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Knowledge update for the KEC 6 assessment of habitat loss effects from offshore wind energy developments for seabirds

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Contents

Contents	3
Summary	5
1 Introduction	6
2 Assignment	7
3 Materials and Methods	8
4 Results	9
4.1 Displacement effects per species	9
4.1.1 Effect distances and displacement effect curves	9
4.1.2 Displacement probabilities	10
4.1.3 Season-specific displacement effects	11
4.2 Demographic parameters	13
4.2.1 Northern gannet	13
4.2.2 Sandwich tern	14
4.2.3 Common guillemot	15
4.2.4 Razorbill	15
4.2.5 Atlantic puffin	16
4.2.6 Northern fulmar	17
4.2.7 Comparison with other MONS/Wozep work	18
4.3 New methods for effect estimation	19
4.4 Population modelling and Acceptable Levels of Impact	20
4.5 KEC 5 review outcomes	20
4.5.1 Displacement mortality levels	20
5 Conclusions & Recommendations	22
5.1 Parameters	22
5.2 Knowledge gaps	22
6 Quality Assurance	24
References	25
Justification	29
Annex 1 Displacement parameters	30
A1.1 Northern gannet	30
A1.2 Sandwich tern	30
A1.3 Common guillemot	31
A1.4 Razorbill	31
A1.5 Atlantic puffin	32
A1.6 Northern fulmar	32

Annex 2	Demographic parameters	33
A2.1	Northern gannet	33
A2.2	Sandwich tern	33
A2.3	Common guillemot	33
A2.4	Razorbill	34
A2.5	Atlantic puffin	34
A2.6	Northern fulmar	34

Summary

The Dutch *Kader Ecology en Cumulatie* (KEC) assessment aims to quantify the ecological effects of current and planned offshore wind farms (OWFs) in (the Dutch part of) the North Sea. As the KEC methodology forms the basis for the ecological impact assessments for permitting individual wind farm sites, it should frequently be updated with the latest scientific knowledge. The current knowledge-based update (KBU) accommodates the most recent scientific knowledge into the assessment framework in preparation for the upcoming sixth version of the KEC assessment.

A literature search revealed new season-specific estimates of displacement effects for northern gannet, razorbill and northern fulmar. Breeding success parameters of the population models used within the KEC were updated with recent data on breeding success from colonies relevant to the Dutch part of the North Sea. New survival estimates were found for Sandwich tern. A recent publication presenting an individual-based model to assess effects of displacement by OWFs in Norwegian waters during the non-breeding season is discussed and its applicability for the KEC is reviewed. In addition, we summarize several other developments within projects related to the KEC assessment for seabirds.

1 Introduction

The Dutch KEC assessment (*Kader Ecologie en Cumulatie*; Rijkswaterstaat, 2025) aims to quantify the ecological effects of current and planned offshore wind farms (OWFs) in (the Dutch part of) the North Sea. For seabirds, population effects of collisions and habitat loss due to avoidance of OWFs are quantified using population models and population impacts are evaluated using the Acceptable Level of Impact methodology (Hin et al., 2024). As the KEC methodology forms the basis for the ecological impact assessments for permitting individual wind farm sites, it should frequently be updated with the latest scientific knowledge (Rijkswaterstaat, 2025). The most recent knowledge base update (KBU) was performed in 2025 (Hin et al., 2025a). That update included a complete description of the methodology to assess habitat loss effects on seabirds for six seabird species occurring in Dutch waters (Table 1-1). Since that update, new knowledge has become available regarding the displacement effects of OWFs for several of these species. Also, new estimates of demographic parameters were published, and an external review of the methodology as used for the last KEC assessment (KEC 5: Soudijn et al., 2025) was performed. The current KBU accommodates the most recent scientific knowledge into the assessment framework in preparation for the upcoming KEC 6 assessment. Because a full description of the methodology was published recently (Hin et al., 2025), only changes with respect to that publication, referred to as "KBU 2025", will be described. Demographic parameters of species that are assessed for both collision effects and habitat loss effects are also discussed in the current KBU.

Table 1-1 Marine bird species included in the current knowledge update for KEC 6 based on their sensitivity to offshore windfarms and occurrence in Dutch waters.

Species	Dutch name
Atlantic puffin – <i>Fratercula arctica</i>	Papegaaaiduiker
Common guillemot – <i>Uria aalge</i>	Zeekoet
Razorbill – <i>Alca torda</i>	Alk
Northern gannet – <i>Morus bassanus</i>	Jan-van-gent
Northern fulmar – <i>Fulmarus glacialis</i>	Noordse stormvogel
Sandwich tern – <i>Thalasseus sandvicensis</i>	Grote stern

2 Assignment

The assignment includes an update of the methodology of the KEC assessment for habitat loss with the latest scientific knowledge regarding the effects of displacement of seabirds by OWFs and demographic rates, in preparation for KEC 6. This will be done for the six seabird species listed in Table 1-1. The knowledge update includes a description of

- New knowledge and methods to assess effects of habitat loss for seabirds,
- New relevant knowledge from Wozep research and related research projects,
- Update of demographic parameters as used in the population models,
- Modifications of the assessment methodology as recommended by the external review performed in 2025,
- Modifications of the assessment methodology compared to Hin et al. (2025a).

3 Materials and Methods

To find newly available literature on displacement effects, displacement effect distances, and the demographic parameters used in the population model, such as adult survival and breeding success, a literature search was conducted. This focussed primarily on peer-reviewed publications, and published research reports, as well as datasets that have been published or updated since the KBU 2025. For this, the database scopus.com and the search engines Google and Google Scholar have been used. In addition, relevant literature cited in studies and reports identified during the literature search was also considered for parameterisation, occasionally leading to the inclusion of older references not covered in the previous knowledge base update for KEC 5. The search primarily included English-language literature but also incorporated relevant publications in Dutch and German. A focus was set on publications reporting values for the Dutch North Sea, the southern North Sea, and further extended to the Greater North Sea and the North-East Atlantic region. Studies from other parts of the world, such as Gulf of Maine (USA) or Newfoundland (Canada), were only considered if no other information was available, and if it was deemed relevant and representative for the Dutch North Sea population.

Search queries combined the species' scientific, English, Dutch, German name with search terms such as 'displacement (probability)', 'avoidance', 'disturbance', 'effect distance or radius' and 'offshore wind' for the displacement parameters. For demographic variables, combinations of species names with the dominant breeding colony names were searched along with terms like 'breeding success', '(breeding) productivity', 'survival', 'adult survival', 'juvenile/immature/first year survival', 'skipped breeding' and 'colony size'. Variables such as breeding success, colony size, and survival were searched in English, Dutch and German. A total of 57 studies that had not been previously added to the KBU dataset were identified with potentially relevant information which included older studies from 1992 to newly published studies from 2026. About thirteen relevant research reports, datasets, and peer-reviewed studies were published since the KBU 2025.

4 Results

4.1 Displacement effects per species

4.1.1 Effect distances and displacement effect curves

Northern gannet

For northern gannet, a mean effect distance of 1,500 m (range: 0 – 3,000 m) was used for all seasons within KBU 2025 and no new values for effect distances were found. However, the previously used source was updated and now exist as preprint, also detailing the methods applied to calculate those values (Peschko et al., 2025), which was not available yet during KBU 2025. The preprint of Peschko et al. (2025) publishes displacement effect curves for northern gannet, which were extracted and used to model displacement as a function of distance to the OWF. This displacement effect curve had a mean effect distance of 1,500m with a range of 0–3,000m (Table 4-1).

Sandwich tern

No new information on Sandwich tern effect distances was found. Therefore, the suggested mean effect distance of 1,500m (van Bemmelen et al., 2024) identified in KBU 2025 is recommended (Table 4-1).

Common guillemot

The most recent information on effect distances for common guillemots was already identified in KBU 2025, based on a paper by Peschko et al. (2024; Table 4-1). No new information was available for displacement effect curves and effect distances for common guillemot. Displacement effect curves are used for four out of six periods (Aug-Sep, Oct-Nov, Dec-Jan and Feb-Mar), while a combination of effect distance and displacement probability is used for the remaining two periods (Table 4-1). The choice for the displacement effect curve of the guillemot and its effect on the outcomes of the KEC assessment were discussed more thoroughly in the KBU 2025 and by Hin & Ransijn (2025).

