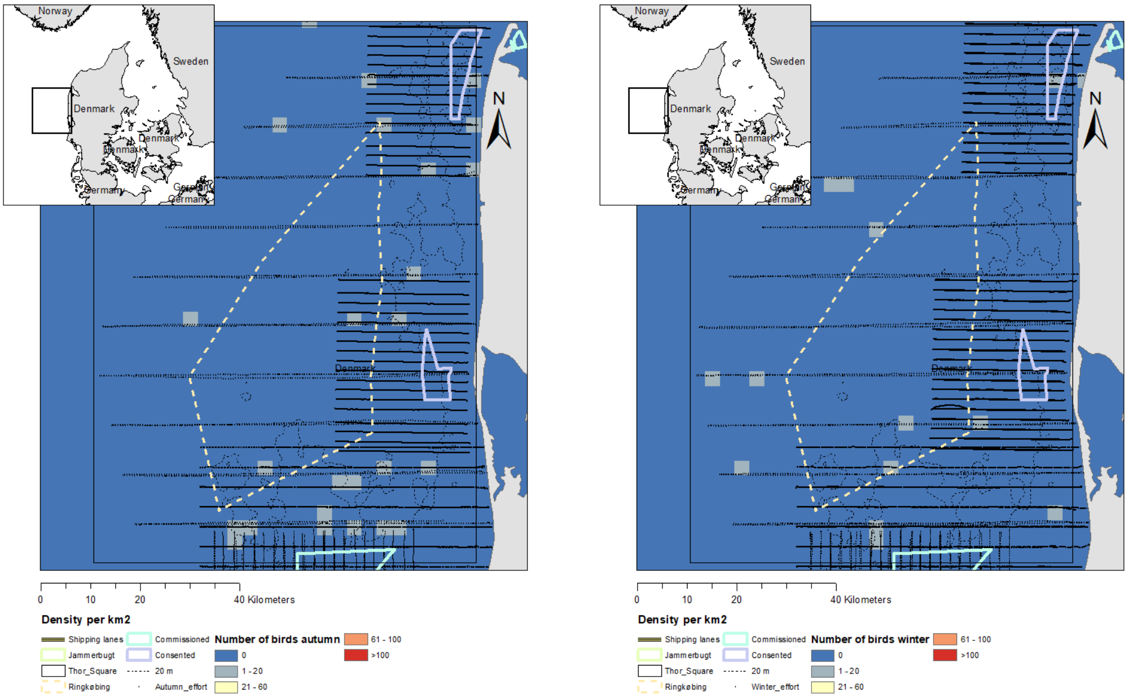
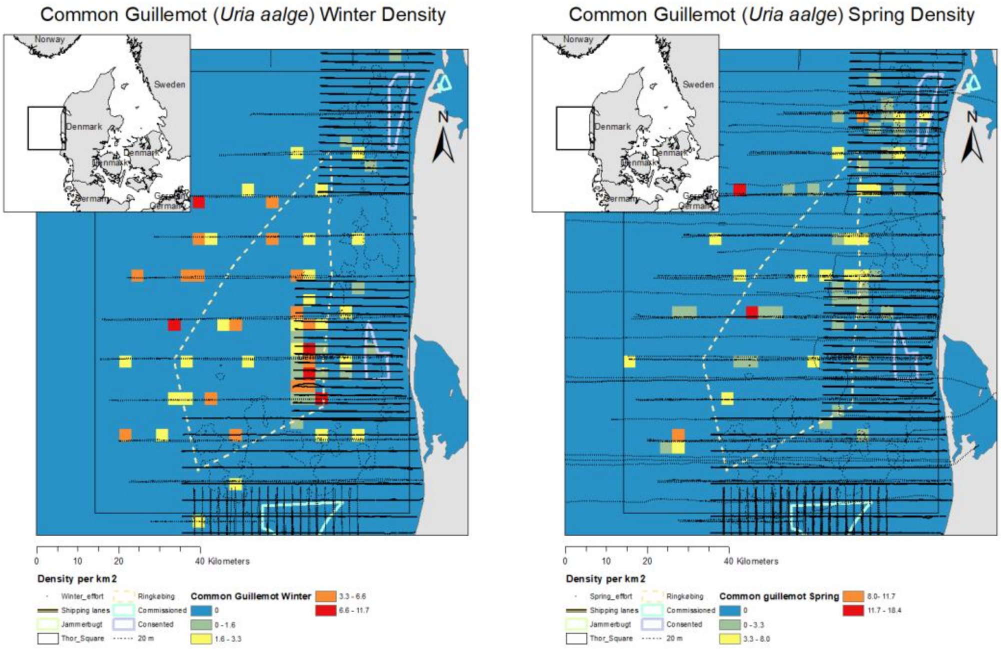


Figure 23 Observed densities of Northern Gannet *Morus bassanus* split by season.

