Assessment of areas for development of offshore wind farms on Rønne Bank in relation to birds

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Assessment of areas for development of offshore wind farms on Rønne Bank in relation to birds

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0 Executive summary

DHI has been commissioned by the Danish Energy Agency to undertake an assessment of areas for development of offshore wind farms on Rønne Bank southwest of Bornholm in relation to birds. The assessment is based on all available data and focuses on Long-tailed Duck *Clangula hyemalis* and migrating Common Crane *Grus grus*. The data basis for the Long-tailed Duck has been established using a fine-scale species distribution model using survey data from the southern part of the Baltic Sea collected since 1987. The data basis for the Common Crane has been rangefinder and GPS telemetry data coupled to a flight height model collected and developed as part of the Danish Kriegers Flak project in 2015 as well as historic (50 years) observations of migrating cranes from southern Sweden and Bornholm.

The Long-tailed Duck distribution model indicated that Rønne Bank is an area of medium densities of wintering Long-tailed Ducks with the distribution largely restricted to offshore areas with a water depth between 10 and 20 m. The densities on Rønne Bank are generally lower than densities recorded in the core wintering areas for the species in Pomeranian Bay, Gulf of Riga and Hoburgs-Midsjö Banks. The wintering population of Long-tailed Duck has suffered severe declines throughout the Baltic Sea since the early 1990es on account of pressures on breeding as well as wintering areas and as shown by this study the size of the wintering population on Rønne Bank has declined by more than 50 % during this period. The total number of wintering Long-tailed Ducks on Rønne Bank in 2020 may not exceed 10,000 birds, which is below 1 % of the total population currently wintering in the Baltic Sea. On the other hand, the relative distribution of the species is very stabile, and has not changed over the course of the 40 years when surveys have been undertaken on the bank.

The planned Bornholm 1 wind farm does not overlap with the modelled areas of suitable habitat to Long-tailed Ducks, whereas the western part of Bornholm 2 does overlap with these densities. The displacement analyses documented that limited displacement of Long-tailed Ducks is likely to take place from Bornholm 1, whereas the displacement zone from Bornholm 2 involves 189 km^2 of suitable habitat and including the extension zone 216 km^2 of suitable habitat. The estimated mean number of displaced ducks from brutto area 2 is 2,989 and including the extension area 3,262. These numbers represent 0.20% and 0.22% of the total Baltic wintering population of Long-tailed Duck, respectively and hence may not represent a significant impact even if they represent a sizable proportion (1/3) of the number of Long-tailed Ducks currently wintering on Rønne Bank. Displacement effects on Long-tailed Ducks from Bornholm 2 could be reduced by approximately 40% by focussing development on the eastern part of the bank.

Of other species of seabirds which regularly use Rønne Bank only the Black Guillemot occur in relatively high densities, and the area has historically been classified as part of the core wintering area for the species in the Baltic Sea. However, quantitative mapping of this species requires the use of ships and due to the absence of ship-based surveys on Rønne Bank since the early 1990'es the current status of Rønne Bank in relation to Black Guillemot is not known.

The avoidance pattern of Common Crane to offshore wind farms will logically lead to a high perceived risk of collision. The migration corridor of Swedish and Norwegian cranes across the Arkona Basin is the focus of offshore wind farm development, and 15 built, consented and planned projects in combination with the planned Bornholm offshore projects will lead to a significant cumulative impact from all projects in the region. The results from the assessment of the horizontal and vertical distribution of the migrating cranes were used as a basis for modelling the cumulative collision risk for cranes crossing the Arkona region. Due to the large size of the planned 15 MW turbines and the large width of the planned arrays for both layout 1 and layout 2 wind farms (excluding extensions) the estimated annual number of colliding Common Crane from the Bornholm project was high; 1,142 birds for layout 1 and 766 birds for layout 2. This leads to a cumulative collision risk at 2,450 Common Cranes with layout 1, and 2,074 for layout 2. The implemented flight models show that the cranes will most likely cross the Bornholm project areas below 300 m, and hence given the height of the turbines of 268 m it means that close to 100 % of cranes will be flying at rotor height during both spring and autumn migration.

Compared to the estimated Potential Biological Removal (PBR) threshold for a stabile population of 1,887 birds, the combined collision impact on the Swedish-Norwegian population of Common Crane of the two scenarios equal 129.8 %, and 109.9 % of the PBR threshold, respectively. If setting the population to be increasing the PBR threshold rises to 2,642 birds and the collision potential for layout 1 will be slightly below and for layout 2 clearly below the threshold. This means that unless the population is still increasing it most likely will not be capable of compensating the loss of birds imposed by the 17 projects by 2023. If unmitigated the collision mortality imposed by the full development of the 17 wind farms in the western Baltic Sea, including the Bornholm project may result in a decline in the size of the Swedish-Norwegian population of Common Crane. As the PBR threshold should only be used as a first indication of the sustainability of the development of large-scale wind energy facilities in the region it is recommended to assess the long-term cumulative impacts on cranes by undertaking population modelling.

1 Resumé

DHI har fået til opgave af Energistyrelsen at foretage en vurdering af områder til udvikling af havmølleparker på Rønne Banke sydvest for Bornholm i forhold til fugle. Vurderingen er baseret på alle tilgængelige data og fokuserer på havlit *Clangula hyemalis* og trækkende traner *Grus grus*. Datagrundlaget for havlit er etableret ved brug af udbredelsesmodellering i fin skala på basis af kortlægningsdata fra den sydlige del af Østersøen, der er indsamlet siden 1987. Datagrundlaget for vurderinger på traner er data indsamlet med laserkikkert og koblet til en højdemodel, som blev udviklet under det danske Kriegers Flak-projekt i 2015 samt historiske (50 år) observationer af trækkende traner fra det sydlige Sverige.

Udbredelsesmodellen for havlit viser, at Rønne Banke er et område med middelhøje tætheder af overvintrende havlit, hvor fordelingen stort set er begrænset til offshore-områderne med en vanddybde mellem 10 og 20 m. Tæthederne på Rønne Bank er generelt lavere end tæthederne registreret i de vigtigste områder for arten i Pommerske Bugt, Riga-bugten og Hoburgs-Midsjö-bankerne. Den overvintrende bestand af havlit har undergået en alvorlige tilbagegang i hele Østersøen siden begyndelsen af 1990'erne forårsaget af presfaktorer i såvel yngle- som vinter-områderne, og som det fremgår af denne undersøgelse, er størrelsen af den overvintrende bestand på Rønne Banke faldet med mere end 50% i denne periode. Det samlede antal overvintrede havlit på Rønne Bank i 2020 beregnes ikke at overstige 10.000 fugle, hvilket er under 1% af den samlede bestand, der overvintrer i Østersøen idag. På den anden side er den relative udbredelse af arten meget stabil og har ikke ændret sig i løbet af de 40 år, hvor undersøgelser er foretaget på banken.

Den planlagte Bornholm 1 havmøllepark overlapper ikke de modellerede områder med god habitatkvalitet for havlit, mens den vestlige del af Bornholm 2 overlapper disse områder. Analyser af fortrængningseffekt dokumenterede, at begrænset fortrængning af havlit sandsynligvis vil finde sted fra Bornholm 1, mens fortrængningzonen fra Bornholm 2 involverer 189 km^2 god habitat og med de planlagte potentielle udvidelser 216 km^2 af god habitat. Det anslåede gennemsnitlige antal af fortrængte havlit fra brutto-område 2 er 2.989 og inklusive udvidelsesområdet 3.262. Disse tal repræsenterer henholdsvis 0,20% og 0,22% af den samlede baltiske overvintringsbestand af havit og repræsenterer derfor sandsynligvis ikke en signifikant påvirkning på bestanden selvom de repræsenterer en ret stor andel af de ovevrintrende havlit på Rønne Banke (1/3). Fortrængningseffekter på havlit fra Bornholm 2 kunne reduceres med omkring 40% ved at fokusere udviklingen af havmølleparken på den østlige del af banken.

Af andre arter af vandfugle, der regelmæssigt bruger Rønne Bank, forekommer kun tejst i relativt høje tætheder, og området er historisk blevet klassificeret som en del af overvintringsområdet for arten i Østersøen. Kvantitativ kortlægning af denne art kræver dog brug af skib, og på grund af fraværet af skibsbaserede undersøgelser på Rønne Bank siden begyndelsen af 1990'erne kendes den nuværende status for tejst på Rønne Bank ikke.

Undvigelsesadfærden hos trækkende traner overfor havmølleparker vil logisk set føre til en høj risiko for kollision. Trækkorridoren for svenske og norske traner over Arkonabassinet er fokus for udviklingen af et stort antal havmølleparker, og 15 byggede, godkendte og planlagte projekter i kombination med de planlagte projekter ved Bornholm vil føre til en betydelig kumulativ påvirkning fra alle projekter i regionen. Resultaterne fra vurderingen af den rumlige og højdemæssige fordeling af de trækkende traner blev brugt som grundlag for modellering af den kumulative kollisionsrisiko for traner, der krydser Arkona-regionen. På grund af størrelsen af de planlagte 15 MW vindmøller og bredden af de planlagte arrays for både layout 1 og layout 2 havmølleparker (eksklusiv udvidelse) var det estimerede årlige antal kolliderende traner fra Bornholm-projektet højt; 1.142 fugle til layout 1 og 766 fugle til layout 2. Dette fører til en kumulativ kollisionsrisiko ved 2.450 almindelige kraner med layout 1 og 2.074 for layout 2. De implementerede flyvemodeller viser, at tranerne sandsynligvis vil krydse Bornholm-projektområderne i en højde under 300 m, og derfor i betragtning af møllernes højde på 268 m betyder det, at næsten 100% af tranerne vil flyve i rotorhøjde under både forårs- og efterårs-trækket.

Sammenlignet med den estimerede 'Potential Biological Removal' (PBR) tærskel på 1.887 fugle udgør den kombinerede kollisionspåvirkning på den svensk-norske bestand af traner af de to scenarier

henholdsvis 129,8% og 109,9% af PBR-tærsklen. Hvis tranebestanden stadig stiger vil PBR-tærsklen stige til 2.642 fugle, og kollisionspotentialet for layout 1 vil være lidt lavere og for layout 2 meget lavere end tærsklen. Dette betyder, at medmindre bestanden stadig vokser vil den højst sandsynligt ikke være i stand til at kompensere for det tab af fugle, som de 17 projekter vil påføre bestanden inden 2023. Kollisionsdødeligheden ved den fulde udvikling af de 17 havmølleparker i det vestlige Østersø inkl. Bornholm-projektet kan derfor resultere i et fald i størrelsen af den svensk-norske bestand af traner. Da PBR-tærsklen kun skal bruges som en første indikation af bæredygtigheden af udviklingen af store havmølleparker i regionen, anbefales det at vurdere de langsigtede kumulative påvirkninger på traner ved at foretage egentlige bestandsmodelleringer.

2 Introduction

DHI has been commissioned by the Danish Energy Agency to undertake an assessment of areas for development of offshore wind farms on Rønne Bank southwest of Bornholm in relation to birds. The assessment should be based on all available data and published reports focusing on Long-tailed Duck *Clangula hyemalis* for wintering waterbirds and migrating Common Crane *Grus grus*. The spatial extent of the assessment is the Danish EEZ surrounding Bornholm. The focus for the Long-tailed Duck is on areas shallower than 20 m on Rønne Bank and areas close to Bornholm, while the focus for the migrating Common Crane is the migration corridor for the Swedish and Norwegian populations across the Baltic Sea between Sweden and Germany (Figure 1). The assessment aims to determine the suitability of these areas based on an evaluation of the sensitivity of Long-tailed Ducks and Common Crane to wind farms and an assessment of the statistical certainty related to documented distribution and flight patterns.

The data basis for the Long-tailed Duck has been established using fine-scale species distribution models using all available survey data in the southern part of the Baltic Sea. In addition, the distribution of other less important species of waterbirds, i.e. Common Scoter *Melanitta nigra*, Velvet Scoter *Melanitta fusca* and Black Guillemot *Cepphus grille* were mapped by aggregating available data.

As the seabird distribution has been 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 has been identified and given less weight in the final delineation of suitable areas. On the basis of the delineation of suitable areas and available reports on the status of non-breeding waterbirds around Bornholm the need for further waterbird surveys is assessed.

The data basis for the Common Crane has been rangefinder and GPS telemetry data coupled to a flight height model collected and developed as part of the Danish Kriegers Flak project as well as historic observations of migrating cranes from southern Sweden and Bornholm.

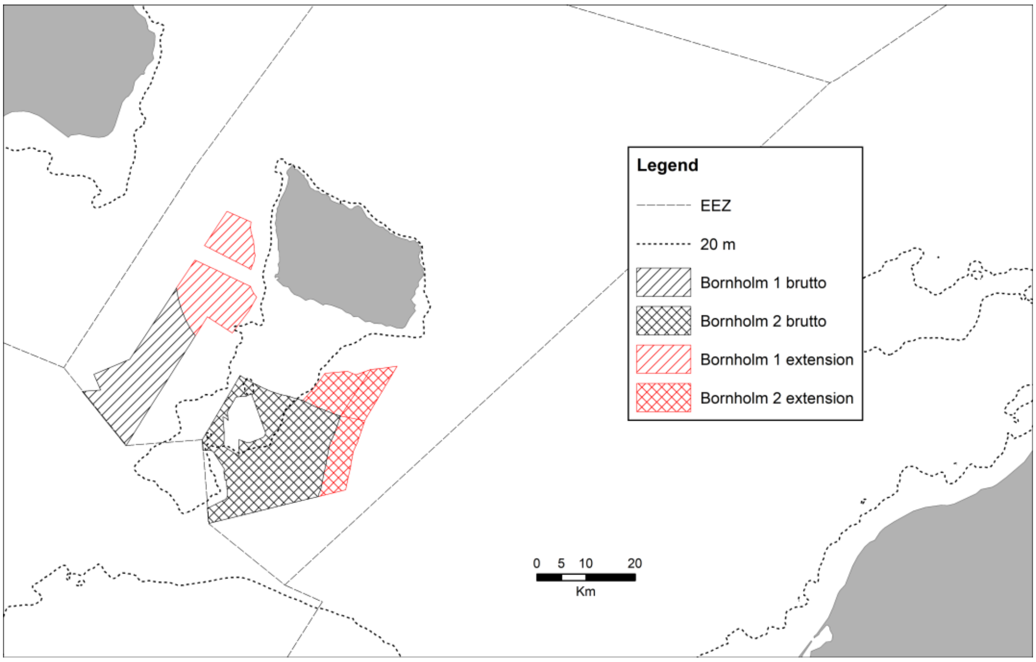


Figure 1 Overview of the area on Rønne Bank outlined by the 20m depth contour in the Danish sector and the two brutto and extension areas designated for offshore wind farm development

3 Methodology

3.1 Survey data

The following data sets from visual and digital aerial transect surveys as well from ship-based transect surveys of seabirds were received and processed:

• Four aerial NOVANA surveys 2004, 2008, 2013 and 2016 (courtesy DCE, Denmark)

• Baseline aerial data collected in relation to the EIA for Bornholm Offshore Wind Farm (courtesy NIRAS, Energistyrelsen 2015, NIRAS 2015)

• Ship-based surveys undertaken in relation to the designation of the NATURA 2000 area south of Gotland (SPA SPA/SCI SE0330308 Hoburgs Bank and the Midsjö Banks) between 2001 and 2009 (courtesy Kjell Larsson, Larsson 2018)

• Aerial surveys undertaken south of Gotland as part of Swedish midwinter counts between 2009 and 2016 (courtesy Kjell Larsson)

• Ship-based surveys undertaken in relation to the identification of important bird areas in the Baltic Sea between 1987 and 2000 (courtesy European Seabirds at Sea Database, Durinck et al. 1994)

• Digital aerial surveys undertaken west of Bornholm in relation to the baseline for the EIA for the Gaz System Baltic Pipe project during 2017-18 (courtesy Rambøll)

An overview of the coverage of surveys included in this investigation is given in Figure 2. In the southern Baltic Sea intensive coverage has been achieved in the shallower (< 30 m water depth) areas known to hold the highest densities of waterbirds, especially seaducks, divers, grebes and Black Guillemot for which species this part of the Baltic Sea holds a significant proportion of the total number wintering in the Baltic Sea (Durinck et al. 1994). Far less coverage has been allocated to the deeper areas of the Arkona and Bornholm Basins which hold very low densities of the above groups of waterbirds.

