JNCC Report 732

Review of data used to calculate avoidance rates for collision risk modelling of seabirds

Luke Ozsanlav-Harris, Richard Inger & Richard Sherley

March 2023

ISSN 0963 8091

JNCC's report series serves as a record of the work undertaken or commissioned by JNCC. The series also helps us to share, and promote the use of, our work and to develop future collaborations.

For further information on JNCC's report series please contact:
Joint Nature Conservation Committee
Quay House
2 East Station Road
Fletton Quays
Peterborough
PE2 8YY
https://jncc.gov.uk/
Communications@jncc.gov.uk

This report was produced for JNCC under an external contract, by Luke Ozsanlav-Harris, Richard Inger & Richard Sherley (University of Exeter), for/under the Framework Agreement F21-0708-1581(14). The report and underlying analysis were largely undertaken in 2022 and any references to Ozsanlav-Harris *et al*. (2022) refer to this current report, which was published in 2023.

This report should be cited as:
Luke Ozsanlav-Harris[1], Richard Inger[1] & Richard Sherley[1]. March 2022. Review of data used to calculate avoidance rates for collision risk modelling of seabirds. *JNCC Report 732 (Research & review report)*, JNCC, Peterborough, ISSN 0963-8091.
https://hub.jncc.gov.uk/assets/de5903fe-81c5-4a37-a5bc-387cf704924d

Author affiliation:
[1]*Centre for Ecology and Conservation, College of Life and Environmental Sciences, University of Exeter, Cornwall Campus, Penryn, Cornwall TR10 9EZ, UK*

Acknowledgments:
Thanks to Dr Aonghais Cook (BTO) for providing copies of all relevant reports and Dr Julie Black (JNCC) for chairing the scientific steering group. We thank all members of the scientific steering group for their helpful and insightful comments; Aly McCluskie (RSPB), Glen Tyler (NatureScot), Matthew Murphy (Natural Resources Wales), Tom Evans (Marine Scotland Science), Tim Frayling (Natural England), Emma Ahart (Ørsted), Robert Iredale (RHDHV).

Summary

Collision risk modelling is a valuable tool to assess the impact of wind farms on seabird populations. The mortality estimates generated from collision risk modelling are sensitive to some key parameters including the avoidance rate. The avoidance rate is typically thought of as quantifying active avoidance behaviour in response to wind farms. The purpose of this report was to conduct a review of the avoidance rates recommended in Cook (2021). The instigation for this review was a jackknife analysis, carried out by MacArthur Green (Trinder 2021), which found a single site (Kleine Pathoweg) was highly influential on the avoidance rates recommended by Cook (2021). We reviewed each dataset used by Cook (2021) and assessed their suitability for calculation of avoidance rates. Following consultation with the JNCC scientific steering group, the dataset used in Cook (2021) was refined to address any spatiotemporal mismatches between the input parameters. Alternatively, data from whole sites could be removed if they were deemed inappropriate. Avoidance rates were then recalculated using two variants of the Band (2012) collision risk model and their stochastic implementations (Mc Gregor *et al*. 2018) that each reflect various levels of realism, following the methodology outlined in Cook (2021). This led to an increase in the avoidance rates calculated for all gulls, large gulls, and all gulls & terns across all models compared to those provided in Cook (2021). Species-specific avoidance rates altered negligibly in comparison to Cook (2021) as much of the data altered related to grouped species values. These findings increase the avoidance rate of all gull species group by up to 3.0% (0.926 to 0.953), and the large gull species group by up to 5.6% (0.910 to 0.961) depending on the model used and have implications for the predicted level of seabird mortality in environmental impact assessments.

Contents

1 Introduction

1.1 Background

The use of wind energy will be vital to reduce CO_2 emissions and achieve UK government targets. However, the use of wind farms can have negative ecological impacts, such as the direct mortality of birds and bats, that need to be assessed (Barthelmie & Pryor 2021). Direct mortality of seabirds, is especially pertinent due to the increase in offshore wind farms (Higgins & Foley 2014) and the need to ensure the long-term viability of seabird populations whilst switching to renewable energy sources.

