Hornsea Project Four

Auk Displacement and Mortality Evidence Review

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Review of Evidence to Support Auk Displacement and Mortality Rates in Relation to Offshore Wind Farms

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1.2	04/11/21	All	All	Final review prior to client	SS
1.2	17/11/21	All	All	Client review	Ørsted
2.0	20/12/21	All	All	Amends following client review & additional data received	RC
2.1	21/12/2021	All	All	Final review prior to client issue (incl tracks)	RC / SS
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1. Executive Summary

This technical report presents an evidence-based review and meta-analysis, focussing on auk species guillemot (*Uria aalge*) and razorbill (*Alca torda*), to determine whether auk displacement and associated mortality rates for use in the Hornsea Four Development Application (within the Environmental Impact Assessment (EIA) and Report to Inform Appropriate Assessment(RIAA) reporting) are supported. Evidence has been collated from multiple sources, including offshore wind farm (OWF) post-consent monitoring reports, published research papers and online study reports that provide data on displacement effects and mortality associated with auk species.

The report has compiled study data from 21 OWFs to form a comprehensive review of the evidence for displacement effects on auks from OWFs. Displacement effects varied from strong attraction to strong avoidance, however, OWFs could be separated into two groups: 1) OWFs with inferred avoidance or displacement rates higher than 50%, 2) OWFs with no significant displacement effect or suggested weak avoidance of <25% displacement.

Review of the analysis methods and data inputs used in each of the studies identified that OWFs reporting high displacement rates were associated with low count data which included high zero counts within the data set. The use of statistical methods that are unable to manage such zero-inflated data sets may lead to displacement rates that are misleading. An independent re-analysis of data from OWFs using Integrated Nested Laplace Approximations (INLA), a statistical method that can incorporate the issues mentioned above, demonstrated no significant effect for two OWFs which previously reported displacement and the other OWFs reporting high displacement effects could not be re-analysed using INLA, with the recommendation that their displacement rates should be treated with caution. Indeed, a later re-analysis of selected surveys using INLA from an OWF previously reporting a displacement rate of 60% concluded that the displacement rate could be as low as 45%.

The compilation of study data and associated OWF design metrics from this report has provided the opportunity to examine variables associated with displacement effects. Twelve variables were tested for differences in pairwise comparisons between OWFs grouped according to whether a displacement effect was shown or inferred and those shown to have no significant displacement effect. Four variables were shown to be significantly different between groups inferring an association with displacement effect, these variables were: auk abundance, density (total windswept area as a percentage of the array footprint), distance from shore and geographical region.

The review highlights that other factors may also be associated with the magnitude of an effect and OWFs with similar attributes are likely to demonstrate similar displacement effects. There is a contrasting difference in three attributes: OWF layout, WTG density and marine traffic density, between OWFs reporting high displacement rates for auks and the Hornsea Four development site. Therefore, by considering OWF site attributes the displacement rate can be refined from the broad range reported across all OWFs and tailored to an individual development based on similar attributes known to effect displacement rate and thereby removing a high level of uncertainty.

The current range (30-70%) advocated by NE has been compiled regardless of the quality of the study or confidence in the derived rate, furthermore it does not account for studies that have shown no significant displacement effect or attraction. This report recommends a

precautionary displacement rate of up to 50% for auks to be applied for the Hornsea Four OWF impact assessment, which is based on the most comprehensive evidence to-date. This takes into consideration weak displacement effects that may have gone undetected in studies that have reported no significant effects due to the power of the study to detect small changes. The confidence of auk displacement rates exceeding 50% is uncertain, however such levels may apply to specific OWF sites and environmental conditions, though applying these higher rates to other OWF sites such as Hornsea Four, are not justified based on evidence from developments with similar attributes.

Evidence for the mortality rate of displaced birds has been derived from two studies that predict the population level consequence of displaced seabirds, including auks, from OWFs using simulation models and a recent modelling study estimating changes in guillemot adult survival from OWF displacement. Empirical evidence has also been sought from auk colony data to determine whether any changes have occurred to colony population trends since the operation of local OWFs in support of high mortality rates of up to 10%.

The results of simulation models on the impacts of OWF displacement on auk adult survival are incompatible with a mortality rate of 10% and are more likely to be considerably less. As one study showed that incorporating a 10% additional mortality rate had far greater population level consequences than those based on simulation models for the non-breeding season. Although it is difficult to translate predicted population level effects to additional mortality rates for auks displaced from OWFs, an estimation of additional mortality has been made for auks displaced from Hornsea Four connected to the Flamborough and Filey Coast Special Protection Area (FFC SPA), using predicted population effects from simulation models for the SPA colonies in proximity to proposed Forth & Tay OWFs. Our calculations predict an additional mortality for displaced birds from Hornsea Four of approximately up to a 1% maximum. However, it is likely that using the outputs from this model for our calculations we may have over-estimated the mortality effects, as Hornsea Four OWF is located at a greater distance to the FFC SPA than the Forth & Tay OWFs are to the SPAs in the simulation models. The distance of an OWF from an SPA (or nesting colony more specifically) is a critical model parameter and Hornsea Four is located towards the extreme end of the mean maximum foraging range for guillemots and razorbills (Woodward et al., 2019). The modelled outputs demonstrated that as the distance between the SPA and the OWF increased the predicted additional mortality effects diminished and could even result in increased survival if the OWF displaced birds that forage at a distance back towards the SPA.

The most recent modelling studies of changes in adult survival from displacement effects from OWFs demonstrated that modelled estimates of additional mortality to combined OWF footprint displacement can be lower than 1% and in certain cases even reduce mortality rates. Two SPAs assessed were of similar distance to the OWFs that the FFC SPA is to Hornsea Four OWF; Buchan Ness SPA and St. Abb's Head to Fast Castle SPA and therefore more comparable. The additional annual mortality rates for displaced guillemots predicted for Buchan Ness SPA and St. Abb's Head to Fast Castle SPA were 0.2% and -2.7%, respectively. The models suggest that OWFs approaching the mean maximum foraging range from breeding colonies have little or no negative impact on adult survival and may indeed increase adult survival if birds are displaced back to distances nearer their colony which reduce energetic costs.

Additional mortality effects from displacement at the Heligoland colony population level also appear negligible under current monitoring conditions as the colony has continued to show an increasing population trend since the development of OWFs locally. This is despite a reported displacement rate of 44% during the breeding season from four local OWF, which have been in operation since 2015. Therefore, this report concludes that the empirical evidence supports mortality rates of considerably less than 10%, with 1% implied to be the most realistic (yet still precautionary) rate to be applied in assessments of displacement for guillemot and razorbill.

2. Introduction

The aim of the review was to collate, analyse and interpret the latest reported displacement data from offshore wind farm (OWF) sites within the North Sea and UK Western Waters. This was to better understand what explanatory factors might be influencing the varying degree of displacement reported at different operational OWFs. The review's objective was to utilise these data to provide a more evidenced-based displacement rate for use in assessing potential impacts on auks from OWFs and to better understand the likelihood of any such levels of displacement in terms of consequential mortality.

Seabird displacement analysis has been considered a major challenge requiring advanced statistical methods to contend with substantial zero counts, spatial correlation, temporal correlation and non-linear relationships. However, due to not having reached a consensus as to the statistical approach to incorporate into these studies for impact assessment, various statistical methods have been used to analyse displacement effects. For this reason, results need to be treated with caution because of uncertainties regarding their statistical validity and significance. While some studies have reported displacement of auks from offshore wind farms (OWFs) (e.g., Leopold *et al*., 2013; Vanermen *et al*., 2015; Skov *et al*., 2016), others have reported little or no displacement (Vallejo *et al*., 2017, MacArthur Green, 2021). However, studies with high numbers of zero counts (>75%) are accepted to have problems in reliably predicting a displacement rate as spatial and temporal variations in distribution, which occur naturally in mobile species, will dwarf a displacement effect, as highlighted in Leopold (2018). This would make data from the Alpha Ventus, Bligh Bank, Thorntonbank, Horns Rev and similar OWF data sets problematic to derive a reliable displacement rate, as statistical models have yet to be developed that can incorporate these types of data sets. Conclusions from an international workshop (Leopold, 2018) and the re-analysis of data sets (Zuur, 2018) have resulted in Integrated Nested Laplace Approximations (INLA) analysis to be a recommended method of choice, which incorporates and examines the issues mentioned above to some extent.

3. Review of Evidence of Displacement Rates for Auks

Displacement studies on auks in response to OWFs have previously been summarised in a published review (Deirschke *et al*., 2016), which included the results of auk displacement effects from 13 OWF sites. Since the publication of that displacement review there have been several additional OWF sites to have reported displacement effect studies on auks (APEM, 2017, Webb *et al*., 2017, Peschko *et al*., 2020, APEM, 2021 and MacArthur Green, 2021) or updates from their monitoring programs (Vanermen *et al*., 2019). Datasets from three OWF sites have also been re-analysed utilising INLA resulting in different displacement effects being concluded for some (Zuur, 2018). A breakdown of the latest displacement rates reported at various OWF sites for guillemot and razorbill have been collated and summarised in **Table 1** and **Table 2**, respectively. Within **Table 1** and **Table 2**, the 'years of operational phase monitoring data' refers to the year(s) to which data have been analysed from or combined to, since operational commencement of the OWF. Displacement rates shown in red are to be treated with caution as these data sets have either been re-analysed and shown to have different displacement results, or are problematic due to containing high numbers of zero counts and therefore derived displacement rates incur a higher degree of uncertainty. All sources of information used to populate these tables are cited in **Section 3.1**, which summarises the results and conclusions of displacement analysis for each OWF.

Table 1 Results from assessments of guillemot or auk group level displacement effects/rates at OWFs according to reports from monitoring studies.

