



Evaluating the sensitivity of the KEC 5 habitat loss assessment to different displacement-effect curves for the common guillemot

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Summary

Offshore wind farms (OWFs) can displace seabirds from their foraging or resting habitats, which leads to habitat loss with potential population consequences. As part of the KEC assessment, population effects of displacement from OWF areas were assessed for several seabird species and tested using the 'Acceptable Level of Impact' (ALI) methodology (Soudijn et al. 2025). The ALI methodology tests whether population effects exceed predefined species-specific threshold values. Because mortality effects of displacement are highly uncertain, the KEC 5 assessment used four different mortality levels (1%, 2%, 5% and 10%).

In the KEC 5 assessment, habitat loss was modelled using fixed effect distances and displacement probability distributions that were invariant with respect to the distance from OWFs. However, displacement effects might be better represented by a *displacement effect curve*, which describes the attenuation of displacement effects with distance from OWFs. Here we considered three different published displacement effect curves (from Peschko et al. 2024, Szostek et al. 2024 and Grundlehner et al. 2025) and analyse their impact on the outcome of the KEC 5 assessment for the common guillemot.

The type and shape of the displacement effect curve considerably influenced the estimated population effects of habitat loss and all displacement effect curves led to lower population impacts compared to the KEC 5 assessment. However, the displacement effect curve of Peschko et al. (2024) did not alter the ALI outcome compared to the approach used within KEC 5, where the ALI was violated for the two highest mortality levels (5% and 10%). For the displacement effect curve of Grundlehner et al. (2025), the ALI threshold was only violated for the 10% mortality level, and applying the Szostek et al. (2024) displacement curve no longer resulted in an ALI violation for any of the mortality levels considered.

Future research should aim to reduce uncertainty in the estimates of displacement for the guillemot and other species that are known to strongly avoid OWFs. Our analysis mainly points to a large sensitivity of season-specific displacement effects, and it is therefore crucial to measure displacement in different times of the year. In addition, impact assessment of habitat loss effects should use precautionary estimates of displacement, and as much as possible include uncertainty and known sources of variability such as seasonality and distance from OWFs.

1 Introduction

The Dutch 'Kader Ecologie en Cumulatie (KEC)' is a repeating assessment commissioned by the Dutch government to estimate the ecological impacts of current and planned offshore wind farms (OWFs) on the (Dutch part of the) North Sea. As part of the most recent update (*i.e.* KEC 5), the population effects of habitat loss due to displacement and avoidance of OWF areas were assessed for several seabird species (Soudijn et al. 2025). The KEC 5 assessment distinguished between three national OWF scenarios: *i)* the *Basic* scenario included all Dutch OWFs built up to 2020, *ii)* the *Basic-plus* scenario included all OWFs approved up to 2024, and *iii)* the *Total* scenario included all OWFs planned up to 2033. Within this impact assessment, the *Acceptable Level of Impact* (ALI) methodology (Hin et al. 2024) was used to evaluate whether the estimated population effects exceeded predefined, species-specific threshold values. For the assessment of habitat loss effects, the ALI criteria was violated for both the common guillemot (*Uria aalge*), and the northern gannet (*Morus bassanus*), although this depended on the assumed level of mortality that birds suffered as a result of displacement from OWF areas. While many sources of uncertainty remain, the KEC 5 habitat loss assessment indicates that northern gannet and common guillemot populations might suffer from future offshore wind energy developments on the Dutch Continental Shelf (DCS) and that targeted additional research and more profound assessment methods are required to reduce these uncertainties.

One of the key uncertainties in the current assessment methodology for habitat loss effects relates to the so-called 'effect distance', which is the minimum distance from the boundary of an OWF at which there is no longer any significant reduction of bird density (Szostek et al. 2024). Together with the (planned) size of OWFs, the effect distance determines which part of a species' current habitat will become unavailable as a result of the construction of OWFs. There is considerable uncertainty associated with the effect distance, because it describes the behavioural tendency of birds to stay away from OWFs, which, among other reasons, is hard to quantify, varies between individuals and with local environmental conditions.

For the common guillemot, the KEC 5 assessment for habitat loss (Soudijn et al. 2025) used an effect distance of 19.5 km, which was reported by Peschko et al. (2024) as the mean distance from the border of OWFs up to which guillemot density in autumn was significantly affected. This implies that guillemots within a range of 19.5 km of the boundary of an OWF can be displaced and, as a consequence, might experience elevated mortality. This effect distance is considerably larger than the 500 m used in KEC 4 (Soudijn et al. 2022), when no studies on displacement were available for guillemots. In the assessment by Soudijn et al. (2025), guillemots within OWFs, including the 19.5 km surrounding area, suffered a mean displacement probability of 0.79 (95% CI = 0.74 – 0.83), which was reported by Peschko et al. (2024) as the mean reduction in guillemot autumn density within the affected area (*i.e.* OWF area + 19.5 radius). Because of the high uncertainty about the effects of displacement, displaced birds were subject to four discrete annual mortality levels (1%, 2%, 5% or 10%), where the 5% mortality level corresponded to the mortality used within previous KEC assessments (van der Wal et al. 2018, Soudijn et al. 2022). The ALI methodology, which relies on stochastic population modelling, revealed unacceptable population impacts for all three OWF scenarios with 10% displacement mortality and for two out of three OWF scenarios (Basic plus and Total) for the 5% displacement mortality (Soudijn et al. 2025). The effect distance of 19.5 km considerably increased the affected area compared to the size allocated to OWFs and therefore contributed towards the ALI violations that were established for the common guillemot.