It is concluded that a reasonably large amount of survey data exists on the occurrence of seaducks in the Danish EEZ around Bornholm. Data on the environmental habitat drivers for the distribution of wintering Long-tailed Ducks in the southern Baltic is additionally available from a much larger volume of surveys, not least from the waters south of Gotland. The complete set of available survey data spans a period of 32 years between 1987 and 2019. This means that lack of knowledge of the distribution and abundance of the species during certain periods can easily be compensated for by predictive modelling using couplings between distribution and the marine biological conditions found in the southern part of the Baltic Sea.

In addition, the temporal trend in the densities of Long-tailed Ducks wintering in the southern Baltic Sea can be described by the model by incorporating survey data from the long time series available. The trend since the early 1990'es to 2009 shows a sharp decline from 4,272,000 to 1,500,000 birds (Skov et al. 2011). According to the most recent counts, the decline in recent years seems not to be as steep as up to 2009. The observed values fit well with a yearly population decline of 7% until around 2009 and 2% from 2011 onwards (Heinänen et al. 2018). The aim of the model predictions is to estimate the densities of Long-tailed Ducks wintering around Bornholm at present time (2020).

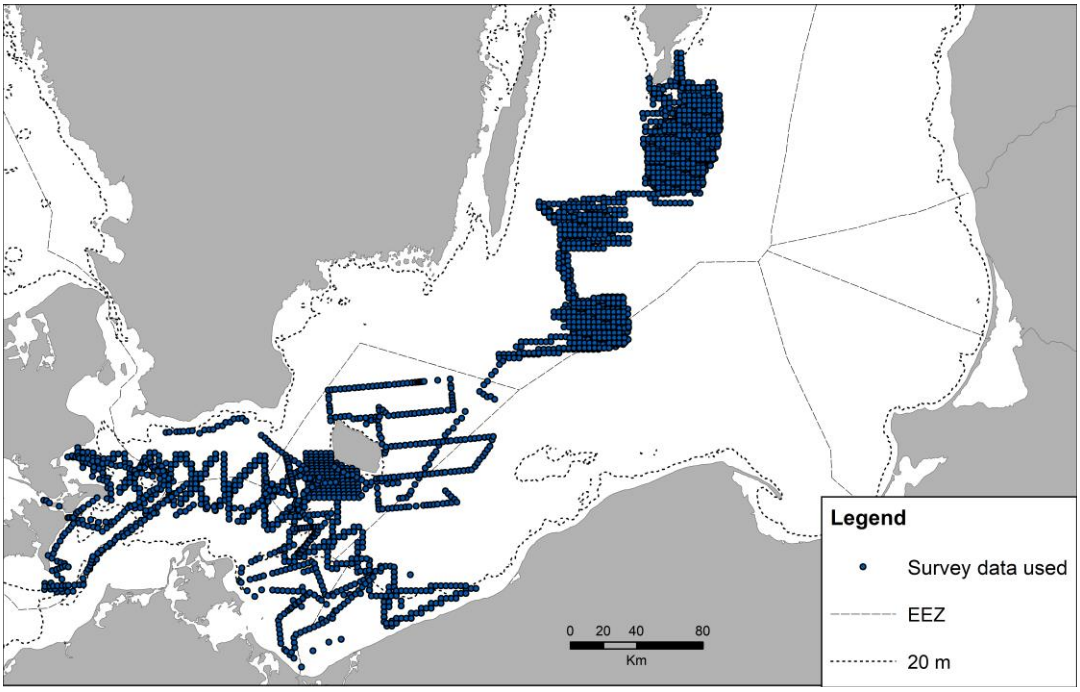


Figure 2 Survey data used for modelling the distribution of Long-tailed Duck *Clangula hyemailis* in Bornholm waters

Table 1 Seabird survey data included in the investigation

Area	Period	Method	Source
Danish EEZ Bornholm	Winters 2004, 2008, 2013 and 2016	Aerial visual line transect survey	AU/DEC – Novana
Rønne Bank	Winter 2015	Aerial visual line transect survey	NIRAS – Baseline Bornholm Offshore Wind Farm
Waters south of Gotland	2001, January 2001, December 2003, March 2009, March	Ship-based line transect survey	University of Gotland
Waters south of Gotland	2009, March 2010, March 2011, March 2016, February	Aerial visual strip and line transect surveys	Lund University – Swedish national waterbird counts
Southern Baltic Sea	1987-2000, January-March	Ship-based line transect surveys	European Seabirds at Sea Database
Bornholm south waters	2017-2018	Aerial digital surveys	Gaz System Baltic Pipe (Rambøll)

3.1.1 Distance analysis

The raw survey data on wintering Long-tailed Ducks 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).

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).

3.1.2 Geo-database on seabird survey data

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 3000 m segments, by adding up segments until 3000 m was reached. In this way equal weighting of aerial survey data in high resolution and ship-based survey data in lower resolution could be achieved. 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 predictor variables described below were extracted to the corrected survey data based on position and time.

3.2 Crane observations and flight height measurements

In connection with the baseline investigations for the Krieger's Flak OWF project the flight behaviour of migrating Common Crane was investigated using satellite telemetry, rangefinder and radar tracking (Skov et al. 2015). These unique data provided high resolution tracks showing flight trajectories and altitudes as Common Cranes cross the Krieger's Flak area during different meteorological conditions. The data have been made available for the assessment of the Bornholm development area.

Eight Common Cranes were equipped with high-resolution GPS satellite transmitters. Radar tracking of migrating Common Crane was carried out from the FINO 2 research platform in the German part of Krieger's Flak, where tracking was done using a high-performance solid-state radar (SCANTER 5000) with enhanced capacity for tracking over long distances and suppression of sea clutter. In addition, laser rangefinders were used to collect 3-D flight data from the FINO 2 platform, from the Falsterbo Rev Lighthouse and from the coasts of eastern Denmark and southern Sweden.

In order to establish the horizontal distribution of migrating cranes from/to the coast of southern Sweden in relation to the development area at Bornholm we investigated 50 years of observations available in SLU's species data portal https://www.artportalen.se/. The data covered 1,019 coastal observations of migrating cranes which were mainly undertaken by amateur ornithologist over the period 1960-2011 (Figure 3). The data were combined with meteorological wind measurements available from SMHI's weather station at Falsterbo (6-hour intervals) www.smhi.se. The focus of the assessment of the distribution of migrating cranes was on the eastern coastal sector between Simrishamn and Ystad. In addition, observations of migrating Common Cranes at Bornholm were mapped using data from DOF-Basen (www.dofbasen.dk) from the period 1974-2020.

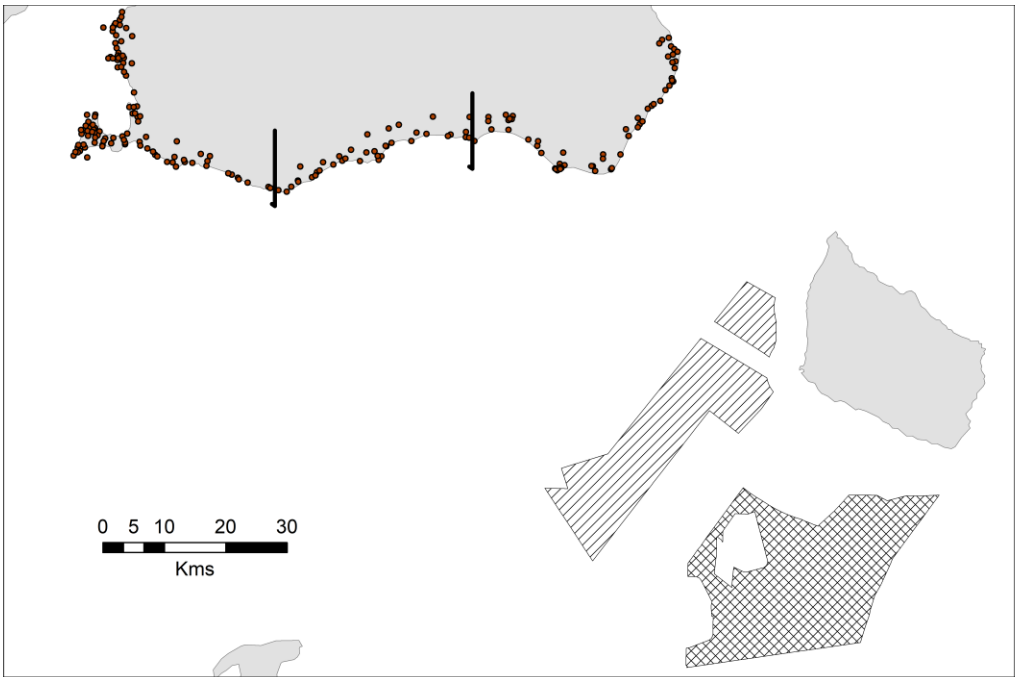


Figure 3 Location of coastal observations of migrating Common Crane *Grus grus* in southern Sweden 1960-2011 used in the assessment of the horizontal distribution of the migration and the proportion likely to cross the development region at Bornholm. The Swedish coastline is split into three sectors used for the assessment

3.3 Seabird distribution modelling

3.3.1 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.

3.3.2 Displacement of Long-tailed Ducks from offshore wind farms

Seaducks like the Long-tailed display avoidance towards offshore wind farms, an avoidance which is manifested as lower use of the wind farm array and the immediate vicinity even if food supply and habitat conditions are suitable otherwise. The general experience regarding displacement of seaducks from offshore wind farms is that no species seem to completely avoid the perimeter of the wind farm (Petersen et al. 2006, 2014, Skov et al. 2012). However, the displacement typically involves an area surrounding the wind farm. Following 20 years' of offshore wind farm development there is no evidence of habituation of seaducks to these installations. Early indications of habituation of Common Scoter to the Horns Rev 1 offshore wind farm have later been revised as more post-construction monitoring data became available (Petersen & Fox 2007, Petersen et al. 2014, Petersen et al. 2018).

3.3.3 Design of Long-tailed Duck model

A high-resolution (3,000 m) model of the winter distribution of LTD in the central Baltic Sea was developed using all available and suitable survey data collected in the region between 1987 and 2019 (Table 1). Although the model has been constructed to accurately describe the spatial distribution of Long-tailed Ducks in the whole region the model is only applied for the focal area of interest in Bornholm waters (Figure 4). The model area covers Bornholm waters and shallows in coastal areas south of Skåne, in the northern part of the Pommeranian Bay (German and Polish EEZ) and the western part of the Slupsk Bank.

Due to the strong decline in Long-tailed Duck population in the Baltic Sea and in the study region over the period the model has been designed to take account of the year-to-year variation. Due to a lack of obvious temporal trends within the winter season, most likely due to uneven temporal survey coverage, the survey month has not been included as a co-variable.

The distribution model was based on the design used for modelling the distribution of Long-tailed Ducks in the Baltic Sea (Skov et al. 2011), and focused on estimating the distribution using the following co-variables:

- Bathymetry (depth and slope)
- Mussel growth index (modelled using mean values from DHI's Baltic Sea model)

Compared to the model applied by Skov et al. (2011) shipping density was not included as a predictor variable but will be included in the revised version to improve the description of avoidance patterns seen in Long-tailed Ducks at traffic lanes. The data on LTD density and associated environmental co-variables were aggregated and used in the model as response variable with the same resolution as the raw data files. The extracted mean environmental variables were included as predictor variables, smoothed terms in the distribution model together with years as a factor variable.

Figure 4 Model area marked by the hatched square

Generalized additive mixed models (GAMMs) were used as a basis for distribution modelling as these models are capable of fitting different family distributions and nonlinear responses (Hastie and Tibshirani 1990). To be able to deal with zero inflation a ''2-step'' GAMM, also called a ''delta'' or a ''hurdle'' model has been used (Stefánsson 1996, Heinänen et al. 2008). The first step of the modelling process was to fit a presence–absence model (binomial distribution), and the second step was to fit a positive model, wherein all records with 0 observations of birds are excluded (Potts and Elith 2006). The positive (density) part of the model was then fitted with a gamma distribution and a log link (Stefánson 1996). To account for non-independences, due to the transect design survey day was included as a random effect and a corARMA correlation structure grouped by survey hour was also included to account for fine scaled spatio-temporal residual correlation within each transect. Only significant variables were retained in the model. The model was fitted in R (R Development Core Team 2004) using the "mgcv" package (Wood 2006).

The final density predictions (birds km^2) were derived by multiplying the probability of presence (derived from the binomial model) with the expected density (derived from the gamma model).

3.3.4 Assessment of uncertainty in modelled distribution of Long-tailed Duck

The uncertainty about the predicted seabird distributions was assessed using 95% confidence intervals for the function estimate of the models. The confidence intervals were mapped to define areas of higher uncertainty.

