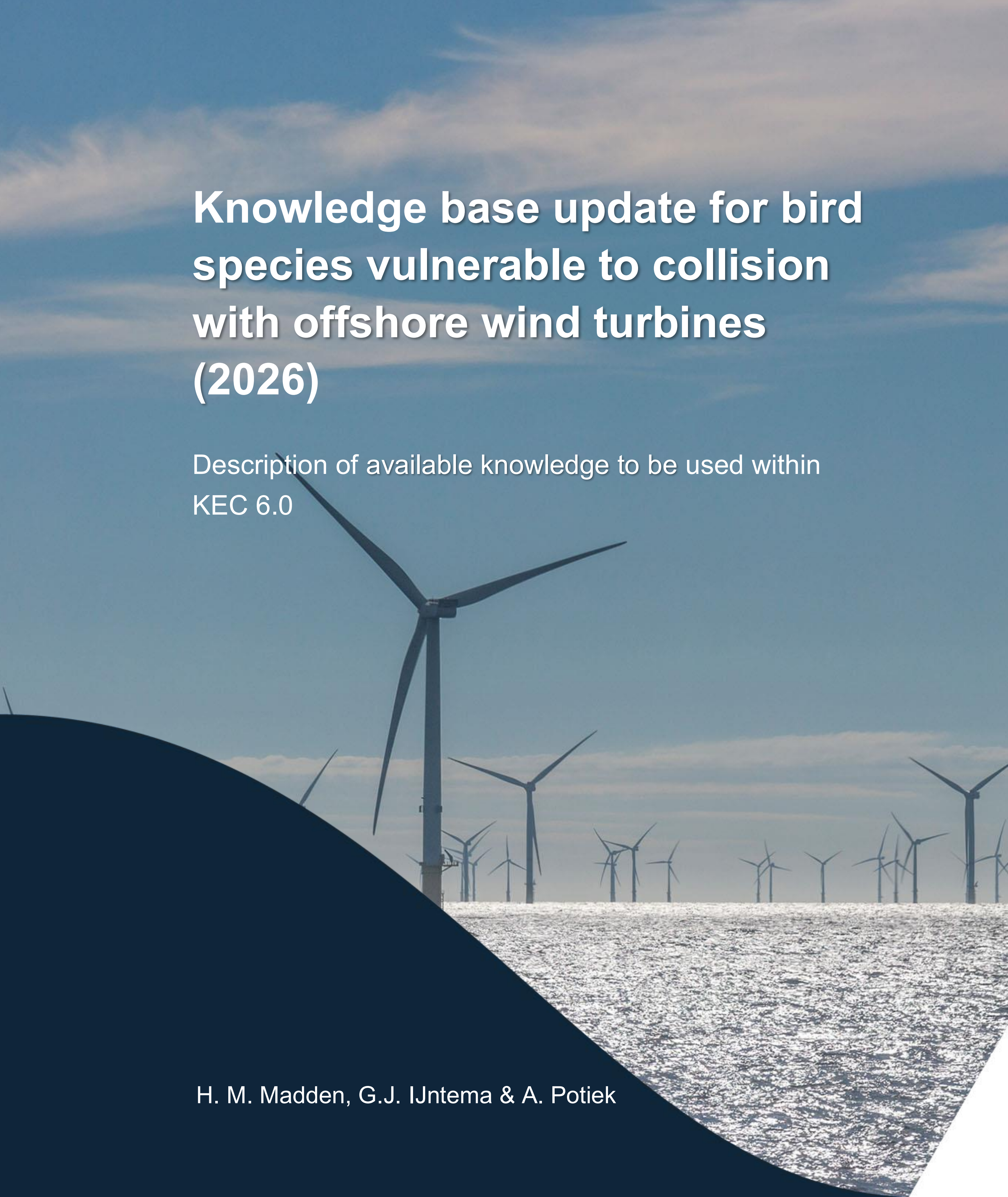

Knowledge base update for bird species vulnerable to collision with offshore wind turbines (2026)

Description of available knowledge to be used within KEC 6.0

H. M. Madden, G.J. IJntema & A. Potiek

WAARDEN BURG Ecology

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Contents

1 Introduction

1.1 Background

The intended development of offshore wind energy in the Dutch North Sea may lead to cumulative effects on seabird and/or migratory bird species, in terms of estimated numbers of collision victims. In the Framework for Assessing Ecological and Cumulative Effects (Dutch name for the framework: Kader Ecologie & Cumulatie; or in short KEC), the cumulative effects of all existing and planned Dutch and foreign wind farms in the southern and Central North Sea are predicted and evaluated.

Given the potential negative effects of wind energy on the natural environment, the KEC includes several environmental impact assessments on the projected future wind farms. One focus area of these assessments is the potential mortality of birds. As a result, within the KEC programme, Waardenburg Ecology and Wageningen Marine Research are tasked with estimating the potential future mortality of birds due to (scenarios of) planned wind farms in the form of collisions (executed by Waardenburg Ecology) and habitat loss (executed by Wageningen Marine Research).

Since the first version of the KEC (Rijkswaterstaat 2015), the assessment has been updated several times (Rijkswaterstaat 2019; Potiek *et al.* 2022; IJntema *et al.* 2025b). The knowledge gained in this knowledge base update, as well as the update from 2025 (Bebbington *et al.* 2025) will be used in KEC 6.0. This report presents an overview of the knowledge base update for the species that are considered relevant for collision mortality.

1.2 Objective

The aim of this report is to update the data, parameters and methods used within KEC with the most recent scientific insights. We provide an overview of the parameters and methods that can be updated, leading to a conclusion about which updates will be incorporated in KEC 6.0.

This knowledge base update is based on published parameter values. No new analyses have been carried out for this report. Note that given the limited data availability for little gull, additional analyses of survival rates and possibly fecundity will be performed for this species as part of KEC 6.0. The results of these analyses were not available at the time of writing this knowledge base update, but will be reported in the final report. Updated parameter values will be used within the analyses.

2 Scope of this knowledge base update

Within earlier KEC studies, species were classified as vulnerable to collision based on their presence in the Southern and Central North Sea as well as their expected vulnerability to collisions with wind farms (Table 2.1). Within this knowledge base update, we updated the parameters for these species, building upon values used in KEC 5.0 (IJntema *et al.* 2025b) and the knowledge base update in 2025 (Bebbington *et al.* 2025). Recently studies have started to reassess the selection of relevant species concerning impact assessment of offshore wind farms (Heße and Melis (2025) for seabirds, Lamers *et al.* (2026) for migratory birds). Because the reports were not finished yet, it was decided in coordination with RWS to work with the original species selection for KEC 6.0. When, in future KEC assessments, the reports are finished, the new species list will be used for the KEC and the models that are needed to do the calculations (e.g. population models) will be developed.

Table 2.1 Species previously identified as vulnerable to collision with offshore wind farms. Differences between the 'seabird approach' and the 'migratory bird approach' are described in text.

Common species name	Scientific species name	Approach
Northern gannet	*Morus bassanus*	Seabird approach
Arctic skua	*Stercorarius parasiticus*	Seabird approach
Great skua	*Stercorarius skua*	Seabird approach
Black-legged kittiwake	*Rissa tridactyla*	Seabird approach
Little gull	*Hydrocoloeus minutus*	Seabird approach
Lesser black-backed gull	*Larus fuscus*	Seabird approach
Herring gull	*Larus argentatus*	Seabird approach
Great black-backed gull	*Larus marinus*	Seabird approach
Common tern	*Sterna hirundo*	Seabird approach
Sandwich tern	*Thalasseus sandvicensis*	Seabird approach
Bewick's swan	*Cygnus (columbianus) bewickii*	Migratory bird approach
Brent goose	*Branta bernicla*	Migratory bird approach
Common shelduck	*Tadorna tadorna*	Migratory bird approach
Eurasian curlew	*Numenius arquata*	Migratory bird approach
Bar-tailed godwit	*Limosa lapponica*	Migratory bird approach
Red knot	*Calidris canutus*	Migratory bird approach

Common species name	Scientific species name	Approach
Black tern	*Chlidonias niger*	Migratory bird approach
Common starling	*Sturnus vulgaris*	Migratory bird approach

The modelling process within KEC for collisions consists of the following:

1. Estimation of bird density or flux, followed by estimating the number of collision victims (collision rate model)
   Product: estimated number of victims per wind farm per year (for seabirds based on bimonthly calculations)
2. Compilation of different wind farm scenarios
   Product: estimated number of victims per wind farm scenario per year
3. Assessment of the impact on the population (population model)
   Product: population projection for the scenario with and without wind farms
4. Test whether this results in violation of the acceptable level of impact (ALI)
   Product: violation or non-violation of set threshold.

A detailed description of the modelling 'train' as applied in the KEC can be found in (IJntema *et al.* 2025b), and is described in more detail in Appendix I.

In short, data requirements for the CRM used include species-specific as well as wind farm specific data. For the population models, species-specific demographic data (survival rates and fecundity) are required.

3 Knowledge base update

This knowledge base update consists of two parts:

- an update of the methodology used, and
- an update of the input parameters used.

Both parts build upon KEC 5.0 (IJntema *et al.* 2025b), and the knowledge update performed in 2025 (Bebbington *et al.* 2025). Moreover, the comments from the KEC 5.0 external review are also taken into consideration (Searle & Mulder 2025).
Note that the update of input parameters concerns collision rate modelling as well as population modelling.