OWF	Guillemot (Auk) Displacement Rate							
	Construction Phase	Years of Operational Phase Monitoring Data						Assessment Period
		1	2	3	4	5	6	
Beatrice		NSE						Breeding
Robin Rigg	(-)	(-)	(-)/NSE	(-)[1]				Year Round
Westernmost Rough			NSE[2, 3]					Post-Breeding
North Hoyle	+50%	(-)	+55%[4]	+112%				Year Round
Thanet	67%[5]	79%[5]	NSE	NSE				Winter
Kentish Flats			NSE					Year Round[6]
Lincs				NSE[3]				Year Round
London Array	87%[3]			68%[3]				Winter
Gunfleet Sands	(-)	(-)[11]						Winter
Bligh Bank (Belwind)*	~70%			71%		75%		Non-Breeding
Thornton Bank Phase I, II, III*	~70%[ns]			68%	69%		60 (45-78%)[7]	Non-Breeding
Prinses Amalia* †		NSE		45%[8]				Non-Breeding
Egmond aan Zee* †			NSE		25%			Non-Breeding
Horns Rev 1*			NSE		(-)[3, 11]			Year Round
Alpha Ventus*				75%[3]				Non-Breeding
BARD 1	(-)	(-)						Year Round[9]
Horns Rev 2*				(-)[3, 11]				Non-Breeding
Helgoland Cluster & Butendiek				63%/44%				Spring/Breeding Season[10]

*Table Note: Displacement rates shown in red are to be treated with caution as derived rates will incur a degree of uncertainty. * analysis from combined survey data from sites with low auk abundance (i.e., high numbers of zero counts), † re-analysis of combined post-monitoring site data using INLA suggest previous reported displacement effects to be non-significant (Zuur, 2018). [1] weak distance effect suggested after re-analysis, [2] data from 3 surveys only conducted during July, [3] data not analysed to species* *level but at auk group level, [4] compared to construction phase, [5] reduction in abundances were also seen in the control suggesting that the reduction within the wind farm may not have been a result of the construction/initial operation of the wind farm but rather part of wider scale population changes, [6] auks mostly absent with the exception of winter season but still in low numbers, [7] exploratory INLA analysis, [8] analysis of combined data includes 1 year during construction phase, [9] auks mostly absent with the exception of the post-breeding dispersal period but still in low numbers. [10] Spring = Feb to May, Breeding Season = May to July, [11] statistical significance of displacement not* tested. NSE; no significant effect, (-); avoidance inferred by authors, but displacement rate not quantified, +; attraction.

Table 2 Results from assessments of razorbill displacement effects/rates at OWFs according to reports from monitoring studies.

OWF	Razorbill Displacement Rate							
	Construction Phase	Years of Operational Phase Monitoring Data						Assessment Period
		1	2	3	4	5	6	
Robin Rigg	(-)	(-)	NSE					Year Round
North Hoyle		(-)	NSE	NSE				Year Round
Thanet	89%[1]	95%[1]	NSE	NSE				Winter
Bligh Bank (Belwind)*	~65%			64%		67%		Non-Breeding
Thornton Bank Phase I, II, III*	~75%			55%[NS]	~30%		75%	Non-Breeding
Prinses Amalia*		NSE		80%[6]				Non-Breeding
Egmond aan Zee*			NSE		NSE			Non-Breeding

*Table Note: Displacement rates shown in red are to be treated with caution as derived rates will incur a degree of uncertainty. * analysis from combined survey data from sites with low auk abundance (i.e., high numbers of zero counts), [1] razorbill recorded in low numbers suggesting that displacement effects may have been a result of the analysis method. NSE; no significant effect, (-) avoidance inferred by authors, but displacement rate not quantified.*

3.1 Summaries of the OWF reports and publications

For each OWF below grey-literature reports and peer-reviewed publications have been collated and reviewed. Site conditions and study outcomes have been summarised and displacement effects described. Attention has been paid to the limitations of the study including design, results and conclusions and any reasons for applying caution when interpreting the displacement rate. This has permitted any uncertainties in the confidence of study results and reported displacement rates to be taken into account for each OWF when deriving a displacement rate for auks to OWFs in general, which is discussed in further detail in Section 3.2.

3.1.1 Beatrice

Survey data for Beatrice OWF included one year of pre-construction surveys from 2015 and one year of post-construction surveys from 2019, six surveys in total from each year within the months May to July. For both guillemot and razorbill there were general increases in abundance across the whole survey area from 2015 to 2019. For guillemot a significant increase was shown to be within the centre of the study region and extending to the southern edge, but outside of the array area. For razorbill a significant increase was throughout most of the study area including the array area. Displacement analysis was performed by determining distributions in relation to Wind Turbine Generator (WTG) locations. The pooled densities of birds within circles of radius 100m, 200m, 300m and 400m around the WTG locations for each auk species were determined together with a histogram of densities obtained for 1,000 randomly offset WTG layouts. The recorded density of birds for both guillemot and razorbill were located within the middle of the bootstrapped distributions, indicating that the seabirds did not appear to be avoiding the WTGs (MacArthur Green, 2021). Therefore, no clear trends in density with increasing distance from the WTGs was observed. However, as no comparison was made of densities within versus outside the array area, birds that have entered the array area may be less sensitive to disturbance effects from WTG proximity, i.e., solely looking at the effects on the birds that have entered the array area or in close proximity. Therefore, results should be interpreted with caution when extrapolating these results to suggest there is no displacement effect, although densities in relation to proximity to planned WTG locations in the pre-construction phase analysis were similar (MacArthur Green 2016); auk abundance had increased post-construction in the study area suggesting some avoidance may have occurred.

3.1.2 Robin Rigg

Survey data from the Robin Rigg OWF includes three years of post-construction data covering all seasons and has a high abundance of auks year-round. The post-monitoring report after two years of operation suggested a decline in auks during the construction phase with a degree of recovery in the post-construction years (Canning *et al*., 2012). Statistical analysis by Vallejo *et al*., (2017) could not detect a displacement effect after two years of operation. However, an independent re-analysis of the guillemot data set using R-INLA with three years of operational data suggested there could be a weak distance effect, but with low statistical significance (Zuur, 2018).

3.1.3 Westernmost Rough

Analysis of auk displacement at Westernmost Rough OWF demonstrated that there was no evidence to suggest a displacement effect (APEM, 2017). Three surveys were conducted after two years of operation during July, which represents the end of the breeding season and start of the dispersal period for auks. Although no significant displacement effect was detected, subtle distance effects may have gone undetected due to the small number of surveys conducted.

3.1.4 North Hoyle

Monthly surveys were conducted year-round at the North Hoyle OWF. The first-year operational monitoring report inferred a general shift by guillemots and razorbills away from the array area, however no detailed analysis was conducted (May, 2005 and PMSS, 2006). The second-year monitoring report suggested guillemots to be making more use of the array area site since it became operational, with an estimated increase of 55% compared to the construction phase, which was statistically significant (PMSS, 2007). The third-year monitoring report showed high numbers of guillemots were continuing to enter the array area, with an estimated increase of 112%, although this increase did not reach a significant (95% confidence) level (PMSS, 2008). Although these data suggest a general increase in numbers across the North Hoyle OWF post-construction, the surveys also suggested a local shift in auk distributions towards the array area possibly as a consequence in changes to prey distribution. Moreover, although these data suggest an increase in guillemot numbers within the North Hoyle OWF, they are also compatible with a small reduction of less than 25%, albeit with very low significance (PMSS,2008). Data for razorbill did not demonstrate any significant displacement effects after three years of operation (PMSS, 2008).

3.1.5 Thanet

Guillemot density was reduced in the Thanet OWF site during construction (67%) and the first year of operation (79%) and up to 1 km from the array area (Hillyer, 2010, Ecology Consulting, 2012). There was an increase in numbers in the second and third-year post-construction surveys across the whole survey area, including the control zone, in comparison with the construction phase and first year of operation (Percival, 2013). The decline in guillemot abundance within the array area during construction and the first year of operation was statistically significant. However, the decline in the construction and first post-construction year also occurred across the remainder of the survey area, including the control zone, suggesting that the reduction within the array area may not have been a result of the construction/initial operation of the wind farm but rather part of wider scale population changes. By the third year of operation guillemot abundance increased compared to during construction, which was statistically significant and no statistically significant effects were shown compared to pre-construction, suggesting habituation. Razorbill exhibited a similar behaviour, with reduced density in array area during construction (89%) and first year of operation (95%), however considerably lower numbers were recorded than guillemot. Like guillemot, numbers were much higher in the second and third year of post-construction monitoring, including the control zone. Conclusions from the final report suggested any significant declines of auks from construction and operation was short-term (Percival, 2013), however it should be noted that analysis of these displacement effects were based on mean counts and no modelling of distributions and abundances were conducted.

3.1.6 Kentish Flats

Guillemot numbers were very low with a substantial number of zero counts for the entire Kentish Flats OWF array area in the majority of the surveys. Highest numbers of guillemots were seen from November to January, with peak numbers occurring in December with an estimated mean abundance of 17 in the array area. Density comparisons suggested lower densities post-construction from January to March, however due to the very low and variable monthly counts this effect should be treated with caution that guillemots have avoided the array area. A secondary analysis showed that these changes were not statistically significant (Gill *et al*., 2008).

3.1.7 Lincs

Data for the Lincs OWF were analysed at auk species-group level, however 86% were guillemots. Auks occurred in the highest abundance in the non-breeding season, peaking between August and November, with relatively few in the breeding season. The study utilised over 8,000 counts for the analysis using a Before-After Gradient (BAG) method with three years of post-construction data. The analysis showed that although there were spatially explicit changes across the survey area there were no statistically different changes in abundance between pre- and post-construction phases within the array area, nor was there a gradient effect in abundance from the array area (Webb *et al*., 2017).

3.1.8 London Array

Analysis of the London Array OWF was performed at auk group level and modelling based on winter surveys (November to February) consisting of two years pre-construction, two years construction and three years of post-construction data (APEM, 2021). Two zones where surveyed; zone 1 surrounding the array area and zone 2 an adjacent reference area. These data were analysed using the statistical R package MRSea (Scott-Hayward *et al*., 2013), a package which does not consider large natural fluctuations in bird abundance between years. Therefore, a lower density or shift in distribution within a year does not necessarily mean that a local event in that year is the cause of that observation. However, as MRSea can identify areas in which increases and decreases occur, local events can be correlated to these changes, but cannot imply causality (Mendel *et al*., 2019). The proportion of auks displaced from the array area were estimated to be approximately 87% and 68% during construction and post-construction, respectively. However, these analyses indicated that there was a shift in auk distribution within both the array area (zone 1) and the reference area (zone 2), implying natural occurring shifts in auk distribution in the surrounding area across the phases of development. Mean auk densities between the development phases within the array area (except for the south-eastern portion) significantly decreased during construction, and a significant increase in densities is observed on the eastern edge of zone 1 beyond the array area.

During the operational phase mean auk densities increased, but not to pre-construction densities. This pattern in mean densities between development phases also occurred, but to a lesser extent, in reference zone 2 with a decrease in mean densities during the construction phase and an increase in densities on the southern edge of the zone not quite reaching significance, suggesting changes in mean densities were being influenced at least to some degree by natural redistributions.