The assumption of 19.5 km effect distance was considered a precautionary assumption by Soudijn et al. (2025), as it reflected the largest effect distance observed by Peschko *et al.* (2024). Furthermore, the study by Peschko et al. (2024) was judged as the most extensive study available, as it covered a large spatial area, with data from multiple seasons and years, and more than ten OWFs in German waters. The 19.5 km effect distance was found within the autumn period (mid-July to September), which is the period with highest guillemot numbers on the German and also the Dutch EEZ. For the winter period (October – February), a smaller effect distance of 16.5 km was reported by Peschko et al. (2024). Although the effect distance of

19.5 km was established in German waters, this was considered representative for the Dutch context as well (Soudijn et al. 2025).

A study by Grundlehner et al. (2025) also found a substantial effect distance for common guillemots of at least 10 km, but only for a single wind farm in Dutch North Sea (Gemini) and for a single winter season. Grundlehner et al. (2025) did not examine whether displacement effects were still present for distances larger than 10 km. In another study, Szostek et al. (2024) analysed data from aerial and ship-based surveys collected over an eight year period from post-construction monitoring of all 22 wind farm in the German North Sea and found a consistently larger effect distance of guillemots in autumn (6 – 12 km) than in winter (0.4 – 2 km). For both seasons, these effect distances are smaller than those reported by Peschko et al. (2024), but this analysis was a 'Before-After Control Impact' (BACI) study covering a larger time frame including baseline years back to 2003.

In the KEC 5 assessment, only a single effect distance with a homogenous displacement probability of 79% for birds within the effect distance range around an OWF was considered. In reality, the displacement effect is a gradient, with lower bird densities close to the OWF and increasing densities until no significant displacement effect is measurable (Szostek et al. 2024). Instead of a single effect distance combined with a displacement probability, the displacement effect of OWFs on bird density can therefore be better represented by a *displacement effect curve*, which describes the continuous change in displacement (relative effect on bird density) with increasing distance from the boundary of an OWF.

Here we perform a sensitivity analysis with respect to the effect distance as used in the KEC 5 assessment for habitat loss (Soudijn et al. 2025). As opposed to using a single effect distance, we describe how the assessment results change when using different *displacement effect curves*. We implement the season-specific displacement effect gradients as found by Peschko et al. (2024), Grundlehner et al. (2025) and Szostek et al. (2024) and compared them with the approach used within KEC 5 (Soudijn et al. 2025) by calculating their effects on the estimates of displacement-induced mortality and subsequent population consequences.

2 Assignment

The aim of this assignment is to perform a sensitivity analysis regarding outcome of the KEC 5 assessment for habitat loss for the common guillemot, with respect to the assumptions on displacement effects. As opposed to using a single effect distance (19.5 km) for the common guillemot and a single displacement probability distribution, we studied the effect of using *displacement effect curves* as found by three different studies (i.e. Szostek et al. 2024, Peschko et al. 2024, Grundlehner et al. 2025). This sensitivity analysis includes a refined spatial analysis to capture the variation in displacement probability as a function of distance from OWFs, season, and uncertainty. In addition, variation and uncertainty of bird distributions is taken into account by using 1,000 randomly generated bird distribution maps, as was done by Soudijn et al. (2025). The population effects of displacement are estimated for each displacement effect curve using the population models and ALI methodology as described by Soudijn et al. (2025). The sensitivity analysis was only performed for the Dutch "Total" OWF scenario, which includes all OWF plans for the DCS up to 2033 (Soudijn et al. 2025).

3 Materials and Methods

3.1 Spatial analysis

3.1.1 Displacement effect curves

We considered the three displacement effect curves (**Figure 1**) for common guillemots as published by Peschko et al. (2024), Grundlehner et al. (2025) and Szostek et al. (2024) and analyzed their effect on the outcomes from the KEC 5 assessment (Soudijn et al. 2025). Characteristics of three different studies are summarized in **Table 1**. Both Peschko et al. (2024) and Szostek et al. (2024) present separate displacement effect curves for the autumn and winter period, while Grundlehner et al. (2025) only studied the winter season. Where applicable, displacement effect curves of different seasons were taken into account and divided over the six bimonthly periods that were considered in the KEC 5 assessment (**Table 1**). Effectively, the autumn displacement effect curves from Peschko et al. (2024) and Szostek et al. (2024) were applied to the bimonthly periods April-May, June-July and August-September and the winter displacement curves were applied to the remaining periods (October-November, December-January and February-March). The winter displacement effect curve as estimated by Grundlehner et al. (2025) was applied year-round.

Figure 1 illustrates the estimated guillemot displacement probability in relation to distance from offshore wind farms during autumn and winter for the different studies considered. The grey bars at the top of each panel indicate the displacement estimates including uncertainty used in KEC 5 (Soudijn et al. 2025). The published values (displayed as point ranges) served as the basis for resampling displacement probabilities 1,000 times while incorporating the reported uncertainty. The resulting resampled distributions are displayed as coloured lines. The comparison highlights both seasonal differences and variation among studies in the extent and distance over which guillemot displacement is expected to occur. Negative displacement values were not considered and truncated to zero.

3.1.2 Uncertainty propagation

Uncertainty in the number of guillemots displaced was estimated by re-sampling both the displacement probabilities and the parameters of the fitted bird distribution models. Displacement probabilities were applied spatially using a shapefile representing offshore wind farm (OWF) areas in the Dutch EEZ. This shapefile included OWFs belonging to the Total scenario as used by Soudijn et al. (2025). For each displacement study (i.e. Peschko et al., 2024; Grundlehner et al., 2025; Szostek et al., 2024) and season (where available), displacement probability values were associated with distance from OWFs (**Figure 1**).

As we did not have access to the original displacement models from the studies considered, we relied on the reported estimates and associated uncertainty (e.g., mean displacement values and confidence intervals) provided in the publications. These reported values were used as the basis for constructing displacement probability surfaces, which were then applied in our analysis through simulation and spatial interpolation techniques.