3.1 Knowledge update regarding used methodology

We describe the adjustments in methodology compared to KEC 5.0 (IJntema *et al.* 2025b) and the knowledge update performed in 2025 (Bebbington *et al.* 2025). For more background information, the overall methodology used in the KEC is described in Appendix I.

3.1.1 Wind farm scenarios

Similar to earlier versions of the KEC, wind farm scenarios are provided by RWS. However, based on new insights and methodological adjustments, some aspects of the scenarios were reevaluated in 2025 and these are summarised below.

1) Following operational dates of wind farms more accurately

To date, all wind farms within a scenario were assumed to be operational from year 1 of the simulation onwards, for 40 years. However, in reality, some of the wind farms were already operational prior to year 1, while others are planned for the future. A more realistic approach is to define, for each scenario, which wind farms are operational in each year of the simulation. As a result, the modelled impact is not constant within a scenario, but varies between years depending on which wind farms are operational. The methodology of the population models has been adjusted, in order to allow for such variation between years. This new approach will be applied in KEC 6.0.

2) Nearshore and coastal wind farms

As described by IJntema *et al.* (2025a), nearshore and coastal wind farms would ideally be accounted for. However, the methodology currently does not allow a direct comparison of estimated victims from nearshore and coastal wind farms with those from offshore wind farms. Hence, nearshore and coastal wind farms will not be included in the KEC 6.0 scenarios.

3) Discounting the impacts of existing wind farms

As described by (IJntema *et al.* 2025a), the effects of currently operational wind farms cannot be assumed to be discounted for within the population models, because the demographic data currently available are not recent enough. In line with the precautionary principle, KEC 6.0 will follow the same approach as KEC 5.0: the effects of currently operational wind farms are not assumed to be discounted. Consequently, operational wind farms are also included in the scenarios.

4) The geographic scope of the international scenario

As recommended by (IJntema *et al.* 2025a), the international study area will, whenever possible, be expanded to match the OSPAR area of the 'Greater North Sea' (OSPAR Region II). We should mention that in doing so we are dependent on the scope of the seabird density maps, some of which do not facilitate assessing the full OSPAR II area. In this case we will assess as much of the area as possible.

3.1.2 Collision rate models (CRMs)

Since the 2025 KEC knowledge update (Bebbington *et al.* 2025), several papers have been published regarding the collision mortality assessment methodology using collision rate models (CRMs). We found two new modelling frameworks and two studies addressing the underlying assumptions of the current KEC assessment model, as well as one ongoing project that may be relevant for future KEC assessments. These are described in more detail below, with each source in **bold** for clarity:

Models and frameworks that directly address the impact of collisions

Vallejo *et al.* (2025) developed the OCcAM assessment tool for rapid cumulative assessments on the effects of offshore wind on birds in the United Kingdom. This tool is built as an easy-to-use Excel tool around the Band (2012) CRM. However, the OCcAM tool uses an older, basic version of the Band model that disregards uncertainty in favour of a more rapid assessment. Within the KEC 6.0 assessment framework, we currently see no added value in the use of the OCcAM tool because:

1) the Acceptable Levels of Impact (ALI) policy framework for testing acceptable thresholds explicitly requires a set of simulated outcomes that represent uncertainty. This uncertainty estimate is lacking in the OCcAM tool. Given the importance of accounting for uncertainty to indicate the range and certainty of our predicted effects more transparently, we are of the opinion that OCcaM is unsuitable for the KEC assessment.
2) KEC 6.0 covers more species than just the five species supported within the OCcAM tool.
3) We expect the Excel-based structure to be somewhat rigid in the application of the models, hindering proper application of all the nuances within an ecological and policy context.

Buckingham *et al.* (2026) developed an individual-based model to assess multiple stressors of offshore wind farms on seabirds in the non-breeding season, parameterised for the black-legged kittiwake colony at Ålesund in Norway using geolocation immersion loggers. The collision module of the model applies a module from the Band model to calculate collision probability for a single transit. Using density maps based on the loggers, the model assigns travel paths to birds. It then calculates how much time an individual likely spends flying through a wind farm (correcting for avoidance) and translates this into an estimated number of turbine transits. Accounting for collision probability and turbine transits for the number of consecutive days in the non-breeding season, the model calculates collision mortality during the non-breeding season.

The model could potentially provide a way to simultaneously model collisions and habitat loss. However, the authors point out that information on the energetic costs of displacement is lacking, and the outcome of the model is highly sensitive to this parameter.

Whilst we recognise the potential to apply parts of this model in future assessments, the model is currently highly specific and parameterised to a single colony of one species in Norway. Consequently, there are three main reasons that prevent it from being applied within the available timeframe of the upcoming KEC 6.0 assessment:

1) Implementing this model would require significant development to tailor it to the requirements and local context of the KEC 6.0 assessment.
2) The model builds strongly on an extensive analysis of geolocation immersion loggers. Currently, the KEC assessment framework does not include such loggers and would therefore necessitate extensive analysis and development before the data are ready to feed into models used within the KEC assessment framework.
3) The model was developed for the non-breeding season. To fit a model for a year-round assessment, a compatible and complementary model for the breeding season would need to be adapted or developed to include Buckingham *et al.* (2026) insights in the KEC assessment model.

Based on the above, we chose to retain the newest iteration of the Band model for seabirds using the StochLAB package in R (Caneco *et al.* 2022). The package is regularly maintained and updated. We will use the latest version of this model, version 9th May 2026.

Methodological assumptions and data usage in addressing collision impacts
As part of the additional KEC assignments in 2025, **Madden (2025)** explored a new method in order to make flight height distributions more realistic. Based on this method, the flight height distributions will be 'smoothed', which resolves the problem of unrealistic peaks due to inaccuracy in GPS altitude measurements. This method will be applied where possible within KEC 6.0.

Within the WOZEP modelling project ZV4-5-6 *(Complexe vogelmodellen),* the resolution of Flight Height Distributions (FHDs) was reconsidered. The question was whether the currently used one-metre height bands in CRMs matches the quality of the underlying GPS data. It was concluded that one-metre height bands are often too specific for the underlying data, but is currently too early to say how this will affect the results. As part of this project, the underlying R scripts required to execute the KEC assessments are currently being adapted to facilitate different height band resolutions and other adjustments to the FHDs used in the KEC framework. We expect this project to lead to some recommendations and script improvements for species with high-resolution underlying GPS data. However, these results are unlikely to be available within the KEC 6.0 timeframe. In future KEC assessments, or within KEC 6.0 if results are available on time, the outcome of this study can be used to decide whether more coarse height band resolutions or smoothing methodologies are required, based upon a re-evaluation and joint decision between RWS and WE.

Fritz *et al.* (in prep) addressed the different technical assumptions of wind turbines considered in collision rate models, specifically StochLAB (Caneco *et al.* 2022). Fritz *et al.* (in prep) propose to align wind turbine science to better represent a realistic space use of turbine blades. Within StochLAB, space use of turbine blades is relevant for calculating the probability that a bird and turbine blade may occupy the same physical location at the same time, thus colliding with each other. Specifically, Fritz *et al.* (in prep.) propose three adaptations to collision risk modelling using StochLAB:

1) <u>Blade profiles</u>: Fritz *et al.* (in prep) argue that the default wind turbine blade of a 5MW turbine used in StochLAB can be replaced with industry-defined reference turbine blade profiles. Within the wind energy community, reference turbines are defined for 5MW, 10MW, 15MW and 22MW and could therefore replace the current default blade shape. Given the relative ease with which custom blade shapes can be defined in StochLAB, this requires little technical effort to do so. However, decisions about which reference blade shape most accurately mirrors specific existing and proposed offshore wind turbines should be made with policy and technical experts.
2) <u>Wind speed</u>: Fritz *et al.* (in prep) propose that the parameters rotation speed and pitch can be modelled as a function of wind speed. While defining rotor rotation speed and pitch as a function of wind speed is relatively easy in StochLAB, implementation will require an additional analysis step beforehand i.e. modelling probability distributions for wind speeds occurring at each wind farm site. Modelling wind speed within the KEC 6.0 assessment would yield four additional technical considerations:
   i. Site-specific wind speed probabilities would either need to be analysed or assumed: obtaining site-specific wind speeds requires large-scale data analysis and consultation with wind energy experts, whereas assuming wind speeds at sites requires thorough consultation with wind energy experts and an agreed policy on which wind speeds represent a worst-case scenario for bird collisions.
   ii. In StochLAB, modelling wind speed probability is restricted to a truncated normal distribution. However, Fritz *et al.* (in prep) use a Weibull distribution, which is not supported by StochLAB. Wind speed should therefore either be modelled using a truncated normal distribution, or the underlying StochLAB scripts would require revision to facilitate a Weibull distribution. Both would require significant additional analysis time, and it is yet unclear how this will affect the model outcome. Although a Weibull distribution would make the model more realistic, other model assumptions such as avoidance rate have a stronger impact on the model outcome.

iii. The relationship between wind speed, rotation speed and pitch are specific to blade shape. Hence, the aforementioned decisions about which reference blade shape most accurately reflects existing or future wind turbines also affects the implementation of rotation speed and pitch as a function of wind speed.
iv. In StochLAB modelling, only annual distributions for wind are supported. However, given that bird distributions and flyovers can be highly seasonal, loading annual distributions can result in mismatches between bird presence and wind speeds; implementing an annual wind speed distribution might make the predictions less accurate. Sensitivity analyses on monthly and annual wind speed distributions should therefore be considered prior to implementing annual wind speed distributions.