Densities in the post-construction phases remain significantly lower within and around the array area, but not in the southern portion. However, such significant decreases in densities post-construction are also observed in the reference zone 2. These data suggest natural redistributions over time within both zone 1 and zone 2, which appear to also be influenced by construction phase activities within and in close proximity to the array area. However, the southern portion of the array area is not significantly impacted by the construction phase, suggesting either natural redistributions are masking these effects, or suggested OWF effects between phases are artefacts of these redistributions. A gradient effect of density with distance from the array area was presented out to a distance of 5 km and suggested as conclusive evidence of a causal link between the operational phase and auk redistribution. However, the gradient has not been tested to determine whether it is statistically significant and appears to occur only in one direction from the array area and could also be caused by a redistribution in prey densities.

3.1.9 Gunfleet Sands

Analysis of guillemot displacement effects for Gunfleet Sands OWF consisted of survey data collected between October to March during the first year of operation. Guillemot counts were low (mean estimates of 0 to 9) and only observed during the December and January surveys. Pre-, during- and post-construction comparison inferred guillemots were displaced from the array area (Percival, 2010), however effects were not statistically tested, which would be problematic to do so given the low abundance and high zero counts.

3.1.10 Bligh Bank

Auk displacement effects were based on four and a half years of post-construction data, including all months for Bligh Bank OWF. Guillemot densities were reported as having decreased by 75% and razorbill by 67%. However, abundance counts were low, with only 166 auks in total used in the analysis for the whole operational period (Vanermen *et al.,* 2016).

3.1.11 Thorntonbank

Auk displacement effects for Thorntonbank OWF are based on six years of year round monthly post-construction data. However, these data only contained counts of 104 guillemots and 59 razorbills, respectively, suggesting very low abundance and high zero counts within the dataset. Statistically significant displacement effects of 60% and 63% were shown for the full model and multi-model inferred (MMI) OWF coefficient, respectively for guillemot (Vanermen *et al*., 2019). Statistically significant displacement effects of 75% and 80% were shown for the full model and multi-model inferred (MMI) OWF coefficient, respectively for razorbill (Vanermen *et al*., 2019). Explorative INLA analysis conducted on selected surveys (five from the months Dec to Feb) based on guillemot counts and proportion of non-zero counts predicted a displacement effect of 45-78% on this limited dataset for guillemot (Vanermen *et al*., 2019).

3.1.12 Prinses Amalia and Egmond aan Zee

Analysis of Prinses Amalia and Egmond aan Zee OWFs was conducted under one study (Leopold *et al*., 2013). Guillemot abundance and spatial pattern within the study area showed high variation between and within months and years. Avoidance of both OWF's array areas were shown to be statistically significant for guillemots with displacement rates of 45% and 25% for Prinses Amalia and Egmond aan Zee, respectively, but also for the reference anchorage area (Leopold *et al*., 2013). The higher displacement rate for Prinses Amalia may have been due to data for the first year including surveys prior to the completion of the construction phase. Razorbills were less numerous over the study area and were widely spread. Avoidance of the Prinses Amalia OWF only was shown to be statistically significant for razorbills with a displacement rate of 80%, but also for the anchorage area (Leopold *et al*., 2013). An independent re-analysis of these data using INLA demonstrated displacement effects to be statistically insignificant (Zuur, 2018).

3.1.13 Alpha Ventus

Alpha Ventus is a small OWF of only 4 km^2 consisting of 12 WTGs. A spatial gradient analysis was designed to detect small scale differences in the spatial distribution of seabirds resulting from the presence of the OWF without the inclusion of pre-construction data. Auk counts were low with a total of 546 auks across 77 surveys of which approximately 30 were within the array area, suggesting a high number of zero counts. The results suggested auks were 75% less abundant inside the array area than outside (Welcker and Nehls, 2016).

3.1.14 BARD 1

Guillemots were assessed for displacement effects utilising data from three years of construction phase and the first year of operation for BARD 1 OWF. Surveys were conducted year-round with guillemot densities peaking in the post-breeding dispersal period. By comparison to a reference area the analysis suggested guillemots to be displaced from the array area during construction and first year of operations with a gradient in guillemot numbers increasing with distance from the array area, however the displacement effect was not quantified (Braasch *et al*., 2015).

3.1.15 Horns Rev 1

Surveys of the Horns Rev 1 OWF demonstrated auks were present throughout the year in low numbers, with peaks in winter (Dec to Mar) and distribution patterns differing considerably between surveys. The analysis was performed at auk group level, after two years of operation, with these data suggesting avoidance of the array area. However, due to the variability in distributions between surveys it was not possible to demonstrate significant changes between pre- and post-construction phases (Petersen *et al*., 2006). Post-construction monitoring surveys analysed for year four of operations covering January to April suggested lower than expected numbers of auks were entering the array area, however, no statistical significance was reported (Petersen and Fox, 2007).

3.1.16 Horns Rev 2

Data for Horns Rev 2 OWF were analysed at the auk group level in the third year of operations, with survey data covering October to April. Peak abundance occurred in October and abundance was relatively low in all other months. Distributions of auks across the study area inferred a possible avoidance of the array area, however, this effect was not statistically tested (Petersen *et al*., 2014).

3.1.17 Helgoland Cluster & Butendiek

An area including the Helgoland OWF cluster (Amrumbank West, Nordsee Ost and Meerwind OWFs) and the Butendiek OWF was analysed using a Before / After Control Impact (BACI) approach, with a long-term dataset covering 14 years pre-construction and three years operation. Guillemot relative density in the array areas decreased post-construction by 63% in spring (Feb to May), and by 44% (May to July) in the breeding season, suggesting different seasonal responses depending on the annual life-cycle stage (Peschko *et al*., 2020).

3.2 Deriving an evidence-based displacement rate for auks

A compilation of post-construction monitoring studies from 21 OWFs reporting on the assessment of displacement effects for auks has been presented in this report. These studies suggest auk displacement effects vary considerably within different study sites showing attraction, no significant effect, or an avoidance effect (displacement). The studies included: one OWF with positive displacement effects, eight OWFs with no significant effects or weak displacement effects, four with inferred displacement but not statistically tested and eight with negative displacement effects. The displacement effects from the studies that provided a defined displacement rate range from +112% to -75%. Therefore, formulated simply on the basis of conclusions from all available reports a range of 25-75% would cover all potential outcomes for predicting negative impacts on auks. This range closely mirrors that advocated by Natural England and the RSPB of between 30-70% displacement for auks. However, this range has been compiled regardless of the quality of the study or confidence in the derived rate, furthermore it does not account for studies that have shown no significant displacement effect or attraction. In addition, use of a broad range of this type with no explanatory variables as to why there is such a range just adds to the uncertainties in predicting displacement effects for a specified development.

For example as detailed below, examination of the displacement analysis methods and the quality of the data sets used in the 21 OWF studies within this report suggest that not all predicted displacement effects are equally reliable, nor should they all be applied in general in deriving a range without consideration to their applicability to other OWF developments. These uncertainties include the majority of reports suggesting displacement rates of 60% or more and therefore without careful consideration of which rates are reliable and applicable only , adds to the uncertainty of the impact assessment. For instance, various studies have not incorporated statistical modelling appropriate for the data collected and some have not even conducted any form of statistical verification in support of the displacement effect reported. Indeed, many sites with predicted high displacement rates have low or very low auk abundance and at times a complete absence in auk observations during some surveys. These studies, which have high numbers of zero counts, make displacement rate prediction highly problematic and inaccurate given natural spatial and temporal variation in this highly mobile group of species. Therefore, displacement rates reported from these types of data sets are considered likely to be unreliable, especially if the statistical method employed is not suitable for data sets of this kind. For example, the re-analysis of the data for Prinses Amalia and

Egmond aan Zee, which previously reported significant displacement effects (rates of up to 45%), was not able to detect a significant effect using INLA analysis (Zuur, 2018). Furthermore, displacement effects reported for the Alpha Ventus (75%), Blighbank (75%), Thorntonbank (60%) and Horns Rev 1 and 2 (avoidance inferred) OWFs, may also be considered to be misleading as independent analysis of these datasets concluded that they could not be analysed using INLA (a recommended method of choice), due to the issue of them containing high numbers of zero counts making modelled predictions unreliable (Zuur, 2018). These OWFs constitute the majority of the reported displacement rates for auks of over 50% with the exception of London Array and Helgoland cluster OWFs, so when considering the recommendations of the Zuur (2018) report they should be considered with caution and not presented as strong evidence in support of high displacement effects in general for auks to OWFs.

In reaching a displacement rate for auks which can be applied broadly to any OWF, it would appear that the conclusion of an earlier review by Dierschke *et al*. (2016) is generally correct; displacement effects range from strong attraction to strong avoidance, but the mean effect tended to be weak avoidance, a statistically significant displacement rate of less than 50%. This review has added a further eight OWF displacement assessments to the evidence base and considered the strengths and weakness of each analysis. Although these data would suggest that there is a wide range in the rate of displacement, results need to be treated with caution because of uncertainties regarding their statistical validity and significance. **Table 3** below presents a summary of the displacement studies for each OWF collated in this review. The OWFs in **Table 3** are listed in order of auk mean peak abundance with blue indicating moderate to high abundance (5> birds/km^2) and red indicating low to very low abundance (<5 / <1 birds/km^2) and studies with three or more years of operational survey data shown in bold. The purpose of ordering OWF displacement rates by study area auk abundance and highlighting the number of years of survey data in the table was to determine whether dataset quality or issues relating to low counts correlated to the predicted displacement rate/effect. The ordering of the OWFs in this manner in the table clearly shows an interesting relationship between auk abundance and displacement effect and based on study area auk abundance) Hornsea Four OWF with a study area abundance of ~50 auks/km^2 would be predicted to group with OWFs that have no significant displacement effect, this relationship is discussed further in section 3.3.

Displacement rates exceeding 50% have been reported from five studies (~25%), with all these studies having three or more years of operational data, although all have low or very low auk abundance (~5 to <1 birds/km^2) within their study areas. Three years of post-construction monitoring has usually been the standard period for impact assessment and Bligh Bank and Thorntonbank surpassed this with four and a half and six years data, respectively, in their latest assessment. However, power analysis calculations from studies of sites with low auk abundance have suggested that a reliable rate may not be achieved without a minimum of ten years data (Vanermen *et al*., 2019). Furthermore, none of these assessments were performed using INLA, with three of these studies having been suggested to be misleading using their statistical approach (Zuur, 2018); and the re-analysis of selected surveys from Thorntonbank using INLA reported the displacement rate could be as low as 45% from a previously calculated rate of 60% (Vanermen *et al*., 2019).