For each study, a custom simulation approach was used to generate 1,000 realizations of the displacement probability. For example, in the case of the Grundlehner et al. (2025), residuals were generated using normally distributed random noise given the mean probability with associated confidence interval. The uncertainty was assumed to remain constant across all distances from offshore wind farms. These residuals were then smoothed across distance using a loess regression to reflect spatial structure in the uncertainty. This approach generated a set of displacement probability according to distance from OWF that accounted for both the central estimates and the spatially-varying uncertainty derived from each study.

Table 1 Overview of study characteristics. Assigned seasons correspond to the months for which guillemot density maps matched with the displacement probabilities from the three studies considered.

	Peschko et al. (2024)	Grundlehner et al. (2025)	Szostek et al. (2024)
Location	German EEZ	Dutch EEZ	German EEZ
Wind farms included	20 OWFs in 5 OWF clusters	Gemini wind farm	All 22 OWF projects operational in 2021
Survey period	2003 – 2020	2022 – 2023	2014 – 2021
Data seasons	Autumn (16.07 – 30.09) & Winter (01.10 – 28.02)	Winter (October – March)	Autumn (01.07 – 30.09) & winter (01.10 – 28.02)
Seasons applied	Autumn (April – September) & Winter (October – March)	Winter (applied year round)	Autumn (April – September) & Winter (October – March)
Reference	Before, during and after construction	Post-construction only	Post-construction only
Survey sample size & methods	<ul style="list-style-type: none"> ship-based surveys, observer-based digital aerial surveys 	8 digital aerial surveys with “HiDef” system	<ul style="list-style-type: none"> 277 digital aerial surveys (German Federal Maritime & Hydrographic Agency standard using “APEM”, “DAISI” & “HiDef” techniques) 297 ship-based surveys (ESAS method with 1.5 detection correction for swimming and diving birds)
Statistical analysis	‘Before-After Control Impact’ (BACI) analysis	Zero-Altered Gamma Generalized Linear Model and Integrated Nested Laplace Approximation (INLA)	Gaussian Markov Random Fields in INLA

For each bimonthly guillemot abundance map (see KEC 5; Soudijn et al. 2025), a bootstrapping procedure with 1,000 iterations was used to combine uncertainty from both displacement probability and bird distribution predictions. In each iteration, a single re-sampled displacement surface was selected (from the study-specific simulations), and a single re-sampled prediction of guillemot distribution was drawn from the fitted model. These were then multiplied spatially which produced an estimate of the number of affected guillemots.

This calculation was carried out using a shapefile that included spatial locations of all OWFs included in the Total scenario used within KEC 5 (all Dutch OWFs planned up to 2033). Before the application of the displacement effect curve, the OWF shapefile was adjusted to reflect the realized footprint of the wind farm (e.g., turbine array layout), thereby accounting for the reduction in OWF size compared to the OWF search area.

3.1.2.1 Adjustments to the KEC 5 spatial analysis approach

The spatial analysis here differed slightly from the approach used in the KEC 5 assessment (Soudijn et al., 2025). These differences were related to the method of converting OWF search areas to realized OWF areas and to the spatial analysis technique required to account for changes in displacement effects with distance from OWFs. To ensure comparability, the KEC 5 assessment approach (i.e. an effect distance of 19.5 km with a fixed displacement distribution) was implemented in the same manner as the three displacement effect curves. This ensured that differences in outcome between approaches were not obscured by changes in methodology.

The correction for the realized vs. planned size of OWFs was conducted on the OWF shapefile and this shapefile was used to directly calculate the number of displaced birds. In contrast, the KEC 5 assessment first estimated the number of displaced birds using the planned OWF search areas and subsequently corrected the results to reflect the smaller realized OWF sizes. Although the latter approach includes birds

from a larger area (the search area itself), it does not account for the shift in location that birds are displaced from. Additionally, the application of displacement effect curves in this study required using a different spatial analysis technique to accommodate the change in the displacement effect with distance from OWFs. This different technique also introduced a small discrepancy with the results as presented by Soudijn et al. (2025).