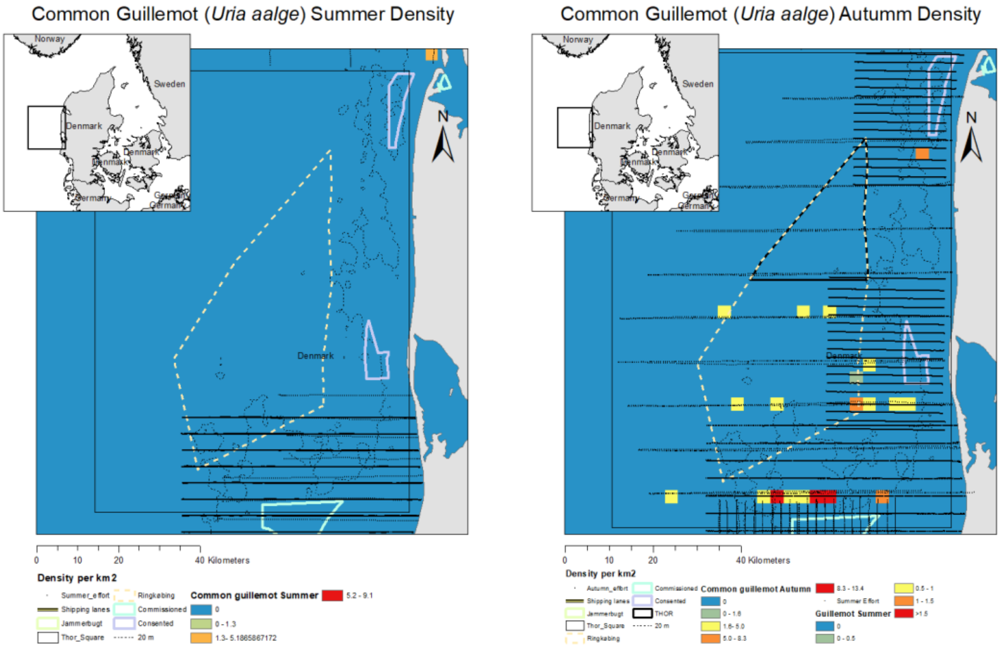
3.2.3 Common Guillemot

The Common Guillemot is abundant in the Norwegian Trench during the non-breeding season but occurs in low-medium densities in the rest of the Danish part of the North Sea (Skov et al. 1995, Figure 24). Within the investigated region the species occurs widespread, but primarily in areas deeper than 20 m with good water transparency, including at the Thor site. At no time of the year are higher densities (> 10 birds/km^2) of Guillemots expected in this area.