3.3.5 Assessment of importance of areas to Long-tailed Ducks around Bornholm

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.

3.3.6 Assessment of habitat displacement of Long-tailed Ducks around Bornholm due to Bornholm wind farms

The assessment of the sensitivity of areas of higher densities marked by the 90th percentiles of modelled distributions of Long-tailed Ducks to displacement from offshore wind farms was made using the best available data from monitoring programmes in the Baltic Sea. The general experience regarding displacement of seaducks from offshore wind farms is that no species seem to completely avoid the perimeter of the wind farm (Petersen et al. 2006, 2014, Skov et al. 2012). However, the displacement typically involves an area surrounding the wind farm. Very few data exist on displacement of Long-tailed Duck from offshore wind farms, yet the data from Nysted wind farm provide some information (Petersen et al. 2014). Comparisons of the sampled abundance between pre- and post-construction periods revealed a reduction in numbers of Long-tailed Duck to two kilometres distance from the wind farm, yet only the reduction within the wind farm was statistically significant when accounting for imperfect detection, local surface features and autocorrelation (Petersen et al. 2014).

Looking at the encounter rates, mean abundance of Long-tailed Duck dropped by almost 90 % within the wind farm, and by 67 % in the 2 km buffer zone. However, judged by the lower bounds of the 95 % confidence intervals of the encounter rates the reductions were 61 % and 28 % within the wind farm and the buffer zone, respectively. Accordingly, taking a conservative approach a displacement rate of 75 % within the wind farm and 50 % within the 2 km buffer zone was applied in this assessment of the potential displacement of the species from offshore wind farms in Bornholm waters.

3.4 Assessment of migration patterns of Common Crane at Bornholm

3.4.1 Assessment of the horizontal and vertical distribution of Common Crane

In order to generalise the satellite tracking, radar and rangefinder observations flight models were developed which coupled flight heights to weather parameters using Generalised Additive Mixed Models. These models are suitable for explaining the differences in flight altitude related to wind and weather conditions (wind speed, air pressure, relative humidity, clearness and temperature) and distance to land (seasonal departure coast for the birds). If the flight altitude of Common Crane changes significantly with weather conditions the probability for collision will most likely also vary at the site, and the overall collision mortality will depend on the frequency of adverse conditions which cause the birds to fly at rotor height. To be able to model the non-linear relationships (between the altitude and predictor variables), non-normally distributed errors and also account for the spatial and temporal autocorrelation (non-independencies in the residuals) in the data we used the semi-parametric and data driven generalized additive mixed modelling approach (GAMMs, Wood 2006). Species-specific GAMMs with a suitable error distribution, either a Tweedie error distribution (with a log link and a power parameter between 1 and 2) or a gamma distribution (with log a link) were fitted. To account for the temporal and spatial autocorrelation in the data we include the date (day and month) as a random term and a first order autocorrelation structure, corAR1, grouped by the individual tracks. The random effect and correlation structure were needed as one of the assumptions of the statistical method is that the samples (within the rangefinder, GPS telemetry or radar tracks) are independent of each other. This assumption is naturally violated as the succeeding samples in the various tracks are highly dependent on the previous samples.

We included distance to departure coast and clearness as smooth functions. Wind speed was included as a smooth function and directions as a factor variable. The weather data were obtained from modelled weather data from the regional model (WRF) by StormGeo (www.storm.no). Modelled weather data were used in order to link obtained radar and rangefinder tracks at all locations to local weather conditions based on closest possible match in space and time. The regional weather model is based on the global weather model run by the European Centre for Medium-Range Weather Forecasts (UK). The spatial resolution of the WRF model is 0.1 x 0.1 degree, and the temporal resolution is one hour. The GAMM models were fitted using R version 2.13.0 (R Development Core Team, 2004) and the “mgcv” package (Wood, 2006).

The predictive accuracy of the models was evaluated by using a split sample approach, fitting the model on 70% of the tracks and evaluating the models on the remaining 30%. The agreement between the observed and predicted altitudes was tested using the Spearman’s rank correlation coefficient. The model fit was also assessed by the adjusted R-square values (variance explained) and an inspection of the residuals. We further used the models (based on all tracks) for predicting the average flight altitude at Krieger’s Flak during average weather conditions (in the species-specific data set) during tail, head and cross winds.

3.4.2 Assessment of cumulative collision risk with existing and planned projects

The behavioural responses of migrating cranes were decomposed into micro, meso and macro avoidance using the framework proposed by Cook et al. (2014) and further elaborated on by May (2015). According to May (2015) macro avoidance generally reflects the displacement of flying birds from the wind farm perimeter, while meso avoidance reflects the aversive flight behaviour of the birds towards individual turbines. Micro avoidance reflects the last second behavioural response of the birds in or near the rotor-swept zone in order to avoid collision with the rotor blades. Macro and meso avoidance rates of migrating cranes were measured by the radar and rangefinder tracking at the Baltic 2 wind farm in relation to the Danish Krieger’s Flak project (Skov et al. 2015), while in the absence of detailed recordings from the rotor-swept zones of the wind farm the micro avoidance rate was taken from Winkelmann (1992) who reported a general rate of 0.92 for birds at land-based wind farms. The macro avoidance zone was defined as the area around the wind farm, while the meso avoidance zone was defined as the rotor zone including a 10 m buffer (Cook et al. 2014). The geometry of the rotor zone was determined in real time by aligning the rotor perpendicularly to the direction of the wind at the time of the bird crossing. The rotor zone had a width of 13.5 m (chord width of the rotor blades + 10 m). All crane tracks recorded as intersecting the Baltic 2 wind farm perimeter including the buffer around the rotor zone were classified as non-macro avoidance, and tracks recorded as intersecting a rotor zone plus buffer area were classified as non-meso avoidance.

Macro and meso avoidance rates were estimated by summarizing the number of tracks recorded as intersecting and non-intersecting using either radar or laser rangefinder using the following formula:

$$\text{Avoidance rate} = \frac{(N\ tracks\ non{-}intersecting)}{(N\ tracks\ non{-}intersecting)+(N\ tracks\ intersecting)}$$

The overall avoidance displayed by the cranes to the Baltic 2 wind farm was calculated by integrating the specific macro, meso and micro avoidance rates as:

$$\text{Total avoidance} = 1 - ((1 - macro)\ x\ (1 - meso)\ x\ (1 - micro))$$

The number of annual collisions of Common Crane for the Bornholm wind farm layouts 1 and 2 was estimated using the Band (2012) collision model for single transits of the same individual, which has been widely applied to land-based and offshore wind farms in order to assess likely collision risks for migrating birds. The Band model provides predictions of the number of birds likely to be killed annually due to collisions with the specified design conditions for the two layouts using a range of parameters relating to the flight behaviour and morphological details of the species and the estimated avoidance rates from the behavioural records at the Baltic 2 wind farm (Table 2).

The Band collision model is split into five stages. Stage A assembles data on the number of flights which, in the absence of birds being displaced or taking other avoiding action, or being attracted to the windfarm, are potentially at risk from wind farm turbines. Stage B uses the flight activity data to estimate the potential number of bird transits through rotors of the windfarm. Stage C calculates the probability of collision during a single bird rotor transit. Stage D multiplies these to yield the potential collision mortality rate for the bird species in question, allowing for the proportion of time that turbines are not operational, assuming current bird use of the site and that no avoiding action is taken. Finally, stage E allows for the proportion of birds likely to avoid the windfarm or its turbines, either because they have been displaced from the site or because they take evasive action.

Table 2 Input parameters for the Band collision model. Measurements of bird length and wingspan was derived from www.dofbasen.dk and flight speed from Alerstam et al. (2007). Nocturnal activity and flight type is assumed based on expert knowledge. Proportion at rotor height and proportion of flight upwind during migration is based on the collected track data combined with historical meteorological measurements from Falsterbo, Sweden (www.smhi.se) and a 3.6 MW turbine with a maximum height of 141 m.

Parameter	
Avoidance rate	0.83
Bird length (m)	1.15
Wing span (m)	2.15
Flight speed (m/sec)	13.6
Nocturnal activity*	1
Flight type; gliding (G) or flapping (F)	F
Width of migration corridor (km)	140
Proportion at rotor height	79%
Proportion flight upwind	50%

* Degree of nocturnal activity indicated by a range from 1 (low) to 5 (high).

The collision estimates are thus derived by combining the 5 stages. Stage A defines flight activity of birds, which is used in Stage B for estimating the “flux” of birds trough the rotors due to the passage rates. In order to estimate the passage rates through the development area the 50 years of coastal observations of migrating Common Crane from southern Sweden (between Simrishamn and Falsterbo) were analysed in relation to the location and wind direction. All observations involving more than 10 birds were analysed. Based on the wind statistics from Falsterbo the probability for cranes migrating through the easternmost 1/3 of the Swedish coastline was calculated given the probability of observations during head, tail, eastern cross and western cross winds. This probability was converted to passage rates by combining with the mean frequency of the four types of winds over the course of the 50-year period.

In stage C the probability of collision during a single transit is calculated based on the wind turbine and bird characteristics. Stage B and C are further combined in Stage C by multiplying the number of bird transits with the single transition collision risk and the proportion of time the windfarm is operating, which gives the number of collisions per month assuming no avoidance reactions. In Stage D the number of collisions is multiplied by the overall avoidance rate to yield the final collision estimate per month.

Several wind farms are planned in the region of the Arkona Basin, of which four have been consented and six have been submitted or are in the process of submitting consent applications to the Danish, Swedish and German planning authorities (Figure 5, Table 3). Once built, each of these 15 wind farms will inevitably cause additive mortality to Common Cranes migrating between Germany and Sweden due to collisions. Although a significant collision impact on the Swedish and Norwegian populations of Common Crane from the planned wind farms at Bornholm alone may be unlikely adverse effects arising from in-combination collision risk with all planed wind farms in the migration corridor between Bornholm and Falster-Sjælland may not be precluded and as such possess a potential significant impact. The cumulative collision risk was assessed in combination with the Bornholm layouts 1 and 2, respectively (COWI 2020).

Table 3 Overview of planned, consented and built offshore wind farm projects in the Arkona Basin.

Name	Country	Status	Year of construction	Turbine size (MW)	Number of turbines
Middelgrunden	DK	Built	2000	2	20
Lillgrund	SE	Built	2006	2.3	48
Breitling	DE	Built	2006	2.5	1
Baltic 1	DE	Built	2010	3	48
Avedøre Holme	DK	Built	2009	3.6	3
Baltic 2	DE	Built	2013	3.6	80
Wikinger Nord	DE	Built	2016	5	70
Arkona	DE	Built	2019	6	60
Arcadis Ost	DE	Consented	2020	4	58
Wikinger Süd	DE	Consented	2020	5	18
Gennaker	DE	Planned	2020	8	100
Kriegers Flak I	DK	Consented	2021	8	72
Nordre Flint	DK	Planned	2022	5	32
Aflandshage	DK	Planned	2022	5	50
Baltic Eagle	DE	Planned	2022	6	83
Kriegers Flak II	SE	Consented	2023	5	128

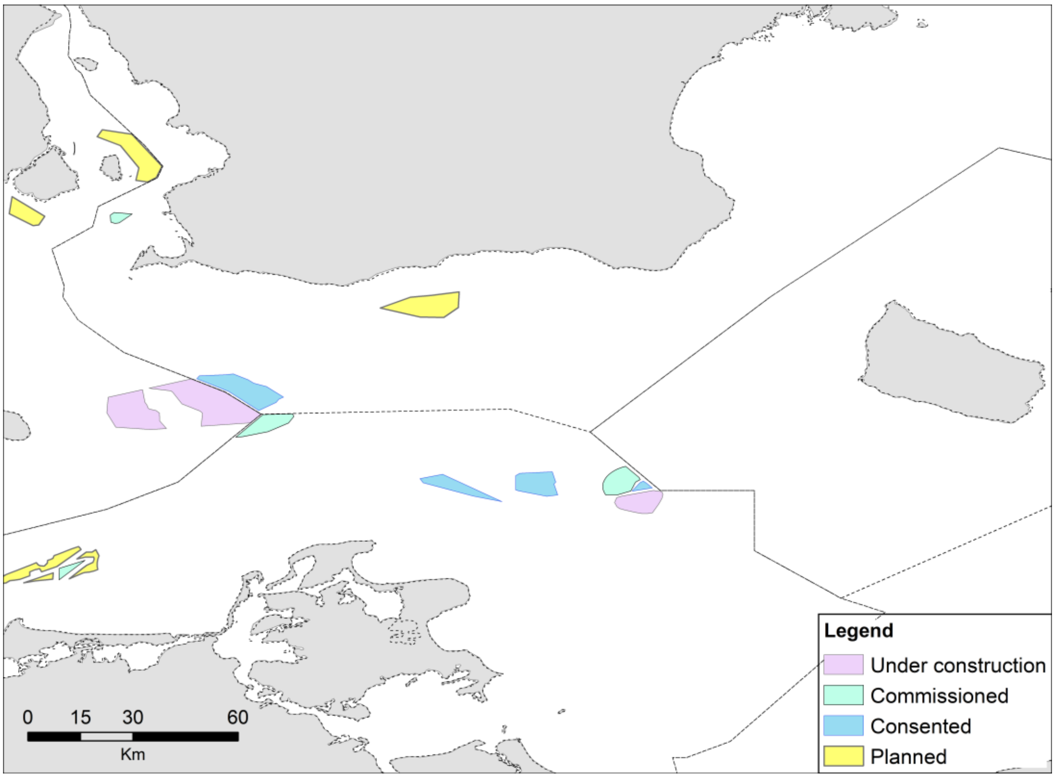


Figure 5 Overview of planned, consented and built offshore wind farms in the Arkona Basin.

Indications of potential population level effects on account of the estimated collision rates of Common Cranes at the Bornholm wind farm layouts were obtained using thresholds for sustainable removal following the Potential Biological Removal (PBR) concept. In addition, population level effects of estimated collision rates related to the construction of planned offshore wind farms in Danish, German and Swedish parts of the western Baltic Sea were also assessed. Almost all Common Cranes migrating across the region are recruited from the Swedish-Norwegian population. The Swedish and Norwegian population of Common Crane is estimated to 75,000 and 9,000 individuals, respectively. Of these, all 84,000 birds were set to cross the wind farm development region in the western Baltic Sea, although smaller numbers occasionally pass both east and west of this region (Swanberg 1987). The PBR approach which defines the threshold of additional annual mortality, which could be sustained by a population, is widely used to guide conservation and management of long-lived species like marine mammals (Wade 1998) and has been demonstrated as a useful tool to assess impacts of fisheries by-catch mortality on birds (Žydelis et al. 2009). Although PBR should only be used to derive indications of potential unsustainable impacts on populations, the metric accounts for potential bias due to density dependence, uncertainty in estimates of the population size and stochasticity (Wade 1998, Taylor et al. 2000, Milner-Gulland & Akcakaya 2001). Additive mortality exceeding PBR would indicate potentially overexploited populations.