There are nine (50%) OWF assessments that have reported no significant displacement effects or possible weak avoidance; with six of these studies having three or more years of operational data. These studies are considered to be relatively reliable as three of these assessments were analysed using INLA analysis (Zuur, 2018). A further four assessments were from OWFs with moderate to high auk abundance, and therefore would not necessarily require a statistical analysis such as INLA to account for problematic zero count data and therefore should be considered relatively reliable. However, the failure to detect changes in bird numbers should not be taken to mean that no changes are occurring, and may only reflect the sensitivity of the analysis to detect low levels of displacement.

An important factor which needs to be considered is study design, which is critical to the statistical power to detect change (Degraer *et al*., 2012), but is often not adequate for this purpose. The power to detect change from survey data alone is related to the frequency of surveys, their temporal extent and spatial coverage (Maclean *et al*., 2013). The number of years of data that may be needed to be able to demonstrate statistically significant changes (due to 'natural' year-to-year fluctuations in populations), has been suggested to be more than the typical three-years of monitoring studies often employed (Vanerman *et al*., 2012). Unless declines are substantial (e.g., > 50%) or survey effort is considerable (e.g., > 80 surveys), the likelihood of being able to detect declines is likely to be low (Maclean *et al*., 2012).

Table 3 Summary results of auk displacement analysis and their predicted effects/rates from the most recent monitoring report or published studies; blue: moderate to high abundance (5> birds/km2); red: low to very low abundance (<5 / <1 birds/km2); studies with three or more years of operational survey data shown in bold.

OWF	Predicted Displacement Rate Guillemot/(auk)	Number of Years Pre-Construction Data	Number of Years Operational Data	Analysis Period	Array Density (turbines/km^2)	Post-construction Guillemot/Razorbill/ (Auk) Wind Farm Mean Peak Density (n/km^2)
Beatrice	NSE	1	1	May-July	1.56	100/6.0
Thanet	NSE	1	**3**	Oct-Mar	2.86	11.6/2.6
Westermost Rough	(NSE)	N/A[5]	2[5]	July	1.00	(10.5)
North Hoyle	(+)/<25%[3]	<1[winter]	**3**	All Months	3.11	8.9/4.8
Robin Rigg	NSE[1]	2[4]	**3**	All Months	3.16	5.1/4.1
Prinses Amalia	NSE[2]	1.5[6]	**3**	Sept-Mar	4.30	4.1/1.9
Egmond aan Zee	NSE[2]	1.5[6]	**4**	Sept-Mar	1.30	4.1/1.9
London Array	(68%)	2	**3**	Nov-Feb	1.64	(5.58)
Lincs	(NSE)	3	**3**	All Months	2.14	(5.0)
Thornton Bank Phase I, II, II	60%	2-10[10]	**6**	All Months[9]	2.71	3.0/1.0
Bligh Bank (Belwind)	75%	2-10[10]	**4.5**	All Months[9]	3.24	2.0/2.5
BARD 1	(-)	2	1	All Months	1.36	2.5/-
Alpha Ventus	(75%)	N/A[7]	**3**	All Months	3.05	(<2)[8]
Helgoland Cluster & Butendiek (4 OWFs)	63%/44%[11]	14	**3**	All Months	2.65 1.36 2.01 2.56	0.23 – 1.58[NB]/- 0.30 – 0.83[B]/-

OWF	Predicted Displacement Rate Guillemot/(auk)	Number of Years Pre-Construction Data	Number of Years Operational Data	Analysis Period	Array Density (turbines/km^2)	Post-construction Guillemot/Razorbill/ (Auk) Wind Farm Mean Peak Density (n/km^2)
Kentish Flats	(NSE)	3	2	All Months[9]	3.02	(<1)[8]
Gunfleet Sands	(-)	1	1	Oct-Mar	3.04	<1/-
Horns Rev 1	(-)	N/A[7]	1	Jan-Apr	3.87	(<1)
Horns Rev 2	(-)	2	1	Oct-Apr	2.74	(<1)

Table Note: [1]weak distance effect with low statistical significance suggested after re-analysis, [2] displacement effects shown to be statistically non-significant after re-analysis by INLA [3] a positive displacement effect was predicted however a weak (<25%) negative displacement rate was also compatible with the data. [4] surveys not conducted in consecutive years (2001/2 and 2004) and a minimum of six years prior to operation,[5] gradient analysis conducted with data from 3 surveys conducted in July during second year of operation, [6] pre-construction surveys cover two winter seasons, [7] inside/outside wind farm analysis was conducted, [8] density not provided but estimated at less than 2 from count data, [9] displacement effects are representative of the winter season only due to low/zero counts during other periods, [10] monthly surveys covering 2 to 10 years for different months, [11] non-breeding and breeding displacement effects, respectively. NSE; No Significant Effect, -; avoidance inferred rate not quantified.

3.3 Variables Influencing Displacement Rate for Auks

Despite the number of studies reporting on displacement effects, there has been very little discussion on variables that influence displacement rate. Therefore, a meta-analysis of data collated in this review has been conducted as an attempt to identify any explanatory variable that is associated with displacement effect. This is useful not only to predict a displacement rate for the assessments for Hornsea Four, but also to determine when a higher displacement rate may be applicable to an OWF assessment. A comparison of the OWF environmental variables and OWF design metrics that have been used to examine variables associated with displacement effect are shown in **Table 4**. OWFs were split into two groups according to whether a displacement effect was shown or inferred and those shown to have no significant displacement effect or attraction, as indicated in **Table 3**. Each environmental variable and the OWF design metrics were compared between the two groups using an unpaired t-test to test for significant differences.

Table 4 Comparisons of OWF environmental variables and OWF design metrics

OWF	Location	Year Fully Operational	Number of Turbines	Array Area (km^2)	Capacity (MW)	Array Density (turbines/km^2)	Density (% total windswept area)[1]	Blade gap height above MSL	Rotor Diameter	Distance from Shore	Post-construction Guillemot/Razorbill/ (auk) Peak Density (n/km^2)
Hornsea P4	UK Southern North Sea	N/A	180	492	1000	0.37	2.67	40	305	65.0	45.7/5.0*
Beatrice	UK Northern North Sea	2019	84	131	588	0.64	1.19	33	154	13.5	100/6.0
Thanet	UK Southern North Sea	2010	100	35	300	2.86	1.83	22	90	12	11.6/2.6
Westermost Rough	UK Southern North Sea	2015	35	35	210	1.00	1.90	22	155	8	(10.5)
North Hoyle	Irish Sea	2004	30	9.6	60	3.11	1.55	30	80	7.2	8.9/4.8
Robin Rigg	Irish Sea	2010	58	18.3	90	3.16	3.00	25	110	11.0	5.1/4.1
Prinses Amalia	Dutch North Sea	2008	60	21.6	120	4.30	1.40	21	80	23	4.1/1.9
Egmond aan Zee	Dutch North Sea	2006	36	24.5	108	1.30	0.94	20	90	10	4.1/1.9
London Array	UK Southern North Sea	2013	175	107	630	1.64	1.85	22	120	20	(5.58)
Lincs	UK Southern	2013	75	35	270	2.14	2.43	22	120	8	(5.0)

OWF	Location	Year Fully Operational	Number of Turbines	Array Area (km^2)	Capacity (MW)	Array Density (turbines/km^2)	Density (% total windswept area)[1]	Blade gap height above MSL	Rotor Diameter	Distance from Shore	Post-construction Guillemot/Razorbill/ (auk) Peak Density (n/km^2)
	North Sea										
Thornton Bank Phase I, II, III	Belgian North Sea	2013	54	19.7	325.2	2.71	3.40	32	126	27	3.0/1.0
Belwind (Bligh Bank)	Belgian North Sea	2010	55	17	165	3.24	2.06	27	90	46	2.0/2.5
Bard Offshore 1	German North Sea	2013	80	58.9	400	1.36	1.58	30	122	101	2.5/-
Alpha Ventus	German North Sea	2010	12	3.9	60	3.05	3.51	30	126	56	(<2)[2]
Helgoland Cluster & Butendiek	German North Sea	2015 2015 2014 2015	80 48 80 80	30.2 35.3 39.80 31.3	302 295 288 288	2.65 1.36 2.01 2.56	3.00 1.69 2.27 2.89	30 34 29 32	120 126 120 120	35 57 53 32	0.23 – 1.58[NB]/- 0.30 – 0.83[B]/-
Kentish Flats	UK Southern North Sea	2005	30	9.95	90	3.02	1.92	25	90	8.5	(<1)[2]
Gunfleet Sands	UK Southern North Sea	2010	48	15.8	172.8	3.04	2.72	22	107	7	<1/-
Horns Rev 1	Danish North Sea	2003	80	20.7	160	3.87	1.94	30	80	17.9	(<1)

OWF	Location	Year Fully Operational	Number of Turbines	Array Area (km²)	Capacity (MW)	Array Density (turbines/km²)	Density (% total windswept area)[1]	Blade gap height above MSL	Rotor Diameter	Distance from Shore	Post-construction Guillemot/Razorbill/ (auk) Peak Density (n/km²)
Horns Rev 2	Danish North Sea	2009	91	33.21	209.3	2.74	1.86	21	93	31.73	(<1)

*Table Note: [1] Density (% total windswept area) represents the total windswept area of the turbines as a percentage of the array footprint, [2] density not provided but estimated from count data. * pre-construction abundance estimate, NB; non-breeding season, B; breeding season.*

High displacement rates have previously been suggested to be due to small OWF size and/or their high-density WTG layout. However, other OWF sites such as Robin Rigg and North Hoyle of similarly small sizes with similar densities of WTGs have shown little or no displacement effects. Indeed, Prinses Amalia OWF is a relatively high WTG density site, and after a re-analysis of these data it was predicted to have had no displacement effects, which would suggest that WTG density may not be a predominant factor influencing displacement rates in auks. Indeed, comparison of array area and WTG layout density between OWFs with or without reported displacement effects showed no significant difference. However, OWF density represented as total windswept area as a percentage of the array area footprint showed a significant difference (p = 0.038) between groups (**Figure 1**), implying that OWF design and layout which increase density of this type are associated with displacement effect. This association does not correlate with WTG height or blade diameter as these variables showed no significant difference between the two groups of OWFs. This type of density may correlate to the amount of shadow flicker over the array area leading to disturbance effects or more accurately reflect the perceived nature of an OWF as birds approach.