3) In StochLAB, the relevant surface of the turbine blade is represented using a projection based on the blade chord. However, Fritz *et al.* (in prep) argue that the projection based on the chord should be adjusted for the projected airfoil. StochLAB does not, however, support such a correction, and implementing this would require a significant revision to the underlying StochLAB package code. Revising the underlying script is currently not feasible within the KEC 6.0 timeframe. Moreover, any adjustment of the underlying script would result in it no longer being compatible with the original StochLAB package, making the KEC analyses less reproducible.

In conclusion, adjusting the blade profile (1) is practically feasible, but requires assumptions about the specifications. For KEC 6.0, the technical assumptions have already been set. Following consultation with RWS, it was decided to use these set specifications. As the suggestions by Fritz *et al.* (in prep.) improve the realism of the model assumptions, we recommend considering these suggestions by Fritz *et al.* (in prep) for future technical specifications. Adjusting the blade profile would improve realism of the space occupied by the blade at any point in time. However, given our limited understanding of avoidance behaviour, it remains to be seen whether the space occupied by the blade is of true importance to predict the number of collision casualties.

The suggestion to take wind speed into account (2) as well as the suggestion regarding the surface of the turbine blade both require additional assumptions and methodological changes to the CRM package, which are not feasible within the current KEC 6.0 timeframe. As the StochLAB package keeps evolving, however, these adjustments may be possible in the future. For future assessments, the points should be reconsidered.

Hence, although the suggestions by Fritz *et al.* (in prep.) would improve realism, it is not feasible to apply those suggestions in KEC 6.0. For future assessments, this should be reconsidered.

Ongoing developments relevant to identifying the impacts of collisions

We are aware that two promising models are in development that may be able to incorporate the wealth of novel data and data types being collected offshore. Unfortunately, it is our opinion that none of these developments are currently at a stage that they can be directly applied within the existing KEC assessment framework. However, these developments should provide relevant input in the future.

One example is the development of a new collision rate model in project ZV4-5-6 *(Complexe vogelmodellen)* within the WOZEP research programme. Future KEC knowledge updates should closely follow the development of these new models and their potential for improving the KEC framework.

Another example is the Australian Collision Risk Framework Collision Risk Model (ACRF CRM) by Symbolix and Biosis, as contained in the package *collision* (Stark *et al.* 2026). The model and tool are currently still under peer review and therefore not yet fully completed. The model provides a flexible, new, way to model collision risks for both onshore and offshore environments. For example, the model will enable the inclusion of short-term migrant birds and spatial heterogeneity, such as different collisions risks per turbine. When finished, it should be studied to assess the usability of (parts of) the model for use in the KEC framework.

3.1.3 Assessment population-level impact using population models

The population models used in KEC 6.0 will be based on the models used in KEC 5.0, with updated input parameters as presented in this knowledge base update. In addition, the assumption regarding not incorporating density dependence has undergone further evaluation.

Density dependence
The importance of incorporating density dependence has been re-evaluated(Hin *et al.* 2025). We conclude that the available knowledge about the importance and the manner in which density dependence plays a role is currently too limited to realistically take this process into account in KEC 6.0. While we recommend further evaluating the possibility of incorporating density dependence, these processes will not yet be incorporated in KEC 6.0.

3.1.4 Considerations relevant to, but outside the current scope of KEC

Some developments and considerations may currently be outside the scope of the KEC framework methodology, but may prove to be relevant in future versions of the framework. Here we describe three such considerations:

Ecosystem impacts in the form of potential changes in **food availability** may significantly affect both seabird populations and the presence of birds near wind farms. Several studies investigated the effects of offshore wind development on different fish species (e.g. Methratta (2025) and Friedland *et al.* (2021)), the results of which indicated ecosystem changes as a result of the fishing ban as well as the application of hard substrate in offshore wind farms. These changes in species abundance can subsequently impact seabirds via food availability. The impacts of offshore wind farms on fish in the North Sea are currently being studied within MONS (Couperus *et al.* 2022), but a clear impact on specific bird species has currently not been quantified. The NESTORE project in France studied multiple ecosystem impacts of offshore wind farms (Le Marchand *et al.* 2025), using a nested modelling approach in which food webs are simulated inside and outside wind farms. Preliminary results showed that offshore wind farms are expected to cause a decline in total biomass of all living organisms. Specifically for birds, the combination of climate change and offshore wind farms is modelled to result in a biomass decline of 3% (Le Marchand *et al.* 2025). If the species-specific impacts on birds are better understood, such nested models can provide better insights into the indirect impact of offshore wind farms on birds via prey distribution. For now, the models used cannot be directly implemented within the KEC framework.

Since the 2025 knowledge update, we have investigated how **barrier effects** of offshore wind farms might be assessed within the KEC framework (IJntema 2026). The framework proposed in this report describes the functional steps required to include barrier effects in the KEC framework, concluding that most technical methods would require further development. Hence, a methodology to assess barrier effects within the KEC framework will not be ready at the time of executing KEC 6.0. Future developments of this barrier effects assessment framework should be closely monitored for their eventual inclusion in the future KEC assessment framework.

External reviews of the KEC framework indicated that discussing the **effectivity of different mitigating measures** on seabird populations would be a good addition. However, much is yet unknown about the effectivity of mitigating measures. We expect current ongoing projects to provide insights into this matter in the future. An example of such a project is the Ecowende programme (www.ecowende.nl). Given the current lack of knowledge on mitigation measures, we foresee only a brief discussion of the possibilities within KEC 6.0.

Another crucial development we expect to be useful in the near future, is the application of **detection systems** in offshore wind farms. Several detection systems to measure real-time bird collisions in (offshore) wind farms are under development. The SPOOR system has been installed on one turbine in European Offshore Wind Deployment Centre (EOWDC) in Aberdeen Bay, and preliminary results have been reported by (Cook 2026). During the 19 months of monitoring, no collisions were detected during daylight and in good weather conditions. In addition, observed flight behaviour during this time was used as an input for collision rate models. Comparison to CRMs with assumed flight behaviour, the observed flight behaviour resulted in clearly lower estimated number of victims. These type of data are crucial to improve flight behaviour assumptions, and to quantify collision victims. However, some points of caution should be noted:

- These results reflect the situation for one turbine in one location; with a different species spectrum, the results may differ, but these may differ even within the same wind farm at another wind turbine.
- Measurements were only possible during daylight hours with good visibility, urging caution for nocturnal species and under conditions of reduced visibility.
- It is not yet clear whether the SPOOR system misses collisions. However, conducting a validation offshore is not realistic, as collision victims fall in the water. It is crucial that the SPOOR system is validated in (ideally multiple) onshore wind

farms, where the comparison with the outcome of carcass searches can provide insights into the system's performance.

3.1.5 Reproducibility of the methodology

External reviews of the KEC framework urged safeguarding its reproducibility and identifying whether an independent researcher/expert could execute the assessment using the scripts and data provided. Last year, Altenburg and Wymenga, in collaboration with BioConsult, used the KEC scripts to perform an environmental impact assessment for the upcoming wind farm Nederwiek Noord. As part of KEC 6.0, we aim to consult these parties to identify the reproducibility of the methodology and data usage of the KEC framework. Feedback resulting from this consultation will be considered within the KEC 6.0 assessment.

3.2 Update used input parameters

Part of this knowledge basis update was to update the parameters based on an extensive literature review for input parameters, for both the collision rate and population models. This knowledge update was performed for all seabird and migratory species listed in Table 2.1.

We performed all literature searches in Google Scholar and Waardenburg Ecology's EndNote library. For each species, we searched for recent (2025 and 2026) studies using the species' common name and Latin name as separate search terms. We also performed more targeted searches consisting of the species' common name combined with a term related to population or collision rate model parameters (such as 'survival', 'fecundity', 'reproduction' or 'flight').

Collision rate model parameters
For the collision rate model parameters, we updated the most recent knowledge database (Bebbington *et al.* 2025; IJntema *et al.* 2025b) to include recent relevant studies. We gathered information on body length (m), wingspan (m), flight speed (m/s), nocturnal activity (proportion), avoidance rate (proportion) and ratio flying (proportion). In addition, for local seabirds we searched for updates on flight height distributions, while for migratory birds we searched for new data on the proportion of birds flying at rotor height.

Demographic rates
Input for the population models consists of estimated life stage-specific survival rates, fecundity and proportion of non-breeding adults (floaters). We updated the knowledge database based on the demographic rates used by Bebbington *et al.* (2025) to include recent relevant studies.

For the weighing of different data sources, each source within this updated knowledge base was scored for representativeness and data quality, following the approach used in previous KECs (e.g. IJntema *et al.* (2025b)), which is based on Horswill and Robinson (2015); see Box 1 for a description of the approach. Age of first breeding is highly species-specific and constant between colonies. Hence, this parameter is generally based on a single data source.