Razorbill

Previously selected effect distances for razorbill for Oct–Mar were based on a study at the Dutch Gemini OWF (Grundlehner et al., 2025; Annex 2, Table A1.4). Now, new values based on a Before-After-Control-Impact (BACI) analysis from the German EEZ are available as preprint. Peschko et al. (2025) used long-term data (2003–2020) from the German North Sea to model relative changes in seabird abundance due to OWFs and their respective response radii. For razorbill, a response radius range of 0–3,000m was identified along with the mean effect distance of 1,500m (Peschko et al., 2025). This mean value is only slightly lower than the 2,000m reported by Grundlehner et al. (2025). As the study from Peschko et al. (2025) covers a larger area and uses a longer timeseries of seabird abundance data to model the effects than Grundlehner et al. (2025), the new values are recommended to be used for the months Oct–Mar instead (Table 4-1;). The displacement effect curve presented by Peschko et al. (2025), associated with the mean effect distance of 1,500 m was therefore used for the period Oct–Mar.

For Aug–Sep, a relatively large effect distance range of 6,000–11,000km was suggested in KBU 2025 based on (Szostek et al., 2024). However, as razorbills are present in very low numbers in Dutch waters between April and September, these months had to be grouped into a summer period in order to be able to predict razorbill distributions in the maps underlying the KEC (van Donk et al., 2026). Therefore, the value of 1,000m from Searle et al. (2025) identified in KBU 2025 is recommended to be used in this summer season instead. While razorbills spend the summer season largely at their UK colonies and numbers of razorbills in Dutch waters are highest in Apr–May (van Donk et al., 2026)), the effect distance of 1,000m from the UK presented by Searle et al. (2025) selected for Apr–May is recommended to be used for the entire summer season (Apr–Sep; Table 4-1).

Atlantic puffin

There is little information on displacement for this species. This is primarily due to the limited number of case studies currently available in which OWFs coincide with the species' distribution range. Previously, mean effect distances of 1,500m and effect ranges of 1,000–2,000m were found as displacement areas assumed in two UK OWF applications as reported by Searle et al. (2025). These values were suggested in KBU 2025, and no new information is available (Table 4-1; see Annex 2, Table A1.5).

Northern fulmar

Effect distance ranges of 0–3,000m in Jun–Jul and 3,000–6,000m for the other months were previously based on a presentation by Garthe et al. (2022). As for northern gannet, these values were largely confirmed by the study conducted by Peschko et al. (2025). The main difference lays in the effect distance range reported for Aug–Sep, which previously was 3,000–6,000m and is now in reported with 0–3,000m (Peschko et al., 2025; Table 4-1). While Garthe et al. (2022) presented effect ranges only, Peschko et al. (2025) also reported mean effect distances of 1,500m for effect distances ranging between 0–3,000m, and 4,500m for ranges 3,000–6,000m (see Annex 2, Table A1.6). For all six bimonthly periods, the displacement effect curves reported by Peschko et al. (2025) were implemented in the framework.

4.1.2 Displacement probabilities

Northern gannet

Updated displacement probability values are available as preprint by Peschko et al. (2025). In their BACI analysis, they provided updated values representing changes in seabird abundance inside the OWFs plus the respective response radii. This translates into mean displacement probabilities of 0.74 ± 0.206 (standard deviation (SD) inferred from 95% confidence intervals (CI)) from May to July and 0.81 ± 0.356 (SD inferred from 95% CI) from Aug–Nov (Table 4-1). These values are recommended for use in KEC 6. Previous values identified in KBU 2025 were 0.70 for Apr–May and 0.75 for Jun–Jul, and 0.85 from Oct–Mar (Annex 2, Table A1.1). Parameter values recommended based on the most recent literature deviate from the values suggested in KBU 2025. However, the differences are small, with deviations of not more than 0.04 compared to earlier values (Annex 2, Table A1.1).

Sandwich tern

As for effect distances, no new displacement probability values were found for Sandwich terns. Therefore, the values identified in KBU 2025 (van Bemmelen & Fijn, 2024) are recommended to be used in KEC 6 (Table 4-1; Annex 2, Table A1.2).

Common guillemot

The most recent information on displacement probabilities for common guillemots was already identified in KBU 2025, based on a paper by Peschko et al. (2024; Table 4-1; Annex 2, Table A1.3). No new information was available. Hin & Ransijn (2025) studied the effect of different displacement effect curves for the guillemot on the outcome of the KEC assessment.

Razorbill

For razorbill, values from a Garthe et al. (2022) presentation were recommended to be used for Aug–Mar in the KBU 2025, while values for Apr–Jul were based on assumed displacement rates (Searle et al., 2025). No new information was found for the summer months Apr–Sep. As described above (section 4.1.1), razorbill distribution maps for Apr–Sep are available as grouped summer season only because of very low numbers present in the Dutch part of the North Sea during this period. Following the same approach as for the effect distances, the use of a combined displacement probability based on the displacement rates for Apr–Jul is therefore recommended for the entire summer season (Apr–Sep; Table 4-1). As for northern gannet and northern fulmar, Peschko et al. (2025) provides updated values for razorbill displacement rates. For the winter months Oct–Mar, new mean displacement probabilities of 0.67 ± 0.346 (SD inferred from 95% CI) are recommended for KEC 6 (Table 4-1). These values are 0.12 higher than the previous values from Garthe et al. Annex 2, Table A1.4). This difference is possibly caused by additional data included in the Peschko et al. (2025) analyses.

Atlantic puffin

As for the effect distances, very limited information is available for displacement probabilities in Atlantic puffins and it remains largely understudied. Due to the lack of new information, the previously identified displacement rate value of 0.60 suggested to be used in UK OWF assessments by (NatureScot, 2023) is suggested to be used in KEC 6 (Table 4-1; Annex 2, Table A1.5).

Northern fulmar

As for northern gannet, Peschko et al. (2025) reported new displacement probability values for northern fulmar. A mean displacement probability of 0.83 ± 0.238 (SD inferred from 95% CI) is recommended to be used for the Feb–May period in KEC 6 (Table 4-1). Based on Peschko et al.'s (2025) spring season, a mean displacement probability of 0.79 ± 0.379 (SD inferred from 95% CI) is recommended for Jun–Sep (Table 4-1). Values selected in KBU 2025 presented by Garthe et al. (2022) deviate from these values, with the largest deviation in Jun–Jul (0.15; Annex 2, Table A1.6). This deviation is likely caused by a different season interpretation from the Garthe et al. (2022) presentation used in KBU 2025 and possibly additional data included in the Peschko et al. (2025) analysis compared to the Garthe et al. (2022) presentation.

4.1.3 Season-specific displacement effects

The season classification used by Peschko et al. (2025) does not fully align with the bimonthly seasons used in the seabird distribution maps used in KEC. Consequently, minor adjustments were required when assigning effect distances and displacement probabilities. For example, displacement probability values for northern gannet were only available for the period 1 May–31 Oct. For the bimonthly periods Dec–Mar, the higher mean displacement probability of 0.81 from the autumn season (1 Sep–31 Oct) reported by Peschko et al. (2025) was applied, following a precautionary approach. Where seasonal definition differed between Peschko et al. (2025) and the bimonthly periods used in KEC, parameter values for effect distances and displacement probabilities were assigned based on closest temporal overlap. For instance, northern gannet values from the Peschko et al. (2025) summer season (1 May–31 Aug) were applied to the bimonthly periods Apr–May and Jun–Jul, while autumn values (1 Sep–31 Oct) were applied to Aug–Sep and Oct–Nov (Table 4-1).

For northern fulmar and Sandwich tern, available information on displacement is limited, as not all bimonthly periods are covered in the literature included in this knowledge update. To address these gaps, missing bimonthly periods were assigned the highest available values from other periods, following the precautionary principle. For instance, the periods Oct–Nov and Dec–Jan were assigned values derived from the mid-March to mid-May period reported by Peschko et al. (2025). For Sandwich tern specifically, displacement parameters were only defined for the summer period (Apr–Sep), as the species is not present in Dutch waters during the remainder of the year.

As outlined in KBU 2025, species that predominantly occur in Dutch waters during the non-breeding season (northern gannet, razorbill, Atlantic puffin, and common guillemot) mainly originate from breeding colonies along the east coast of Great Britain. Therefore, where available, UK-derived parameter values were applied for the breeding period (Apr–Sept). For example, values recommended for razorbill and Atlantic puffin in UK offshore wind farm assessments were adopted for these months (see section 3.4.3.3 in Hin et al., 2025a). In contrast, for northern fulmar, although parts of the population using Dutch waters also breed along the UK coast, no UK-derived parameters were available for any period. Therefore, values derived from Peschko et al. (2025) were applied instead.