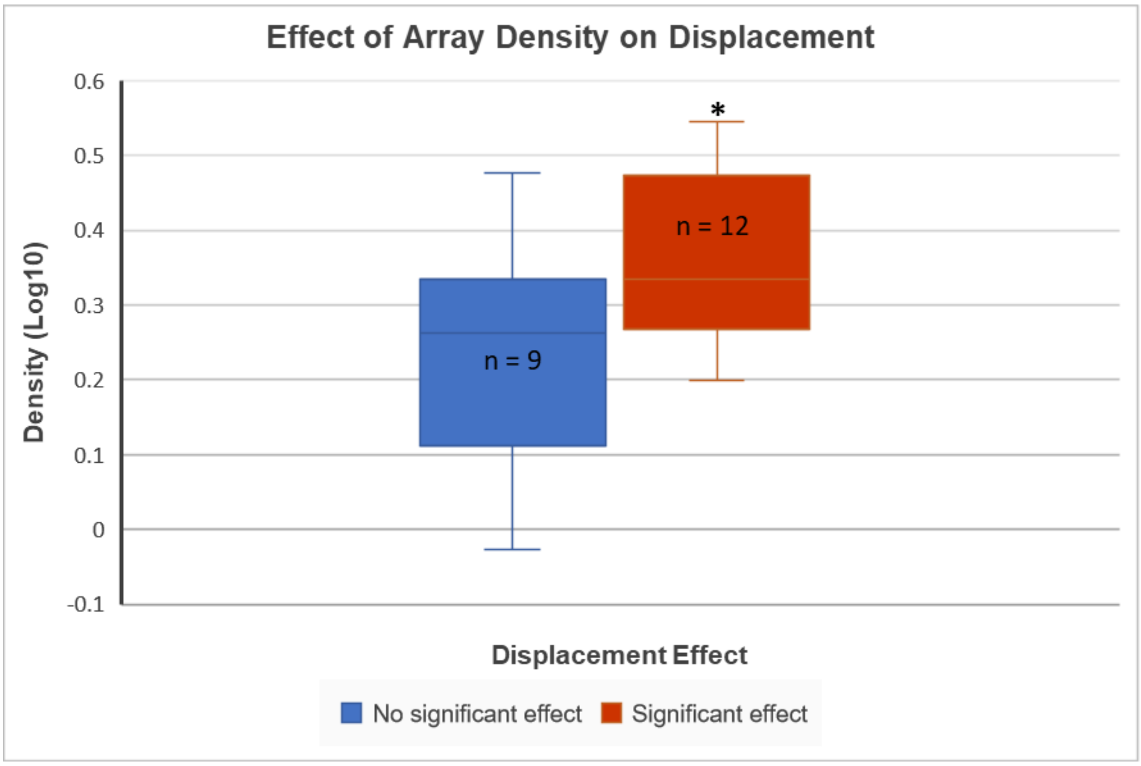

Figure 1 Effect of array density presented as total windswept area as a percentage of the array footprint on displacement effect. The box-and-whisker plot shows the minimum, first quartile, median, third quartile, and maximum of the data. Groups represent OWFs that have reported no significant displacement effect (blue) and OWFs that have reported a significant or inferred effect (red), *; p = >0.05.

The data presented in **Table 3** would suggest that OWF sites with moderate to high abundances of auks (densities of ≥5 birds/km^2) tend (with the exception of only London Array OWF) to have reported no displacement effects or weak avoidance (as demonstrated from the studies such as Beatrice, Robin Rigg, Westernmost Rough, North Hoyle, Lincs and Thanet OWFs). These data also suggest that where higher displacement rates were demonstrated these are within OWFs that are associated with low auk abundance. Indeed, when auk abundance was tested it was shown to be significantly different ($p = 0.002$) between the two groups of OWFs (**Figure 2**). The influence of auk abundance on displacement effect is not clear but could relate to the importance or quality of the habitat. Therefore, displacement effects appear to be related to the importance of the respective area of sea for auks with regard to breeding, migrating, moulting or non-breeding activities. For example, in an area of moderate or high auk density competition for food between birds is greater, and individual birds may become more tolerant of any real or perceived disturbance and hence displacement effects would be negligible. In locations with low auk densities, the birds may select habitat with sufficient prey, but as competition for food between birds is reduced in such areas, they can also select areas where real or perceived disturbance is lower and choose to move away from array areas. This may in part explain the highly variable displacement effects reported between OWF sites according to auk abundance.

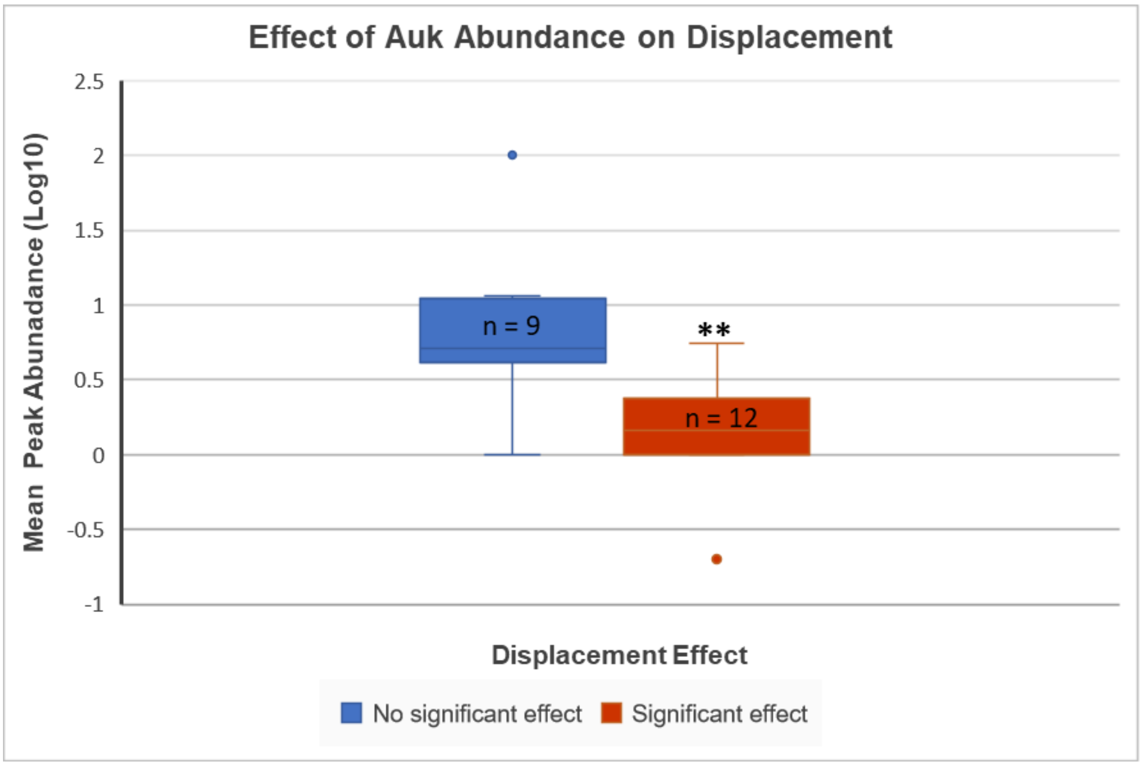

Figure 2 **Effect of auk abundance on displacement effect.** The box-and-whisker plot shows the minimum, first quartile, median, third quartile, and maximum of the data with values outside 1.5 times the interquartile range considered to be outliers and are represented by dots. Groups represent OWFs that have reported no significant displacement effect (blue) and OWFs that have reported a significant or inferred effect (red), **; p = >0.01.

Only two other variables demonstrated a significant difference between groups: distance from shore (p = >0.001) and geographical region, (**Figure 3** and **Figure 4**, respectively). The association of distance from shore with a displacement effect may simply reflect the greater flexibility in the choice of alternate areas of quality habitat, which increases with distance from the shore. Whereas OWFs closer to shore may reduce this choice to areas in a seaward direction only as areas of quality habitat are unlikely nearer to the shoreline. The influence of distance from the shore on displacement may also be an associated factor with bird abundance mentioned above that should be considered.

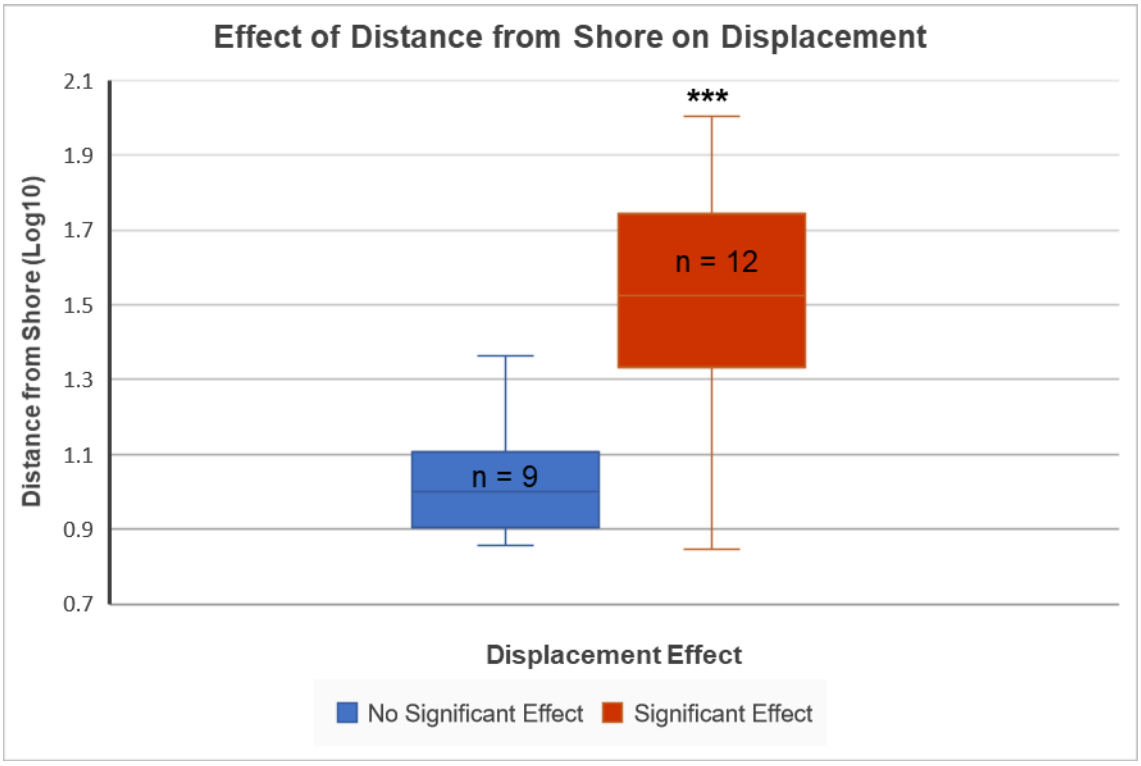

Figure 3 **Effect of distance from shore on displacement effect.** The box-and-whisker plot shows the minimum, first quartile, median, third quartile, and maximum of the data. Groups represent OWFs that have reported no significant displacement effect (blue) and OWFs that have reported a significant or inferred effect (red), ***; p = >0.001.