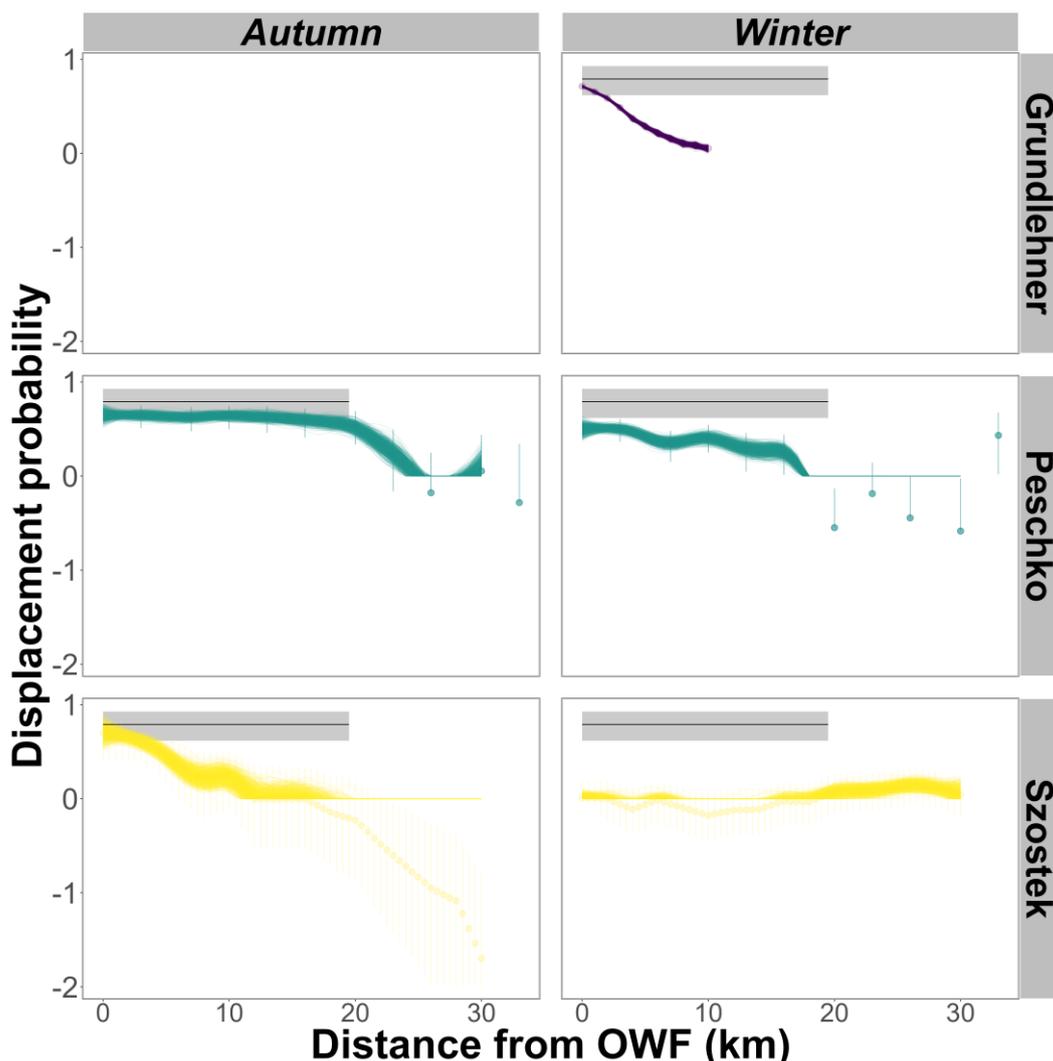


Figure 1 Guillemot displacement probability as a function of distance from offshore wind farms, based on three studies (Peschko et al., 2024; Grundlehner et al. 2025; Szostek et al., 2024). Reported displacement estimates (shown as point ranges) were used to resample displacement probability 1,000 times, accounting for uncertainty. The resulting distributions are displayed as coloured lines. Grey ribbons (uncertainty) and black line (mean) represent the displacement effect as used within KEC 5.

3.2 Mortality calculation

The annual additional mortality resulting from displacement by OWFs was calculated following the approach from the KEC 5 assessment (Soudijn et al. 2025). For each iteration, the number of displaced guillemots per bimonthly period was averaged across the six bimonthly periods and divided by the number of guillemots in August-September. The number of birds in August-September was chosen, because this period has the highest number of guillemots on the Dutch Continental Shelf (DCS) (mean abundance = 141,693), and was therefore most representative as a measure of the 'Dutch' guillemot population. This resulted in the proportion of the population affected by displacement. The mortality resulting from displacement by OWFs was calculated by multiplying this proportion by a fixed mortality level. The level of additional mortality that birds experience as a result of displacement by OWFs is unknown and, following Soudijn et al. (2025), we

used levels of 1%, 2%, 5% or 10% additional mortality per year, where the 5% mortality level corresponds to the mortality level used within earlier KEC assessments (van der Wal et al. 2018, Soudijn et al. 2022).

3.3 Population modelling & ALI

The stage-based, stochastic population model for common guillemots described by Soudijn et al. (2025) was used to assess population effects of additional, displacement-induced mortality. For each combination of displacement effect curve and mortality level, we ran 10,000 replicate simulations over 40 simulated years. We also ran 10,000 replicate simulations that represented the KEC 5 approach, with a fixed effect distance of 19.5 km and a fixed displacement probability distribution. These simulations were compared against 10,000 unimpacted simulations without additional displacement-induced mortality, but with the same randomly generated population matrices and bird distributions.

The ALI methodology (Hin et al. 2024) was used to evaluate the relative difference between a pair of impacted and unimpacted population abundances after 40 simulated years. If in a particular pair of simulations this difference exceeded $X = 10.89\%$ (for the common guillemot), the X threshold was exceeded. The ALI test was violated if more than 5% (the ALI Y threshold) of the paired simulations exceeded the X threshold, i.e. resulted in a relative difference $> 10.89\%$.

4 Results

The estimated surface area from which guillemots are potentially displaced according to the different studies and seasons, and expressed as percentage of DCS, is illustrated in **Figure 2**. The coloured boxplots represent the distribution of resampled estimates, reflecting the reported uncertainty of each study. Especially the autumn displacement effect curve of Peschko et al. (2024) results in a large affected area, with a median estimate around 40% of the DCS. This is slightly higher than the surface area affected when using the 19.5 km approach from KEC 5. This higher value can be explained by the displacement effect in the Peschko autumn curve (see **Figure 1**) that extends beyond 19.5 km. The winter displacement effect curve of Peschko et al. (2024) leads to potential displacement area much lower than used in the KEC 5, and more comparable to the results of Szostek et al. (2024). The displacement effect curve from Grundlehner et al. (2025) results in the lowest area affected for both seasons, although it should be noted that this curve is derived from winter data and we imposed it year-round. It is noteworthy that the KEC 5 estimate appears relatively conservative in winter, whereas in autumn the area affected as reported by Peschko et al. (2024) is even larger than that used in KEC 5. This larger autumn effect found for the Peschko et al. (2024) curve is partly because of the uncertainty in the displacement effect for distances larger than 19.5. The KEC 5 approach assumes no displacement effect at distances larger 19.5 km, but here we account explicitly for the uncertainty in displacement effects and, for the Peschko et al. (2024) curve allow for the possibility of displacement at distances larger than 19.5 km.