Table 4-1 Parameters recommended to model displacement effects per marine bird species. Shapes of the distributions for the parameter values are suggested. Effect distances and displacement probabilities are presented per bimonthly period. Mean values, value ranges, standard deviation (SD), and 95% confidence intervals (CI) are provided where possible. Values without an indication are general values without further specification provided in the respective sources. Values already described in KBU 2025 are presented in parentheses. All new values are from Peschko et al. (2025) and are presented as normal text. For a comparison with values identified in KBU 2025, see tables in Annex 1. An * indicates the use of a reported displacement effect curve, in which the displacement effect varies as a function of distance to the OWF.

Parameter	Bimonthly period	Northern gannet	Sandwich tern	Common guillemot	Razorbill	Atlantic puffin	Northern fulmar
Effect distance around OWFs (m)	December-January	(mean = 1,500)* range = 0-3,000	-	(mean = 16,500)* (range = 15,000-18,000)	mean = 1,500* range = 0-3,000	(mean = 1,500) (range = 1,000-2,000)	mean = 4,500* range = 3,000-6,000
	February-March	(mean = 1,500)* range = 0-3,000	-	(mean = 16,500)* (range = 15,000-18,000)	mean = 1,500* range = 0-3,000	(mean = 1,500)	mean = 4,500* range = 3,000-6,000
	April-May	(mean = 1,500)* range = 0-3,000	(1,500)	(range = 1,000-2,000)	(1,000)	(range = 1,000-2,000)	mean = 4,500* range = 3,000-6,000
	June-July	(mean = 1,500)* range = 0-3,000	(1,500)	(range = 1,000-2,000)	(1,000)	(mean = 1,500)	mean = 1,500* range = 0-3,000
	August-September	(mean = 1,500)* range = 0-3,000	(1,500)	(mean = 19,500)* (range = 18,000-21,000)	(1,000)	(range = 1,000-2,000)	mean = 1,500* range = 0-3,000
	October-November	(mean = 1,500)* range = 0-3,000	-	(mean = 16,500)* (range = 15,000-18,000)	mean = 1,500* range = 0-3,000	(mean = 1,500)	mean = 4,500* range = 3,000-6,000
Displacement probability (beta distribution)	December-January	OWF + response radius: mean = 0.81 CI = 0.58-0.91 SD = 0.356 (inferred from CI)	-	(mean = 0.51) (CI = 0.42-0.58) SD = 0.173 (inferred from CI)	OWF + response radius: mean = 0.67 CI = 0.48-0.80 SD = 0.346 (inferred from CI)	(0.60)	OWF + response radius: mean = 0.83 CI = 0.6-0.92 SD = 0.238 (inferred from CI)
	February-March	OWF + response radius: mean = 0.81 CI = 0.58-0.91 SD = 0.356 (inferred from CI)	-	(mean = 0.51) (CI = 0.42-0.58) SD = 0.173 (inferred from CI)	OWF + response radius: mean = 0.67 CI = 0.48-0.80 SD = 0.346 (inferred from CI)	(0.60)	OWF + response radius: mean = 0.83 CI = 0.6-0.92 SD = 0.238 (inferred from CI)
	April-May	OWF + response radius: mean = 0.74 CI = 0.63-0.82 SD = 0.206 (inferred from CI)	(mean = 0.67) (CI = 0.51-0.78)	(0.30)	(0.40)	(0.60)	OWF + response radius: mean = 0.83 CI = 0.6-0.92 SD = 0.238 (inferred from CI)
	June-July	OWF + response radius: mean = 0.74 CI = 0.63-0.82 SD = 0.206 (inferred from CI)	(mean = 0.52) (CI = 0.41-0.62)	(0.30)	(0.40)	(0.60)	OWF + response radius: mean = 0.79 CI = 0.55-0.90 SD = 0.379 (inferred from CI)
	August-September	OWF + response radius: mean = 0.81 CI = 0.58-0.91 SD = 0.356 (inferred from CI)	(mean = 0.49) (CI = 0.00-0.74)	(mean = 0.79) (CI = 0.74-0.83) (SD = 0.097 (inferred from CI))	(0.40)	(0.60)	OWF + response radius: mean = 0.79 CI = 0.55-0.90 SD = 0.379 (inferred from CI)
	October-November	OWF + response radius: mean = 0.81 CI = 0.58-0.91 SD = 0.356 (inferred from CI)	-	(mean = 0.79) (CI = 0.74-0.83) (SD = 0.097 (inferred from CI))	OWF + response radius: mean = 0.67 CI = 0.48-0.80 SD = 0.346 (inferred from CI)	(0.60)	OWF + response radius: mean = 0.83 CI = 0.6-0.92 SD = 0.238 (inferred from CI)

4.2 Demographic parameters

As for KEC 5, model parameters were based on demographic rates from colonies closest to the Dutch North Sea. For species such as northern gannet and northern fulmar, individuals using the Dutch North Sea likely originate from multiple colonies, and mean breeding success values were weighted by colony size (number of breeding pairs, occupied nests, sites or burrows). Breeding success values were either derived directly from the literature consulted or calculated from reported numbers of fledged chicks per monitored site divided by the number of monitored breeding pairs, apparently occupied sites, nest, or burrows. In case no colony size information was available, linear interpolation was used to estimate colony size for a given year based on trends at that colony or at other relevant colonies. Breeding success values for KEC 6 were based on the most recent six-year period (2020–2025) where available, following the approach in KBU 2025 (Hin et al., 2025a). Survival estimates, however, were limited to modelled survival rates, usually spanning multiple years of data, and therefore not constrained to the period of 2020–2025. The following presents newly identified data sources and corresponding model parameters by species. All newly derived values were rounded to two significant figures.

4.2.1 Northern gannet

For northern gannet, the parameters breeding success and the adult survival standard deviation were updated based on recently published information. The other demographic parameters remain unchanged (Table 4-2).

Breeding success values were compiled from three different colonies that are likely the main location of origin of northern gannets using the Dutch North Sea. These colonies are Helgoland in Germany, Bempton Cliffs at the Flamborough and Filey Coast Special Protection Area (SPA) in England, and Bass Rock at the Forth Islands SPA in Scotland. Where possible, productivity values from these colonies were used for the years 2020–2025. For Bass Rock, productivity values were not available for each year. In these cases, aggregated productivity values for multiple Scottish colonies were used instead.

According to Fort et al. (2012), who deployed geolocator tags on 86 northern gannets originating from five European breeding colonies, individuals from the Norwegian colonies of Stortappen and Store Ulvøyholmene were recorded within Dutch waters during winter (December). We consulted the Norwegian SEAPOP database to assess the availability of colony size and breeding success data for these colonies. Colony size estimates were available for both sites, with the most recent counts dating from 2022. However, no breeding success data were available for either colony (Norwegian Institute for Nature Research, 2025). Consequently, these colonies were not considered for the breeding success parameter for northern gannet.

In 2022 and 2023, breeding success and colony sizes were drastically suppressed due to the highly pathogenic avian influenza (HPAI). These years were not included in the calculation of productivity values presented here as the influence of HPAI would lead to parameter values not representative for long-term trends.

New breeding success information was available from the Seabird Monitoring Programme (SMP) for Bass Rock and Flamborough and Filey Coast SPA (BTO & JNCC, n.d.). Updated values for Helgoland were provided in personal communication with V. Dierschke. The updated productivity value based on data from 2020–2025 resulted in a mean value of 0.64, with a standard deviation of 0.097 (Table 4-2). This value is lower than identified in the last KBU, reflecting the decrease in breeding success at the respective colonies in Scotland and England. On Helgoland, on the other hand, breeding productivity remained relatively stable across 2020–2025 (J. Dierschke et al., 2023; V. Dierschke, 2020, 2021, pers. communication).

For adult survival, new values were found for the years 2011–2024, extending the dataset used for the adult survival parameter in KBU 2025 (Lane et al., 2026). Excluding the HPAI years 2022 and 2023, the adult survival value (0.94) is the same as in KBU 2025, but the SD is now 0.026 and therefore lower than the one previously identified.

No new values for the other parameters were available.