Similar to the approach used in KEC 5.0 IJntema *et al.* (2025b), reported demographic rates that may include impacts from the recent High Pathogenic Avian Influenza (HPAI) outbreak of 2021-2023. Since these data were collected during an unusual mass-mortality event, it is unclear to what extent the survival and fecundity parameters are relevant for long-term population projections. However, since the majority of the species included in this report have low annual reproductive rates and high longevity, the mass mortality caused by HPAI is likely to be visible in Dutch populations for many years to come. For that reason, we chose to consider including these new publications in our report; where new parameters are reported from HPAI-affected populations, these are explicitly discussed in the text.

Note that in the years following such a mass outbreak, demographic rates may (temporarily) be different to those in normal years. For example, decreased competition for breeding sites or food may result in higher survival or fecundity rates, as well as breeding at a lower age. This means that post-HPAI parameters may be less representative for long-term demographic rates.

For each case of new published parameters based on data collected during or shortly after an HPAI outbreak, we discuss whether we recommend using the new estimates. In general, we do not recommend using estimates from studies based on single years, since these are not representative for long-term demographic rates. However, where longer time series data are available, those from years during or shortly after HPAI should be included.

Selecting the final values to be used in collision rate and population models

Depending on the available data, and the quality and representativeness of the data sources, we used one of the following approaches:

1. Recommended values based on large reviews: When recent large reviews with recommended parameters were available, the recommended values provided were used. When no new values were published following the publication of said reviews, we assumed all values published prior were considered and adopted the recommendations from those reviews directly.
2. Use 'best' reference: When one reference has clearly higher data quality and representativeness than the other sources available, that reference was used.
3. Calculate weighted averages: When several data sources are available, these can be weighted by data quality and representativeness (see Box 1).

Box 1 Weighing of data sources for input parameters of the population model, based on the approach described by Horswill and Robinson (2015), which was also used for previous versions of the KEC.

This approach described by Horswill and Robinson (2015) is based on the following criteria to assess data quality:

- Q1) number of years (>10).
- Q2) number of individuals, and
- Q3) whether variation between years or areas (standard deviation) or a range of error (standard error) was reported.

Each of these criteria is scored with 0, 1, or 2: 0 for ‘poor’, 1 for ‘intermediate/unknown’ and 2 for ‘good’. This means that the maximum data quality score is 6.

Similarly, we assess the representativeness of each data source. This is scored based on:
- R1) how recent the data are (score = 2 for data <10 years old; the threshold between score 1 and 0 depends on the species and data availability),
- R2) how representative the area/site is for the Dutch part of the North Sea, and
- R3) how representative the data are for local current trends in the Dutch part of the North Sea.

For all parameters, if European estimates are available we use those estimates, as we consider them more representative.

Again, each of these criteria is scored with 0, 1, or 2: 0 for ‘poor’, 1 for ‘intermediate/unknown’ and 2 for ‘good’. This gives a maximum score for representativeness of 6.

For each species, the defined life stages are described using the following general structure:
- first-year stage (stage J0),
- followed by one or more immature stages (stages starting with I, for example I1 to I4),
- and an adult stage (stage A).

Demographic rates are reported using the same stage indices, for example SI1 being survival of the I1 stage. Fecundity is presented as the number of fledglings per breeding pair. For most species a proportion of floaters is assumed, where possible based on published literature. This is depicted in the species-specific tables, with demographic rates as incidence of missed breeding.

Regarding the selection of avoidance rates, we used the same decision tree from KEC 5.0 to decide which studies are most relevant to rely on (Figure 3.1). The foremost criterium was whether avoidance rates from offshore studies are available. If so, those studies were scored on data quality and representativeness (see Box 1), and the resulting weighted average was used.

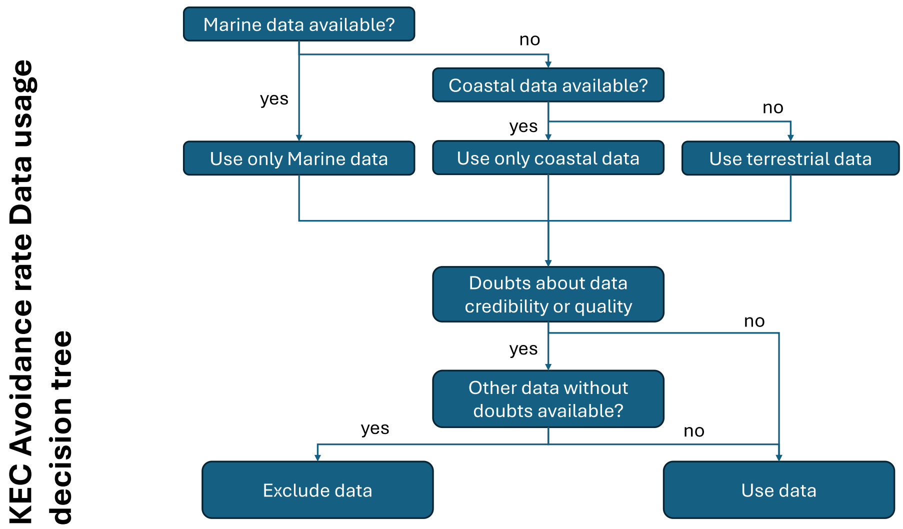

Figure 3.1 Decision tree for prioritising studies that report avoidance rates.

Later in this chapter we provide, per species, an overview of the most recent values, together with an advice about which values are considered relevant. These values were accounted for based on the above selection criteria and weighing. The final values to be used in future impact assessments are published in the Wozep repository, available at https://wozep.nl/git/wozep/kec-6.0.

3.2.1 Seabird species

Northern gannet

Since the last knowledge update, we found one study reporting CRM parameters for Northen Gannet: Skov *et al.* (2025) report a flight speed of 3.10 m/s (SD ± 1.03) and a meso-avoidance value of 0.5 (SD ± 0.38) from nine track nodes within 30 meters of a turbine blade tip. Since our current parameter database holds no values for micro-avoidance of Northen gannets to complement this value into full avoidance, we cannot include the meso-avoidance value in KEC 6.0. Should future studies provide reliable estimates for micro-avoidance of Northern gannets we recommend reconsidering including this value. Given the high relevance of the flight speed value to the North Sea population of Northen gannets, we recommend including this estimate in the final parameter value for flight speed.

Northern gannet is a species that is vulnerable to collision as well as habitat loss. As in the KEC 5.0 study, Northern gannet population model parameters were updated by WMR as part of a separate KEC 6.0 Habitat loss report (Melis & Hin 2026).

Arctic skua

No new studies were found that reported parameters relevant to the Arctic skua sCRM model.

One new study was found regarding demographic rates. Langlois Lopez *et al.* (2026) cite 1.09 fledglings per breeding pair (n = 12 clutches) based on a publication by Ryabitsev and Ryzhanovskiy (2022) from Russia based on historical data collected in 1983. No minimum or maximum values were provided. Given the historical nature of the data, and the fact that only one estimate is provided, as well as the small sample size, it was decided not to include this as a new value for the current report.

Great skua

No new studies were found that reported parameters relevant to the great skua sCRM model.

Using data from a breeding colony in Murmur Island, Russia, Krasnov *et al.* (2025) reported 0.8 fledglings per breeding pair (*n* = 21 clutches/42 eggs) based on data collected between 1991 and 1995. No minimum or maximum values were provided. Similar to the Arctic skua above, given the historical nature of the data and small sample size, it was decided not to include this as a new value for the current report.

Black-legged kittiwake

Since the last knowledge update, we found one study reporting direct values for CRM parameters for black-legged kittiwakes: Skov *et al.* (2025) report a flight speed of 6.27 m/s (SD ± 0.48) and a meso-avoidance of 0.5 (SD ± 0.22) from 170 track nodes within 30 meters of a turbine blade tip. Given the high relevance of both values to the North Sea population of black-legged kittiwakes, we recommend including both values in the new parameter estimates for KEC 6.0 for flight speed and avoidance respectively. Since our database only contains a single estimate for micro-avoidance at 100%, we cannot combine the reported meso-avoidance into a full avoidance rate as this would make the estimate statistically meaningless. Furthermore, always assuming 100% does not represent a worst-case scenario when other parameter estimates suggest the value may not be 100% all the time.

Additionally, (Gillies *et al.* 2026) is relevant to the nocturnal activity parameter as it demonstrates latitude-dependent variation in diel activity rhythms. Gillies *et al.* (2026) demonstrated that diel activity rhythms in black-legged kittiwakes vary strongly across latitude, with clear dawn and dusk peaks at lower latitudes but flatter, more variable patterns at high latitudes. Their results suggest that kittiwake activity is strongly influenced by sun elevation and local light-dark conditions. Although the study does not provide a direct replacement for the nocturnal activity parameter used in collision risk modelling, it suggests that nocturnal activity should not be treated as a fixed species-level parameter, but may vary with latitude, season and local light conditions. However, because the study covers a wide geographic range, its relevance for KEC depends on whether the included colonies are representative of the populations that contribute to kittiwake occurrence in the southern and central North Sea. Before using this study to update the nocturnal activity parameter, whether colony- or region-specific estimates can be extracted for colonies relevant to KEC should be assessed. In the absence of directly applicable estimates, the study can be considered as evidence for geographic variation and associated uncertainty in nocturnal activity, rather than a direct replacement for the current KEC value.