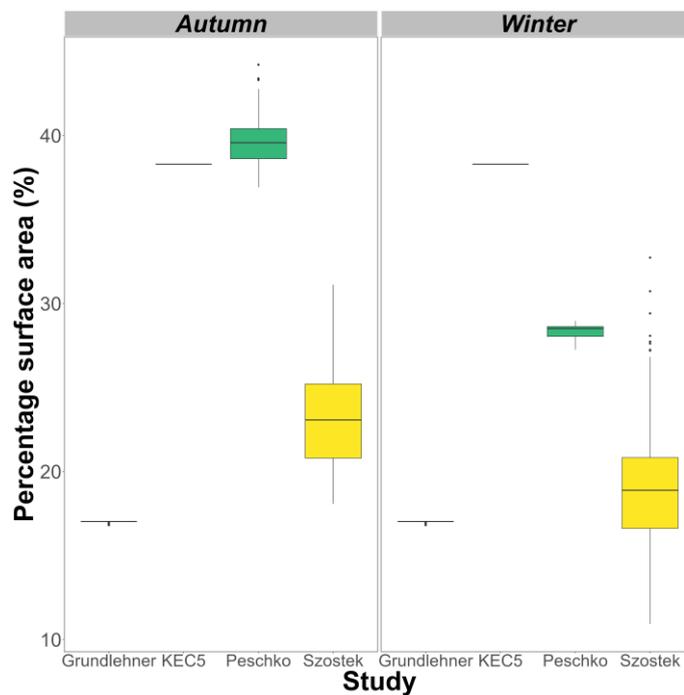


Figure 2 The surface area, expressed as percentage of the Dutch Continental Shelf (DCS), where guillemots are potentially affected by displacement, shown separately for each study and season (KEC 5: Soudijn et al. (2025); Peschko et al. 2024; Grundlehner et al. 2025 & Szostek et al. 2024). All OWFs on the DCS planned and realized up to 2033 are included. For the Grundlehner case the winter displacement curve was applied to the autumn season as well, as only a single displacement curve was estimated.

4.1 Number of birds displaced from (future) OWFs

The number of birds displaced from OWF areas included in the Total scenario was highest when applying the approach as used within the KEC 5 assessment (Soudijn et al. 2025), followed by the displacement effect curve from Peschko et al. (2024; **Figure 3**). This was true for all bimonthly periods, but the differences between the KEC 5 results and those from Peschko et al. (2024) was largest for the bimonthly periods in which the winter displacement effect curve from Peschko et al. (2024) was applied (Oct.-Nov., Dec.-Jan. & Feb.-Mrch.). The lowest mean number of displaced birds varied between periods and either resulted from the displacement effect curve from Grundlehner et al. (2025; Aug.-Sep.) or Szostek et al. (2025: all other periods; **Table A1**).

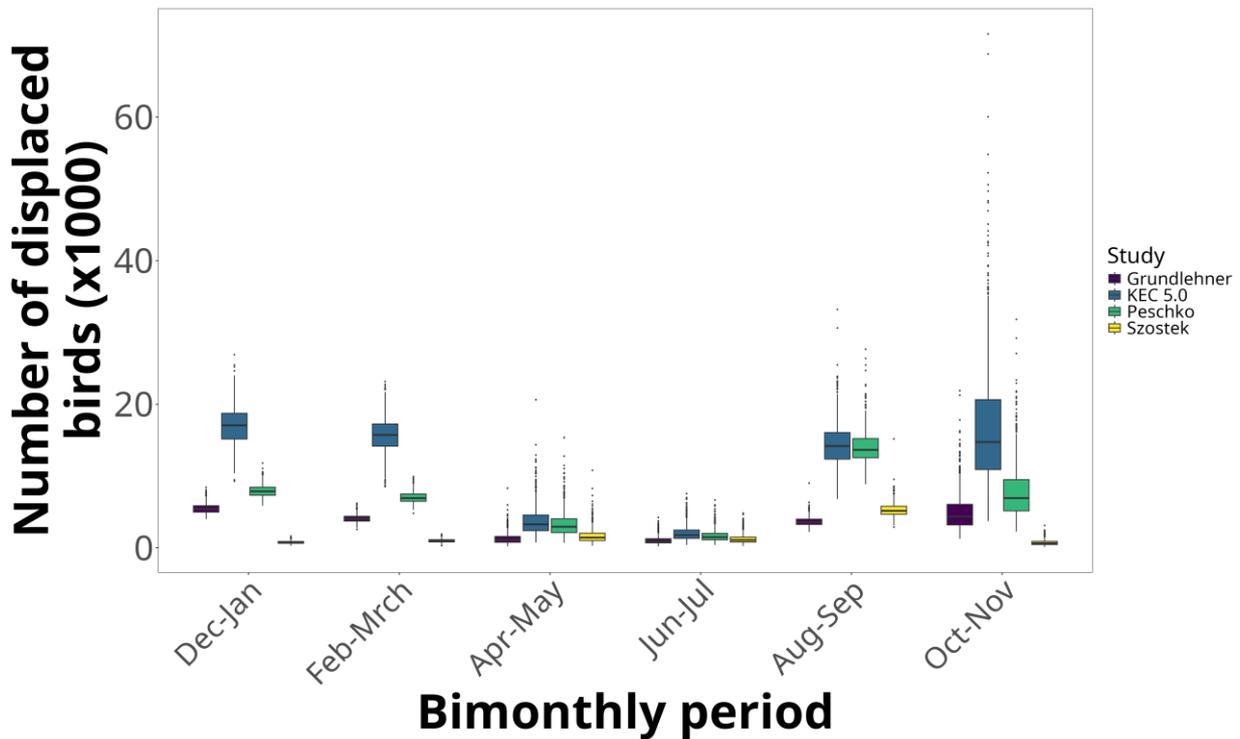


Figure 3 The distribution of the number of birds displaced from OWFs in the Dutch 'Total' scenario per bimonthly period and displacement effect curve study (colours). For each bimonthly period, the displacement probability as applied within KEC 5 resulted in the highest mean number of birds displaced.