If the aim of metrics in population modelling is to test whether or not the conservation objectives of a site will be met, for example on the integrity of the SPA network for Common Crane, any approach used must typically be capable of assessing whether the resultant additional mortality will mean a population can be maintained at its current level. For this reason, PBR has its limitations in its application (Cook & Robinson 2015, Green et al. 2016). Wade (1998) demonstrated that if the additional mortality resulting from a project is equal to that obtained from estimates of PBR, populations can reach equilibrium at a point well below the carrying capacity of the available habitat. PBR is calculated using the following general equation (Wade 1998):

$$PBR = \frac{1}{2} R_{\max} N_{\min} f$$

where R_{max} is maximum recruitment rate, N_{min} is minimum population size for a range of years, and *f* is recovery factor used to account for uncertainty in population growth rate and population size. Maximum recruitment rate is calculated considering maximum annual population growth rate:

$$R_{max} = \lambda_{max} - 1$$

where λ_{max} is maximum annual population growth rate, which is solved using the equation suggested by Niel & Lebreton (2005), which requires only adult bird annual survival probability (S_{ad}) and age of first reproduction (α):

$$\lambda_{max} = \exp\left(\left(\alpha + \frac{S_{ad}}{\lambda_{max} - S_{ad}}\right)^{-1}\right)$$

For minimum population size (N_{min}) Wade (1998) suggested using the lower bound of the 60% confidence interval of a given population estimate. As only one number was available as population estimate for Common Crane, we followed Dillingham & Fletcher (2008) and estimated N_{min} using the 20th percentile of the population estimate assuming coefficient of variation $CV_{\bar{N}} = 0.05$.

The population recovery factor *f*, used to account for uncertainty in population growth rate and population size, ranges between 0.1 and 1. Dillingham & Fletcher (2008) suggested a recovery factor *f* = 0.7 for increasing populations, *f* = 0.5 for stable populations, *f* = 0.3 for declining, *f* = 0.1 for rapidly declining.

Several thresholds were defined in order to inform the assessment of potential population effects on Common Crane. The PBR threshold for a stable population (*f* = 0.5) was estimated at 1,887 birds, while the threshold for an increasing population (*f* = 0.7) was assesses at 2,642 birds. Annual survival probability was set to 0.9 and age of first reproduction to 4 (Robinson 2005). The final PBR values are sensitive to the f value assumed, with an increase in f from 0.1 to 0.5 reflecting a five-fold increase in the PBR value estimated. However, the value selected is rarely based on empirical evidence and indeed in this case there was a notable absence of information on recent changes in anthropogenic sources of mortality of relevance to Common Crane. The value of 10 % annual mortality mentioned in Robinson (2005) originates from studies of Sandhill Cranes Grus canadensis in the 1970'es (Johnsgard 1983). Hence, little evidence exists of the current influence of a number of potential additive mortality factors on mortality and survival rates in Common Cranes. These factors include:

- Impairment of breeding habitats due to decline in area of wetlands caused by climatic changes;
- Impairment of breeding habitats due to decline in area of wetlands caused by drainage and agricultural practices;
- Disturbance during breeding from increased anthropogenic activities
- Increased disturbance during non-breeding from increased anthropogenic activities
- Increased mortality due to collisions with power lines and wind farms

Swedish monitoring data based on countrywide point counts (716 routes) show a general 4% increase in the number of breeding pairs since 1997 (Figure 6, www.fågeltaxering.lu.se). However, the trend shows a stabilisation after 2006, and observations of staging cranes at Hornborgasjön, Västergötland (http://extra.lansstyrelsen.se/hornborga) and Pulken, Skåne (www.artportalen.se) show stabile trends since 2013 (Figure 7). These recent trends are corroborated by the overall trend in Europe after 2000 (Prange 2005).

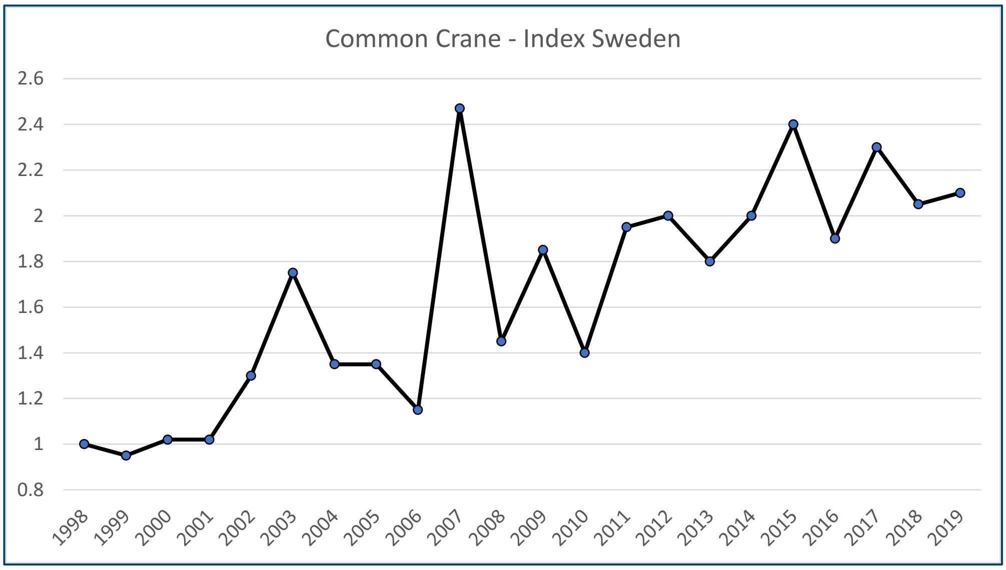


Figure 6 Trend in the number of breeding pairs of Common Crane monitored through the Swedish standardised point counts between 1997 and 2019

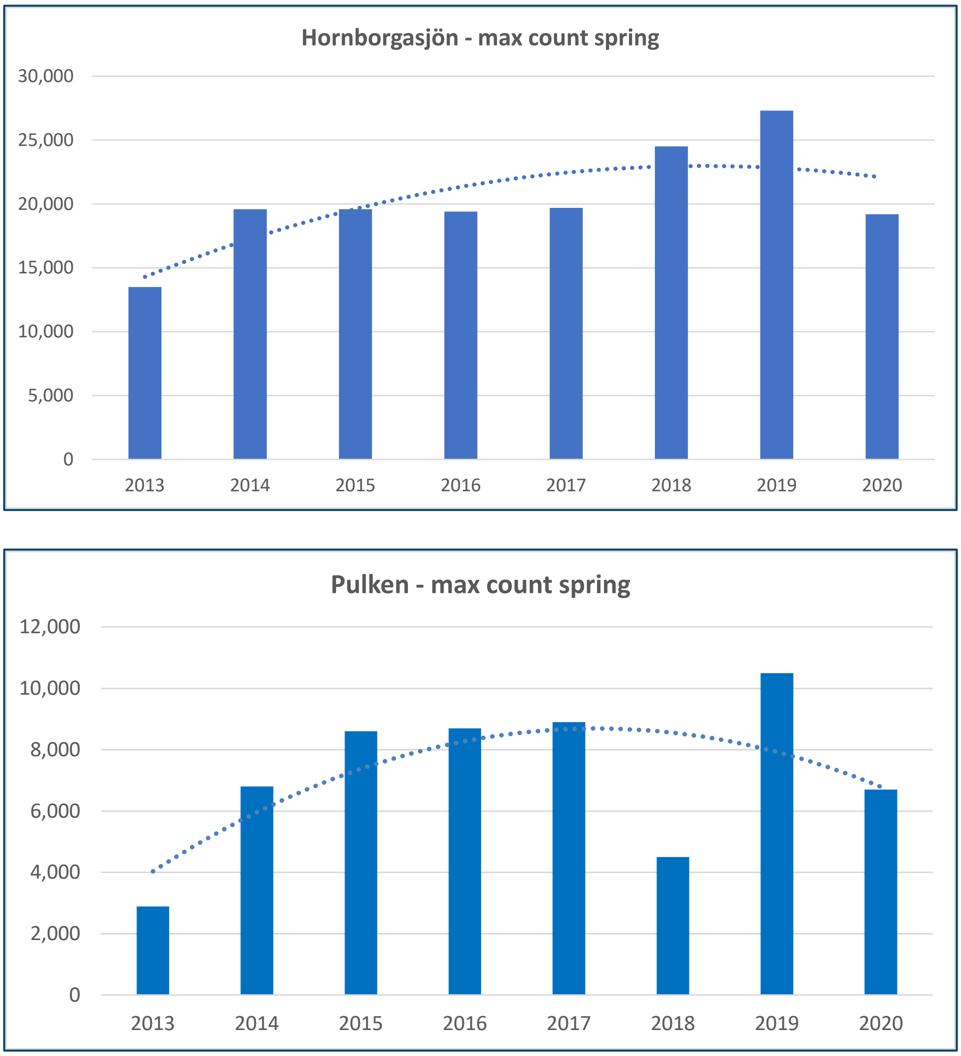


Figure 7 Recent trends in the number of Common Crane (maximum count) staging during spring at Hornborgasjön (Västergötland) and Pulken (Skåne)

Accordingly, a stabile Swedish population was used as a reference population in a precautionary fashion in view of the most likely population development over the future 10-year period of wind energy production in the region. The less likely scenario with a continued increase of the population was also applied for comparison.

4 Results

4.1 Distribution models

4.1.1 Long-tailed Duck

The results of the Long-tailed Duck distribution model are shown in , and the modelled relationships are shown in Figure 8. The preference of the species for shallow water and areas of high mussel biomass is well described by the model. The model further describes the rapid decline in the occurrence of the species since the mid 1990es with a somewhat smaller decline during recent years. The abundance is mainly governed by water depth and shows a peak in areas between 10 m and 20 m water depth. The comparison between observed and modelled densities along the survey lines indicates good correspondence and predictive power of the model (

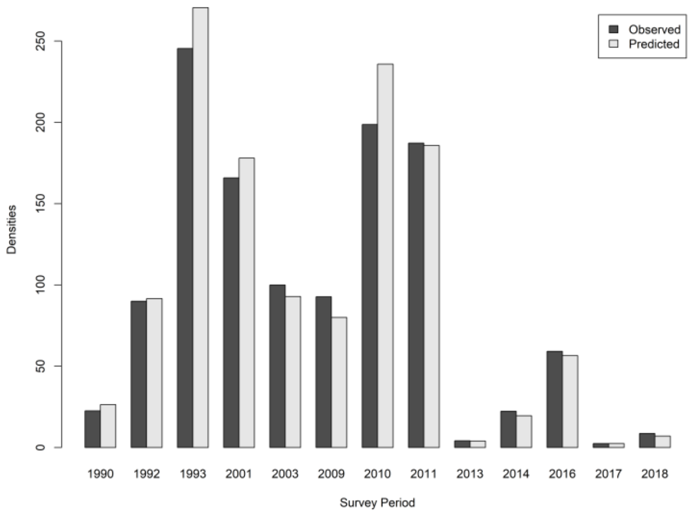


Figure 9).

In Figure 10 the spatial distribution of predicted densities of Long-tailed Ducks for the winter 2020 are mapped. The model predicts medium densities above 15 birds/km^2 in all areas, including Rønne Bank with water depths between 10 m and 20 m. The area of medium densities on Rønne Bank overlaps the brutto area of the wind farm area 2 (Figure 11). The Arkona and Bornholm Basins generally hold very low densities of Long-tailed Ducks according to the model predictions, and this includes the whole area of wind farm area 1 as well as the extension of wind farm area 2.

The patterns of model uncertainty displayed by the 95% confidence intervals show that the distribution of Long-tailed Ducks has been reliably modelled both with respect to shallower areas of medium densities and the deeper areas of lower densities (Figure 12).

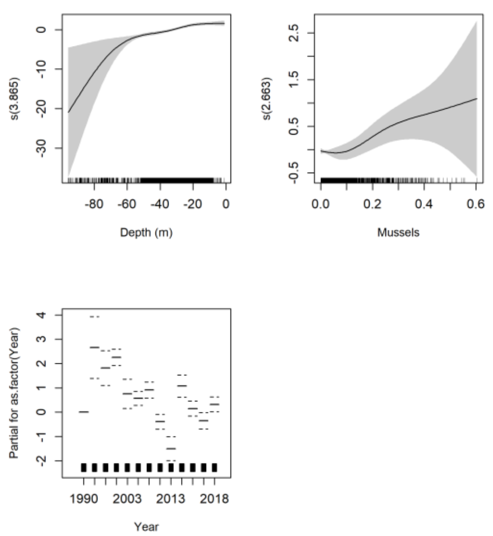
Bornholm 1 hardly overlaps with the modelled distribution of medium densities of Long-tailed Ducks, whereas the western part of Bornholm 2 does overlap with these densities. The estimated potential displacement of the species from the two wind farm areas is shown in Figure 13 and Table 5. The mapped areas of high habitat suitability to Long-tailed Ducks show a coherent zones of suitable habitat in all areas between 10 m and 20 m water depth, including most of the Rønne Bank. Limited displacement of Long-tailed Ducks from suitable habitat is estimated from wind farm area 1, whereas the displacement zone from brutto area 2 covers 189 km^2 of suitable habitat, and including the extension zone 216 km^2 of suitable habitat. The estimated mean number of displaced ducks from brutto area 1 is 0, while the estimate for brutto area 2 is 2,989, including the extension 3,262. These numbers represent 0.20% and 0.22% of the total Baltic wintering population of Long-tailed Duck, respectively

(Skov et al. 2011, Table 5). The displacement from Bornholm 2 could be reduced by approximately 40% by developing only the eastern part of the area (Table 5).