Collision risk modelling is an integral tool used to assess the impact of wind farms on seabird populations (Masden & Cook 2016). These models are sensitive to some key parameters including flight heights, flight speeds, bird densities and the avoidance rate (Equation 1), (Black *et al.* 2019). There is therefore a need to ensure that the avoidance rate is as accurate as possible and that it reflects the true behaviour of seabirds. The avoidance rate is calculated by comparing the number of birds that collide with turbines, corrected for imperfect detection, with the number of birds predicted to collide in the absence of any avoidance rate (Cook *et al.* 2014). Hence an avoidance rate of 0.99 is indicative of high avoidance/low mortality rates whilst 0.01 denotes low avoidance/high mortality rates. These avoidance rates are typically calculated as specific rates for key species and species groups to allow behaviour to differ on a species-level.

Predicting the number of collisions in the absence of avoidance also requires several input parameters (Equation 2). These include the specifications of each turbine, the whole turbine array, and a series of species-specific morphological measurements that are used to calculate the probability that a bird collides with a rotor blade if it passes through the rotor sweep zone (*Pcol*). These typically have low measurement error and avoidance rates are robust to at least a 10% error in their measurement (Cook 2021). There are two other key input parameters: the *total flux* (the total number of birds passing through the turbine array during the study period) and the *proportion passing through the rotor sweep zone* (proportion of the total flux passing through the rotor sweep zone during the study period). Avoidance rates are less robust to a 10% measurement error in these two input parameters (Cook 2021).

$$Avoidance\ rate = 1 - \left(\frac{Number\ of\ observed\ collisions}{Predicted\ collisions}\right)$$

Equation 1

$$Predicted\ collisions = Pcol\ \times total\ flux\ \times proportion\ passing\ through\ sweep\ zone$$

Equation 2

The data available, and used in Cook (2021), relates to micro- and meso-avoidance (described in Cook *et al.* 2014) but not macro-avoidance. Therefore, this report presents wind farm avoidance rates, which capture both micro- and meso-avoidance. For most key species it is expected that this captures total avoidance, but for some species (e.g. northern gannet (Dierschke *et al.* 2016)) that exhibit macro-avoidance there will be a need for macro-avoidance to be either added to the within-wind farm avoidance rates presented here, or captured at another stage within the collision risk modelling process. This is outside of the scope of this project but needs to be considered when using the avoidance rates recommended.

1.2 Project Rationale

Cook (2021) conducted a series of analyses with four model variants widely used to calculate avoidance rates, basic Band, extended Band, basic stochastic collision risk model, extended stochastic collision risk model (Band 2012; McGregor *et al.* 2018), a helpful summary of each of these models can be found in Cook (2021, pp. 11–12). The key differences between these models are in how *Pcol* and the *proportion passing through the rotor sweep zone* are calculated and, whether measurement error in the input parameters are incorporated into the 95% confidence interval of the avoidance rate estimate. Avoidance rates were calculated using data from 18 onshore wind farms and one offshore wind farm (Figure 1) with rates obtained for key species and species groups. A review and appraisal of Cook (2021) was subsequently carried out by an environmental consultant, MacArthur Green (Trinder 2021). Trinder (2021) carried out a jackknife analysis to assess whether any individual wind farm was having an undue influence on avoidance rates. They found one wind farm, Kleine Pathoweg, was highly influential on the avoidance rates for all gulls and large gulls. Given the sensitivity of collision risk models to avoidance rates this review of the data included within Cook 2021 was commissioned to fully understand decisions made about parameters extracted from wind farm monitoring reports, and to ensure that avoidance rates are calculated based on most the appropriate input data.