Three recent studies provided fecundity estimates for the black legged-kittiwake, broadly reported in a global synthesis by Schekkerman *et al.* (2025). The estimated number of fledglings/pair from Norway ranged from 0.26 to 0.66 (SD ± 0.26 – 0.39; *n* = 8 – 24). These estimates were derived from mainland Norway as well as the Norwegian- and Barentz Sea (Fayet *et al.* (2024); reported by Schekkerman *et al.* (2025)). The UK national average fledglings/pair was estimated at 0.69 (± 0.3) based on Horswill and Robinson (2015) (*n* = 100), again reported by Schekkerman *et al.* (2025) in their synthesis of published studies. Finally, Schekkerman *et al.* (2025) report that provide model estimates on fecundity for the Greater North Sea at 0.72 (± 0.19). Given the explicit focus of Frederiksen *et al.* (2025) to estimate a value for the whole of the Greater North Sea, we recommend using only this value.

Age of first breeding ranged from 4.3 – 4.5 years (± 0.4 – 0.9; reported by Schekkerman *et al.* (2025)), based on historical data from France and the UK). This corresponds with the assumed age of first breeding of 4 in other versions of the KEC.

Schekkerman *et al.* (2025) estimated juvenile survival for the countries around the North Sea was estimated at 0.61 (± 0.1) and immature survival was at 0.78 (± 0.07); Using studies form Iceland, Norway and the United Kingdom, Schekkerman *et al.* (2025) reported a mean adult survival of 0.83 (± 0.04) for Europe. Given the explicit focus of Schekkerman *et al.* (2025) to recommend and estimate population model parameters for the North Sea, we recommend the values mentioned here to be used directly in KEC 6.0.

For breeding propensity, Schekkerman *et al.* (2025) reach an average of 0.76 (±0.08), leading to an incidence of missed breeding of 0.24 (±0.08). for the reasons mentioned above we recommend using this value as parameter estimate in KEC 6.0.

Little gull

No new studies were found that reported parameters relevant to the little gull sCRM model.

We also found no new studies reporting input parameters for the population model. In general, very little is known about reproduction and survival in this species; as in previous versions of this knowledge update, we therefore (for now) incorporate demographic data from a closely related species, the black-headed gull *Chroicocephalus ridibundus*, to inform the population model. Note that within this KEC 6.0 project, an additional analysis to estimate survival analysis based on existing ringing data was recently granted and will be published in a separate forthcoming report. Outcomes from this analysis will, if applicable, form input for the KEC 6.0 analyses.

Lesser black-backed gull

No new studies were found that reported parameters relevant to the lesser black-backed gull sCRM model.

Schekkerman *et al.* (2025) estimated 0.51 (± 0.31) fledglings/pair from all breeding sites in the Netherlands between 2014 and 2024 (*n* = 95). They also estimated 0.87 (± 0.03) immature survival and 0.67 (± 0.15) juvenile survival from the Greater North Sea based on data published by Frederiksen *et al.* (2025). Adult survival from the same area was estimated to be 0.89 (min 0.82; max 0.94; SD 0.03). Finally, Schekkerman *et al.* (2025) cite several values for breeding propensity (and therefore also incidence of missed breeding); All values reported by Schekkerman *et al.* (2025) were found in earlier versions of the KEC and are therefore already included in earlier parameters.

Morel *et al.* (2026) studied juvenile post-fledging survival in relation to exploratory traits, finding that more than half of the individuals died within six months upon fledging (without further detailed specification). Note that this survival over six months cannot directly be implemented into the population models. Hence, we will use the estimate from the meta-analysis by Schekkerman *et al.* (2025) for KEC 6.0.

Herring gull

Since last knowledge update, we found one study reporting direct values for CRM parameters for herring gull: Skov *et al.* (2025) report a flight speed of 5.47 m/s (SD ± 0.13), a meso-avoidance of 0.7 (SD ± 0.15) and a micro-avoidance of 0.97 from 170 track nodes within 30 meters of a turbine blade tip. Combining meso- with micro-avoidance yields an meso-micro-avoidance of 0.991 (SD ± 0.0045). Given the high relevance of both values to the North Sea population of herring gulls, we recommend including both values in the new parameter estimates for KEC6.0 for flight speed and avoidance respectively. Since our database contains one parameter estimate for macro-avoidance for herring gull, we can combine the reported meso-micro-avoidance into a full avoidance rate for use in the CRMs. Using a weighted average for macro-avoidance estimates available in our database (Skov *et al.* 2018; Leemans *et al.* 2022; Vanermen *et al.* 2022), we calculated an average macro-avoidance rate of 0.43. Combining this macro-avoidance value with the meso-micro-avoidance from Skov *et al.* (2025), yields an avoidance parameter estimate of 0.9949, which we recommend including in the calculation to reach a final recommended avoidance value for the herring gull in KEC 6.0.

Schekkerman *et al.* (2025) performed a meta-analysis based on data from the Netherlands, Belgium, Germany, France, UK and Norway, as well as published modelled survival rates for Arctic waters, Greater North Sea and Celtic Seas (Frederiksen *et al.* 2025). This meta-analysis resulted in adult annual survival rates varying from 0.74 to 0.91, with a mean of 0.84 and between-year variability (SDp) of 0.06. Based on the same meta-analysis by Schekkerman *et al.* (2025), available estimates of juvenile survival average around 0.59 (SDp 0.08), while survival of immatures is closer to that of adults with a mean of 0.83 (SDp 0.06). Given the high relevance of these survival estimates for the study area, we suggest using these mean parameters and between-year variability (SDp) values as input for KEC 6.0.

In addition, Schekkerman *et al.* (2025) performed a meta-analysis for fecundity. Based on this, the mean breeding productivity estimate is 0.73 (± 0.38) young fledged per breeding pair, with a higher interannual variation (SDp) of on average 0.30 (41% of the mean). Again, given the high relevance of these survival estimates for the study area, we suggest using this mean fecundity and between-year variability (SDp) as input for KEC 6.0.

Finally, Schekkerman *et al.* (2025) also reported values for the breeding propensity, taken from Calladine and Harris (1997) at 0.65. Due to reasons mentioned above, we again recommend using this value as input for KEC 6.0.

To date, age of first breeding was assumed to be 4 years (5th year of life) in previous KEC studies. Schekkerman *et al.* (2025), however, report an age of first breeding of 4.9 years. Hence, we will adjust the age of first breeding to 5 years (6th year of life).

Great black-backed gull

Since last knowledge update, we found one study reporting direct values for CRM parameters for great black-backed gull : Skov *et al.* (2025) report a flight speed of 4.07 m/s (SD ± 0.41), a meso-avoidance of 0.5 (SD ± 0.25) and a micro-avoidance of 0.96 (for black-backed gulls in general) from 170 track nodes within 30 meters of a turbine blade tip. Combining meso- with micro-avoidance yields a meso-micro-avoidance rate of 0.98 (SD ± 0.0164). Given the high relevance of both values to the North Sea population of great black-backed gulls, we recommend including both values in the new parameter estimates for KEC 6.0 for flight speed and avoidance respectively. Since our database contains a parameter estimate for macro-avoidance by great black-backed gulls, we can complement combine the reported meso-micro-avoidance into a full avoidance rate for use in the CRMs: combining the meso-micro avoidance of 0.98 (SD ± 0.0164) (Skov *et al.* 2025) with a macro-avoidance of 0.469 (Skov *et al.* 2018) leads to a full avoidance estimate of 0.98938.

With regard to demographic rates, new fecundity estimates were reported by Madden *et al.* (2026 (in press)) and Schekkerman *et al.* (2025). Madden *et al.* (2026 (in press)) estimated 1.5 (SDp ± 1.1) fledglings/pair from one breeding location in Norway based on data collected in 2024 (*n* = 50). Recent (from 2024), high resolution flight height data from 50 GPS-tracked individuals are available (Ecowende 2025) and can now be incorporated into collision risk models for KEC 6.0.

Schekkerman *et al.* (2025) provided fecundity estimates of 1.11 (SDp ± 0.23), 1.2 (0.54) and 1.41 (SD ± 0.47) from the Netherlands (Delta area; *n* = 14), UK colonies (*n* = 116) and the Greater North Sea, respectively. Given the relevance of the meta-analysis by Schekkerman *et al.* (2025), and the very similar estimate by Madden *et al.* (2026 (in press)), we suggest applying these estimates for the Greater North Sea of 1.41 (SD ± 0.47) by Schekkerman *et al.* (2025) for KEC 6.0.

New survival estimates were also reported by Schekkerman *et al.* (2025): adult survival was estimated to be 0.86 (SD ± 0.05); immature survival was estimated at 0.78 (SD ± 0.02), and juvenile survival was estimated at 0.48 (SD ± 0.13). Given the relevance of the meta-analysis by Schekkerman *et al.* (2025), we suggest incorporating the reported survival rates.

Schekkerman *et al.* (2025) also set the age of first recruitment at 5 years, based on Horswill and Robinson (2015). We follow this and recommend using this value in KEC 6.0.

Common tern

No new studies were found that reported parameters relevant to the common tern sCRM model. Upon checking the parameters used in KEC 5.0, we did however find an inconsistency. Since KEC 4.0, an average flight speed of 9.2 m/s was assumed in the sCRM. This estimate was based on Fijn and Gyimesi (2018) and Wakeling and Hodgson (1992) Recalculation however gives an average of 9.6 (SD ± 3.3). Hence, we will repair these values for flight speed.

Age of first breeding was estimated to be 3.2 (SD ± 0.8) years based on data collected between 1992 and 2001, with the mean age of females being 3.2 and males being 3.6 years (Schekkerman *et al.* 2025). In the population used so far within KEC, the assumed age of first breeding was 4 (5^{th} year). Based on this data source, we will adjust the age of first breeding to 3 (4^{th} year).