Table 4 Smooth and parametric terms and adjusted R-square values for the Long-tailed Duck distribution model. Edf (effective degrees of freedom), 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	z	p-value	Estimate	t	p-value
Parametric terms						
1990	-1.034	-5.416	0	4.132	25.949	0
1992	2.658	4.195	0	0.294	0.672	0.502
1993	1.817	5.093	0	1.671	4.341	0
2001	2.253	13.318	0	1.299	6.235	0
2003	0.753	2.525	0.012	0.841	1.979	0.048
2009	0.566	3.933	0	0.914	4.114	0
2010	0.912	5.576	0	1.86	7.783	0
2011	-0.392	-2.604	0.009	2.287	8.868	0
2013	-1.502	-6.103	0	-1.459	-3.169	0.002
2014	1.075	4.716	0	-0.987	-3.487	0.001
2016	0.146	0.965	0.335	0.841	3.399	0.001
2017	-0.35	-2.09	0.037	-2.037	-7.095	0
2018	0.319	2.088	0.037	-1.39	-5.848	0
		edf	p-value	edf	F	p-value
Depth		3.865	0	3.421	12.083	0
Mussel biomass		2.663	0.012			
R-sq.(adj)	0.288			0.051		
Sample (n)	4,143			1,880		

PA model part



POS model part

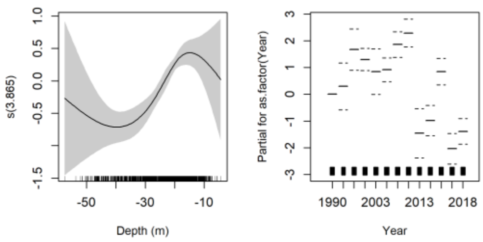


Figure 8 Partial GAMM plots for the Long-tailed Duck *Clangula hyemalis* distribution model – presence-absence (upper panel) and positive density (lower panel) parts. The values of the key environmental variables are shown on the X-axis and the probability on the Y-axis in the scale of the linear predictor. The grey shaded areas and the dotted lines (for factors) show the 95% Bayesian confidence intervals.

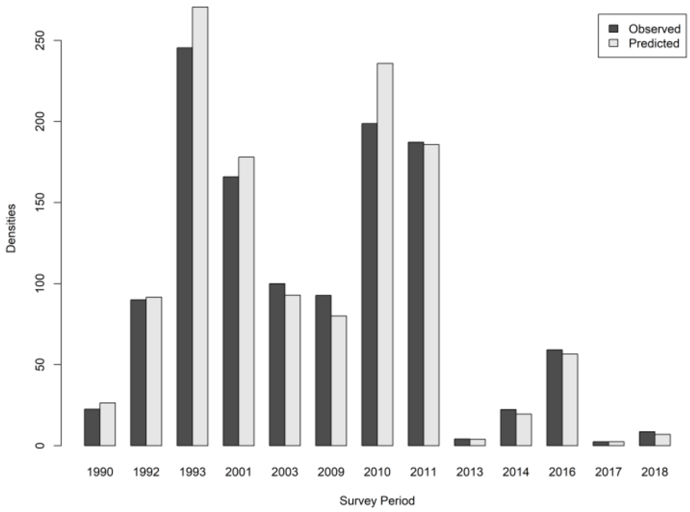


Figure 9 Comparison of predicted versus observed numbers of Long-tailed Duck *Clangula hyemalis* along the surveyed transect lines.

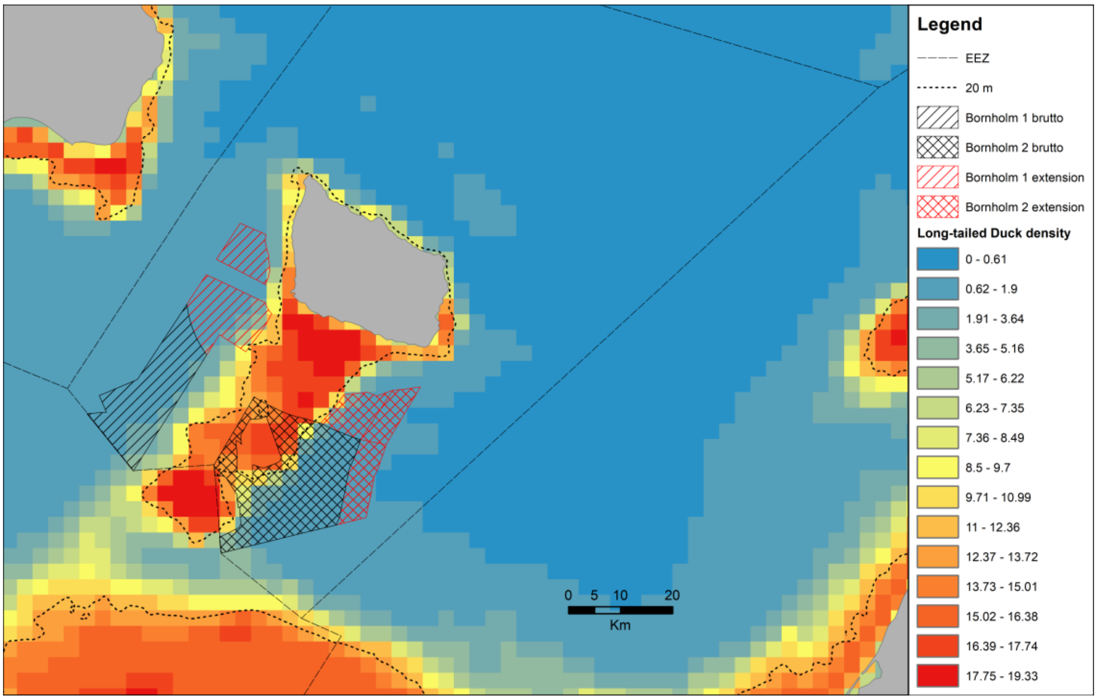
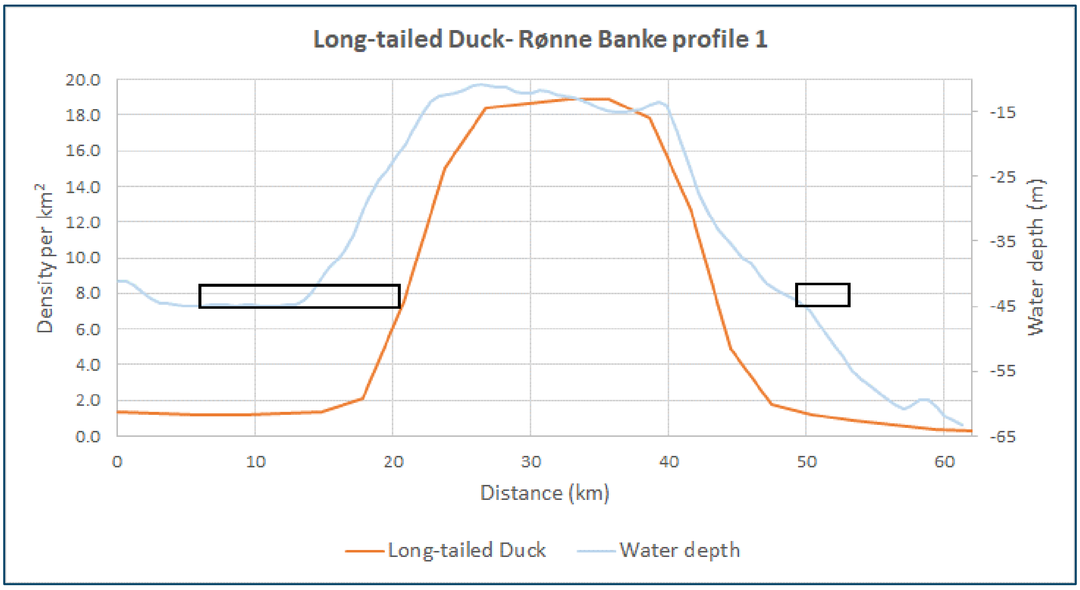


Figure 10 Predicted densities of Long-tailed Ducks *Clangula hyemalis* in 2020 within and around the Danish EEZ at Bornholm



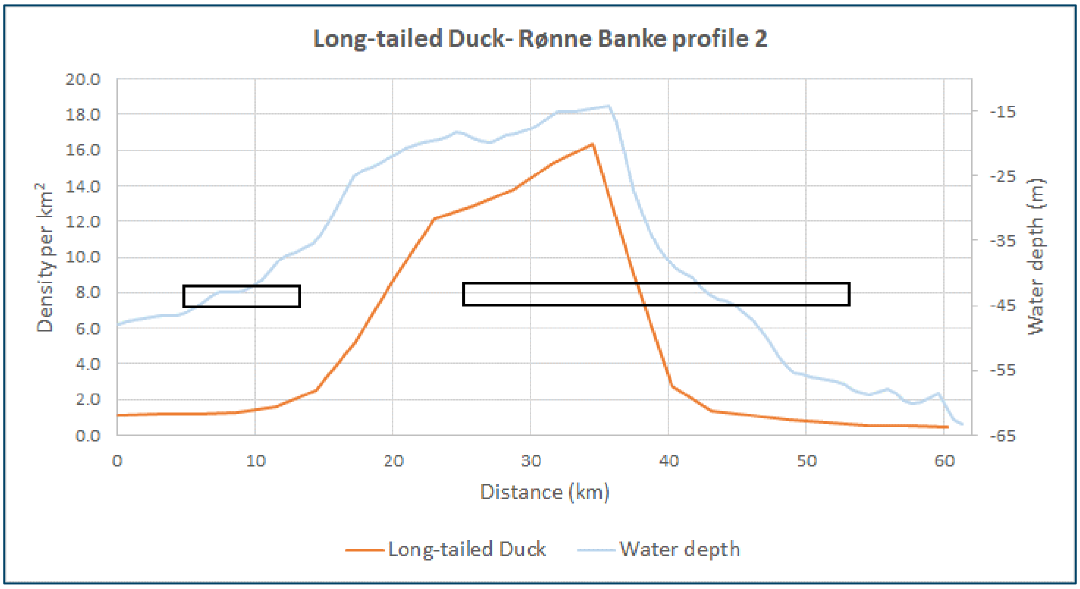


Figure 11 Predicted gradients in the mean monthly density (n/km^2) of Long-tailed Ducks *Clangula hyemalis* along two profile lines crossing Rønne Bank. Boxes indicate the location of the planned wind farms

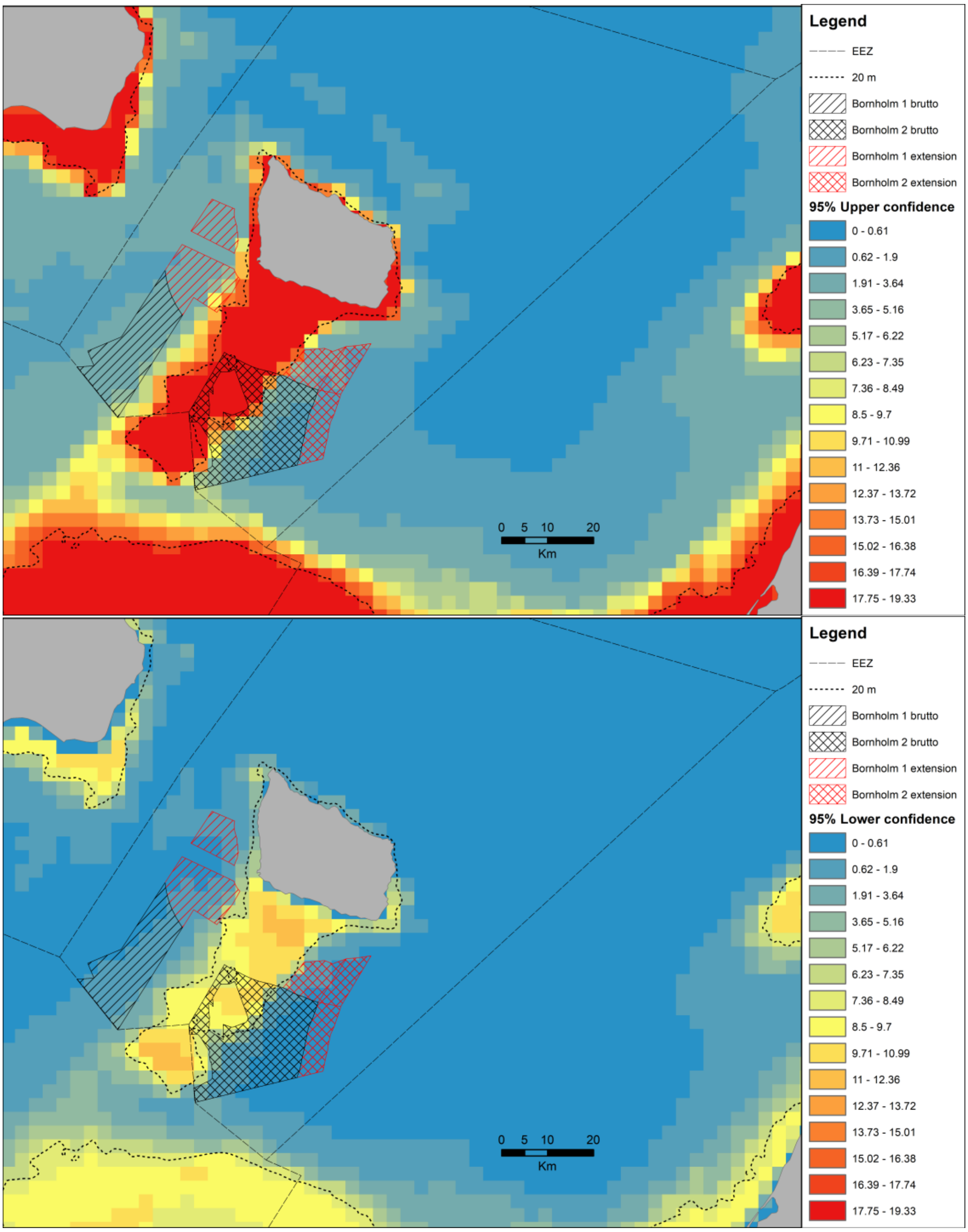


Figure 12 Uncertainty of predicted mean density (n/km^2) of Long-tailed Ducks *Clangula hyemalis* in 2020 in the Danish EEZ around Bornholm expressed as upper and lower 95% confidence levels