Why sea region is shown to be associated with displacement effect is unclear. As shown in **Figure 4**, more southerly areas of the North Sea such as within Belgium, German and Dutch waters are more likely to be associated with OWFs with reported displacement effects, whereas areas of the Irish Sea and UK North Sea tend to be associated with OWFs with no displacement effects. This may reflect differences in data collection and assessment methods between regions or geographical distributions and abundances, which has been shown to correlate with displacement effects.

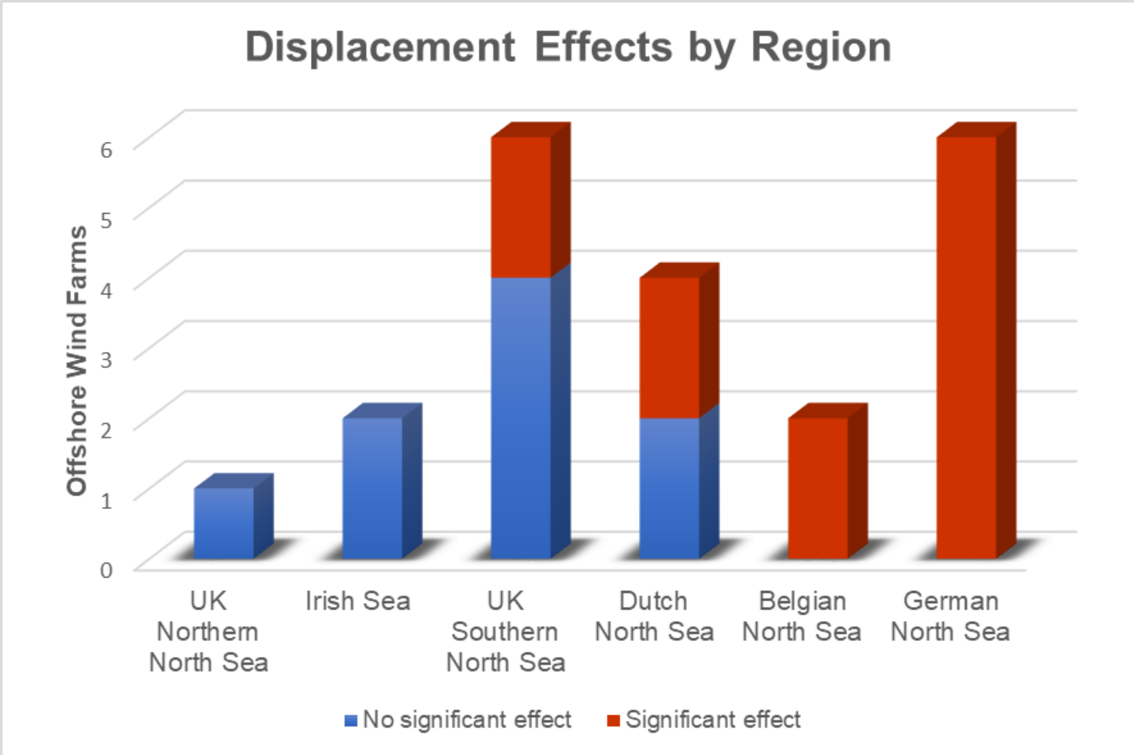

Figure 4 **Displacement effect by region.** Groups represent OWFs that have reported no significant displacement effect (blue) and OWFs that have reported a significant or inferred effect (red).

3.4 Importance of comparing attributes of OWF Sites for predicting impacts for Hornsea Four

Displacement studies of auks at OWFs often estimate impacts in isolation, in a particular season and to a particular breeding colony. However, it is undetermined to what extent or whether at all impacts identified by one study apply to other OWFs, breeding colonies or seasons. The previous sections of this report's review and meta-analysis highlight the importance of considering differences between OWF sites such as; their array layout, WTG density within the array, environmental and ecological variables when predicting impact effects of OWF developments. The review suggests that various factors may strongly influence the magnitude of an effect and OWFs with similar attributes are likely to demonstrate similar displacement effects. The review also demonstrates that sites with considerably different in design layouts that also have very different environmental and ecological characteristics are unlikely to have similar displacement effects. This was demonstrated in the graphs in Section 3.3, where OWFs can be segregated into non-significant/significant displacement effect groups based on particular attributes. This, to some degree, accounts for the considerable range of displacement rates observed between OWFs and that applying this range in predicting impacts to other OWF developments would simply add to the uncertainties of impact assessments.

Various attributes of the Hornsea Four proposed development are clearly different to OWFs that have reported high displacement rates for auks. Figure 5 shows the contrasting difference in three attributes: OWF layout, WTG density and marine traffic density, between three OWFs reporting high displacement rates for auks and the Hornsea Four development site. It is quite clear that all three OWFs (shown in Panels A to C of Figure 5) have high WTG density and complex layouts forming part of a larger cluster of OWFs. This attribute is rarely, if at all, taken into account when assessing the displacement rate, in particular the impact of the other OWFs in close proximity during their construction phases and how their layouts effect bird behaviour to the OWF being studied.

Hornsea Four shows a contrasting layout to these OWFs with a more open regular layout (Panel F of Figure 5). Differences in marine traffic density is yet another attribute not often considered, but a known disturbance affecting bird behaviour / distribution. The OWFs with high displacement rates all display high levels of marine traffic and are located in the vicinity of major shipping lanes. This contrasts to the Hornsea Four array area, which has low existing marine traffic and is not close to any major shipping lanes. Vessel traffic with its associated disturbance effect, which is well documented, together with complex, high density OWFs arranged in clusters and located in areas of low auk abundance constitute a unique environmental scenario that is likely to precipitate the high displacement rates reported from these OWFs. Hornsea Four displays contrasting attributes with low marine traffic, a simple regular WTG layout and moderate to high auk abundance. Therefore, by considering OWF site attributes the displacement rate can be refined from the broad range reported across all OWFs and tailored to an individual development based on similar attributes known to effect displacement rate and thereby removing the high level of uncertainty.

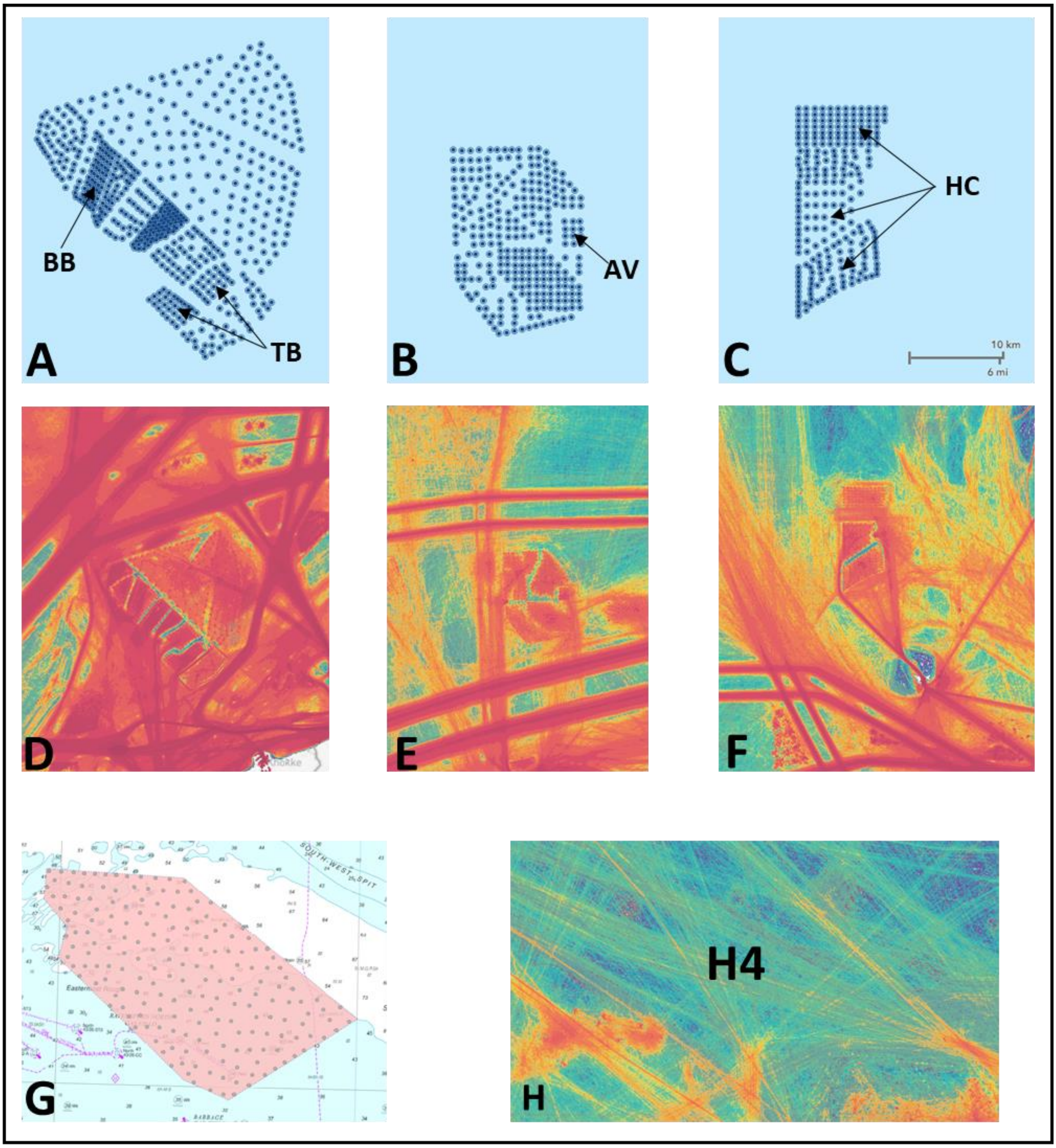

Figure 5. OWF site comparison. OWF layout is shown in A; Belgium/Dutch OWF cluster showing the location of Bligh Bank (BB) and Thortonbank (TB), B; German OWF cluster showing the location of Alpha Ventus (AV) and the Helgoland OWF cluster (HC). The blue dots represent individual turbines. The corresponding heats maps D, E and F represent vessel traffic density for the years 2019 and 2020 surrounding the OWFs in panels A, B and C, respectively. The bottom panels G and H shows for comparison the proposed turbine layout and vessel traffic surrounding the Hornsea Four site (H4). All panels are shown at the same scale. OWF turbine layouts compiled from 4Coffshore accessed December 17, 2021, https://map.4coffshore.com/offshorewind/, Marine traffic density compiled from MarineTraffic accessed December 17, 2021, https://www.marinetraffic.com/.