1.3 Project Aims

The aims of this study were to review all reports that contributed data to the avoidance rates in Cook (2021). This necessitated an assessment of the data collection protocol in each report and cross referencing that the correct values were derived from each report by Cook (2021). After guidance from the JNCC scientific steering group, data from whole reports could be added/removed and/or specific values used in Cook (2021) refined if appropriate. Thereafter, avoidance rates would be recalculated using the basic Band, extended Band, basic stochastic collision risk and extended stochastic collision risk models (Cook *et al.* 2014; Cook 2021) for the following species and species groups:

- Black-legged kittiwake *Rissa tridactyla*
- Black-headed gull *Chroicocephalus ridibundus*
- Lesser black-backed gull *Larus fuscus*
- Great black-backed gull *Larus marinus*
- Herring gull *Larus argentatus*
- Sandwich tern *Thalasseus sandvicensis*
- Small gulls
  - Including Black-legged kittiwake, Black-headed gull and Common gull *Larus canus*
- Large gulls
  - Including Herring gull, Lesser black-backed gull, Great black-backed gull, Yellow-legged gull *Larus michahellis*, Caspian gull *Larus cachinnans*, Iceland gull *Larus glaucoides*, Glaucous gull *Larus hyperboreus* and large gulls not identified to species level
- All gulls
  - All above gull species and gulls not identified to species or group level
- All terns
  - Including Sandwich tern, Little tern *Sternula albifrons* and Common tern *Sterna hirundo*)
- All gulls and tern
  - All of the above species

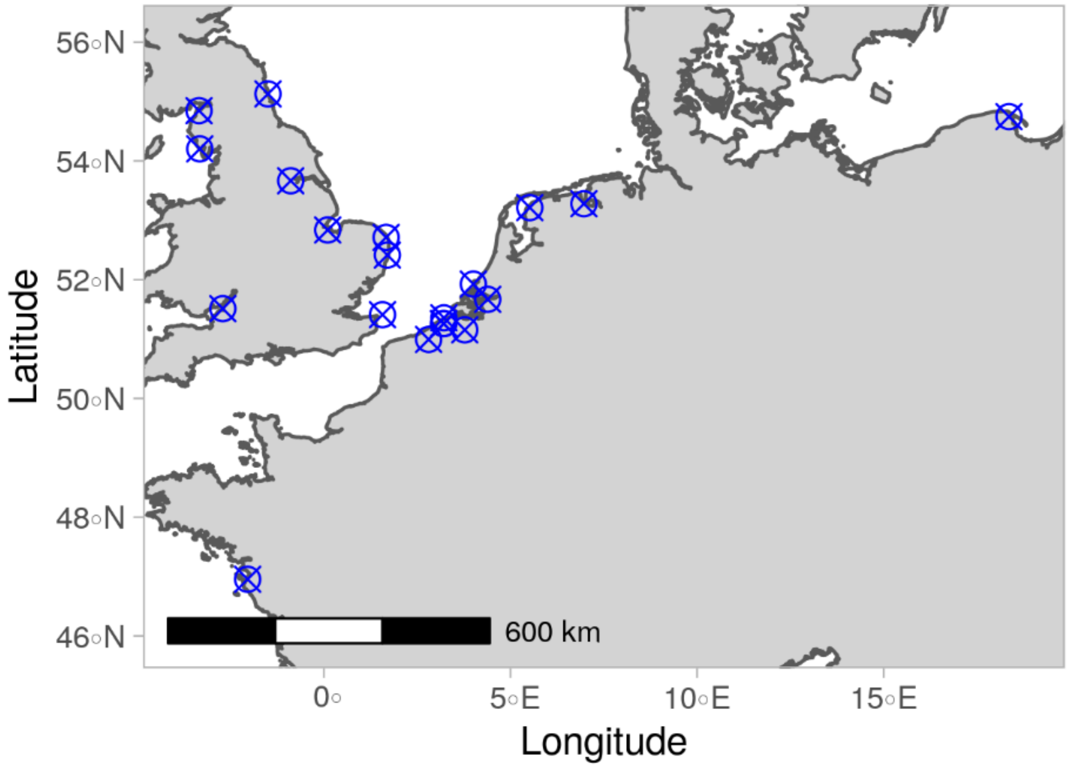

Figure 1. Map depicting the 19 wind farms from which data were available to calculate avoidance rates.