Common Guillemot (*Uria aalge*) Winter Density

Common Guillemot (*Uria aalge*) Spring Density



Common Guillemot (*Uria aalge*) Summer Density

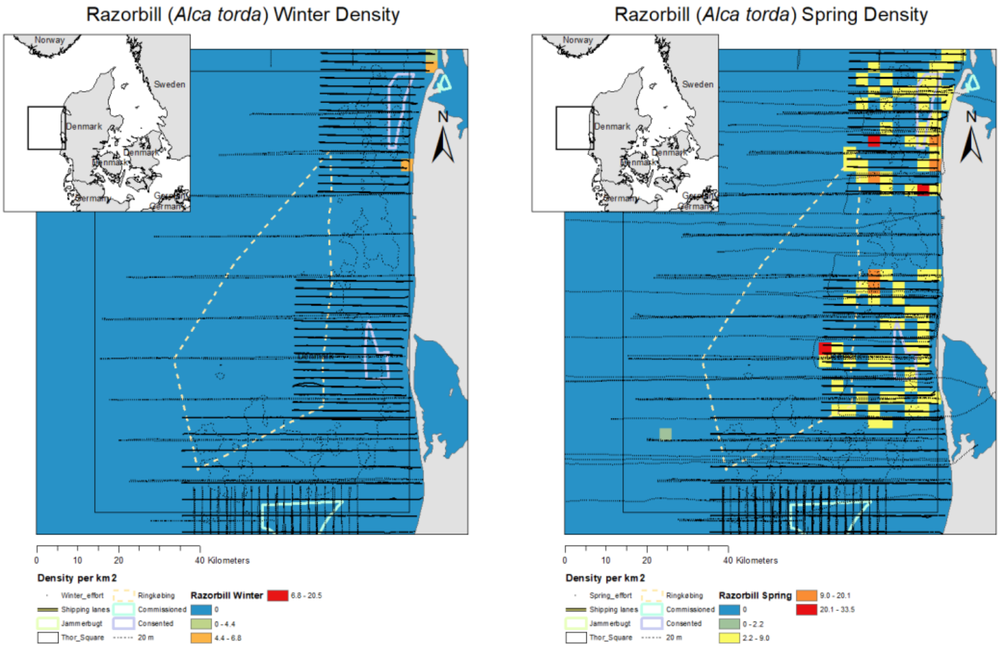
Common Guillemot (*Uria aalge*) Autumm Density

Figure 24 Observed densities of Common Guillemot *Uria aalge* split by season.

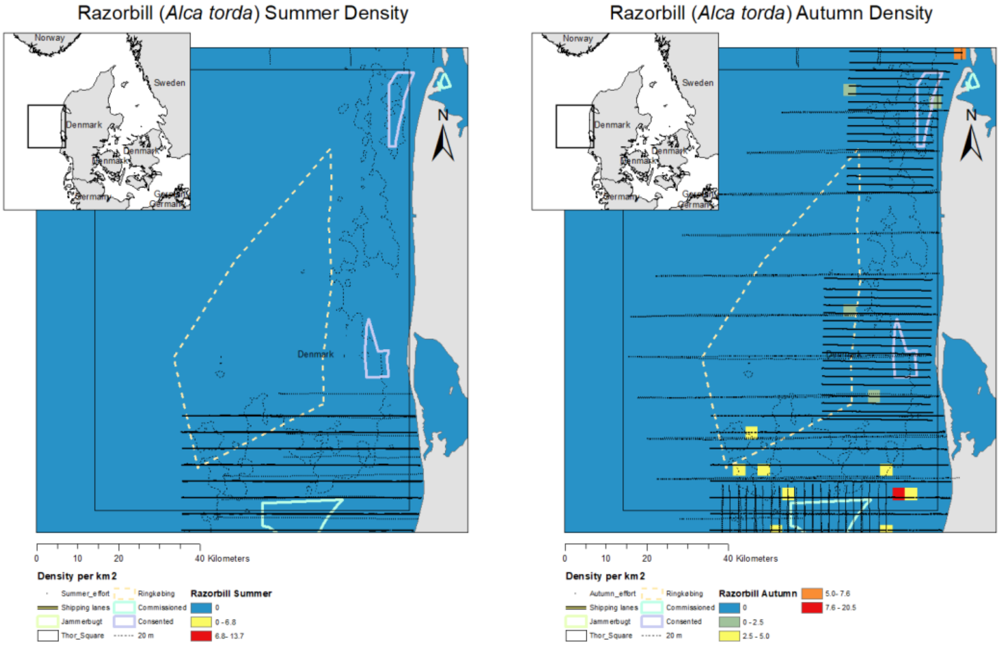
3.2.4 Razorbill

Razorbills do not moult in Danish waters, but winter here in large numbers. The main wintering areas to this species are located in the central and eastern part of the Kattegat where the largest known winter concentrations of this species have been recorded (Laursen et al. 1989, Skov et al. 1995).

Like many other pelagic seabird species, the Razorbill's occurrence in the North Sea is related to the deeper areas with high salinity and good water clarity. It is therefore not likely that high densities (> 10 birds/km^2) occur regularly in the Thor site.