The percentage of birds displaced from OWF areas was highest when using a fixed effect distance and a mean displacement probability of 79% as used in the KEC 5 assessment, with a mean of 8.3%, followed by the Peschko et al. (2024) results (mean = 4.9%), the Grundlehner et al. (2025) results (mean = 2.4%) and the results from Szostek et al. (2024; mean = 1.3%; **Figure 4**). The absolute amount of variation was largest for the KEC 5 method, but the relative amount of variation as quantified through the coefficient of variation ($cv = \text{standard deviation} / \text{mean}$) was approximately equal between the different studies (~ 0.15), although slightly lower for the Peschko et al. (2024) results (~ 0.12).

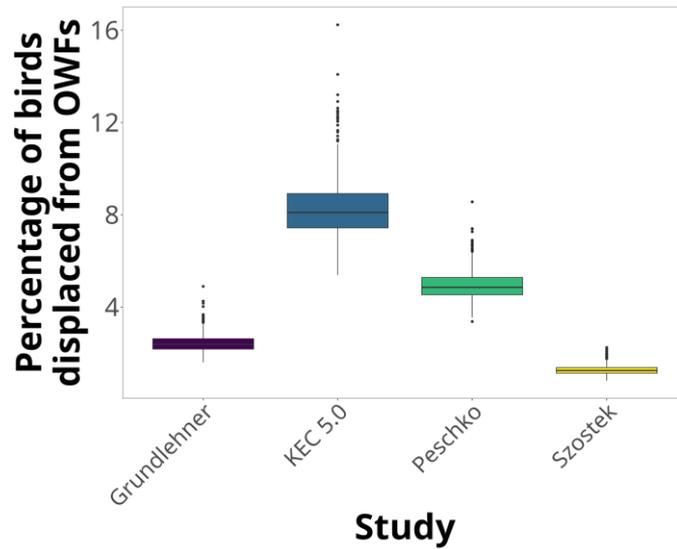


Figure 4 The distributions of the percentage of displaced birds calculated as the mean number of displaced birds from OWFs per bimonthly period, divided by the number of birds in August-September. The latter statistic was equal between the different displacement studies applied.

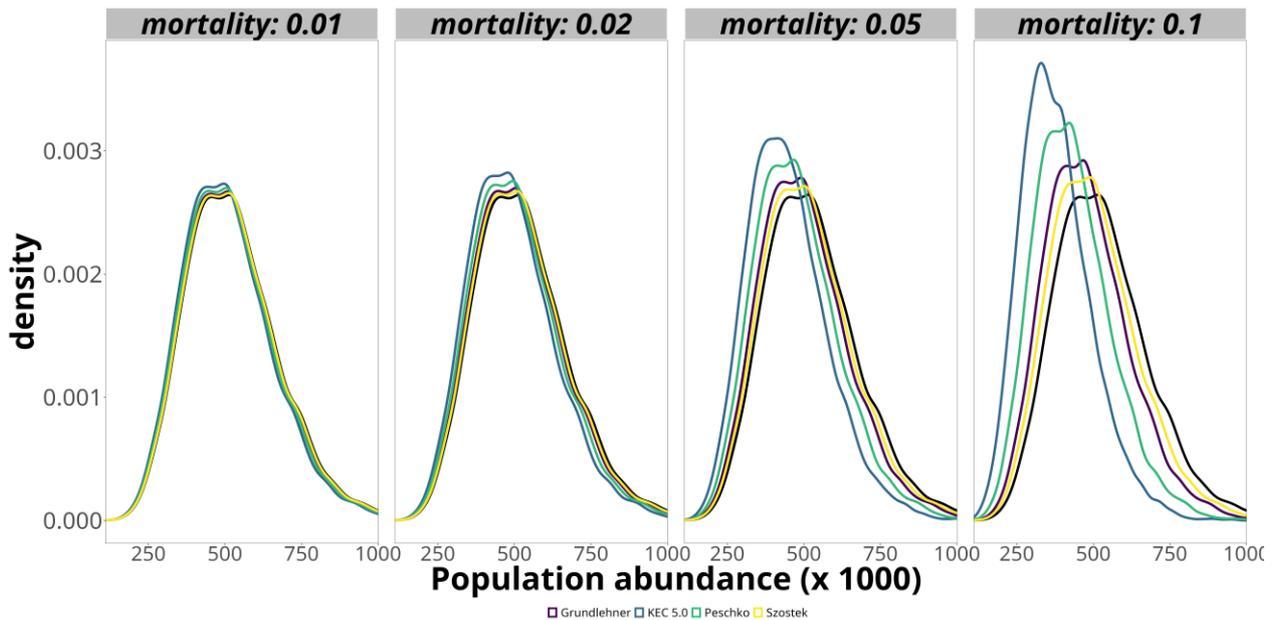


Figure 5 Probability density distributions of projected population abundance after 40 simulated years. Black lines indicate the unimpacted scenario without additional displacement-induced mortality. Coloured lines show the density distribution of abundance for the different displacement effect curves applied. Outcomes using different levels of displacement mortality are plotted in different panels. The mortality level of 0.05 corresponds to that used within KEC 4.