2 Methods

2.1 Data reviewed

All reports provided as references in table 2 from Cook (2021, p. 9) were reviewed. One additional report was reviewed, (Everaert 2003), to allow full assessment of the data from Zeebrugge and Boudwijnkanaal. A full list of the reports reviewed is available in Appendix 1.

2.2 Report review procedure

Five criteria, detailing how data were collected and collated, were used to assess the suitability of each report for the calculation of avoidance rates:

1. Were there no/only negligible spatiotemporal mismatches between the collection of passage rate data and carcass searches?
2. Were there no/only negligible spatiotemporal mismatches between the collection of passage rate data and observations of the proportion of birds flying at the height of the rotor sweep zone (proportion at rotor height)?
3. Did passage rate data, carcass search data, and proportion at rotor height data all have the same species groupings, if the data was grouped at all?
4. Were suitable corrections factors used to correct the number of carcasses for imperfect detection?
5. Were there no/only negligible spatiotemporal mismatches between the carcass searches and collection of correction factor data?

If the report satisfied all the criteria above and was approved by the scientific steering group, the data therein were included in subsequent analyses unaltered. If a report did not satisfy one of the above criteria, then the data derived from that report could be removed completely from subsequent analysis or if more suitable values were available then those were used instead, given approval from the scientific steering group.

Several key terms from above are described below:

- **Passage rate:** The number of birds passing through the turbine array per hour. This is typically collected for the entire turbine array and representative samples are periodically collected to calculate a mean passage rate over the entire study period.
- **Carcass searches:** Searches conducted for the carcass of collision victims. These can be conducted over all or a proportion of the turbines within an array and the total length of the monitoring period can differ to that of the passage rate measurements.
- **Proportion at rotor height:** the proportion of birds passing through the turbine array that fly at the same height as the sweep zone of the rotor blades. This is generally collected concurrently with the passage data.
- **Correction factor**: The number of carcasses found is multiplied by these factors to correct for the imperfect detection of carcasses. These include corrections for predation, search efficiency and the proportion of the search area accessible. These can be calculated as average values across the whole array or be specific to individual turbines.

2.3 Models used to calculate avoidance rates

The basic Band, extended Band, basic stochastic collision risk and extended stochastic collision risk models were used to calculate avoidance rates. We followed the approach outlined in Cook (2021) and Cook *et al.* (2014) for each of these models. We provide a summary of each model, but a more thorough explanation is available in Cook (2021, pp. 11–12)).

2.3.1 Basic Band model

1. The number of birds passing through the wind farm per hour during the day is calculated (*passage rate)*. This is derived from direct measurements in each report.
2. The total number of birds passing through the wind farm during the daytime is calculated by multiplying the passage rate by the total number of daylight hours (sunrise to sunset) during the study period. The total number of birds passing through the wind farm at night (sunset to sunrise) is calculated by multiplying the passage rate by the number of hours of night and a nocturnal correction factor (0.25 for gulls and 0 for terns). The total passage during the day and night are summed together to give the *total flux*.
3. The *total flux* is multiplied by a site-specific estimate of the proportion of birds flying within the height of the rotor sweep zone (*proportion of birds at rotor height*).
4. The proportion of the *total flux* at rotor height is multiplied by the proportion of the survey frontal area at rotor height that is taken up by the rotor sweep zones. This gives the number of birds passing through the rotor sweep zone during the entire study period (*flux through sweep zone*).
5. The predicted number of collisions in the absence of avoidance (*predicted collisions*) is calculated by multiplying the *flux through sweep zone* by the probability of collision if a bird passes through the rotor sweep zone (*Pcol*), estimated following Band (2012) (Equation 3). *Pcol* accounts for the dimensions and rotor speed of the turbine and size and flight speed of the bird.
6. Avoidance rates are calculated from the *predicted collisions* and the observed number of carcasses using Equation 1. The delta method (Powell 2007) is used to estimate standard deviations and 95% confidence intervals, reflecting the variability in avoidance rates between sites and years.