Schekkerman *et al.* (2025) estimated 0.49 (SD ± 0.41) fledglings/pair from all coastal breeding colonies in the Netherlands between 2014 and 2024 (*n* = 288). They also estimated a UK national average of 0.76 (± 0.47) fledglings/pair (*n* = 100+) based on data collected between 1986 and 2014. For the Greater North Sea region, Schekkerman *et al.* (2025) estimated 0.52 (SD ± 0.19) fledglings/pair (*n* = 34), based on data published by Frederiksen *et al.* (2025). Given the fit of the scope, the value based on Frederiksen *et al.* (2025) is recommended as value to be used in KEC 6.0

Survival of third year birds was estimated to be close to adult survival (mean 0.80 SD 0.13). Immature (third and fourth year) survival from the Greater North Sea was estimated at 0.86. Survival was lower in the first year than second. Adult survival was estimated at 0.88 (± 0.03; min 0.85 – max 0.93)(Schekkerman *et al.* 2025). Juvenile survival was estimated at 0.68 based on Frederiksen *et al.* (2025) We recommend using 0.68, 0.86 and 0.88 as values for juvenile, immature and adult survival respectively.

Additionally, Schekkerman *et al.* (2025) report a new value for the breeding propensity of common terns at 0.92 from Szostek and Becker (2012), leading to an incidence of missed breeding of 0.08. Given that the previous value for this parameter was a rough estimate, we recommend adopting this value for KEC 6.0.

Sandwich tern

No new studies were found that reported parameters relevant to the Sandwich tern sCRM model.

As Sandwich tern is a species vulnerable to collision as well as habitat loss, final demographic values are chosen in coordination with WMR.

3.2.2 Migratory birds

Bewick's swan

No new studies were found that reported parameters relevant to the Bewick's swan sCRM model.

Two new studies were found reporting measures for fecundity. Koffijberg *et al.* (2025) reported a mean brood size of 1.9 during the winter count (January) (min. 1.7, max 2.1; *n* = 227 cygnets in 122 families where brood size was recorded), based on data collected in 2000 from northeast and northwest Europe. In addition, Tal *et al.* (2026) derived breeding propensity estimates (i.e. the decision to breed or not) and nesting success (i.e. probability of completing a nest) from 60 Bewick's swans, based on data collected from 2017-2024) breeding in the Arctic. Tal *et al.* (2026) estimated overall nest success of 0.16; hatchling survival of 0.70; and an overall breeding propensity of 0.30. Although this is informative, the population models require information on number of fledglings per breeding pair, either in combination with breeding propensity or not.

Given the sample size, relatively recent data, and its relevance for the population models, it was decided to use a weighted estimate based on this new value by Koffijberg *et al.* (2025) and the estimate by Nuijten (2020) based on data from 1995-2015 for KEC 6.0. Note that, as in KEC 5.0, this estimate must be recalculated to number of fledglings by correcting for survival up to January. The weighted estimate for number of juveniles per family in wintering grounds is 0.894. Recalculation with assumed survival during the first six months (square root of first-year survival of 0.908 gives a survival estimate during the first six months of 0.953), gives an estimated fecundity of 0.938 fledglings per pair. Note that this estimate is for all pairs, including non-breeding pairs.

Brent goose

No new studies were found that reported parameters relevant to the Brent goose sCRM model.

Regarding demographic rates, one recent study by Ebbinge *et al.* (2025) provided limited quantitative fecundity components in relation to predation pressure (e.g. clutch size and percentage of juveniles in winter flocks) based on historical data (1990-2008) from Siberia. However, this estimate is not directly usable within the KEC population models. For this reason, it was decided to omit this from the current report.

Common shelduck

No new studies were found that reported information relevant to the common shelduck collision risk or population models.

Eurasian curlew

Bowgen *et al.* (2025) provide recent information on breeding success and migration routes for a UK breeding population of Eurasian curlew. The productivity estimate (0.62 fledglings/pair (*n* = 26) based on data collected in 2023 and 2024) is not directly compatible with the current KEC fecundity parameterisation and was therefore not used to update the population model. Since this estimate is not for successful breeding pairs, but for all breeding pairs, it cannot correctly be combined in a weighted estimate with the data sources currently used. We therefore use the same value as in KEC 5.0.

GPS tracking data from the same study (Bowgen *et al.* 2025), based on a sample size of 19 adult curlews, show that the tracked individuals migrated over the Irish Sea, not the North Sea. This suggests that there is limited direct relevance for migration-route assumptions, although the small and colony-specific sample size limits broader inference for the entire population. We therefore conclude that this study does not provide relevant information for KEC 6.0.

Bar-tailed godwit

No new studies were found that reported information relevant to the bar-tailed godwit collision risk or population models.

Regarding migratory routes, Conklin *et al.* (2025) report tracking results for three individuals. Given the low sample size, these data will not be used to adjust migratory routes in KEC 6.0. However, the approach used by the authors – namely combining tracking data with genetic assignment of non-breeding individuals to reassess flyway population structure – may be relevant as inspiration for future Wozep research on migration routes and population delineation of other migratory species. The authors also report a new estimate for the flyway population; this will be used to update the bar-tailed godwit flux estimate in KEC 6.0.

Red knot

No new studies were found that reported information relevant to the red knot collision risk or population models.

Black tern

No new studies were found that reported information relevant to the black tern collision risk or population models.

Common starling

The collision risk of migrating birds has been studied by comparing radar data with collision monitoring for three migration periods (Liedtke *et al.* 2025). Although radar measurements are not species-specific, this is highly relevant for common starling, being one of the most abundant migratory species. The calculated avoidance rates were high, being 0.9987 during the night and 0.9986 during the day respectively when turbines were operating. For KEC 5.0 (IJntema *et al.* 2025b), the assumed avoidance rate was 0.98 based on a general estimate by Maclean *et al.* (2009). This results in a fourteenfold higher estimated number of collisions. We suggest adjusting this avoidance rate to the estimate of 0.9986.

No new studies were found that reported information relevant to the common starling population models.

4 Conclusions and recommendations

The suggested parameter values for KEC 6.0 are reported in Table 4.1, Table 4.2 (both input parameters collision rate models) and Table 4.3 (population model parameters).

Recommendations:

Species selection
The selection of species included in KEC assessments should be re-evaluated with every periodic update. The species selection is currently being reevaluated (Heße & Melis 2025; Lamers *et al.* 2026).

Knowledge gaps critical seabird species
An ongoing project and report (Meerjarenaanpak kritische soorten wind op zee), currently being drafted for the Ministry of Economic Affairs (in Dutch, Ministerie van Economische Zaken; EZK), provides a targeted assessment of the ecological knowledge gaps for critical seabird species that require additional attention in relation to offshore wind energy development in the North Sea. A number of knowledge gaps raised by EZK and relevant experts are being inventoried and examined in relation to existing programmes, including the Wind op Zee Ecologisch Programma (Wozep), Monitoring, Onderzoek, Natuurversterking, Soortenbescherming (MONS), and Natuurversterking Noordzee (Nature Regeneration North Sea). The goal of this project is to determine which of the knowledge gaps are already being addressed and where key uncertainties remain. The result will be a proposal for complementary research and knowledge development that can support future offshore wind development decisions by reducing uncertainty in key areas, including KEC assessments. The report (expected completion date: September/October 2026) is intended to form a strategic bridge between existing research and the additional knowledge required to support timely, well-founded ecological assessments for critical species.

Input data collision rate models
Regarding input data for collision rate models in particular, some parameters such as flight speed are relatively well-known, while information on other parameters remains scarce. For instance, many species still lack empirical data on nocturnal activity and the values used originate from expert judgments from 20 years ago (Garthe & Hüppop 2004). Filling such knowledge gaps could be solved through dedicated research. However, assessing species-specific avoidance rates at the sensitivity level used in collision risk models seems almost impossible. Therefore, measuring actual collision rates in offshore wind farms, relative to species-specific activity levels, should be the highest priority in future research to improve collision risk models and consequently the input for population models. GPS-logger data might provide valuable information for the collision risk model parameters,

either directly, such as for flight speed and flight height distributions, or after post-processing and additional calculations i.e. nocturnal activity and fraction of time in flight.

Local seabird densities

One of the major inputs in the models is bird density for seabirds and the variation around these values. For six of the ten seabird species, Wageningen Marine Research developed new density maps for the Dutch Continental Plate, which included variation in density. This variation in densities leads to a better representation of the uncertainty in the predicted absolute casualty numbers. The better representation of uncertainty in casualties makes the population models and the test on the ALI threshold violations more valuable. Development of the same type of density maps for the other seabird species is therefore recommended.

While the Dutch seabird monitoring system is well-advanced, some areas of the North Sea are rarely surveyed, leading to large gaps in available bird distribution data in offshore waters. For this reason, van Donk *et al.* (2024) could only develop new maps for the Dutch Continental Plate. Ideally, similar density maps would be developed for international waters for all species. Currently, one of three different types of density maps is being used to calculate the cumulative number of victims, depending on the species. The subsequent test of ALI violation is dependent on a good representation of the uncertainty, and can hence not be performed at international scale (see IJntema *et al.* (2025b); (Soudijn *et al.* 2025)). However, in environmental impact assessments a proper test of cumulative scenarios is legally binding. Therefore, in particular for offshore wind farms planned along international borders, a cumulative impact assessment that violates the national level is essential and should be solved in the future.