4.2 Mortality, population impact & ALI outcome

Estimated additional mortality experienced by birds displaced from OWFs was proportional to the fraction of birds displaced (**Figure 4**), with the proportionality constant equal to the mortality level associated with displacement. Consequently, annual displacement mortality was highest for the KEC 5 approach ranging from 0.00082 – 0.0082 for the four mortality levels considered (**Table A2**). The effect distance curve from Szostek et al. (2024) resulted in the lowest additional mortality (0.00013 – 0.0013).

Consequently, population impacts of displacement were largest for the KEC 5 approach using a fixed effect distance, and smallest for the displacement effect curve from Szostek et al. (2024; **Figure 5**). For the lowest mortality level, the different displacement effect curves result in distributions of population abundance that are similar to the unimpacted distribution, but these distributions diverge with increasing mortality level (**Figure 5**).

The different displacement effect curves lead to changes in outcome of the ALI test compared to the ALI outcome from KEC 5 (**Figure 6**). As in the KEC 5 assessment for habitat loss (Soudijn et al. 2025), the ALI test for the Total scenario of the common guillemot was violated for mortality levels 0.05 (5%) and 0.1 (10%), but not for mortality levels 0.01 (1%) and 0.02 (2%). This is still the case when applying the displacement effect curve of Peschko et al. (2024), although the probability of an X-threshold violation dropped considerably for the 0.05 mortality level (from 0.966 to 0.099; **Table A3**). For the displacement effect curve of Grundlehner et al. (2025), the ALI test was violated only for mortality level 0.1, with a X-threshold violation probability of 0.113. The ALI test was not violated when using the displacement effect curve of Szostek et al. (2024).

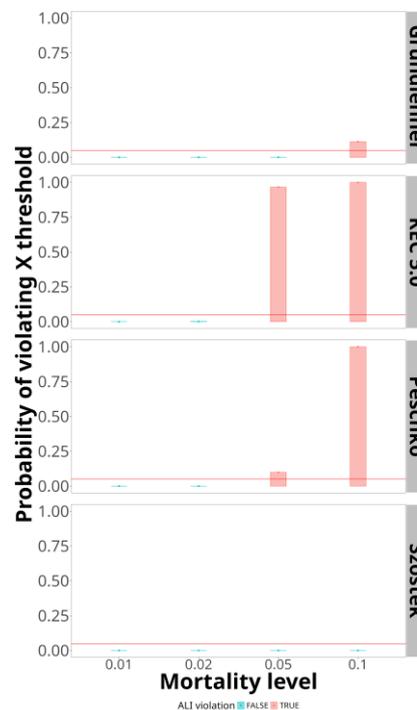


Figure 6 The probability of exceeding the ALI X threshold value, which equals 10.89% for the common guillemot for a period of 40 years. A population impact is considered unacceptable (ALI violation = `TRUE`) if the probability of violating the X threshold value > 0.05. Bars are coloured according to the ALI outcome and the red horizontal line indicates the 0.05 threshold value.

5 Discussion & Conclusion

This study considered three displacement effect curves for the common guillemot (Peschko et al., 2024; Szostek et al., 2024; Grundlehner et al., 2025), analysed their population effects and compared these to the outcomes of the KEC 5 assessment. The type and shape of the displacement effect curve influenced the population effects of habitat loss and all displacement effect curves led to lower population impacts compared to KEC 5. The displacement effect curve of Grundlehner et al. (2025) and Szostek et al. (2024) modified the mortality levels for which the ALI was violated. Moreover, applying the Szostek et al. (2024) displacement curve no longer resulted in an ALI violation for any of the mortality levels considered.

The three published studies provide notably different estimates of guillemot displacement probability and affected surface area. The population effect of displacement found here were lowest for the Szostek et al. (2024) variant, which likely derived from their winter displacement effect curve that is noticeably flat. In contrast, the displacement effect curve of Grundlehner et al. (2025) is much steeper, which translates in a small area affected (**Figure 2**), but still a higher displacement effect compared to the curve from Szostek et al. (2024). Again, it should be pointed out that Grundlehner et al. (2025) did not measure displacement in autumn, a time of year for which the other two studies (Szostek et al. 2024 and Peschko et al. 2024) reported higher displacement effects. In addition, Grundlehner et al. (2025) did not look at displacement for distances larger than 10 km. For these two reasons, the estimated effect of habitat loss derived from the winter displacement curve of Grundlehner et al. (2025) is likely an underestimate.

We compared the approach used within KEC 5, which is based on the 19.5 km effect distance found by Peschko et al. (2024), with the season-specific continuous displacement effects as reported in the same study. This raises the question whether the lower population effect of the Peschko et al. (2024) implementation is derived from the gradual change in displacement effect with distance from OWFs (i.e. the implementation of a displacement effect curve), or from the implementation of the different seasons. Judging from **Figure 3**, the number of bird casualties in the autumn periods are comparable between the Peschko et al. (2024) and the KEC 5 results. This indicates that the displacement effect curve itself has little influence on the number of birds affected. For the winter periods, however, in which a different displacement effect curve was applied for the Peschko et al. case, the number of casualties is much lower than for the KEC 5 approach. This leads us to conclude that the season-specific effect is the main driver of the lower population impact that we observed for the Peschko et al. (2024) displacement curve.

The considerable variation in displacement effects between studies may reflect variation in data sources, modelling approaches, spatial coverage, or assumptions about displacement behaviour. The reported displacement effect curves are surrounded by large uncertainty ranges in most studies, except for Grundlehner et al. (2025), where credibility intervals are noticeably small. Although speculative, this likely arises because the data used by Grundlehner et al (2025) are derived from a single location and a single season.