Razorbill (*Alca torda*) Winter Density

Razorbill (*Alca torda*) Spring Density


Razorbill (*Alca torda*) Summer Density

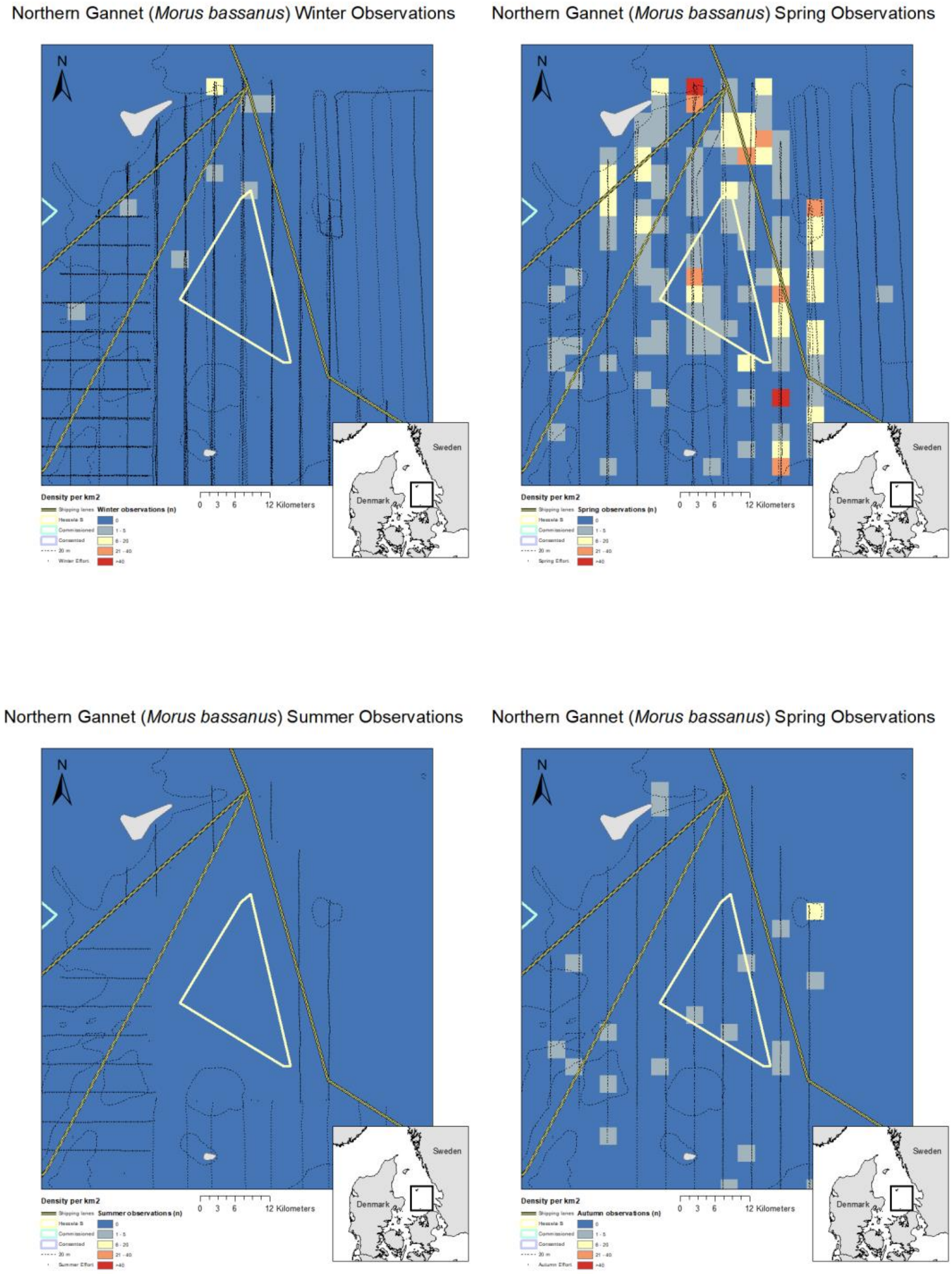
Razorbill (*Alca torda*) Autumn Density

Figure 25 Observed densities of Razorbill *Alca torda* split by season.