Table 4-2 Parameters for the northern gannet population model. For values deviating from the previous knowledge base update (Hin et al., 2025a) or from KEC 4 or KEC 5 (Soudijn et al., 2022, 2025), previous values are indicated in parentheses. Values updated in this knowledge base are presented in bold. For the sources used to derive parameter values in the previous knowledge base update, KEC 4, and KEC 5, refer to the respective reports. For a comparison with values identified in KBU 2025, see tables in Annex 2.

Parameter	Symbol	Mean	Standard deviation	Distribution	Source
Breeding success (productivity)	F_A	0.64 (0.72)	0.097 (0.094)	Beta	BTO & JNCC (n.d.) (SMP data), Burton et al. (n.d.), Cope et al. (2021), J. Dierschke et al., 2023, V. Dierschke (2020, 2021, 2022, pers. communication), Harris et al. (2024, 2026), Lloyd et al. (2020) (KBU 2025)
Probability floater	p_F	(0.05)	(0.13)	beta	(KEC 4)
Survival age 0	S_0	(0.48)	(0.085)	beta	(KEC 4)
Survival age 1	S_1	(0.82)	(0.039)	beta	(KEC 4)
Survival age 2	S_2	(0.88)	(0.029)	beta	(KEC 4)
Survival age 3	S_3	(0.89)	(0.030)	beta	(KEC 4)
Adult survival	S_A	0.94 (0.94)	0.026 (0.0483)	beta	Lane et al. (2026) (KBU 2025)

4.2.2 Sandwich tern

As for northern gannet, the breeding success and adult survival parameters were updated for Sandwich tern. Due to strong impacts on the population caused by HPAI, the years 2022 and 2023 were excluded as well.

The reported productivity for the years 2020, 2021, 2024 and 2025 in the Dutch Delta area resulted in a mean breeding success of 0.36 (SD = 0.085; Table 4-3), slightly lower than the value from the previous KBU (Lilipaly et al., 2024, 2026).

Data from 1995–2021 were used to estimate adult survival in Dutch colonies in the Wadden Sea and the Delta area, yielding a mean adult survival rate of 0.87 (Courtens et al., 2025). This estimate is lower than the value reported in the previous KBU. The difference is likely attributable to reduced survival estimates in both areas in 2020 (Courtens et al., 2022) and 2021, which were not included in the dataset underlying the KEC 4 estimate. The new standard deviation of the adult survival was calculated by multiplying the standard error of the estimates reported by Courtens et al. (2025) with the square root of the number of years on which these estimates were based ($n = 27$).

Courtens et al. (2025) also estimated survival of 1 to 3 years old individuals for the Wadden Sea and Delta area. The mean of these estimates was used as the new value for S_{12} , the survival probability for 1- and 2-year-old individuals. The new standard deviation was derived in the same way as the standard deviation for the adult survival probability.

No new values for the other parameters were available.

Table 4-3 Parameters for the Sandwich population model. For values deviating from the previous knowledge base update (Hin et al., 2025a) or from KEC 4 or KEC 5 (Soudijn et al., 2022, 2025), previous values are indicated in parentheses. Values updated in this knowledge base are presented in bold. For the sources used to derive parameter values in the previous knowledge base update, KEC 4, and KEC 5, refer to the respective reports. For a comparison with values identified in KBU 2025, see tables in Annex 2.

Parameter	Symbol	Mean	Standard deviation	Distribution	Source
Breeding success (female chicks only)	F_A	0.36 (0.40)	0.085 (0.063)	beta	Lilipaly et al. (2024, 2026) (KBU 2025)
Probability floater	p_F	(0.1)	(0.125)	beta	(KEC 4)
Breeding success scalar	ϕ	(0.3)	(0.0)	fixed	(KEC 4)
Survival age 0	S_0	(0.36)	(0.092)	beta	(KBU 2025)
Survival age 1–2	S_{12}	0.637 (0.777)	0.068 (0.0518)	beta	Courtens et al. (2025) (KEC 4)
Adult survival	S_A	0.87 (0.94)	0.121 (0.108)	beta	Courtens et al. (2025) (KEC 4, KBU 2025)

4.2.3 Common guillemot

The most important colony for common guillemots using the Dutch North Sea during non-breeding season is likely to be Bempton Cliffs at the Flamborough and Filey Coast SPA in England. During post-breeding moult (mid-August to mid-September) and mid-winter (early December to early January), tagging data suggest that guillemots from colonies at the Isle of May, Whinnyfold, and East Caithness can be found in Dutch waters as well (Buckingham et al., 2022). Therefore, breeding success and colony size data was used to calculate a weighted productivity estimate. For the colony in Whinnyfold and East Caithness, no productivity information was found. Therefore, the weighted mean productivity was calculated based on data from the Isle of May and Flamborough and Filey Coast SPA.

Productivity values were derived from these colonies for the 2020–2025 period from the SMP database (BTO & JNCC, n.d.) and data published by NatureScot (2025) and Newell et al. (2025), resulting in a parameter value of 0.61 (SD = 0.074) which is the same as the value identified in the KBU 2025 (Table 4-4). However, the SD is larger than previously identified.

No new values for the other parameters were available.

4.2.4 Razorbill

Like common guillemot, razorbill breeding success data was derived from the Flamborough and Filey Coast SPA from the most recent years (2020–2025) from the SMP database. Razorbill productivity experienced a decline in the past years, reaching a new low of 0.36 in 2025 (BTO & JNCC, n.d.), driving the new collated breeding success value of 0.52 (SD = 0.12) which is lower than previously presented in KBU 2025 (Table 4-5).

No new values for the other parameters were available.

Table 4-4 Parameters for the common guillemot population model. For values deviating from the previous knowledge base update (Hin et al., 2025a) or from KEC 4 or KEC 5 (Soudijn et al., 2022, 2025), previous values are indicated in parentheses. Values updated in this knowledge base are presented in bold. For the sources used to derive parameter values in the previous knowledge base update, KEC 4, and KEC 5, refer to the respective reports. For a comparison with values identified in KBU 2025, see tables in Annex 2.

Parameter	Symbol	Mean	Standard deviation	Distribution	Source
Breeding success (productivity)	F_A	0.61 (0.61)	0.074 (0.046)	beta	BTO & JNCC (n.d.) (SMP data), Butcher et al. (2023), Clarkson et al. (2022), Cope et al. (2021), Lloyd et al. (2020), NatureScot (2025), Newell et al. (2025) (KBU 2025)
Probability floater	p_F	(0.07)	(0.03)	Beta	(KEC 4)
Survival age 0	S_0	(0.61)	(0.13)	beta	(KEC 4)
Survival age 1	S_1	(0.77)	(0.11)	beta	(KEC 4)
Survival age 2	S_2	(0.86)	(0.074)	beta	(KEC 4)
Adult survival	S_A	(0.93)	(0.037)	beta	(KBU 2025)

Table 4-5 Parameters for the razorbill population model. For values deviating from the previous knowledge base update (Hin et al., 2025a) or from KEC 4 or KEC 5 (Soudijn et al., 2022, 2025), previous values are indicated in parentheses. Values updated in this knowledge base are presented in bold. For the sources used to derive parameter values in the previous knowledge base update, KEC 4, and KEC 5, refer to the respective reports. For a comparison with values identified in KBU 2025, see tables in Annex 2.

Parameter	Symbol	Mean	Standard deviation	Distribution	Source
Breeding success (productivity)	F_A	0.52 (0.56)	0.12 (0.097)	beta	BTO & JNCC (n.d.) (SMP data), Butcher et al. (2023), Clarkson et al. (2022), Cope et al. (2021), Lloyd et al. (2020) (KBU 2025)
Probability floater	p_F	(0.03)	(0.13)	beta	(KEC 4)
Immature survival	S_{0I}	(0.64)	(0.048)	beta	(KEC 4)
Adult survival	S_A	(0.90)	(0.067)	beta	(KBU 2025)

4.2.5 Atlantic puffin

Breeding success data from three different colonies in the UK were collated to update the parameter for Atlantic puffin, including the Isle of May, Coquet Islands SPA, and Farne Islands SPA (BTO & JNCC, n.d.; NatureScot, 2026). The weighted mean breeding success was calculated for the period 2020–2025 based on colony size. The updated productivity parameter (0.69 ± 0.12) is slightly higher than stated in KBU 2025 (0.68 ± 0.12 ; Table 4-6).