Based on KEC 5.0 (IJntema *et al.* 2025b), the estimated relative impact (fraction mortality) at the international scale is significantly higher than at the national scale for three species: herring gull, great black-backed gull and Sandwich tern. To a lesser extent, this is also the case for northern gannet, arctic skua, black-legged kittiwake, little gull and lesser black-backed gull. For these species, it is of particular importance to gain more insight into the impacts at an international scale.

Data availability in the assessment of migratory birds

A key knowledge gap in the current KEC lies in the assessment of migratory birds. Our knowledge of migratory birds is often limited. Key parameters required in collision risk models, such as indications of the flight altitude (and therefore flights at rotor heights), avoidance rates and the geographic locations of migratory routes are not well known or highly variable:

- Flight altitude is often very variable and dependent on other factors. For instance, Lamers *et al.* (2026) discuss that flight heights of songbirds may be dependent on factors like wind, temperature, cloud cover, pressure or large scale weather patterns. A better understanding of when, why and under what conditions migratory birds cross the North Sea at what height is needed to better assess the impacts of offshore wind on migratory bird populations.

- Avoidance rates of migratory birds are often based of a single value from expert judgement (e.g. Woodward *et al.* (2023). In Woodward *et al.* (2023) the most used source for avoidance rates in the KEC, a confidence level in the avoidance is also given. For most of the migratory species in the KEC this confidence level in avoidance is set at "Very Low", indicating better understanding of avoidance in migratory birds is needed.
- For most of the migratory species in the KEC our knowledge of the migratory routes is severely limited. As a result, we often assume a uniform distribution of individuals along the width of the (southern and central) North Sea. More detailed information on migratory routes would improve the assessment.

In conclusion, future versions of the KEC would greatly benefit from a better understanding of the migratory birds crossing the North Sea. Current data is limited and parameter values used in collision rate models often must fall back to expert judgements or assumptions. We therefore recommend studies into the migratory behaviour, interacting with wind farms, of the KEC species. Which species exactly should be further investigated should also be subject to how the recommendations of Lamers *et al.* (2026) translate to the species list to be assessed in future KEC exercises.

Demographic data and population models

As pointed out by Schekkerman *et al.* (2025), one main knowledge gap is the limited availability of simultaneous collection of data on annual fecundity and survival in combination with food availability for one colony, over a sufficiently long time series. This would provide more insights into the dose-effect relationships of these demographic rates with food availability.

ALI methodology

In workshops with policy makers and regulators, participants expressed the need for further development of the Acceptable Levels of Impact (ALI) assessment framework (Hin *et al.* 2024). Specifically, the need to assess the predicted impacts to thresholds based on the Dutch legal concept of the "staat van instandhouding" (SvI) is desired. The SvI is a measure for conservation status relating for instance to an absolute minimum population size (known as "Gunstige Referentie Waarden" or "GRW"). Currently, a methodology matching this need is in the latest stage of the development (Hin *et al.* in prep). If this methodology and the adjustments in the population model scripts are finished within the KEC 6.0 timeframe, it will be applied in the KEC 6.0 assessments.

Table 4.1 *Recommended values for the parameters used in the collision rate models in KEC 6.0 for local seabirds. Green cells represent values changed since KEC 5.0.*

Species	**Body length** (m) (+-SD)	**Wingspan** (m) (+-SD)	**Flight speed** (m/s) (+-SD)	**Nocturnal Activity** (proportion of daytime activity)	**Avoidance Rate** (proportion of transits)	**Flight height distributions** (reference)	**Proportion in flight** (proportion of time)
Northern gannet	0.940 (0.022)	1.730 (0.030)	10.16 (2.13)	0.143 (0.102)	0.989 / 0.996[1]	(Johnston *et al.* 2014; Cleasby *et al.* 2015)	0.820
Arctic skua	0.435 (0.008)	1.175 (0.025)	13.80 (2.20)	0.05 (no SD)	0.995	(Johnston *et al.* 2014)	0.785
Great skua	0.560 (0.008)	1.360 (0.010)	14.90 (3.80)	0 (no SD)	0.995	(Johnston *et al.* 2014)	0.800
Black-legged kittiwake	0.390 (0.003)	1.080 (0.040)	10.51 (2.03)	0.413 (no SD)	0.9989	(Johnston *et al.* 2014; Skov *et al.* 2018)	0.4861
Little gull	0.260 (0.003)	0.775 (0.008)	7.41 (0.85)	0.25 (no SD)	0.9951	(Johnston *et al.* 2014)	0.6
Lesser black-backed gull	0.580 (0.020)	1.425 (0.025)	10.39 (2.77)	0.428 (no SD)	0.9951	(Johnston *et al.* 2014; Gyimesi *et al.* 2017a)	0.3913
Herring gull	0.600 (0.015)	1.440 (0.020)	9.93 (3.63)	0.013 (no SD)	0.9948[2]	(Johnston *et al.* 2014; Gyimesi *et al.* 2017a)	0.3
Great black-backed gull	0.710 (0.023)	1.580 (0.025)	10.11 (3.59)	0.25 (no SD)	0.9932	(Johnston *et al.* 2014; Gyimesi *et al.* 2017a)	0.34
Common tern	0.330 (0.007)	0.875 (0.035)	9.60 (3.30)	0 (no SD)	0.99	(Johnston *et al.* 2014)	0.75
Sandwich tern	0.385 (0.008)	1.000 (0.020)	9.33 (3.53)	0.05 (no SD)	0.9840	(Johnston *et al.* 2014; Perrow *et al.* 2017; Collier *et al.* 2020)	0.961

[1]Values represent recommended values for breeding and non-breeding gannets

[2]while a new value was used in the calculation of the final value, this did not meaningfully change the estimate

Table 4.2 Recommended values for the parameters used in the collision rate models in KEC 6.0 for migratory birds. Nocturnal activity and proportion of time in flight are not relevant for migratory birds and are therefore not reported here. Green cells represent values changed since KEC 5.0.

Species	**Body length** (m) (+-SD)	**Wingspan** (m) (+-SD)	**Flight speed** (m/s) (+-SD)	**Avoidance Rate** (proportion of transits)	**Flight height distributions** (reference) / **Proportion at rotor height** (proportion of time)
Bewick's swan	1.21 (0.02)	1.96 (0.052)	18.3 (4.3)	0.9885 (0.00091)	(Gyimesi *et al.* 2017b)
Brent goose	0.585 (0.008)	1.15 (0.0167)	17.9 (6.1)	0.9998 (0.00001)	(Gyimesi *et al.* 2017b)
Common shelduck	0.625 (0.015)	1.215 (0.038)	18.21 (4.32)	0.9851 (0.00088)	0.5
Eurasian curlew	0.55 (0.167)	0.9 (0.333)	16.5 (6.105)	0.9996 (0.00002)	1
Bar-tailed godwit	0.38 (0)	0.75 (0)	18.3 (2.1)	0.9996 (0.00002)	1
Red knot	0.24 (0.0033)	0.59 (0.0067)	24.6 (4.6)	0.9996 (0.00002)	1
Black tern	0.23 (0.0033)	0.66 (0.0067)	7.1 (0.64)	0.98 (0)	0.07
Common starling	0.215 (0)	0.395 (0.008)	17 (3.1)	0.9986 (no SD)	0.5

Table 4.3 Recommended values for the parameters used in the population models in KEC 6.0 for local seabirds and migratory birds. For Northern gannet and Sandwich tern, we refer to values defined by WMR for KEC 6.0 Habitat loss. Green cells represent values changed since KEC 5.0.

Species	**Juvenile Survival** (+-SD)	**Immature survival** (+-SD)	**Adult Survival** (+-SD)	**Fecundity** (fledglings/breeding pair) (+-SD)	**Incidence of missed breeding** (+-SD)	**Life year of first breeding attempt** (age+1)
Northern gannet	0.48 (0.085)	*[1]	0.94 (0.026)	0.64 (0.097)	0.05 (0.13)	5 (4 years old)
Arctic skua	0.5506 (0.14)	0.77 (0.05)	0.9011 (0.05)	0.8448 (0.4945)	0.25 (0.05)	5 (4 years old)
Great skua	0.97 (0.05)	0.7967 (0.05)	0.8879 (0.055)	0.6387 (0.2914)	0.089 (0.01)	7 (6 years old)
Black-legged kittiwake	0.61 (0.1)	0.78 (0.07)	0.83 (0.04)	0.72 (0.19)	0.24 (0.14)	5 (4 years old)
Little gull	0.738 (0.02)	0.738 (0.02)	0.827 (0.02)	0.61 (0.2)	0.1 (0.05)	5 (4 years old)
Lesser black-backed gull	0.67 (0.15)	0.87 (0.03)	0.89 (0.03)	0.51 (0.31)	0.4242 (0.0808)	6 (5 years old)
Herring gull	0.59 (0.08)	0.83 (0.06)	0.84 (0.06)	0.73 (0.38)	0.35 (0.05)	6 (5 years old)
Great black-backed gull	0.48 (0.13)	0.78 (0.02)	0.86 (0.05)	1.41 (0.47)	0.1 (0.05)	6 (5 years old)
Common tern	0.68 (0.05)	0.86 (0.05)	0.88 (0.03)	0.52 (0.19)	0.08 (0.03)	4 (3 years old)
Sandwich tern	0.36 (0.092)	0.637 (0.068)	0.87 (0.121)	0.3*0.36*[4] / 0.36 (0.085)	0.1 (0.125)	3 (2 years old)
Bewick's swan	0.908 (0.05)	0.936 (0.05)	0.8504 (0.05)	0.938 (0.1)	*[2]	3 (2 years old)
Brent goose	0.5698 (0.1580)	0.8488 (0.05)	0.8521 (0.05)	0.5564 (0.1)	*[2]	3 (2 years old)
Common shelduck	0.25 (0.05)	0.67 (0.05)	0.8691 (0.05)	3.7 (0.1)	0.35 (0.05)	3 (2 years old)
Eurasian curlew	0.4943 (0.05)	0.7777 (0.05)	0.9131 (0.05)	0.2553 (0.1)	0.1 (0.05)	3 (2 years old)
Bar-tailed godwit	0.57 (0.05)	0.8554 (0.015)	0.8554 (0.015)	0.8 (0.1)	0.1 (0.05)	3 (2 years old)
Red knot	0.78 (0.03)	0.8418 (0.01)	0.8418 (0.01)	0.2831 (0.01)	0.1 (0.05)	3 (2 years old)
Black tern	0.595 (0.05)	0.595 (0.05)	0.8584 (0.05)	0.9212 (0.1)	0.8 (0.05; 3-year-	3/4 (4/5 years old)