3.3 Observed seabird densities - Hesselø site

3.3.1 Northern Gannet

As seen from the maps of observed densities during the aerial surveys in the Kattegat (Figure 26) the distribution of the Northern Gannet is strongly related to the areas deeper than 30m. As the surveys only covered the Danish part of the Kattegat the observations only partly display the full distribution pattern in this region. Like for the North Sea there has been a recent increase in the number of Gannets occurring in the Kattegat, and high numbers may now turn up at any time of the year. During the aerial surveys undertaken by DCE during 2018-2019 the highest numbers were seen in the month of April (Petersen et al. 2019a). As is the case in the North Sea the high densities do not occur in a coherent zone but appear as small patches dispersed across the entire deeper parts and slope areas of the Kattegat, including the eastern part of the Hesselø site. Accordingly, small patches of higher densities of this species should currently be expected to occur regularly at the site. The dynamics of the species are most likely driven by the availability of the primary food source, large herring and mackerel, and hence patches may be ephemeral with Gannets spending a relatively small amount of time at a particular location.



Northern Gannet (*Morus bassanus*) Winter Observations

Northern Gannet (*Morus bassanus*) Spring Observations

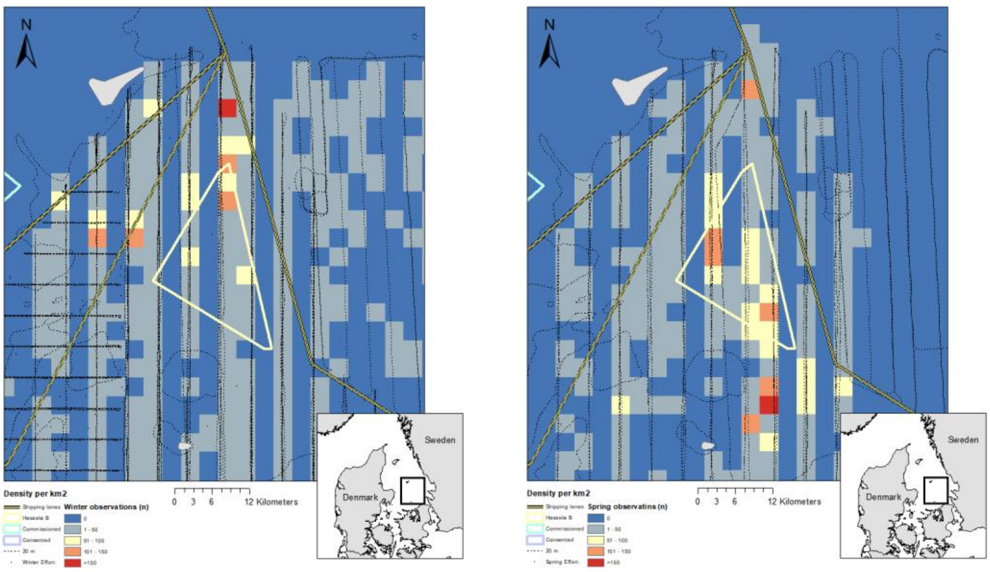
Northern Gannet (*Morus bassanus*) Summer Observations

Northern Gannet (*Morus bassanus*) Spring Observations

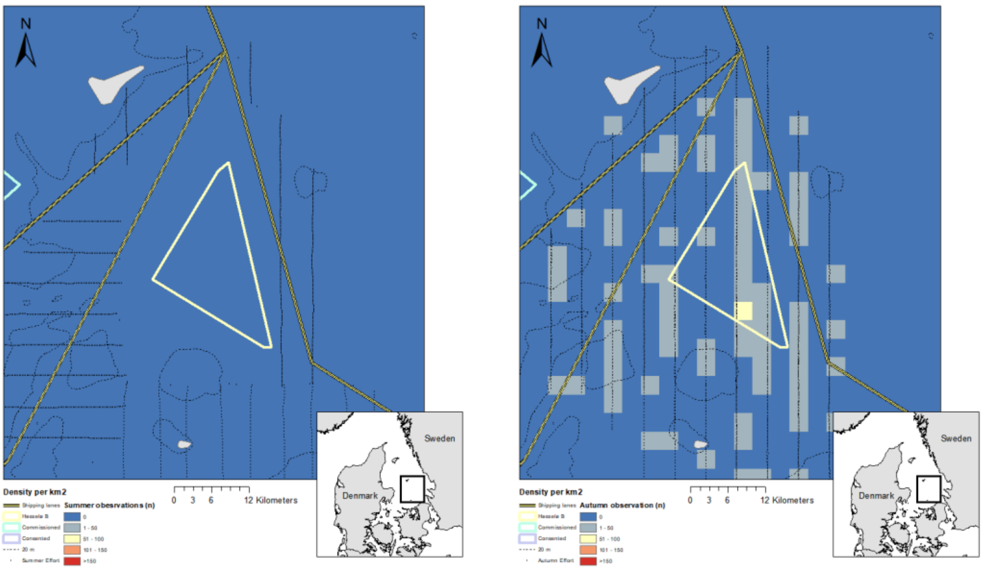
Figure 26 Observations of Northern Gannet *Morus bassanus* split by season.