No new values for the other parameters were available.

Table 4-6 Parameters for the Atlantic puffin population model. For values deviating from the previous knowledge base update (Hin et al., 2025a) or from KEC 4 or KEC 5 (Soudijn et al., 2022, 2025), previous values are indicated in parentheses. Values updated in this knowledge base are presented in bold. For the sources used to derive parameter values in the previous knowledge base update, KEC 4, and KEC 5, refer to the respective reports. For a comparison with values identified in KBU 2025, see tables in Annex 2.

Parameter	Symbol	Mean	Standard deviation	Distribution	Source
Breeding success (productivity)	F_A	0.69 (0.68)	0.12 (0.12)	beta	BTO & JNCC (n.d.) (SMP data), Hendry et al. (2022), National Trust (n.d.), NatureScot (2025, 2026), Newell et al. (2025) (KBU 2025)
Skipped breeding probability (4-year-olds)	p_{F4}	(0.93)	(0.01)	beta	(KEC 4, KBU 2025)
Skipped breeding probability (5-year-olds)	p_{F5}	(0.3)	(0.01)	beta	(KEC 4, KBU 2025)
Skipped breeding probability (adults)	p_F	(0.0)	(0.0)	beta	(KBU 2025)
Survival age 0–3	S_{03}	(0.71)	(0.11)	beta	(KEC 4)
Survival age 4	S_4	(0.78)	(0.092)	beta	(KEC 4)
Survival age 5	S_5	(0.80)	(0.083)	beta	(KEC 4)
Adult survival	S_A	(0.94)	(0.023)	beta	(KBU 2025)

4.2.6 Northern fulmar

For northern fulmar, breeding success information from thirteen colonies around the North Sea were used to calculate a weighted mean value based on reported colony sizes. Colonies included were e.g., Isle of May, Coquet Islands SPA, Farne Islands SPA, Helgoland, The Wash SPA, and Flamborough and Filey Coast SPA. New breeding success information was mainly available from the Seabird Monitoring Programme (SMP) and from the Isle of May Annual Report (BTO & JNCC, n.d.; NatureScot, 2026). Updated values for Helgoland were provided in personal communication with V. Dierschke.

The updated parameter value of 0.41 (SD = 0.22) is slightly lower than previously reported in KBU 2025 (0.42 ± 0.23; Table 4-7). Only for three colonies higher breeding success was reported for 2025 compared to 2024 (Isle of May, Helgoland, Flamborough and Filey Coast SPA), while a reduction in breeding success from 2024 to 2025 was reported for four colonies (Coquet Islands SPA, North Berwick Coast SSSI, The Wash SPA, St Abb's Head to Fast Castle SPA, Troup, Pennan and Lion's Heads SPA) (BTO & JNCC, n.d., V. Dierschke pers. communication). No successful breeding was reported for North Berwick Coast SSSI and North Sutor to Shandwick in 2025 (BTO & JNCC, n.d.). These declines in breeding success drive the reduction in the parameter compared to KBU 2025 (Table 4-7).

No new values for the other parameters were available.

Table 4-7 Parameters for the northern fulmar population model. For values deviating from the previous knowledge base update (Hin et al., 2025a) or from KEC 4 or KEC 5 (Soudijn et al., 2022, 2025), previous values are indicated in parentheses. Values updated in this knowledge base are presented in bold. For the sources used to derive parameter values in the previous knowledge base update, KEC 4, and KEC 5, refer to the respective reports. For a comparison with values identified in KBU 2025, see tables in Annex 2.

Parameter	Symbol	Mean	Standard deviation	Distribution	Source
Breeding success (productivity)	F_A	0.41 (0.42)	0.22 (0.23)	beta	BTO & JNCC (n.d.) (SMP data), Dierschke (2020, 2021, 2022, pers. communication), National Trust (n.d.), Newell et al. (2025) (KBU 2025)
Probability floater	p_F	(0.30)	(0.11)	beta	(KEC 4)
Immature survival	S_J	(0.88)	(0.054)	beta	(KEC 4)
Adult survival	S_A	(0.93)	(0.086)	beta	(KBU 2025)
Prob. recruitment age 5	p_5	(0.13)	(0.01)	beta	(KEC 4)
Prob. recruitment age 6	p_6	(0.25)	(0.01)	beta	(KEC 4)
Prob. recruitment age 7	p_7	(0.38)	(0.01)	beta	(KEC 4)
Prob. recruitment age 8	p_8	(0.5)	(0.01)	beta	(KEC 4)
Prob. recruitment age 9	p_9	(0.63)	(0.01)	beta	(KEC 4)
Prob. recruitment age 10	p_{10}	(0.75)	(0.01)	beta	(KEC 4)
Prob. recruitment age 11	p_{11}	(0.88)	(0.01)	beta	(KEC 4)

4.2.7 Comparison with other MONS/Wozep work

A review of demographic studies was conducted by Schekkerman et al (2025) as part a MONS Seabirds desk study. This review summarised demographic parameters for multiple seabird species, including five species also considered in the present KBU: northern fulmar, northern gannet, Sandwich tern, common guillemot, and razorbill. Atlantic puffin was not included in Schekkerman et al (2025). Their review focused on key demographic parameters such as age-specific annual survival probabilities and breeding productivity. The literature selection primarily covered studies from the North Sea and the wider Atlantic region, including Arctic waters and the Celtic Seas. Where appropriate, North Sea-specific information from their review was incorporated into the present KBU. Some of the references shown in Schekkerman et al (2025) were already used for parameterisation in KEC 4 (Soudijn et al., 2022).

Focusing on breeding success and adult survival, there is partial agreement between the parameter values reported by Schekkerman et al. (2025) and those derived in this KBU. For instance, breeding success values for common guillemot and northern fulmar were comparable between the two approaches, as were adult survival estimates for northern gannet, razorbill, and common guillemot. In contrast, discrepancies are observed in breeding success values for razorbill and Sandwich tern, as well as in adult survival estimates for Sandwich tern and northern fulmar.

These differences can largely be attributed to variation in the spatial and temporal scope of the underlying data. Schekkerman et al (2025) considered a broader geographic range, whereas the present KBU applies a more specific regional focus on the Dutch and southern North Sea. This refinement ensures alignment with the spatial extent of the KEC assessment, for which the present parameter updates are intended. Additionally, differences in the selection of study periods contributed to variation in parameter estimates. For

instance, the present KBU emphasised the most recent six-year period (2020–2025) for breeding success data, while Schekkerman et al (2025) incorporated longer and, in some cases, less recent time series. Methodological differences in literature selection and criteria such as the prioritisation of recent productivity data further explain the observed discrepancies. Nevertheless, despite these differences in approach, several parameter estimates are broadly consistent across the two studies.

For KEC 6, parameter values derived from the present KBU are used, as the parameterisation approach has been specifically tailored to the requirements of this KEC.

4.3 New methods for effect estimation

Buckingham et al. (2026) presents a new individual-based model (IBM) to assess both lethal and sub-lethal effects from OWFs during the non-breeding season for guillemots and black-legged kittiwakes in Norwegian waters. The IBM simulates individual behaviour, movement and OWF interactions through collisions and displacement effects and is parameterized using individual-based tracking data from geolocators. The salt-water immersion data for these loggers were used to estimate activity budgets and energy expenditure.

The IBM was used to demonstrate the impact of 10 OWFs during the non-breeding season on common guillemots breeding at Sklinna (Norway) and black-legged kittiwakes breeding at Ålesund (Norway). Displacement was considered for guillemots and collisions for kittiwakes, although in principle the model was capable of simulating both type of impacts for each species. Displacement effects were modelled by sampling from a displacement probability distribution when a bird entered a displacement zone (OWF + buffer area). Displaced birds were relocated to outside the displacement zone and incurred an energetic cost through a proportional reduction in foraging success for that day. Because there are no data to inform the sublethal effects of displacement, Buckingham et al. (2026) varied the displacement cost proportionality constant between 0 and 1, with the highest value implying a complete reduction of foraging success for the day on which displacement occurred. Mortality was related to body mass by use of a starvation mass threshold below which an individual could die.

The IBM predicted that 53.8% of the modelled guillemot population overlapped with an OWF displacement zone at least once during the non-breeding season, leading to displacement effects for ~50% of the population. Depending on the displacement costs proportionality constant, population level mortality rates varied between 0% and 5.3% and simulated body mass with displacement was 97.1% to 99.8% percent of unimpacted body mass. Buckingham et al. (2026) note that the results are highly sensitive to the degree of displacement costs used, for which empirical evidence is currently lacking.