$$\begin{aligned}
&Predicted\ collisions \\
&\quad = Pcol \\
&\quad \times \big((passage\ rate\ \times N\ hours\ daylight) \\
&\quad + (passage\ rate\ \times N\ hours\ night\ \times nocturnal\ correction)\big) \\
&\quad \times proportion\ of\ birds\ at\ rotor\ height \\
&\quad \times \left(\frac{N\ turbines\ \times (\pi\ \times (rotor\ radius)^2)}{width\ survey\ window\ \times (rotor\ radius\ \times 2)}\right)
\end{aligned}$$

Equation 3

2.3.2 Extended Band model

The extended band model is similar to the basic Band model but in Equation 3 the *proportion of birds at rotor height* is removed and *Pcol* is replaced with a collision integral which calculates both *Pcol* and *proportion of birds at rotor height*. Generic species-specific flight height distributions, presented in (Johnston *et al.* 2014), are accounted for within the collision integral (Band 2012). The collision integral calculates the *flux through sweep zone* using these flight height distributions and allows the probability of collision to change along the radius of the rotor sweep zone. This is important as at the periphery of the rotor sweep zone a bird and rotor blade are less likely to occupy the same point in space and time compared to nearer the centre of the rotor sweep zone.

2.3.3 Basic stochastic collision risk model

In addition to reflecting variability between sites and years, the basic stochastic collision risk model avoidance rate also reflects variability in many of the input parameters. It achieves this using a Monte Carlo simulation approach where avoidance rates are calculated over 1,000 iterations. Within each iteration the basic Band model is run, and avoidance rate calculated but random values for turbine rotor speed and pitch, bird flight speed, wingspan and length are drawn from a normal distribution centred on the mean value for each parameter, and hourly passage rates drawn from a Poisson distribution centred on the mean hourly passage rate. From these 1,000 avoidance rate values, it is then possible to extract the median, standard deviation and 95% confidence intervals.

2.3.4 Extended stochastic collision risk model

The approach for estimating avoidance rates for the extended stochastic collision risk model is broadly similar to those calculated with the basic stochastic collision risk model. The key difference is that each iteration runs the extended Band model instead of the basic Band model. During each iteration of the extended Band model one of 200 random realisations of the flight height distributions presented in (Johnston *et al.* 2014) are used to calculate the predicted collisions. Each random realisation has a slightly different shape, reflecting different proportions of birds at rotor height. This allows error in the proportion of birds at rotor height to be incorporated.

2.4 Sensitivity analysis

2.4.1 Sensitivity analysis 1: Amalgamating Zeebrugge and Slufterdam & Distridam

At Zeebrugge (Everaert 2003; Everaert & Stienen 2007) and Slufterdam & Distridam (Prinsen *et al.* 2013) the number of carcasses and passage rate are provided for each turbine within the array. This is different to all other sites where the number of carcasses and passage rate are provided for the whole array. We propose amalgamating the datasets for

Zeebrugge and Slufterdam & Distridam so that they follow the format of all other sites, with the number of carcasses and passage rate for the whole array for each year. After the amalgamation avoidance rates are recalculated using the basic Band, extended Band, and basic stochastic collision risk models.