3.3.2 Razorbill

The concentration of Razorbill in the Kattegat is the largest known concentration of the species during winter. The birds arrive in Kattegat in late autumn where they are mainly seen between Djursland and Anholt and move in winter to the area of Lille Middelgrund in the Swedish EEZ and the slope region towards Anholt in the Danish EEZ (Figure 27). Densities of Razorbills recorded at the Hesselø site are typically medium (< 1-2 birds/km^2), yet higher densities are observed northeast and northwest of the site.


Razorbill (*Alca torda*) Winter Observations

Razorbill (*Alca torda*) Spring Observations


Razorbill (*Alca torda*) Summer Observations

Razorbill (*Alca torda*) Autumn Observations

Figure 27 Observations of Razorbill *Alca torda* from aircraft and ship split by season. Observations from plane has been supplemented with undetermined observations of Razorbill/Guillemot corrected by observed ratio.

4 Assessment of the sensitivity of Thor and Hesselø sites

The sensitivity of the Thor and Hesselø sites to seabirds has been assessed based on the strength of the evidence regarding the local distribution of the selected key species, the knowledge about the behavioural response of the species to offshore wind farms in terms of habitat displacement and avoidance/collision risk and the significance of the estimated number of potentially affected birds.

4.1 Thor site

The updated modelled distribution patterns clearly indicate that the western part of the Thor site is generally characterised by low densities of divers, while the eastern part houses medium densities. The densities at the Thor site increases during the months of January and April, - during the latter month densities above 0.75 birds/km^2 are predicted in a coherent zone just east of the planned wind farm. The estimated area of high habitat suitability within the wind farm and in the displacement zone reaches its maximum of 263 km^2 during the same month. The modelled densities of divers predicted at Thor have high confidence.

Although there is general consensus regarding the fact that Red-throated and Black-throated Divers display a stronger displacement response to offshore wind farms than other species of seabirds (Dirschke et al. 2016) there is a high degree of uncertainty regarding the actual level of displacement. Adding to this, there is a complete lack of understanding of the underlying process behind the displacement, i.e. answering the question whether the displacement is caused by a behavioural response by the divers or by a change in prey availability. Garthe et al. (2018) found on the basis of post-construction aerial and ship-based surveys that the divers seemed to be entirely (100%) displaced within the wind farms as well as within a 5.5 km buffer. However, displacement impact may extend even further and potentially could cover distances to 10-15 km (Petersen et al. 2014, Mendel et al. 2019, Heinänen et al. 2020). Although habitat dynamics are less likely to have biased these assessments of displacement impacts on divers it should be noted that neither of the above mentioned assessments took the variability of the local oceanography between the field surveys into account. With the evidence at hand, it seems however that the applied 99% displacement within the wind farm and 50% in a 5.5 km buffer is a general characteristic of the displacement of this species.

The potential for displacing divers from Thor is lowest in March and highest in April, when the estimated mean number of displaced divers is 123 birds or just less than 1% of the total number of divers occurring in the Danish part of the North Sea. In comparison, 346 divers are estimated to be displaced from the southern part of the Ringkøbing site representing 2.16% of the divers in the Danish part of the North Sea. Accordingly, assessed on its own the potential displacement of divers from the proposed Thor site is not likely to represent a showstopper for the development of the project, and will be significantly less than the potential displacement from developing the southern part of the Ringkøbing site. The displacement of divers from other sites located in the region of high habitat suitability in the North Sea without a doubt involves a sizeable proportion of the Danish North Sea population of divers. As the displacement in Thor is primarily related to the easternmost part of the wind farm the potential displacement impact will be significantly reduced if focusing the development on the westernmost part of the wind farm area.