Within the Wozep and MONS project on model development for marine birds, a bio-energetic IBM for guillemots and gannets is currently being developed. This model contains a description of individual energy acquisition and use for adult individuals during the non-breeding season. Model parameterization has been completed for guillemots and gannets, and model sensitivity analyses are currently being performed. In parallel, fish distribution maps will be coupled to seabird distribution maps to estimate the amount of prey available to individual seabirds at a given location. The resulting map of prey availability can then be combined with spatial OWF scenarios to estimate the decrease in prey availability resulting from avoidance of OWF areas. The estimated reduction in prey availability will then be used as input in the bio-energetic model to simulate effects on reserve levels and individual survival. This approach will likely result in a more refined estimate of the energetic cost of displacement and its resulting effect on individual survival, which can then be used as an alternative to the displacement-matrix approach.

4.4 Population modelling and Acceptable Levels of Impact

Recently, a first exploration of the effect of including density-dependent processes on the outcomes of the KEC assessment was performed (Hin et al., 2025b). The population models currently used within the KEC assessment for seabirds are density-independent matrix population models, described by Van Kooten et al. (2019), Soudijn et al. (2022) and Hin et al. (2025a). The lack of density-dependent processes in these models is a precautionary assumption based on the notion that density-dependent processes are often colony-specific, and their strength and shape are rarely understood in sufficient detail to warrant inclusion in population viability analysis (PVA). The analysis conducted by Hin et al. (2025b), revealed that density dependence can have a considerable compensatory effect by reducing the relative impact that OWF-induced mortality has on the predicted population trajectory. Because of its potentially strong compensatory effect, including density-dependence in the KEC requires a solid evidence-base on how density dependence operates on the scale of the KEC assessment. Future research, ongoing monitoring and further discussion with experts should reveal for which species the evidence base is sufficient to warrant inclusion of density-dependent processes in the KEC.

The outcomes of the population models are evaluated using the Acceptable Levels of Impact (ALI) methodology (Hin et al., 2024). This method tests whether the population impact of OWFs does not exceed ecological thresholds. The current ALI approach is referred to as an impact approach and gives an indication of the relative impact of OWFs on the population. However, from a legal perspective, the impact of OWFs on the Dutch conservation status (Dutch: *Staat van Instandhouding SvI*) of a population should be tested for licensing and site allocation decisions. Hence, it is desirable to directly assess the population effects of OWFs against the Dutch SvI. Currently, a methodology is being developed that directly relates the population effects of OWFs to the SvI. This methodology is called the ALI status approach and is currently being finalized. As the ALI status approach requires the use of population models that are calibrated based on the population trend observed on the DCS, adopting the ALI status approach will also have repercussions for the population models used within the KEC.

4.5 KEC 5 review outcomes

The KEC 5 report on habitat loss effects was reviewed by an external reviewer in 2025¹, which resulted in several recommendations (Table 4-8). Several of these recommendations for further research are beyond the scope of the KEC, but will ultimately contribute to the KEC framework, such as the development of an IBM to quantify sublethal effects of displacement. Other recommendations involve a more extensive discussion of several assumptions of the assessment methodology, or the request for sensitivity analysis. These recommendations will be followed up in the main KEC 6 report. Specific changes to the methodology that are considered here relate to the use of a distribution of displacement mortality rate, instead of using fixed discrete values, which is discussed below. The review of empirical evidence on non-breeding distribution of guillemots and razorbills has been described in the section of demographic rates and led to inclusion of additional source colonies for estimation of guillemot breeding success.

4.5.1 Displacement mortality levels

In KEC 5 four different mortality levels (1%, 2%, 5%, and 10%) were applied to birds displaced from OWF areas, and the ALI methodology was applied to each of these four levels. The review of the KEC 5 framework performed in 2025 suggested to replace the four mortality levels with a single probability distribution. In this section we explain why we refrain from adopting this suggestion.

There exists no empirical evidence on the level of mortality that birds experience when that are displaced from OWF areas (Searle et al., 2025). Likely, the mortality impact from displacement will depend on the ability to find food in the area where birds are displaced to, which in turn depends on environmental conditions, the presence of other birds in the area and bird condition. In the KEC 5 assessment, the four different mortality levels were used to reflect this major source of uncertainty. In addition, a species-specific benchmark mortality level was calculated using the displacement probability per species, and the Relative

¹ <https://noordzeeloket.nl/publish/pages/246412/review-kec-5-0-findings-and-recommendations.pdf>

Displacement Risk Score (RDRS) as used within KEC 4 (see KBU 2025 for details). The RDRS is a semi-quantitative sensitivity scoring from Leopold et al. (2014), who modified the seabird sensitivity scores of Bradbury et al. (2014) and applied an arbitrary mortality level of 10% to species with the highest sensitivity score. Because some species are more sensitive to displacement than others, the RDRS value differs between species. Although the RDRS scores were used to calculate the number of casualties from displacement in later assessments (F. Soudijn et al., 2022; van der Wal et al., 2018), the upper level of 10% mortality remains an arbitrary, worst-case assumption without any empirical basis. Because the use of different mortality levels reflects the uncertainty about the mortality effects of displacement, this approach was adopted for KEC 5, in which a more extensive treatment of uncertainty was performed. In essence, the different mortality levels are a type of sensitivity analysis that can inform on the level of mortality that would lead to unacceptable ecological impacts. The suggestion to use a single probability distribution for displacement mortality would obscure the relationship between mortality levels and population impacts as evaluated by the ALI. In addition, there is no empirical justification for the shape (parameters) of such a distribution. Because the ALI violation is determined by the 5% quantile values of highest impact, the variance (or standard deviation) of such a hypothetical distribution will have a considerable impact on the ALI outcome. As there would be no basis for choosing a narrow probability distribution (considering the uncertainty regarding displacement effects), an ALI violation is likely to result for the species for which it was also found at a level of 10% mortality in the previous KEC (Soudijn et al., 2025). However, because it was derived from a single distribution, we would have no information on the actual displacement mortality levels that resulting in the ALI violation within doing further sensitivity analysis. We therefore use the four different mortality levels, so that we can directly study the relationship between the assumed level of mortality and the population outcomes. In addition, without additional information of the level of displacement mortality, the benchmark mortality levels used within KEC 5 will be adopted.

Table 4-8: Overview of recommendations from the review of the methodology as used within KEC 5.

Type	Recommendation	Addresses where
General	Explore GLS data to estimate bird 'turn-over' rate for guillemots and razorbill	MONS bird models
General	Include more discussion and caveats around comparison between relative population sizes and nature conservation population targets	Acceptable Levels of Impact methodology
Framework	Use probability distribution of displacement mortality rate, instead of fixed discrete value	Current KBU
Framework	Study new empirical evidence on non-breeding distributions of guillemots & razorbill	Current KBU
Framework	Include uncertainty of displacement effects (effect distances & displacement probabilities)	KBU 2025
Framework	Add Atlantic puffin & northern fulmars as study species	KBU 2025
Analysis / reporting	Include clear summary section that describes how uncertainty is quantified and propagated through the framework	Upcoming KEC 6 report
Analysis / reporting	Include explanation of the use of averaging over casualty estimates and include sensitivity of the mortality calculation (max. abundance estimate)	Upcoming KEC 6 report
Analysis / reporting	Include comparison modelled trend and current trend	Upcoming KEC 6 report

5 Conclusions & Recommendations

5.1 Parameters

Apart from breeding success data, little new information was available for demographic parameters. The only exceptions were adult survival estimates for Sandwich tern. One additional study providing updated information on adult and juvenile survival, as well as skipped breeding for common guillemot, northern fulmar, and northern gannet, was identified but not included in this KBU. This study (Merrall et al., 2026) uses revised demographic parameter values derived from Horswill & Robinson (2015). However, these updated values are based on a JNCC report that, according to Merrall et al. (2026), is still under review and not yet publicly available. Consequently, the underlying data and methodology used to derive these values cannot be assessed. It is therefore recommended to conduct an additional KBU prior to any population modelling exercise using these parameters after KEC 6, in order to review this JNCC report once it becomes publicly available and to assess whether the underlying data are suitable for inclusion in KEC analyses.