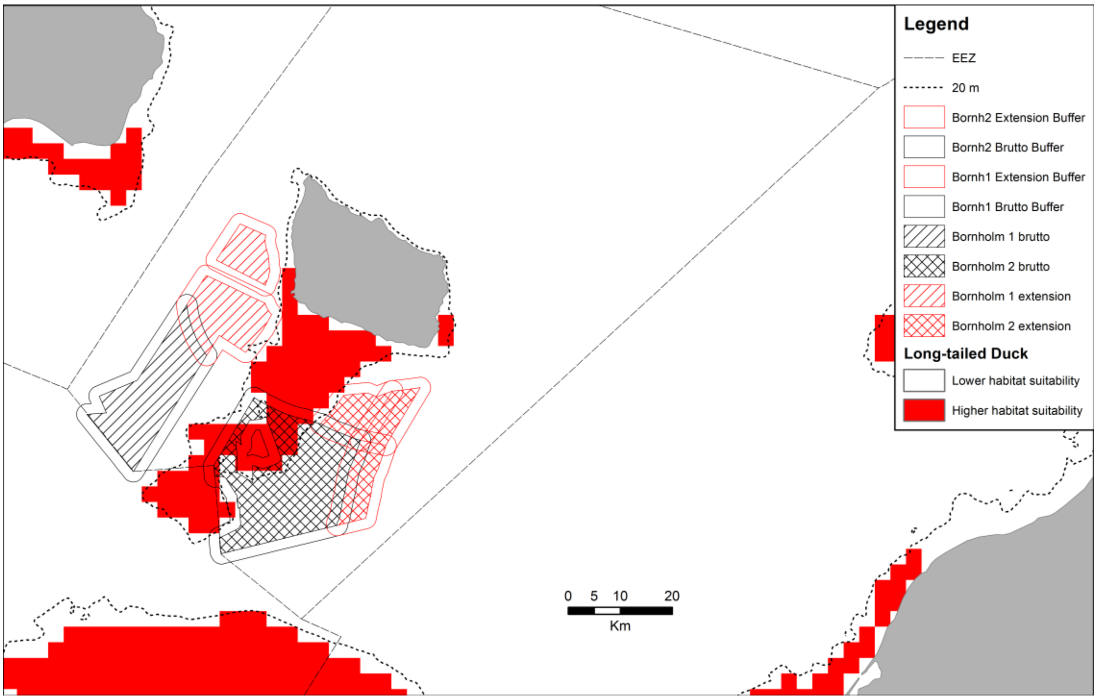


Figure 13 Areas of high habitat suitability to predicted densities of Long-tailed Ducks *Clangula hyemalis* in 2020 in the Danish EEZ around Bornholm and displacement zones from the two brutto and extension areas

Table 5 Statistics on the estimated displacement of predicted densities of Long-tailed Ducks *Clangula hyemalis* in 2020 in the Danish EEZ around Bornholm from the brutto and extension areas. For Bornholm 2 a reduced area in the eastern part is included

Area	Brutto area I	Brutto area II	Brutto area II east	Brutto + extension area I	Brutto + extension area II	Brutto + extension area II east
Area (km^2)	270.22	461.63	389.54	493.64	662.99	590.90
Area of high habitat suitability within displacement range (km^2)	0	189	99	0	216	116
Number of displaced birds	0	2,989	1,778	100	3,262	2,070
% displaced birds of total Baltic Sea population*	0%	0.20%	0.12%	0.007%	0.22%	0.14%

* wpe.wetlands.org

4.2 Observed seabird densities

4.2.1 Common and Velvet Scoter

Common and Velvet Scoter occur in high densities in the Pomeranian Bay south of Rønne Bank (Figure 14). On Rønne Bank and in the planned Bornholm 2 wind farm site they are only found in low densities, and typically close to or on Adler Ground.

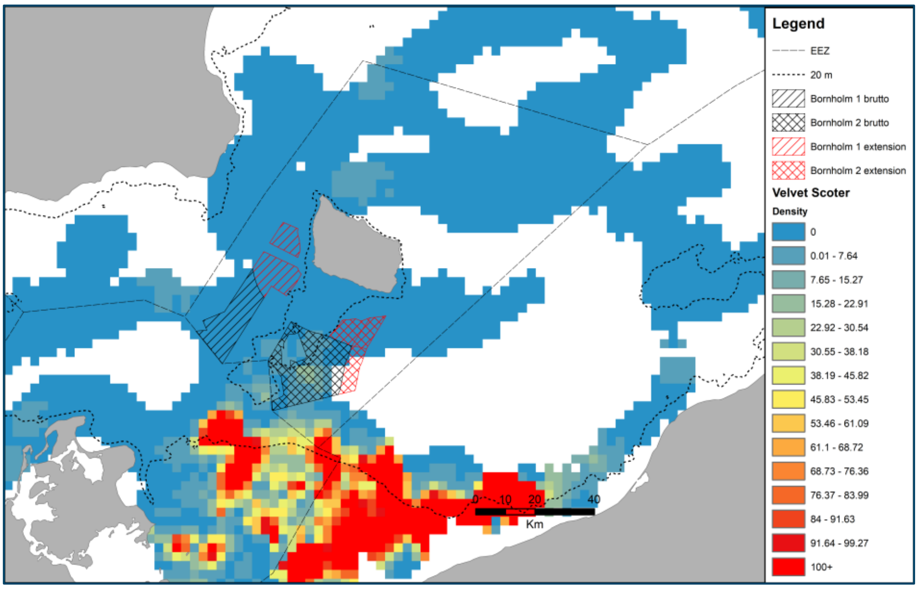


Figure 14 Observed densities of Velvet Scoter *Melanitta fusca* during ship-based surveys in the region around Bornholm

4.2.2 Black Guillemot

Durinck et al. (1994) classified Rønne Bank together with parts of the Pommeranian Bay and Polish coastal waters as a core area for Black Guillemot during winter (Figure 15). Unfortunately, the species is difficult to identify during aerial surveys. As ship-based surveys have not been undertaken on Rønne Bank since early 1990'es the present status of the area in relation to Black Guillemot is not known.

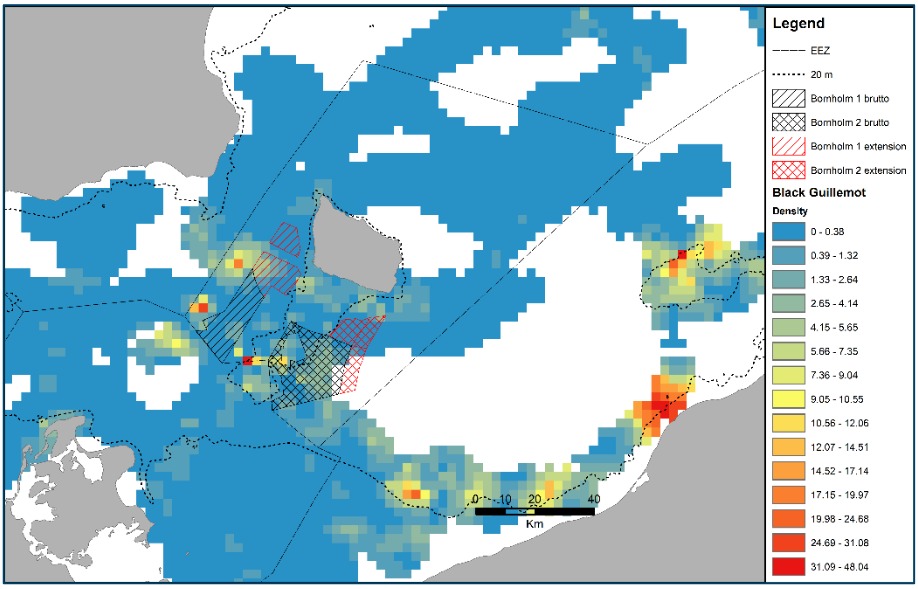


Figure 15 Observed densities of Black Guillemot *Cepphus grylle* during ship-based surveys in the region around Bornholm

4.3 Migration of Common Crane

4.3.1 Migration intensity of Common Crane

The total Swedish and Norwegian populations (including juveniles) which pass the Arkona Basin is estimated at 84,000 individuals (Wetlands International 2012), and they cross the whole region between Bornholm and Falster over a broad front both during spring and autumn. The population in northern Europe has shown an increasing trend at least over the past 27 years; 0.84% per year from 1988-2012 and 2.43% per year from 2003-2012 (Wetlands International 2012). The population in Sweden is estimated to have increased by 4 % annually since 1997 but has stabilised after 2005 (Figure 6).

4.3.2 Horizontal and vertical distribution of Common Crane

Even though the tracks obtained by satellite GPS telemetry during 2013-2014 indicate that most birds may cross centrally, telemetry data from the Swedish University of Agricultural Sciences from 2011-2012 show otherwise and stress that the birds indeed may cross anywhere between Bornholm and the coast of Zealand, Møn and Falster. During autumn most birds stage on wetlands in Rügen, Germany, while during spring most birds stage 50 km further west in the Darss area. Whether these changes in key staging areas give rise to different mean migration routes across the basin during spring and autumn is unknown. The vast majority of directions from Falsterbo recorded during the Kriegers Flak baseline investigations in autumn 2013 were concentrated around south in the direction of Rügen (Figure 16). During spring 2013, the mean direction of migrating Common Crane was 13°.

The analyses of 50 years of observations of migrating Common Crane from Sweden showed that cranes migrate through the eastern sector of the Arkona Basin in all wind conditions (Table 6). Except for eastern cross winds during spring the probability for crane migration through the eastern sector is close to what could be expected if cranes are distributed evenly along the coast. Observations from Bornholm reported between 1974 and 2020 (www.dofbasen.dk) corroborate the expectation of frequent large numbers of cranes passing the island during autumn (Figure 17). The number of observed migrating cranes on Bornholm during spring is clearly lower than during autumn. Despite the lower number of observations from Bornholm during spring the available data do not allow for altering the assumption that cranes will also pass the eastern sector of the Arkona Basin during spring. Historic recordings using a military radar in Skåne during the spring migration highlighted that unlike the situation over land cranes are prone to wind drift when crossing the Arkona Basin (Alerstam & Bauer 1973, Alerstam 1975). The angle between the cranes' heading and track directions over the sea was composed of 68% compensation and 32% drift. Crane flocks departing from Rügen migrated over the sea in a fan-shaped pattern with the mean angular divergence of track directions of 24° (+-7°). Hence, given the above data and the lack of detailed quantitative data on the distribution of migrating cranes across the Arkona Basin the proportion set to migrate through the eastern sector in the collision risk assessment was set to 1/3 of all cranes both during spring and autumn.

The patterns of flight altitude displayed by migrating Common Crane are very similar to those observed for raptors crossing between Sweden and Germany, yet a higher proportion of the Common Crane may cross Rønne Bank at altitudes above 200 m. The general descend in flight altitude from the Swedish coast in autumn is nonetheless very clear (Figure 18). The GPS-tagged birds demonstrate how some Cranes (2 of 11 crossings) during optimal conditions can cross the region at heights above 400 m altitude (Figure 19).

The GAMM flight model for the Common Crane indicates that the birds descend in altitude after leaving the coast, and fly higher in tail winds and clearer weather (Figure

20). During spring, except for during optimal conditions with tail wind and good visibility most Common Crane fly below 300 m when they cross Rønne Bank (Figure 20, Figure 21). During autumn, although optimal conditions may enable birds to soar to heights above 700m before leaving the coast of Sweden they generally descend to altitudes below 300 m over Rønne Bank. The differences in flight height profiles, and the tendency to fly at rotor height of the planned 15 MW turbines during all weather conditions is highlighted by the model results in Figure 22).

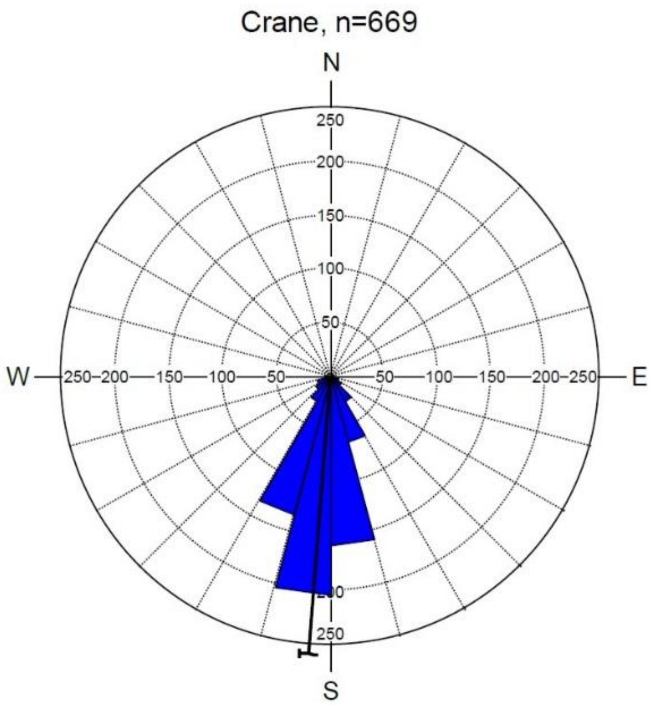


Figure 16 Sampled migration directions of Common Crane at Falsterbo, autumn 2013 (Skov et al. 2015). Numbers on the Y-axes refer to sample size (number of recordings by laser rangefinder). Each wedge represents a sector of 15°. The mean direction is indicated by the black line running from the centre of the graph to the outer edge. The arcs extending to either side represent the 95% confidence limits of the mean direction.