Peschko et al. (2024) and Szostek et al. (2024), although partly based on the same data, both find considerable larger displacement effects in autumn than in winter. The KEC 5 assessment only considers the mean autumn displacement effect as reported by Peschko et al. (2024), and might therefore be overly precautionary for the winter period. In addition, the autumn displacement curves of Peschko et al. (2024) and Szostek et al. (2024) were based on the data collected in July, Augustus and September and we have also applied these curves on the months April, May and June, although neither Peschko et al. (2024), nor Szostek et al. (2024) used data from this time of year. It is likely that displacement effects measured in the German EEZ during spring are lower, because most guillemots wintering in this area will breed elsewhere. If this is the case, the estimated population impacts reported here for the displacement effect curves of Peschko et al. (2024) and Szostek et al. (2024) will be an overestimation of the true impact of displacement. In addition, most impact assessments of displacement effects assume that displacement is caused by the OWFs. However, displacement might also result from increased shipping to and from OWFs or other,

rerouted, shipping traffic and fishing activity. Currently, the KEC assessment method is unable to deal with these sources of disturbance.

Impact assessments should properly account for the different types of uncertainty and variation inherent to biological systems and measurements thereof. Resampling shows that small differences in reported estimates can propagate into large variation in predicted surface area impacts, as was best visible for the Peschko et al. (2024) curve (**Figure 2**). Unfortunately, we did not have access to the fitted statistical models from the studies considered and had to rely on reconstructing the displacement effect curves, which might not properly account for the increasing variation in displacement with distance from OWF (**Figure 1**). The availability of fitted model objects would improve uncertainty propagation and in this way increase robustness of impact assessments. Furthermore, negative displacement probabilities, where bird density is relatively higher with OWFs or after construction, than without OWFs or before construction, though excluded in the current analyses, raise questions about how best to model potential positive responses to OWFs. Possibly, negative displacement probabilities represent birds that are being displaced from the OWFs itself, but still remain within its proximity. If this is the case, negative displacement should not be interpreted as attraction. Furthermore, there may be reasons that lead to a negative displacement outcome unrelated to OWFs, but for example induced by changes in the distribution of prey.

In conclusion, there is substantial uncertainty and variation regarding the displacement by OWFs for common guillemots. This variation matters in terms of the predicted population effects of habitat loss and the choice of displacement effect curve can be decisive for whether population effect of habitat loss are deemed acceptable or not. Our analysis mainly points to a large effect of season-specific displacement effects. Future research should aim to reduce uncertainty in the estimates of displacement for the guillemot and other species that are known to strongly avoid OWFs. It is thereby crucial to measure displacement in different times of the year. In addition, impact assessment of habitat loss effects should use precautionary estimates of displacement that are based on data with a high spatio-temporal representation (multiple years, seasons, and large area), and as much as possible include uncertainty and known sources of variability such as seasonality and distance from OWFs.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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Justification

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Annex 1 Supplemental Tables

Table A1 Mean number of displaced birds per bimonthly period and study expressed as absolute numbers and as a percentage of the KEC 5 results (rightmost column).

Bimonthly period	Study	Mean number of displaced birds	Percentage (%) of KEC 5
Dec-Jan	Grundlehner	5465	32
Dec-Jan	KEC 5	16992	100
Dec-Jan	Peschko	7927	47
Dec-Jan	Szostek	774	5
Feb-Mrch	Grundlehner	4085	26
Feb-Mrch	KEC 5	15697	100
Feb-Mrch	Peschko	7019	45
Feb-Mrch	Szostek	998	6
Apr-May	Grundlehner	1285	34
Apr-May	KEC 5	3735	100
Apr-May	Peschko	3317	89
Apr-May	Szostek	1664	45
Jun-Jul	Grundlehner	1056	52
Jun-Jul	KEC 5	2015	100
Jun-Jul	Peschko	1673	83
Jun-Jul	Szostek	1240	62
Aug-Sep	Grundlehner	3672	25
Aug-Sep	KEC 5	14468	100
Aug-Sep	Peschko	14007	97
Aug-Sep	Szostek	5293	37
Oct-Nov	Grundlehner	4949	29
Oct-Nov	KEC 5	16874	100
Oct-Nov	Peschko	7831	46
Oct-Nov	Szostek	733	4

Table A2 Mean mortality probability resulting from displacement from OWFs per study and displacement mortality level (0.01, 0.02, 0.05 & 0.1).

Study	Mortality level			
	0.01	0.02	0.05	0.1
Grundlehner	0.00024	0.00049	0.00121	0.00243
KEC 5.0	0.00082	0.00165	0.00412	0.00824
Peschko	0.00049	0.00099	0.00247	0.00493
Szostek	0.00013	0.00025	0.00063	0.00126

Table A3 Probability of exceeding the ALI X threshold value and the outcome of the ALI test. An ALI violation occurs if the probability of exceeding the X threshold > 0.05.

Study	Mortality level	Probability exceeding X threshold 40 yrs	ALI violation
Grundlehner	0.01	0.000	FALSE
Grundlehner	0.02	0.000	FALSE
Grundlehner	0.05	0.000	FALSE
Grundlehner	0.10	0.113	TRUE
KEC 5	0.01	0.000	FALSE
KEC 5	0.02	0.001	FALSE
KEC 5	0.05	0.966	TRUE
KEC 5	0.10	1.000	TRUE
Peschko	0.01	0.000	FALSE
Peschko	0.02	0.000	FALSE
Peschko	0.05	0.099	TRUE
Peschko	0.10	1.000	TRUE
Szostek	0.01	0.000	FALSE
Szostek	0.02	0.000	FALSE
Szostek	0.05	0.000	FALSE
Szostek	0.10	0.000	FALSE

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