Although little new information was identified for most parameter values, the observed differences in breeding success across all species, as well as changes in survival and displacement parameters for some species compared to KBU 2025, underline the importance of conducting regular KBUs to incorporate the latest scientific knowledge.

5.2 Knowledge gaps

Based on this knowledge base update, several knowledge gaps can be identified. Breeding success data is available for all six species covered in this knowledge base update, but not for all years and colonies that were considered. With regard to displacement parameters, Atlantic puffin is highly understudied. The values selected for displacement probability and effect distance for Atlantic puffin originate from reports suggesting displacement rates to be used in impact assessments (NatureScot, 2023), or presenting assumed displacement area and rate for different UK OWFs (Searle et al., 2025). No study investigating displacement effects on Atlantic puffins has been done to date. Until more information becomes available on displacement effects in Atlantic puffins, worst-case assumption will need to be made.

For most species, except Sandwich tern and northern gannet, no new adult survival information was available compared to KEC 4. The parameter values for floater probability or immature survival at different age classes used within KEC 4 are still currently used, as no new information has become available since. While survival rates are monitored for different colonies and species and often cover long time spans (Anker-Nilssen et al., 2020; NatureScot, 2025; Newman et al., 2021), limited new information compared to KEC 4 and the KBU 2025 was found.

Colony size data required to calculate weighted averages of breeding productivity were unavailable for some years. Missing values were therefore estimated using linear interpolation. Although this approach ignores interannual variability in colonies sizes, the effect on the aggregated values of breeding success is likely small.

The model by Buckingham et al. (2026) provides a possible method to address one of the main knowledge gaps in the KEC assessment for habitat loss, which is the limited understanding of the faith of displaced birds during the non-breeding season. Potentially, the IBM developed by Buckingham et al. (2026) could be used within KEC, if sufficient data is available on movement and behaviour of guillemots that spend the non-breeding season within the Dutch part of the North Sea. Also, the model requires information on mass changes during the non-breeding season, as mortality rates depend on weight loss that result from displacement-induced loss of foraging. We therefore recommend to study whether sufficient data are available to parameterise this model for guillemots in the Dutch part of the North Sea. Although the IBM

would provide a more sophisticated approach for modelling displacement effects, and a potential way to integrate those effects with collision risks, substantial uncertainty remains regarding the ultimate effect of displacement, as the knowledge gap concerning the individual-level (energetic) consequences of displacement remains unresolved. Research efforts should therefore prioritize refining the consequences of displacement for individual energy acquisition and use, and its effect on individual survival.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system, certified since February 27, 2001 by DNV. ISO 9001 is an international standard for quality management, focused on the continuous improvement of processes and ensuring customer satisfaction.

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Justification

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The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

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Annex 1 Displacement parameters

A1.1 Northern gannet

Table A1 1 Parameter values used for displacement calculations for northern gannet. For both parameters (effect distance and displacement probability), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Mean values, standard deviations (SD), 95% confidence intervals (CI), and value ranges are provided where available. References are indicated by the letters at the end of each parameter value.

Parameter	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Effect distance (KEC6)	mean = 1,500m (e) range = 0-3,000m (e)	mean = 1,500m (e) range = 0-3,000m (e)	mean = 1,500m (e) range = 0-3,000m (e)	mean = 1,500m (e) range = 0-3,000m (e)	mean = 1,500m (e) range = 0-3,000m (e)	mean = 1,500m (e) range = 0-3,000m (e)
Effect distance (KBU2025)	mean = 1,500m (k) range = 0-3,000m (a)	mean = 1,500m (k) range = 0-3,000m (a)	mean = 1,500m (k) range = 0-3,000m (a)	mean = 1,500m (k) range = 0-3,000m (a)	mean = 1,500m (k) range = 0-3,000m (a)	mean = 1,500m (k) range = 0-3,000m (a)
Displacement probability (KEC 6)	OWF + response radius: mean = 0.81 (e) CI = 0.58-0.91 (e) SD = 0.356 (inferred from CI)	OWF + response radius: mean = 0.81 (e) CI = 0.58-0.91 (e) SD = 0.356 (inferred from CI)	OWF + response radius: mean = 0.74 (e) CI = 0.63-0.82 (e) SD = 0.206 (inferred from CI)	OWF + response radius: mean = 0.74 (e) CI = 0.63-0.82 (e) SD = 0.206 (inferred from CI)	OWF + response radius: mean = 0.81 (e) CI = 0.58-0.91 (e) SD = 0.356 (inferred from CI)	OWF + response radius: mean = 0.81 (e) CI = 0.58-0.91 (e) SD = 0.356 (inferred from CI)
Displacement probability (KBU 2025)	mean = 0.85 (k) SD = 0.69 (inferred from Sandwich tern (h))	mean = 0.85 (k) SD = 0.69 (inferred from Sandwich tern (h))	0.70 (f)	0.75 (a)	mean = 0.85 (k) SD = 0.69 (inferred from Sandwich tern (h))	mean = 0.85 (k) SD = 0.69 (inferred from Sandwich tern (h))
Sources	(a) Garthe et al. (2022), (e) Peschko et al. (2025), (f) Searle et al. (2025), (h) van Bemmelen et al. (2024b), (k) Vanermen et al. (2015)					

A1.2 Sandwich tern

Table A1 2 Parameter values used for displacement calculations for Sandwich tern. For both parameters (effect distance and displacement probability), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Mean values, standard deviations (SD), 95% confidence intervals (CI), and value ranges are provided where available. References are indicated by the letters at the end of each parameter value.

Parameter	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Effect distance (KEC6)	-	-	same as KBU 2025	same as KBU 2025	same as KBU 2025	-
Effect distance (KBU2025)	-	-	1,500 (h)	1,500 (h)	1,500 (h)	-
Displacement probability (KEC 6)	-	-	same as KBU 2025	same as KBU 2025	same as KBU 2025	-
Displacement probability (KBU 2025)	-	-	mean = 0.67 (i) CI = 0.51-0.78 (i)	mean = 0.52 (i) CI = 0.41-0.62 (i)	Aug-Oct: mean = 0.49 (i) CI = 0.00-0.74 (i)	-
Sources	(h) van Bemmelen et al. (2024b), (i) van Bemmelen & Fijn (2024)					

A1.3 Common guillemot

Table A1 3 Parameter values used for displacement calculations for common guillemot. For both parameters (effect distance and displacement probability), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Mean values, standard deviations (SD), 95% confidence intervals (CI), and value ranges are provided where available. References are indicated by the letters at the end of each parameter value.

Parameter	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Effect distance (KEC6)	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025
Effect distance (KBU2025)	mean = 16,500 (d) range = 15,000–18,000 (d)	mean = 16,500 (d) range = 15,000–18,000 (d)	range = 1,000–2,000 (f)	range = 1,000–2,000 (f)	mean = 19,500 (d) range = 18,000–21,000 (d)	mean = 16,500 (d) range = 15,000–18,000 (d)
Displacement probability (KEC 6)	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025
Displacement probability (KBU 2025)	mean = 0.51 (d) CI = 0.42–0.58 (d) SD = 0.16 (inferred from CI)	mean = 0.51 (d) CI = 0.42–0.58 (d) SD = 0.16 (inferred from CI)	0.30 (f)	0.30 (f)	mean = 0.79 (d) CI = 0.74–0.83 (d) SD = 0.097 (inferred from CI)	mean = 0.79 (d) CI = 0.74–0.83 (d) SD = 0.097 (inferred from CI)
Sources	(d) Peschko et al. (2024), (f) Searle et al. (2025)					

A1.4 Razorbill

Table A1 4 Parameter values used for displacement calculations for razorbill. For both parameters (effect distance and displacement probability), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Mean values, standard deviations (SD), 95% confidence intervals (CI), and value ranges are provided where available. References are indicated by the letters at the end of each parameter value.