2.4.2 Sensitivity analysis 2: Nocturnal passage rate correction

At Boudwijnkanaal and Kleine Pathoweg the nocturnal passage rate of birds was measured directly using nocturnal vision goggles (Everaert 2008). Everaert (2008) found that the passage rate four hours after sunset and two hours before sunrise of gulls at both sites was almost negligible, see Everaert (2008, p. 50, p. 66). The daytime passage rate is provided for two hours before sunrise and four hours after sunset and therefore includes significant periods of twilight that would normally be classified as nocturnal passage. There is no data as to the relative passage rate throughout the day but since the passage during the twilight periods was already incorporated then it was suggested to not also include a nocturnal correction. Nocturnal activity of 25% of that during daylight is generally assumed for gulls (as a precautionary value in the absence of empirical data). To understand what effect this discrepancy would have on avoidance rates we altered the nocturnal correction factor for gulls at Boudwijnkanaal and Kleine Pathoweg to 0. We then recalculated avoidance rates using the basic Band, extended Band and basic stochastic collision risk models and compared them to the rates calculated using the datasets provided in Appendix 1.

3 Results

3.1 General limitations in calculating avoidance rates

As part of this review, several limitations and pitfalls were identified in the calculation of avoidance rates, in addition to those where sensitivity analysis have been conducted (see section 2.4). These were discussed with the scientific steering group, but it was decided that sensitivity analyses were not required to assess their influence on avoidance rates. Instead, a brief description of each limitation is provided below.

3.1.1 Predicting collisions in turbine arrays versus linear arrangements

When predicting the number of collisions in the absence of avoidance (*predicted collisions*) all sites are presumed to have a linear arrangement of turbines, whereby the total number of turbines is placed linearly within the width of the survey window. This linear arrangement is then used to calculate the flux within the rotor sweep zone (*flux through sweep zone*), from which the predicted number of collisions in the absence of avoidance behaviour is calculated. This approach neglects to account for the 3D arrangement of turbine arrays. As birds travel through a 3D turbine array a portion of them will collide and die at each row meaning that at subsequent rows the number of birds will be reduced and the number of birds “at risk” of collision is reduced. Since the predicted number of collisions does not take into account avoidance behaviour the number of birds colliding at each row can be significant. For a small number of turbine rows not accounting for this effect will have negligible implications but in larger offshore arrays the predicted number of collisions could be overestimated. This overestimation causes avoidance rates to increase and subsequent mortality calculations to decrease. In both Band and stochastic collision risk models a large array correction factor is frequently used but it unclear whether this fully compensates for the increased avoidance rate due to an overestimation of the predicted number of collisions in the absence of avoidance behaviour.

3.1.2 Passage rate buffer windows

Passage rates are often measured within a buffer around the wind farm. Some studies choose to set this buffer to 0 m and count birds only within the bounds of the turbine array, but others use a buffer of up to 1,000 m (Percival 2015), around the turbine array and count birds passing through the array itself and the buffer. For the width of this buffer to have minimal impacts on avoidance rates, any increases in survey frontal area caused by a wider buffer must scale proportionally with the passage rate. For example, if the survey area doubles due to a wider buffer, then the passage rate will also have to double to keep avoidance rates constant. In many cases this is violated, see figure 1 in Desholm and Kahlert (2005) and figure 18 in Percival (2015), as the passage rate increases at a faster rate than survey frontal area as buffer width increases. This is often due to an aggregation of birds immediately outside the footprint of the turbine array. However, given the available data little that can be done to explore or to negate, this influence. It was agreed that a maximum buffer of 1 km was acceptable given the wider context of wind farm scale and distance between turbines.