Table 6 Frequency of relative wind directions as measured at Falsterbo weather station 1960-2011 (www.smhi.se) and the probability for Common Crane migration through the eastern sector on the southern coast of Sweden during the same categories of wind direction

SEASON	RELATIVE WIND DIRECTION	FREQUENCY OF WIND DIRECTION	PROBABILITY OF CRANES EASTERN SECTOR
Autumn	Eastern cross	0.11	0.28
Autumn	Head	0.16	0.22
Autumn	Tail	0.27	0.27
Autumn	Western cross	0.46	0.37
Spring	Eastern cross	0.16	0.04
Spring	Head	0.29	0.41
Spring	Tail	0.17	0.18
Spring	Western cross	0.39	0.44

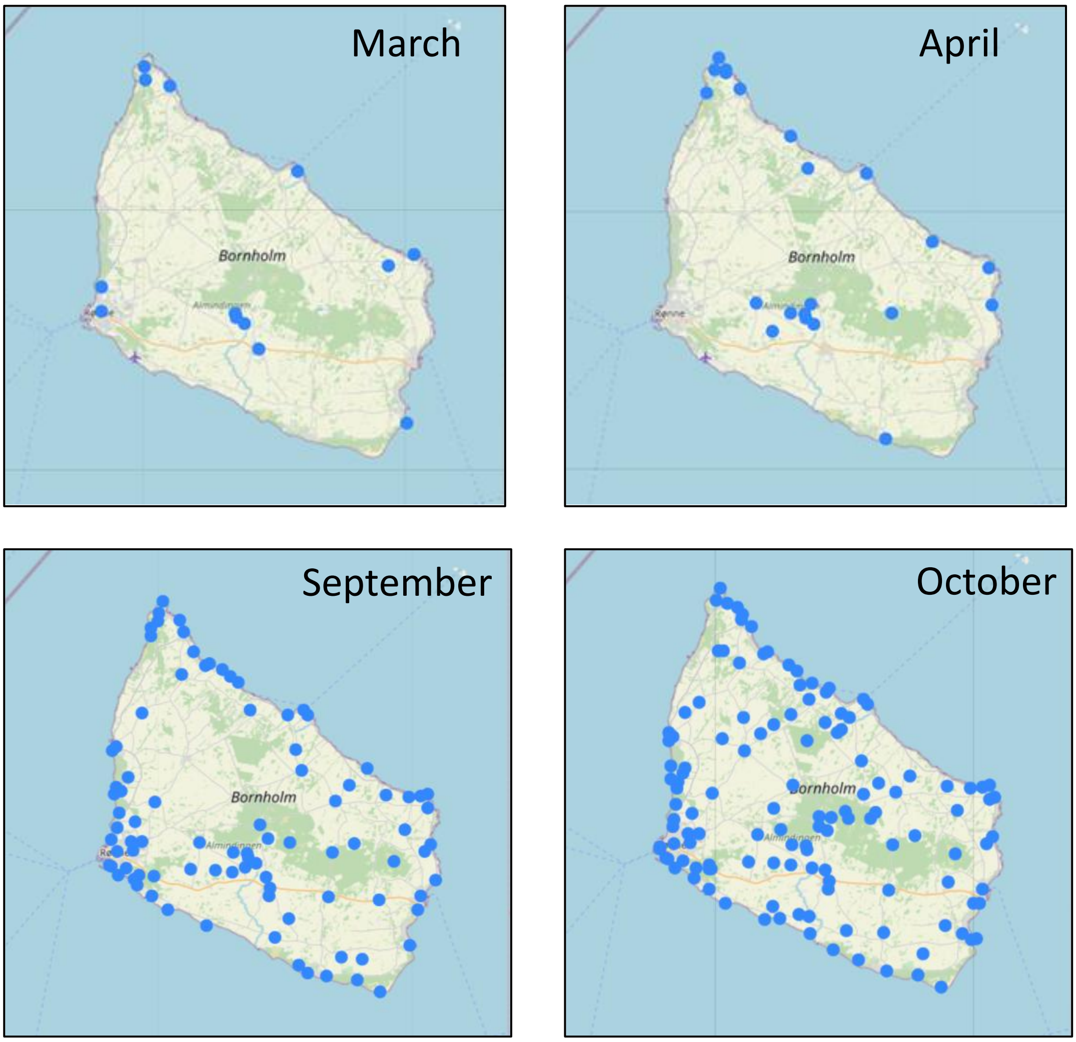


Figure 17 Observations of migrating Common Crane at Bornholm reported to Dofbasen (www.dofbasen.dk) between 1974 and 2020. Each dot represents a flock of at least 50 individuals

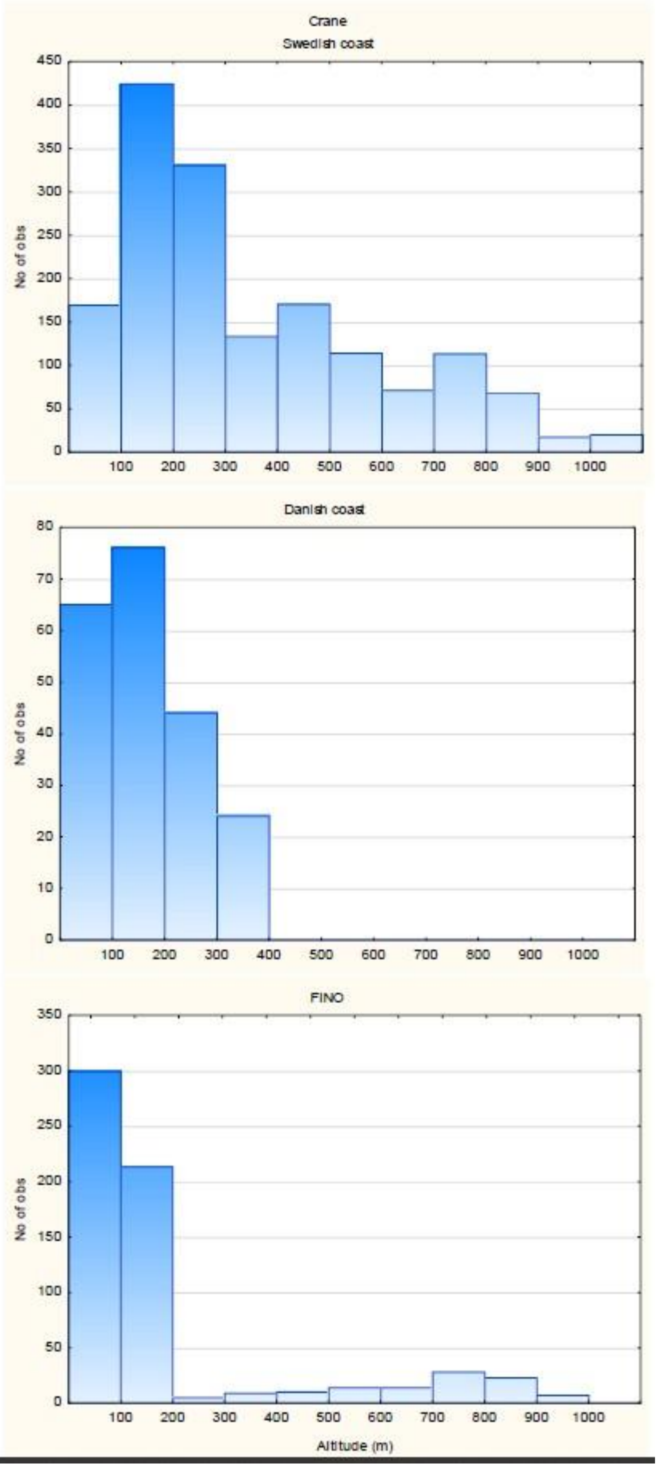


Figure 18 Frequency distribution of altitude measurements of Common Crane by laser rangefinder at the Swedish south coast, at the Danish coast and at FINO 2 during the Kriegers Flak baseline, autumn 2013 (Skov et al. 2015).

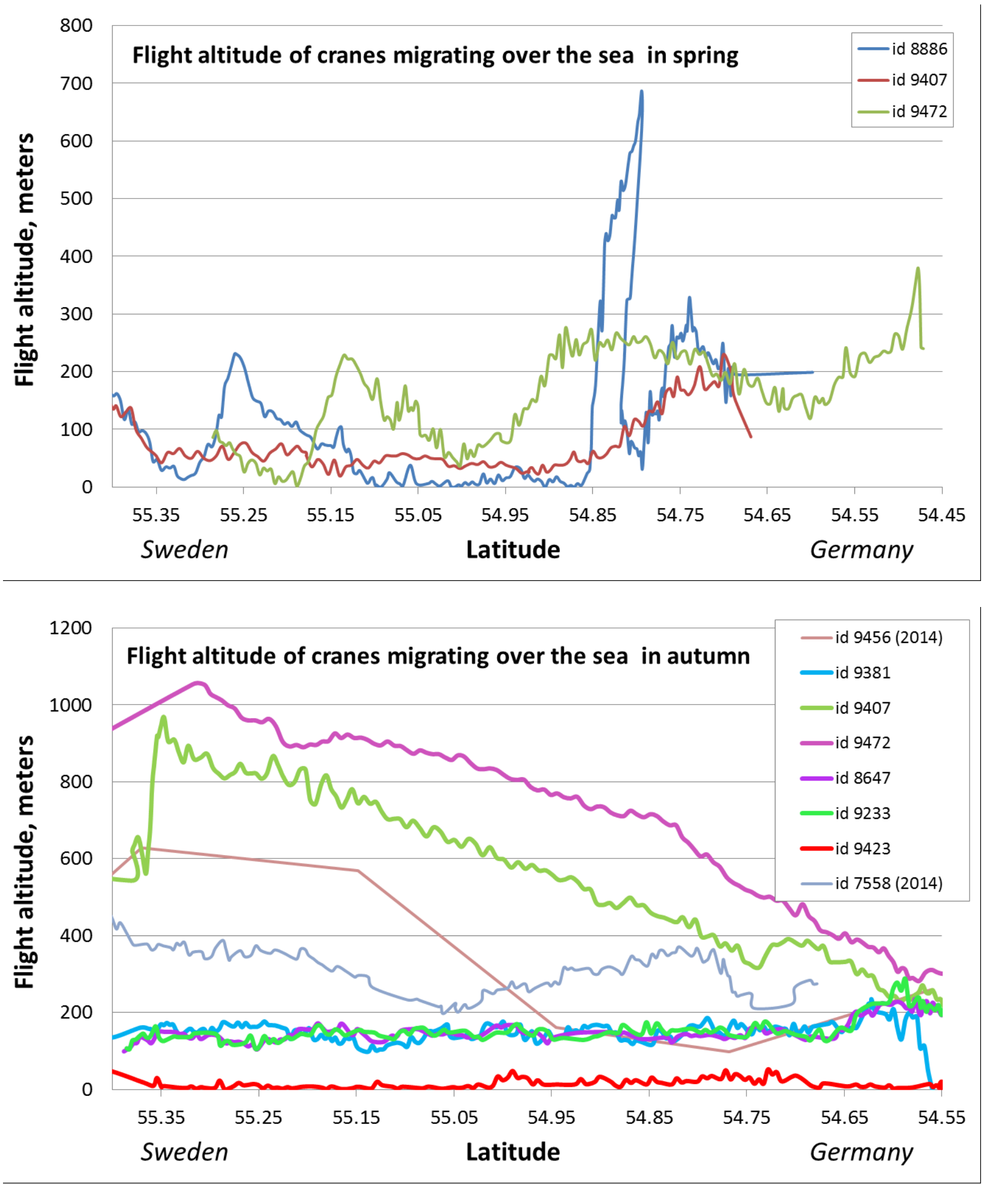


Figure 19 Height measurements of 11 GPS-tagged Common Crane 2013-2015. Krieger's Flak is located at latitude 55.00° N.

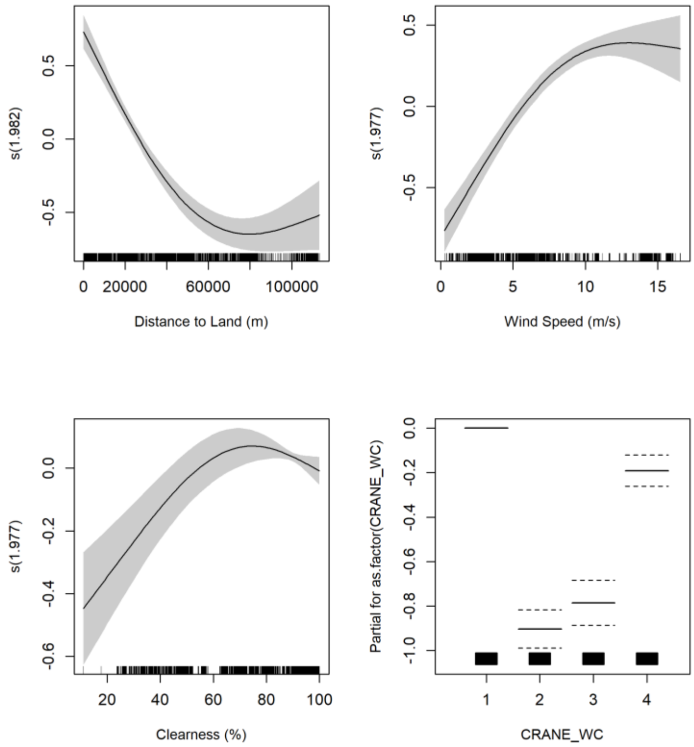


Figure 20 GAMM response curves for the Common Crane based on data from both spring and autumn collected during the Krieger's Flak baseline (Skov et al. 2015). The values of the environmental predictors are shown on the X-axis and the response on the Y-axis is on the scale of the linear predictor. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals.

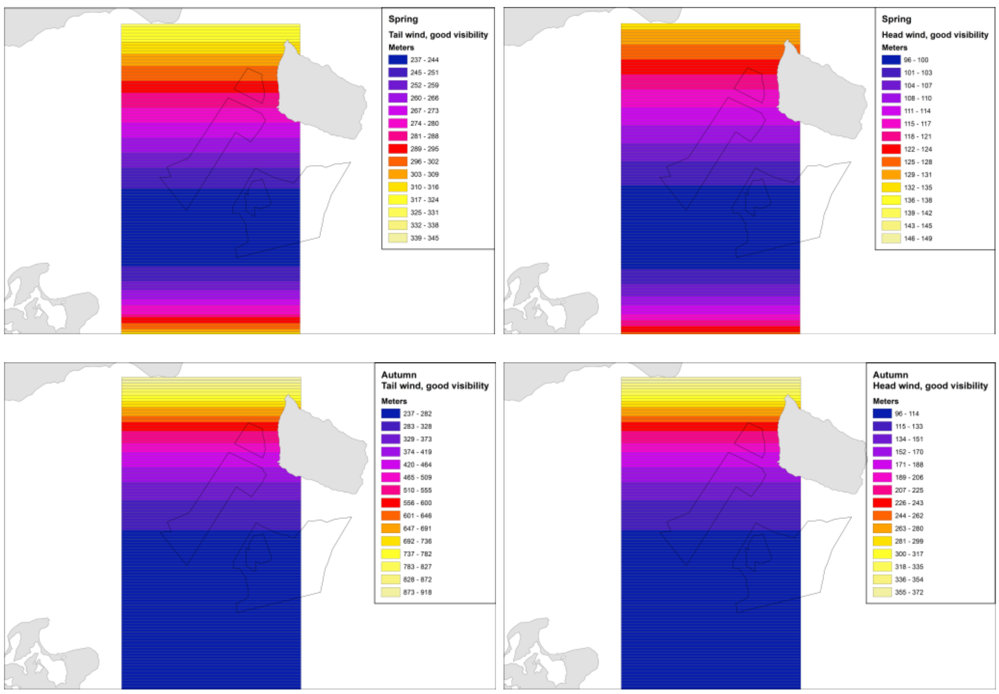


Figure 21 Examples of the modelled flight heights of migrating cranes through the eastern sector of the migration corridor across Bornholm during different weather conditions. Note that the scale of flight height varies to reflect the different height ranges during different wind conditions.