Although Northern Gannets should be expected to occur regularly at Thor throughout the year the observations at hand do not indicate the presence of any coherent zone of higher densities, and give the impression that Gannets occur widespread in deeper areas with ephemeral patches of higher densities. Gannets show displacement from wind farms at relatively short distances and do often concentrate at the periphery (Skov et al. 2018). Hence, the species is more prone to collision risk than the divers. Yet, due to strong avoidance rates seen in the species the collision risk is limited. Cook et al. (2018) in their review of avoidance behaviour found evidence of macro avoidance at the level of 64% following data from Krijgsveld et al. (2011). Skov et al. (2018) based on two years of detailed monitoring at Thanet Offshore Wind Farm observed a higher proportion avoiding the wind farm (80% ± 15%) with an overall avoidance (including avoidance of turbines and rotors) of 99.9%. It is therefore unlikely that collision risk for Northern Gannets at Thor will be at a high level.

The occurrence of Common Guillemot at the Thor site can be characterised as widespread in low-medium densities during the non-breeding season. No concentrations of the species have been recorded at or near the site. The Razorbill occurs in lower densities than Guillemots at the site.

4.2 Hesselø area

The distribution of the Razorbill and Common Guillemot at the Hesselø site was modelled using all available aerial and ship-based line transect data. The Razorbill model clearly indicated large concentrations of wintering Razorbill east of Anholt, over Lille Middelgrund and northeast of Djursland in areas with a water depth between 15 m and 35 m, and higher densities and suitable habitat occurring at a minimum distance of 12 km from the Hesselø site. The model for the Common Guillemot showed large concentrations over Lille Middelgrund with the closest distance to the wind farm site at 19 km.

Estimation of the displacement of these two species of auks is problematic due to the obviously limited scale of displacement observed for this species. The displacement rates used in this assessment, i.e. 75% displacement in the wind farm and 50% in the 2 km buffer were based on the findings of Heinänen & Skov (2018) from their study on Common Guillemots and Razorbill at Dutch offshore wind farms. Based on long-term monitoring data incorporating the oceanographic variability experienced during each survey campaign it was possible to detect a displacement even if the densities of guillemots and Razorbills observed inside the wind farms had actually increased post-construction. The result contrasts those of Vallejo et al. (2017) and Leopold (2018) who reported a lack of displacement impact on the species when analysing pre- and post-construction monitoring data irrespective of habitat variability. The displacement rates used in this assessment should therefore be seen as indicative and precautionary. More post-construction monitoring results are needed before the displacement potential of Razorbills and Common Guillemots can be firmly determined. Despite the limited scale of displacement the two species are regarded as having low vulnerability to collision with offshore wind farms due to their low flight altitude and subsequent low proportion of birds flying at rotor height (<1%, Johnston et al. 2013).

The estimated potential displacement of Razorbills from the Hesselø site indicates that a mean number of 3,925 Razorbills are displaced during the non-breeding season, representing 1.79% of the total estimated number of Razorbills in the Kattegat. The estimated potential displacement of Common Guillemots from the Hesselø site indicates that a mean number of 1,227 Common Guillemots are displaced during the non-breeding season, representing 0.68% of the total estimated number of Common Guillemots in the Kattegat. Accordingly, assessed on its own the potential displacement of the two auk species from the proposed Hesselø site is not likely to represent a showstopper for the development of the project. However, the cumulative displacement from the site with other existing and planned sites located in the areas of high habitat suitability to Razorbills in the Kattegat may involve a sizeable proportion of the Kattegat population of this species. It may therefore be subject to a more elaborate assessment to establish whether long-term cumulative impacts on the population can be discounted.

Like in the North Sea observations of Northern Gannets in the Kattegat occur throughout the year, yet the observations do not indicate the presence of any coherent zone of higher densities with the birds occurring widespread in deeper areas and over slopes with ephemeral patches of higher densities. These ephemeral patches should also be expected to use the Hesselø site. As mentioned for the Thor site Gannets display strong avoidance behaviour towards wind farms and individual turbines (Krijgsveld et al. 2011, Cook et al. 2018, Skov et al. 2018).

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