3.5 Summary of Auk Displacement Rates

In summary, operational monitoring reports covering 21 OWFs would suggest a wide range of displacement effects from +112 to -75%, with negative displacement rates ranging from 25-75%. This negative displacement range closely mirrors that advocated by Natural England and the RSPB of between 30-70% displacement for auks. However, this range has been compiled regardless of the quality of the study or confidence in the derived rate, furthermore it does not account for studies that have shown no significant displacement effect or attraction. In addition, use of a broad range of this type with no explanatory variables as to why there is such a range just adds to the uncertainties in predicting displacement effects for a specified development.

Confidence in displacement rates exceeding 50% have been questioned (Zuur, 2018) for three out of five of these studies which include all studies with a displacement rate of 75%. The remaining two OWF study reports/publications (London Array and Helgoland cluster) have only recently (2021 and 2020, respectively) been published and have yet to be appraised in subsequent publications. Furthermore, our meta-analysis of these studies suggests that there is a relationship between auk abundance at these study sites and displacement effects. Therefore, a factor which should be taken into consideration is that high displacement rates tend to be associated with low auk abundance in the study area. However, it is unknown what the cause of this association is and may reflect either an artifact of using statistical methodologies inappropriate for low count datasets, which inflates the predicted displacement rate or if they are accurate, are due to particular conditions and only apply to specific OWF settings. Therefore, applying these higher displacement rates to other OWF sites is currently not justified.

Until further monitoring data are collected and appropriately analysed at OWF sites, a precautionary approach would be to assign a general displacement rate of up to 50% for auks, particularly at sites such as Hornsea Four that have moderate to high auk abundance. This takes into consideration weak displacement effects that may have gone undetected in some studies and is still precautionary considering the number of studies that have shown no significant effect or indeed an attraction effect.

4. Review of Evidence of Mortality Rates for Displaced Auks

4.1 Understanding Auk Displacement Consequent Mortality

Current evidence suggests that the response of seabirds to OWFs varies depending on the species and of the life stages of individual birds. Birds that avoid OWFs may do so entirely, including an area considered to be a buffer around an array area, or do so partially. Avoidance of OWFs may be either on a spatial scale or temporally according to levels of competition outside the array area or prey abundance within the array area. The loss of foraging or resting areas is ultimately considered to be the consequence of these avoidance behaviours and therefore, a major challenge is understanding how displacement from array areas may impact upon population processes.

Displacement effects may act at differing levels, including the individual, colony and wider population levels and are dependent on key factors:

1) The importance of the array area in the context of the surrounding area;
2) The fraction of the colony/population utilising the array area;
3) The degree (number of birds and distance) of displacement from within and outside the array area; and
4) The consequences of losing the array area and / or buffer to forage and / or reside in (in terms of the survival probability and productivity) as a result of the OWF.

Mortalities are likely to correlate strongly with the quality of the area lost; if a key foraging area is lost and the remaining areas are already close to carrying capacity, then the mortality rates of displaced birds may be considerably higher (Busch and Garthe, 2016).

When considering these points in relation to the Hornsea Four array area and 2 km buffer the quality of the area would be considered as a mosaic of low to moderately important foraging areas when compared to the wider area. This is evident from the auk distribution and density maps produced from the aerial digital surveys of the area (Figures 15 and 18 of A2.5 ES Volume A2 Chapter 5 Offshore and Intertidal Ornithology - Ørsted, 2021). The area outside of the array area and a 2 km buffer consists of two predominant areas of moderate to high important foraging areas to the northeast and south of the array area (Figure 5.3 of A2.5 ES Volume A2 Chapter 5 Offshore and Intertidal Ornithology - Ørsted, 2021). This would imply that if displacement of auks occurred from the array area it would be into areas of equal or higher quality foraging or resting areas. In terms of whether the areas auks may be displaced into are close to carry capacity or not, local colony population trends would provide some indication as to whether this is true if colony populations had reached a plateau. The latest seabird monitoring reports on the auk colony at the FFC SPA indicate gradual increases in productivity for both guillemot and razorbill since 2017 and 2009, respectively (Aitken *et al*., 2017). Colony counts of individuals for both guillemot and razorbill have shown a general upward trend since counts first began in 2009 (Lloyd *et al*., 2019). This would suggest that in general, local foraging areas have yet to reach carrying capacity as increased competition and prey availability are predominant factors regulating colony growth, which at FFC SPA has yet to show signs of a plateau.

The appropriateness of using mortality rates as high as 10% in assessments is unclear, given the lack of evidence, though UK Statutory Nature Conservation Bodies (SNCBs) regularly advise the use of a range of 1 to 10% mortality for guillemots and other auk species based on their opinion (Natural England, 2014). In contrast, environmental consultants working on behalf of Developers consider that the use of 1 or 2% mortality is more appropriate (Norfolk Boreas Limited, 2019; SPR, 2019; Ørsted, 2018b), though these assessments were also almost entirely based on expert judgement. The lack of empirical evidence has led to the 1 to 10% mortality rate range continuing to be used despite it being a 'best guess' to allow for precaution. This was evident following consultation with seabird experts, such as stated by Allen (2013) in the JNCC expert statement on ornithological issues for East Anglia One OWF. At that time there was currently no data (not even anecdotal) with which to support the reliable selection of mortality rates stemming from varying levels of displacement.

4.2 Studies determining Auk Displacement Consequent Mortality

However, since Natural England's interim advice on auk mortality rates was first issued in 2013 and updated in 2017 (SNCBs, 2017) there have been two studies (described below) with updates to predict the fate or population consequence of displaced seabirds, including auks, from OWFs (Searle *et al*., 2014 and 2018; van Kooten *et al*., 2019), and anecdotal evidence is available (presented below) of implied low additional mortality rates from auk colony stability on Helgoland (Dierschke *et al.*, 2018), despite auk displacement rates of 44 to 63% being reported (Peschko *et al*., 2020) and OWFs having been operated in the area since 2014.

4.2.1 Study One

Van Kooten *et al*. (2019) applied an assessment method to estimate full life-cycle population effects in the North Sea caused by OWF-induced habitat loss. The study included assessment of two auk species, razorbill and guillemot, for the non-breeding season and included all existing and planned North Sea OWFs as presented in van der Wal *et al*. (2018). The analysis consisted of habitat quality maps based on seabird distribution data and determined the cost of habitat loss using an individual based energy-budget model. Together, the potential cost of habitat loss in terms of reduced survival rates of bird redistribution, due to a change in the availability and configuration of the foraging area under OWF scenarios, were calculated. Two mortality rates were tested: the first was based on the *Individual Based Model* (IBM), using an energy budget approach to quantify this effect, and the outputs from *Habitat Utilisation Maps* (HUMs); the second was based on a precautionary 10% mortality rate. Displacement rates were set at a realistic maximum of 50% based on Dierschke *et al*. (2016) or an overly precautionary 100% in order to understand complete displacement. The modelling process assumes individual birds have an amount of energy available at any particular time, have an intake of energy and incur energetic costs over time. Utilising the values in the habitat maps, the model calculates energetic gain or losses of moving to different locations to produce a frequency distribution of survival probabilities. The results produced several outputs that may be used to inform the effects of displaced birds from OWFs. The effect of OWF displacement at the North Sea wintering population level are shown below for guillemot and razorbill as the fifth percentile additional monthly mortality rate during the period of OWF exposure, using either a realistic (50% displacement) or overly precautionary (100% displacement) scenario in the IBM model.

Guillemot

<u>50% Displacement;</u>

- 5.02E-04 for juveniles (age 0);
- 2.09E-04 for juveniles (age 1); and
- 8.87E-05 for juveniles (age 2), immatures and adults.

<u>100% Displacement;</u>

- 6.69E-04 for juveniles (age 0);
- 3.13E-04 for juveniles (age 1); and

- 8.87E-05 for juveniles (age 2), immatures and adults.

Razorbill

<u>50% displacement;</u>

- 1.0E-04 for juveniles; and
- 9.3E-05 for immatures and adults.

<u>100% displacement;</u>

- 1.0E-04 for juveniles; and
- 1.9E-04 for immatures and adults.

These additional percentage change mortalities are given at the population level and, therefore, can be difficult to translate to predicted additional mortality for birds that are displaced from OWFs. However, by comparing effect sizes between the 10% mortality scenarios and all IBM mortality scenarios, predicted population growth rate decreases most with OWFs for the 10% mortality scenarios, whereas for all IBM mortality scenarios the effect of the OWFs on population growth rate is negligible (van Kooten *et al.*, 2019).

Guillemot

<u>Median annual population growth rate/relative population size after 30 years:</u>

- Without OWFs; 1.043
- 50% displacement IBM; 1.043/0.992
- 50% displacement 10% mortality; 1.040/0.901

Razorbill

<u>Median annual population growth rate/relative population size after 30 years:</u>

- Without OWFs; 1.015
- 50% displacement IBM; 1.015/1.003
- 50% displacement 10% mortality; 1.013/0.944

The study demonstrates that OWF demographic effects observed using all IBM simulation models are much weaker than those modelled using an arbitrary 10% mortality rate, the latter of which predicts a significantly lower population growth for razorbill and guillemots. This significant difference suggests that applying a 10% mortality rate to displaced birds in the non-breeding season is unrealistic and a considerably lower mortality rate that reflects the effects seen in the IBM scenarios would be more appropriate.