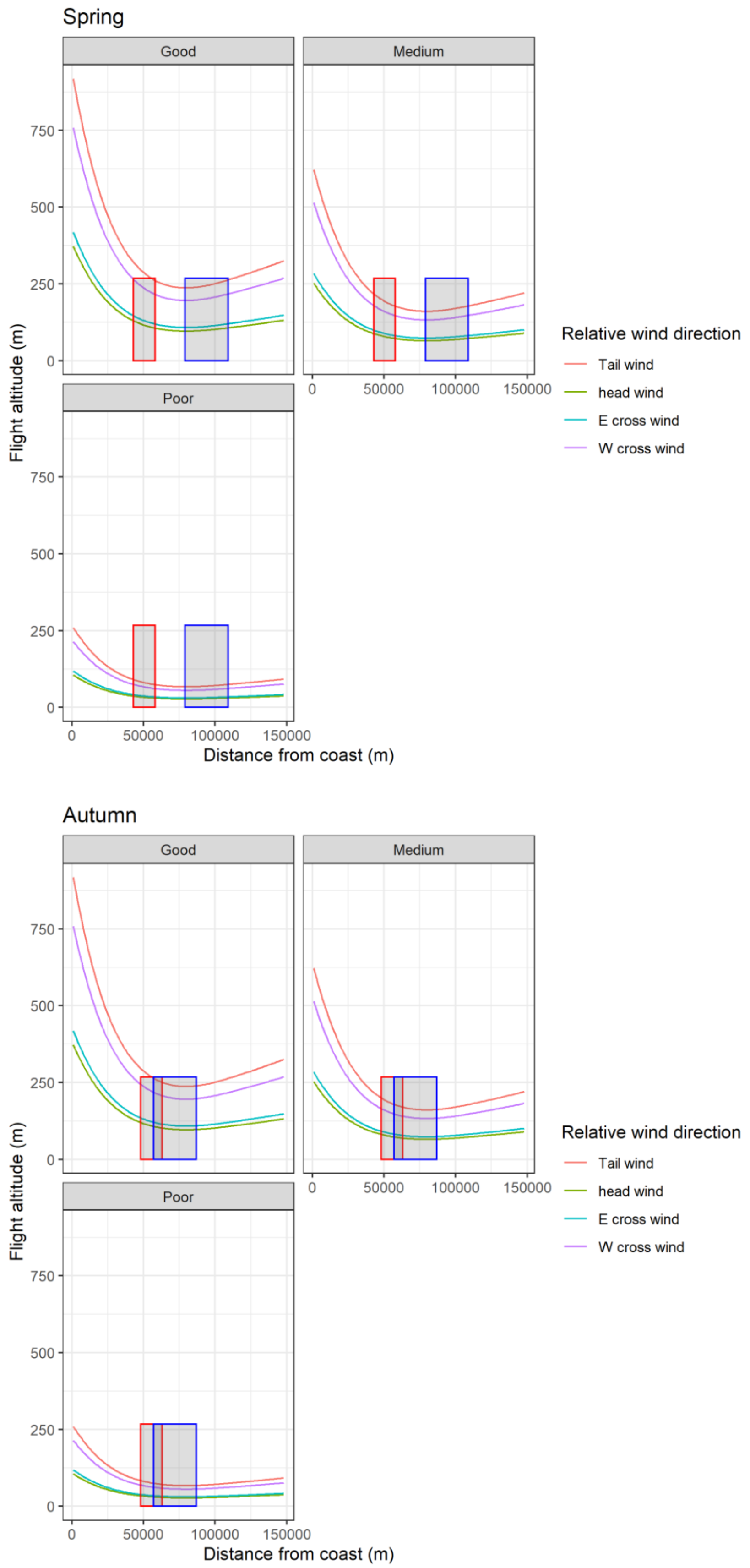
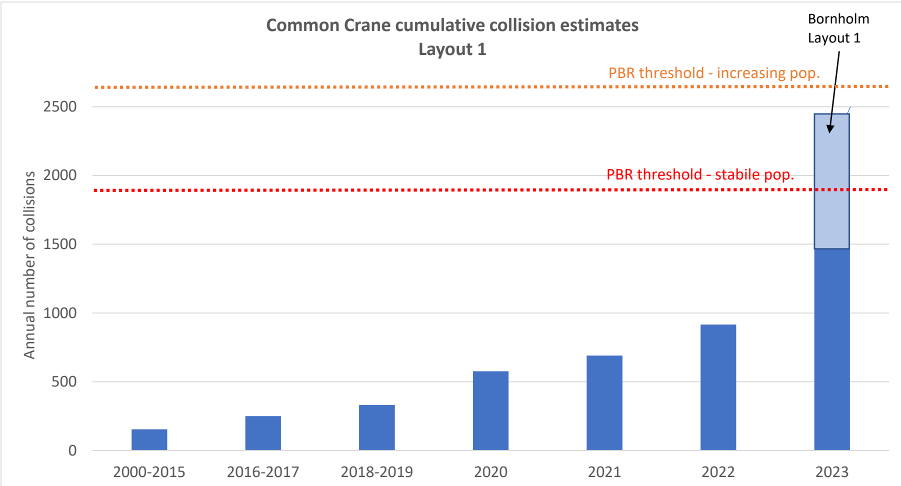


Figure 22 Average altitude for Common Crane in relation to distance from the coast of Sweden during autumn and from the coast of Germany during spring predicted during different visibility (poor, medium, good) and relative wind directions for the spring and autumn seasons. All other predictor variables are set to mean values within the species-specific data set. The lines are the predicted flight altitudes and the red and blue rectangles indicate the rotor swept area by 15 MW turbines in Bornholm 1 (red) and 2 (blue)

4.3.3 Cumulative collision risk of Common Crane

A low level of responsive behaviour by Common Cranes to the perimeter of the Baltic 2 Offshore Wind Farm was recorded, as only one of 14 flocks approaching the wind farm avoided penetrating the front row of turbines. This resulted in a macro avoidance rate of 0.07. Once in the wind farm, Common Cranes displayed relatively strong horizontal and vertical meso avoidance behaviour. Of the 20 recorded flocks 16 avoided entering the rotor-swept zone, 7 of which made evasive horizontal movements while 9 avoided the rotor by increasing flight altitude (vertical meso avoidance). These behavioural characteristics resulted in a meso avoidance rate of 0.8. Combined with the recorded macro avoidance rate and the micro avoidance rate of 0.08 from Winkelmann (1992) a total avoidance rate of 0.83 was estimated.

Yet, the cumulative impact from all projects in the region means that with layout 1 for the Bornholm wind farm 2,450 Common Cranes have the potential to collide annually with the existing, consented and planned offshore wind farms in the near future (Figure 23). With layout 2 this estimate is 2,074. Compared to the estimated PBR threshold of 1,887 birds for a stabile population, the combined collision impact on the Swedish-Norwegian population of Common Crane of the two scenarios equal 129.8 %, and 109.9 % of the PBR threshold, respectively. If setting the population to be increasing the PBR threshold rises to 2,642 birds and the collision potential for layout 1 will be slightly below and for layout 2 clearly below the threshold.



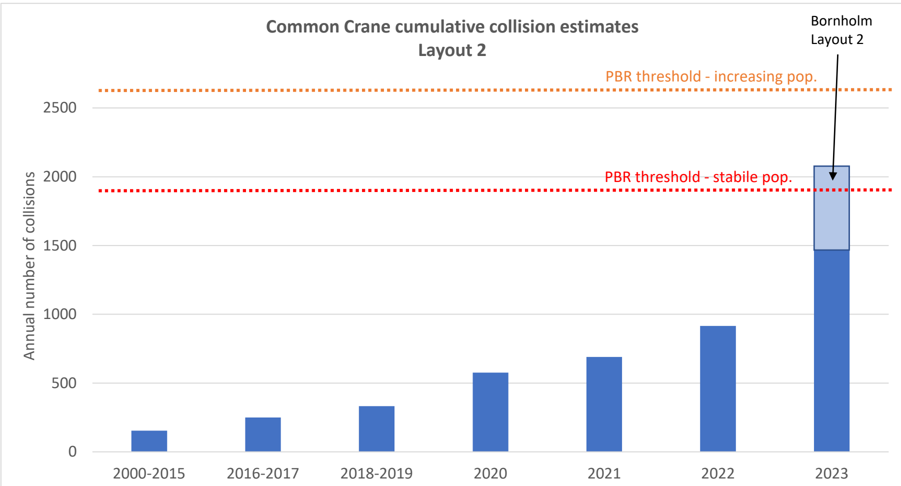


Figure 23 The cumulative number of Common Crane predicted to collide annually with wind farms in the Arkona Basin during different periods between 2000 and 2023. The Bornholm layout 1 and 2 wind farms have been added to 2023. The wind farms include all commissioned, consented and planned wind farms. The PBR threshold indicative of the limit for a sustainable mortality of Common Crane is indicated for both a stabile and an increasing population.

5 Assessment of the suitability of Rønne Bank in relation to birds

5.1 Long-tailed Duck and other species of seabirds

Rønne Bank is an area of medium densities of wintering Long-tailed Ducks with the distribution largely restricted to the shallow offshore areas like in the rest of the southern Baltic Sea. Densities are generally lower than densities recorded in the core wintering areas for the species in Pomeranian Bay, Gulf of Riga and Hoburgs-Midsjö Banks (Durinck et al. 1994, Skov et al. 2011). The available information on population parameters (which is scarce) indicate that the population is still declining although the growth rate has increased since early 2000 (Heinänen et al. 2018). This negative trend is potentially coupled to low carrying capacity of blue mussels on the offshore banks as well as ecological conditions on the breeding grounds (Hearn et al. 2015).

As shown by this study the size of the Long-tailed Duck wintering population on Rønne Bank has clearly declined by more than 50 % since the late 1980'es (Durinck et al. 1994, Skov et al. 2011). There is a lot of uncertainty regarding the drivers behind this decline, yet conditions on feeding grounds as well as wintering areas are likely to be important (Kilpi et al. 2015, Skov et al. 2020). The total number of wintering Long-tailed Ducks on Rønne Bank in 2020 may not exceed 10,000 birds, which is below 1 % of the total population wintering in the Baltic Sea. What the model results also clearly show is that the distribution of the species is very stable and has not changed over the course of the 40 years when surveys have been undertaken on the bank.

The planned Bornholm 1 wind farm does not overlap with the modelled areas of suitable habitat to Long-tailed Ducks as marked by the 90 percentile of the distribution, whereas the western part of Bornholm 2 does overlap with these densities. The displacement analyses documented that limited displacement of Long-tailed Ducks is likely to take place from Bornholm 1, whereas the displacement zone from Bornholm 2 involves 189 km^2 of suitable habitat and including the extension zone 216 km^2 of suitable habitat. The estimated mean number of displaced ducks from brutto area 2 is 2,989 and from the extension area 3,262. These numbers represent 0.20% and 0.22% of the total Baltic wintering population of Long-tailed Duck, respectively and hence may not represent a showstopper for the project. Displacement effects on Long-tailed Ducks from Bornholm 2 could be reduced by approximately 40% by focussing development on the western part. It should be noted that a conservative approach has been taken to the estimated level of displacement of the species from the wind farms. Recent data from post-construction monitoring flights undertaken at Rødsand II Offshore Wind Farm by Århus University indicate a lower level of displacement than recorded immediately after construction of the wind farm (Petersen et al. 2014).

Of other species of seabirds which regularly use Rønne Bank only the Black Guillemot occur in relatively high densities, and the area was classified by Durinck et al. (1994) as part of the core wintering area for the species in the Baltic Sea. However, quantitative mapping of this species require the use of ships and due to the absence of ship-based surveys on Rønne Bank since the early 1990'es the current status of Rønne Bank in relation to Black Guillemot is not known.

5.2 Migrating Common Crane

The recorded distribution of observations of migrating Common Crane from the southern coast of Sweden and Bornholm (this study) combined with the evidence from GPS-tracked cranes (Skov et al. 2015) and radar tracking on Adler Grund (Kulik et al. 2020) unambiguously show that large numbers of cranes use the eastern part of the corridor between Bornholm and Falster (Rønne Bank) during their spring and autumn migration. The exact routes across Rønne Bank are likely to vary in response to wind conditions as reflected by low numbers seen in eastern Skåne during spring during easterly winds and on Bornholm during spring in general. The predominant use by cranes of the sector west of Bornholm is also illustrated by the low frequency of observations of migrating cranes during baseline investigations at planned offshore wind farms in the Polish sector around Slupsk Bank (Zydelis 2014). Most flocks cross the Polish sector during autumn.

The avoidance pattern of Common Crane to offshore wind farms will logically lead to a high perceived risk of collision. The low overall avoidance rate of 0.83 is mainly driven by the complete lack of macro avoidance displayed by this species (Skov et al. 2015, Kulik et al. 2020). The migration corridor of Swedish and Norwegian cranes across the Arkona Basin is the focus of offshore wind farm development, and 15 built, consented and planned projects in combination with the planned Bornholm offshore projects will lead to a significant cumulative impact from all projects in the region. With layout 1 for the Bornholm wind farm 2,450 Common Cranes have the potential to collide annually, while the estimate for layout 2 is 2,074. Compared to the estimated PBR threshold of 1,887 birds, the combined collision impact on the Swedish-Norwegian population of Common Crane of the two scenarios equal 129.8 %, and 109.9 % of the PBR threshold, respectively. This means that the population most likely will not be capable of compensating the loss of birds imposed by the 18 projects by 2023. The less likely situation with a continuously increasing population of Common Crane and a higher PBR threshold of 2,642 birds would mean that the collision potential for layout 1 will be slightly below and for layout 2 clearly below the threshold.

The proportion of the estimated collision mortality which is attributed by the planned Bornholm project is relatively high with 1,142 birds for layout 1 and 766 birds for layout 2. This is explained by the size of the 15 MW turbines combined with the wide area planned for the arrays of both layout 1 and layout 2 which covers a major part of the eastern sector of the migration corridor. The implemented flight models show that the cranes will most likely cross the Bornholm project areas below 300 m, and hence given the height of the turbines of 268 m it means that close to 100 % of cranes will be flying at rotor height during both spring and autumn migration.

If unmitigated the collision mortality imposed by the full development of the 16 wind farms in the western Baltic Sea, including the Bornholm project may result in a decline in the size of the Swedish-Norwegian population of Common Crane. Accordingly, the collision impact may affect the conservation targets and integrity of several EC SPAs, which have been designated on the basis of concentrations of staging Common Crane én route between Scandinavia and wintering areas in Spain. It should however, be stressed that the PBR threshold should only be used as an initial step in assessing the sustainability of large-scale developments of offshore wind farms in the Arkona region in relation to Common Crane. The PBR algorithm is conservative and can be applied quickly yet it suffers from simplifications which may bias its use for assessment of long-term population trajectories (O'Brien et al. 2017). It is therefore recommended that the potential long-term impact on the Swedish-Norwegian population of Common Crane is thoroughly assessed using Leslie matrix population modelling.

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