					olds) / 0.1 (0.05; >3-year - olds)	
Common starling	0.3328 (0.034)	*[3]	0.6366 (0.151)	3.9538 (0.1)	0.01 (0.001)	2 (1 years old)

*[1]: For Northern gannet, immature survival was age-specific, with a survival of 0.82 (sd 0.039) in the second year, 0.88 (sd 0.029) in the third year, and 0.89 (sd 0.030) in the fourth year.

*[2]: for Brent goose and Bewick's Swan, the incidence of missed breeding is included in the fecundity estimate.

*[3]: Common starlings are mature after 1 year, hence no immature life stage is present

*[4]: fecundity in the last two years of immature Sandwich terns is assumed to be 30% of adult individuals

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Appendix I: KEC methodology in more detail

4.1 Collision rate model

Collision rate models are widely used to assess the impacts of offshore wind farms on birds. Previous KEC assessments have incorporated the deterministic SNH collision risk model (Band 2012) and the stochastic sCRM (Masden 2015; Masden *et al.* 2015), while for KEC 5.0 the stochLAB collision risk model was used (Caneco *et al.* 2022). These collision rate models follow the same basic principle of calculating the collision risk of a specific bird species with any turbine in a specific wind farm and then multiplying this by the number of transits in a given month and the number of turbines, and summing this across an entire year. The collision rate model differentiates between seabirds (basic model for birds that use the area locally) and migratory birds (migrant model for birds passing through the area on their seasonal migration). For seabirds, we use the model's 'extended' option, which accounts for the distribution of bird flight heights at collision risk height.

Data requirements for the CRM include species-specific data as well as wind farm-specific data. A complete overview of required data is provided in IJntema *et al.* (2025b).

Bird characteristics

Several types of bird characteristics are used as input for the CRM. Species-specific bird characteristics for use in the collision rate model are compiled through literature reviews. These data include biometric data such as body length and wingspan, and characteristics such as flight speed, nocturnal activity, percentage in flight and avoidance rate. Here, we describe the main data requirements regarding bird characteristics.

Bird abundance and distribution

For local seabirds, the KEC approach is to use external bird density maps of geographically explicit presence of bird species in the North Sea. These data can be obtained from a variety of sources, but in the KEC we preferably use the updated density maps provided by Wageningen Marine Research (hereafter: WMR) (van Donk *et al.* 2024). These van Donk 2026 maps are explicitly developed for KEC 6.0, using the same approach as for KEC 5.0 (IJntema *et al.* 2025b).

Note that WMR updated the density maps only for the Dutch part of the North Sea. Therefore, the maps by Waggitt *et al.* (2020) are used for the international waters of the North Sea. Although these density maps are being further developed within the ongoing project POSEIDON by Natural England, these only cover the UK waters, and hence do not cover the range of our international scenario. For some species, both the van Donk *et al.* (2024) and Waggitt *et al.* (2020) maps are not available; in this case, WMR provided density maps using the approach as applied in KEC 4.0 (inverse-distance-weighing: IDW, originating from the KEC 1.0; Leopold *et al.* (2015)), updated using the most recent survey data (see for the different sources per species). These densities of birds-at-sea are then corrected based on the proportion of birds in flight to provide aerial bird densities required for the collision rate model assessment.

As migratory birds use the southern North Sea for passing through instead of using the area locally, the KEC approach differs from seabirds. For migratory birds, fluxes are defined, generally based on assumptions about the width of the migration corridor across (parts of the) the North Sea, and the size of the migrating population. In the absence of data on the specific migration routes of a species, the width of the migration corridor is assumed to be the distance between the southern tip of Norway and the border between Belgium and France, as the starting point of the Channel, which is 750 km. For example, if 85 million birds pass over a length of 750 km length, the flux is calculated as approximately 114,000 birds/km. Population sizes of migratory bird species are based on Brinkman and Schekkerman (2024) or otherwise on estimates by Leopold *et al.* (2015) updated by population trends published by BirdLife International (2024). For the Bewick's swan and brent goose, specific migration routes across the North Sea were available (Gyimesi *et al.* 2017b) based GPS logger studies. Furthermore, for the black tern certain areas of the North Sea could be defined that are used during migration (Potiek *et al.* 2019b). Based on these sources, fluxes were further refined to distinguish different migration intensities in the different wind farms, based on the geographical location of these wind farms relative to the migration routes. In addition, tracking studies on common shelduck and Eurasian curlew have given further insights into their migration routes (Green *et al.* 2019b; Green *et al.* 2019a; Jiguet *et al.* 2021; Pederson *et al.* 2022; Schwemmer *et al.* 2022; Schwemmer *et al.* 2023). Within the knowledge base update for KEC 6.0, for most migratory species no new data on migratory routes were found. An exception is bar-tailed godwit, for which Conklin *et al.* (2025) report tracking results for three individuals. Given the low number of individuals, this is not directly useful for adjusting migratory routes. The authors also report a new estimate for the flyway population. This estimate will be taken into consideration for KEC 6.0. In addition, in the UK 19 adult curlews were fitted with GPS tracking devices (Bowgen *et al.* 2025). These individuals all used the Irish Sea, not the North Sea. This suggests that individuals from this specific colony preferably use the Irish Sea instead of the North Sea, although the number of individuals is relatively low. Other than that, this study does not provide relevant information for KEC 6.0.

Flight height

Species-specific data on flight height are obtained from published data or from GPS data. For seabirds, a flight height distribution is used within KEC. For most migratory landbird species, detailed data on flight height distributions are not available. In these cases, a proportion at rotor height is used. In a separate study (Madden 2025), different methods were tested to convert raw GPS measurements to smoothed flight height distributions that can be used in collision rate models.

Avoidance rate

The numbers of crossings each month are calculated based on monthly densities (seabirds) or flux (migratory birds), flight height distribution (sea birds) or proportion at rotor height (migratory birds) and flight speed. The following important step is to account for avoidance, i.e. any evasive action taken by a bird to avoid the wind farm, individual turbines and the rotors. This requires species-specific avoidance rates.

Note that for northern gannet, nocturnal activity and avoidance rate are assumed to vary between breeding and non-breeding birds (cf. Collier *et al.* (2022) and Leemans and Gyimesi (2022)). Hence, for wind farms that are located within the foraging range of breeding colonies, nocturnal activity and avoidance rate are adjusted for the breeding season.

Turbine / wind farm characteristics
In addition to bird-specific data, collision risk is affected by turbine data. This encompasses information such as rotor diameter, maximum chord, pitch and rotation speed.

4.2 Wind farm scenarios

New wind farm scenarios were supplied by RWS.
Since KEC 5.0, the inclusion of current wind farms in the scenarios has been reconsidered (IJntema *et al.* 2025a). Based on the demographic data used, the impact of current wind farms cannot be assumed to be discounted. Hence, as with KEC 5.0, these current wind farms are included in the KEC 6.0 scenarios.

4.3 Population models

Population models are used within the KEC approach to project the future population trend. By doing this for the null scenario as well as the impacted scenario, the effect of the impact can be assessed at species population level. Within KEC, stage-structured matrix population models are used (Caswell 2001). These population models are described by (Potiek *et al.* 2019a; Potiek *et al.* 2022).

In order to construct population models, species-specific demographic data are required. Due to the use of stage-specific population models, demographic rates are life stage-specific as well. Depending on the species, this includes an adult stage and one or more sub-adult stages. For the impacted scenarios, survival rate is adjusted based on estimated additional mortality. Using a literature review, we collected input values for each of the life stages for the following demographic rates: survival rates, fecundity and probability of breeding (accounting for non-breeding adults, floaters). These are used as input for the population models constructed in earlier projects, which are part of the R package KEC4popmodels (Hin 2021).

4.4 Test of impact in relation to set thresholds

The outcomes of the population models are assessed in relation to thresholds based on the current law and regulations as well as ecological insights.