4.2.2 Study Two

Searle *et al*. (2014) presented what is still considered to be the most comprehensive assessment of the effects of displacement and barrier effects from OWFs on breeding seabirds, using the best available empirical data coupled with advanced modelling approaches. The study developed time and energy models of foraging during the chick-rearing period to estimate the population consequences of displacement from proposed OWF developments for key species of seabirds, including guillemot and razorbill, breeding at local SPAs. Population effects were modelled for five SPA colonies (Buchan Ness to Collieston Coast SPA, Fowlsheugh SPA, Forth Islands SPA and St Abb's Head to Fast Castle SPA) and four regional OWFs (Neart na Gaoithe, Inch Cape, Seagreen P1 Alpha and Bravo).

The model presented by Searle *et al.* (2014) simulated foraging decisions of individual seabirds under the assumption that they were acting in accordance with optimal foraging theory. Each individual selected a suitable location for feeding during each foraging trip from the colony based on bird density maps and assuming that the foraging behaviour of individual seabirds was driven by prey availability, travel costs, provisioning requirements for offspring, and behaviour of conspecifics. The impacts of the proposed OWFs were assessed by comparing simulated values of adult and chick survival in models that included the OWFs against the baseline simulations. The scenarios run reflected possible assumptions regarding food availability (good, moderate or poor), the spatial distribution of prey (homogeneous or heterogeneous), and the percentage of birds affected by barrier and displacement effects. The final simulations assumed moderate food availability, a 1 km buffer around each OWF, and that 60% of birds experienced displacement and barrier effect.

The results of the model simulations consistently yielded estimated OWF effects on SPA adult survival that corresponded to declines of less than 0.5% for both guillemot and razorbill. For guillemot, SPA changes in adult survival (shown as a percentage point) were estimated for two SPAs and a single OWF. The change in adult survival for the Forth Islands SPA and Neart na Gaoithe OWF were -0.20 and -0.30 and for the Foulsheugh SPA and Seagreen Bravo OWF were -0.04 and 0.10 under homogenous and heterogenous prey distributions, respectively.

For razorbill, SPA changes in adult survival were estimated for the Forth Islands SPA and four OWFs. The changes in adult survival were for each OWF were, Seagreen Bravo; -0.09 and -0.01, Seagreen Alpha; -0.05 and -0.05, Neart na Gaoithe; -0.10, -0.09 and Inch Cape; -0.90 and -0.11, under homogenous and heterogenous prey distributions. Changes in adult survival often reflected the distance of the OWF from the SPA with reduced additional mortality or no negative effect with greater distance. The models implied that birds displaced from OWFs under heterogeneous prey distribution simulations (which would be most applicable to the Hornsea Four array area) can move into areas with richer prey and so incur an advantage over their initial choice of foraging location, that in part offsets the cost incurred. The models also suggest that OWFs approaching the mean maximum foraging range (Woodward et al., 2019) have little or no negative impact on adult survival and may indeed increase adult survival if birds are displaced back to distances nearer the SPA which reduce travel energetic costs, e.g., adult survival for guillemot at Foulsheugh SPA displaced from Seagreen Bravo OWF (at approximately 50 km) increased by 0.10 percentage points under heterogenous prey distribution.

How these modelled changes in SPA adult survival are translated to predict additional mortality for birds that are displaced from other OWFs is not straight forward. The model requires a number of assumptions to be made that would benefit from parameterisation with local data for comparison to the Hornsea Four array area, in particular prey distribution. However, assumptions appear to be similar with a moderate food availability predicted across the Hornsea Four array area, 2 km buffer vs 1 km buffer, and 50% displacement vs 60%. The models demonstrated that the SPA-OWF combinations with the largest declines in adult and chick survival generally correspond to those for which birds spend a substantial proportion of time in the zones that are affected by the OWF. This suggests that changes to FFC SPA adult survival from Hornsea Four would be at the lower rates predicted due to the distance of the colony from the array area in relation to mean maximum foraging distances for guillemot and razorbill and areas of richer prey available for displaced birds. This would suggest from the modelled outputs in Searle et al (2014) the most applicable would be Foulsheugh SPA and Seagreen Bravo OWF at a distance of approximately 50 km from each other. The model predicted a small negative impact (-0.04) under homogenous prey distribution but a small positive impact (0.10) under heterogenous prey distribution on changes to adult survival. Using FFC SPA colony population size, predicted changes in adult survival from the models and mean peak numbers of birds observed in the Hornsea Four array area and 2 km buffer during the breeding season, a crude estimation can be made on mortality effects of displaced birds.

For example:

For guillemot, if we take the FFC SPA population size as 90,861 in 2017 (Lloyd, 2019) and use the predicted -0.04 additional percentage point on adult survival from the model simulations an additional 36 birds would be subject to displacement consequent mortality from Hornsea Four at the SPA level per annum. If we then consider the mean peak number of guillemots observed in the Hornsea Four array area and 2 km buffer, which is 8,553, and apply a displacement rate of 50% then this would mean that of the 4,276 birds displaced 36 would be subject to displacement consequent mortality to account for the predicted FFC SPA level effects. This translates to an additional mortality rate of 0.84% for birds displaced from the Hornsea Four array area and 2 km buffer. However, calculations presume that the majority of birds observed in the array area and 2 km buffer are birds from the FFC SPA colony. If breeding adults only account for 50% of the birds then the mortality rate could be revised to account for this, which in this instance may result in an estimated value of 1.64%, though it should be recognised that this is a simplistic assumption and is highly likely to be overly precautionary due to using model estimates for OWFs that are substantially closer to colonies than Hornsea Four is to the FFC SPA colony. Indeed, the model also predicted that under heterogenous prey distribution the change in adult survival was positive (+0.10) and therefore the mortality rate of birds displaced from an OWF can under certain scenarios be reduced. In support of the relatively low negative impacts on adult survival from displacement effects predicted for Hornsea Four the recent report by Daunt et al., (2020) should be considered. Daunt et al., (2020) applied modelling to a set of hypothetical OWF developments in the Forth and Tay region for five key seabirds including guillemot and razorbill at four SPAs within that region. SeabORD a mechanistic model of seabirds foraging, energetics, demographics and OWF interactions, was utilised, which provides an alternative to the displacement matrix approach. SeabORD modelled interactions between birds and OWFs used generated fictional footprints based on current consented developments (NNG, Inch Cape, and Seagreen Phase 1 - Alpha-Bravo) and potential new developments (Seagreen Phase 2 – Charlie-Delta-Echo-Foxtrot-Golf). Displacement effects were assessed upon annual survival and productivity using abundance maps generated from at-sea survey data and GPS tracking data. Of the SPAs assessed two were of similar distance to the OWFs that the FFC SPA is to Hornsea Four OWF; Buchan Ness SPA and St. Abb's Head to Fast Castle SPA and therefore more comparable. The additional annual mortality rates for displaced guillemots predicted for Buchan Ness SPA and St. Abb's Head to Fast Castle SPA were 0.2% and -2.7%, respectively (Daunt *et al*., 2020).

In summary, OWFs located on favoured foraging habitats that force birds to forage at greater densities in sub-optimal habitats were found to have the highest impact. However, studies using simulation models of time and energy budgets for auks during the breeding and non-breeding season suggest that these displacement effects, even at their highest impacts, are not compatible with an overly precautionary 10% mortality rate for displaced birds. Based on the available evidence from the model simulations, it is suggested that mortality rates for displaced birds is considerably less than 10%. Indeed, Daunt et al., (2020) demonstrated that modelled estimates of additional mortality at SPAs to combined OWF footprint displacement can be lower than 1% and in certain cases even reduce mortality. Therefore, predicted mortality rates for displaced birds from the Hornsea Four array area would be at the lower end of the mortality rate range due in part to suitable foraging areas being available outside the array area and that the array area is not sited on favoured foraging grounds. Although it is difficult to translate population level effects to additional mortality rates for auks displaced from OWFs, estimations can be made based on available evidence from current modelling studies, which suggest additional mortality rates for displaced auks are unlikely to exceed 1% for SPA birds at the limit of their foraging range.

4.2.3 Study Three

Although published studies with empirical evidence to support specific displacement consequent mortality rates are lacking, impacts on demographic effects from OWF displacement can be inferred from colony population trends, where displacement effects on auk distributions have been reported. One such colony is that on Heligoland, in the German North Sea, in which displacement rates for auks have been predicted to be 44% during the breeding season and 63% during the non-breeding season (Peschko *et al.*, 2020). OWFs within the Heligoland cluster have been in operation since 2014 allowing a substantial time for any correlation between operation of the OWFs and changes in colony demographics to be detected, if significant additional mortality from displacement is occurring. These data show that the population of breeding guillemots at the Heligoland colony has continued to show an increasing trend for over 20 years (2000–2021 (Dierschke *et al.*, 2018, Gerlach *et al.*, 2019, FFIVH, 2021), which includes seven years of OWF operation in the vicinity of the colony. This suggests that applying a 10% mortality rate for displaced birds is overly precautionary as at this level of mortality, changes in breeding population trends would have been detectable at the colony, correlating with the period of wind farm development and operation. This study also provides strong supporting evidence that displacement consequent mortality rates of over 1% are not apparent, as the latest breeding population status on Heligoland shows a continued increase for both razorbill and guillemot over the latest five-year period, which has remained unchanged compared to long-term data (Gerlach et al., 2019).

4.3 Summary of Auk Displacement Consequent Mortality Rates

The results of simulation models by Searle *et al*. (2014) and van Kooten *et al.* (2019) on the impacts of OWF displacement on auk adult survival are incompatible with a mortality rate of 10% and are more likely to be considerably less. This would suggest that additional mortality effects from displacement at a colony or population level would be negligible or undetectable under current monitoring conditions if this were true. Whereas an additional mortality level of 10% for displaced birds would likely be detectable after several years of monitoring, especially if continued moderate displacement from an OWF is occurring.

Therefore, applying the current evidence, the use of additional mortality rates of 10% for auks appears overly precautionary. Simulation models of displacement effects at the population level and empirical evidence from colony demographic trends suggest additional mortality rates from displacement effects of up to 1% to be more reflective of the evidence base and still remain precautionary.

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