Parameter	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Effect distance (KEC6)	mean = 1,500 (e) range = 1,000–3,000 (e)	mean = 1,500 (e) range = 1,000–3,000 (e)	same as KBU 2025	same as KBU 2025	1,000 (f)	mean = 1,500 (e) range = 1,000–3,000 (e)
Effect distance (KBU2025)	2,000 (b)	2,000 (b)	1,000 (f)	1,000 (f)	range = 6,000–11,000 (g)	2,000 (b)
Displacement probability (KEC 6)	OWF + response radius: mean = 0.67 (e) CI = 0.48–0.80 (e) SD = 0.346 (inferred from CI)	OWF + response radius: mean = 0.67 (e) CI = 0.48–0.80 (e) SD = 0.346 (inferred from CI)	same as KBU 2025	same as KBU 2025	0.40 (f)	OWF + response radius: mean = 0.67 (e) CI = 0.48–0.80 (e) SD = 0.346 (inferred from CI)
Displacement probability (KBU 2025)	0.55 (a)	0.55 (a)	0.40 (f)	0.40 (f)	0.55 (a)	0.55 (a)
Sources	(a) Garthe et al. (2022), (b) Grundlehner et al. (2025), (e) Peschko et al. (2025), (f) Searle et al. (2025), (g) Szostek et al. (2024)					

A1.5 Atlantic puffin

Table A1 5 Parameter values used for displacement calculations for Atlantic puffin. For both parameters (effect distance and displacement probability), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Mean values, standard deviations (SD), 95% confidence intervals (CI), and value ranges are provided where available. References are indicated by the letters at the end of each parameter value.

Parameter	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Effect distance (KEC6)	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025
Effect distance (KBU2025)	mean = 1,500 (f), range = 1,000–2,000 (f)	mean = 1,500 (f), range = 1,000–2,000 (f)	mean = 1,500 (f), range = 1,000–2,000 (f)	mean = 1,500 (f), range = 1,000–2,000 (f)	mean = 1,500 (f), range = 1,000–2,000 (f)	mean = 1,500 (f), range = 1,000–2,000 (f)
Displacement probability (KEC 6)	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025	same as KBU 2025
Displacement probability (KBU 2025)	0.60 (c)	0.60 (c)	0.60 (c)	0.60 (c)	0.60 (c)	0.60 (c)
Sources	(c) NatureScot (2023), (f) Searle et al. (2025)					

A1.6 Northern fulmar

Table A1 6 Parameter values used for displacement calculations for northern fulmar. For both parameters (effect distance and displacement probability), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Mean values, standard deviations (SD), 95% confidence intervals (CI), and value ranges are provided where available. References are indicated by the letters at the end of each parameter value.

Parameter	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Effect distance (KEC6)	mean = 4,500 (e) range = 3,000–6,000 (e)	mean = 4,500 (e) range = 3,000–6,000 (e)	mean = 4,500 (e) range = 3,000–6,000 (e)	mean = 1,500 (e) range = 0–3,000 (e)	mean = 1,500 (e) range = 0–3,000 (e)	mean = 4,500 (e) range = 3,000–6,000 (e)
Effect distance (KBU2025)	range = 3,000–6,000 (a)	range = 3,000–6,000 (a)	range = 3,000–6,000 (a)	range = 0–3,000 (a)	range = 3,000–6,000 (a)	range = 3,000–6,000 (a)
Displacement probability (KEC 6)	OWF + response radius: mean = 0.83 (e) CI = 0.6–0.92 (e) SD = 0.238 (inferred from CI)	OWF + response radius: mean = 0.83 (e) CI = 0.6–0.92 (e) SD = 0.238 (inferred from CI)	OWF + response radius: mean = 0.83 (e) CI = 0.6–0.92 (e) SD = 0.238 (inferred from CI)	OWF + response radius: mean = 0.79 (e) CI = 0.55–0.90 (e) SD = 0.379 (inferred from CI)	OWF + response radius: mean = 0.79 (e) CI = 0.55–0.90 (e) SD = 0.379 (inferred from CI)	OWF + response radius: mean = 0.83 (e) CI = 0.6–0.92 (e) SD = 0.238 (inferred from CI)
Displacement probability (KBU 2025)	0.91 (a)	0.91 (a)	0.91 (a)	0.64 (a)	0.91 (a)	0.91 (a)
Sources	(a) Garthe et al. (2022), (e) Peschko et al. (2025)					

Annex 2 Demographic parameters

A2.1 Northern gannet

Table A2 1 Updated parameter values for northern gannet. For both parameters (breeding success and adult survival), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Values are provided with standard deviation (SD). For breeding success, data from the most recent six-year period (2020–2025) was used. For adult survival, no time selection was made. References are provided for each parameter. All newly derived values were rounded to two significant numbers.

Parameter		Value	SD	Source
Breeding success	KEC 6	0.64	0.097	BTO & JNCC (n.d.), Burton et al. (n.d.), Cope et al. (2021), J. Dierschke et al. (2023), V. Dierschke (2020, 2021, 2022, pers. comm.), Harris et al. (2024, 2026), Lloyd et al. (2020)
	KBU 2025	0.72	0.094	BTO & JNCC (n.d.), Burton et al. (n.d.), Cope et al. (2021), J. Dierschke et al. (2023), V. Dierschke (2020, 2021, 2022, pers. comm.), Harris et al. (2024, 2026), Lloyd et al. (2020)
Adult survival	KEC 6	0.939	0.026	Lane et al. (2026)
	KBU 2025	0.940	0.0483	Lane et al. (2024)

A2.2 Sandwich tern

Table A2 2 Updated parameter values for Sandwich tern. For both parameters (breeding success and adult survival), values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Values are provided with standard deviation (SD). For breeding success, data from the most recent six-year period (2020–2025) was used. For adult survival, no time selection was made. References are provided for each parameter. All newly derived values were rounded to two significant numbers.

Parameter		Value	SD	Source
Breeding success	KEC 6	0.36	0.085	Lilipaly et al. (2024, 2026)
	KBU 2025	0.40	0.063	Lilipaly et al. (2024)
Adult survival	KEC 6	0.87	0.008	Courtens et al. (2025)
	KBU 2025	0.94	0.108	van Bemmelen et al. (2022), KEC 4

A2.3 Common guillemot

Table A2 3 Updated breeding success parameter values for common guillemot. Values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Values are provided with standard deviation (SD). To derive breeding success estimates, data from the most recent six-year period (2020–2025) was used. All newly derived values were rounded to two significant numbers.

Parameter		Value	SD	Source
Breeding success	KEC 6	0.61	0.074	BTO & JNCC (n.d.), Butcher et al. (2023), Clarkson et al. (2022), Cope et al. (2021), Lloyd et al. (2020)
	KBU 2025	0.61	0.046	BTO & JNCC (n.d.), Butcher et al. (2023), Clarkson et al. (2022), Cope et al. (2021), Lloyd et al. (2020)

A2.4 Razorbill

Table A2 4 Updated breeding success parameter values for razorbill. Values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Values are provided with standard deviation (SD). To derive breeding success estimates, data from the most recent six-year period (2020–2025) was used. All newly derived values were rounded to two significant numbers.

Parameter		Value	SD	Source
Breeding success	KEC 6	0.52	0.12	BTO & JNCC (n.d.), Butcher et al. (2023), Clarkson et al. (2022), Lloyd et al. (2020)
	KBU 2025	0.56	0.097	BTO & JNCC (n.d.), Butcher et al. (2023), Clarkson et al. (2022), Lloyd et al. (2020)

A2.5 Atlantic puffin

Table A2 5 Updated breeding success parameter values for Atlantic puffin. Values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Values are provided with standard deviation (SD). To derive breeding success estimates, data from the most recent six-year period (2020–2025) was used. All newly derived values were rounded to two significant numbers.

Parameter		Value	SD	Source
Breeding success	KEC 6	0.69	0.12	BTO & JNCC (n.d.), Hendry et al. (2022), National Trust (n.d.), NatureScot (2025), Newell et al. (2025)
	KBU 2025	0.68	0.12	BTO & JNCC (n.d.), Hendry et al. (2022), NatureScot (2025)

A2.6 Northern fulmar

Table A2 6 Updated breeding success parameter values for northern fulmar. Values from the previous KBU (KBU 2025) and the current assessment (KEC6) are presented for comparison. Values are provided with standard deviation (SD). To derive breeding success estimates, data from the most recent six-year period (2020–2025) was used. All newly derived values were rounded to two significant numbers.

Parameter		Value	SD	Source
Breeding success	KEC 6	0.41	0.22	BTO & JNCC (n.d.), Dierschke (2020, 2021, 2022, pers. comm.), National Trust (n.d.), Newell et al. (2025)
	KBU 2025	0.42	0.23	BTO & JNCC (n.d.), Dierschke (2020, 2021, 2022, pers. comm.), National Trust (n.d.), Newell et al. (2025)

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