3.1.3 Calculating avoidance rates from multiple sites

Data from multiple sites must be incorporated to calculate avoidance rates for all species and species groups. The current approach is to add together all the predicted number of collisions in the absence of avoidance behaviour for each site (where we have an appropriate species level estimate) and then add the number of collision victims for each site, corrected for imperfect detection. Avoidance rates can then be calculated using Equation 1. This approach risks avoidance rates being unduly influenced by sites that have a large number of predicted collisions; such large collision numbers may be due to genuine variability across sites and would increase our certainty in site-specific avoidance rates. An alternative approach would be to first calculate the avoidance rate for each site for a given species or species group and then calculate a weighted mean of these avoidance rates, weighting by the total flux for each site. There were extensive discussions around these two approaches as part of the Cook *et al.* (2014) avoidance rate analysis, and it was felt that there was currently insufficient justification to move away from the Cook *et al*. (2014), approach.

3.2 Refinements to the datasets

After reviewing each report and consulting with the scientific steering group several alterations were made to the dataset used for calculating avoidance rates, compared to the dataset used in (Cook 2021). All alterations to the dataset can be found in Table 1 and an expanded version of the table in the accompanying Excel spreadsheet entitled “Changes made to dataset in Cook (2021)” (Annex 1).

3.2.1 Removal of entire site datasets

One site-year was removed from subsequent analysis. This was data collected at Gneizdzewo during autumn 2011 (Zieliński *et al*. 2011). The reason for this exclusion was due to two carcasses being found by search dogs that were not reported to species or assigned to a species grouping (see figure 8 of Zieliński *et al*. 2011, p. 27). Since these two carcasses could not be attributed to any species or species group it was deemed that avoidance rates calculated from this site-year would be inaccurate.

3.2.2 Addition of entire site datasets

One site-year was added to subsequent analysis. This was data derived from (Percival *et al.* 2018b) which was collected at Goole Fields I during September 2017 to March 2018. There were no problems with the data provided in the report when assessed against the key criteria in section 2.2. This dataset was perhaps not included originally in Cook (2021) as an almost identical study had been conducted at Goole Fields II, an adjacent wind farm (Percival *et al*. 2018a). However, it was not clear within the reports that the two separate studies were conducted on adjacent sites.

3.2.3 Alterations to specific site values

Numerous alterations were made to specific values in the dataset provided in Cook (2021), with alternative values being extracted directly from the text or tables of the reports. In the case of Kleine Pathoweg, suitable values were not available in the text or in a table but were available in bar plots (figure 69 and figure 71 of Everaert (2008)). The plots contained breakdowns of the number of gull carcasses by month and by turbine that were needed to address a spatiotemporal mismatch between the passage data and carcass search data. Values were extracted from the plots using the web plot digitizer tool (link to application GUI) and the number of carcasses corrected accordingly.

Table 1. Changes made to specific values in the dataset provided by Cook (2021) to calculate avoidance rates.

Wind farm	Species	Year	Input parameter	Old value	New value	Rationale
Bloodgate Hill	Black-headed gull	2007-08	Number of birds recorded	4,503	1,938	Cook (2021) used passage values that cover the wider survey area, the new values match with the width of survey area used (1,500 m)
Bloodgate Hill	Common gull	2007-08	Number of birds recorded	2,207	779	Cook (2021) used passage values that cover the wider survey area, the new values match with the width of survey area used (1,500 m)
Bloodgate Hill	Lesser black-backed gull	2007-08	Number of birds recorded	7	1	Cook (2021) used passage values that cover the wider survey area, the new values match with the width of survey area used (1,500 m)
Bloodgate Hill	Herring gull	2007-08	Number of birds recorded	49	15	Cook (2021) used passage values that cover the wider survey area, the new values match with the width of survey area used (1,500 m)
Bloodgate Hill	Great black-backed gull	2007-08	Number of birds recorded	13	5	Cook (2021) used passage values that cover the wider survey area, the new values match with the width of survey area used (1,500 m)
Blyth Harbour	All species	2016-17	Correction for Area	1	2.2	In Percival *et al.* (2017) it states that only 44% of the total areas was searchable
Sabinapolder	All species	2009-11	End date	03/12/2010	03/09/2011	This is the time period when the 17 carcasses, used in Cook (2021), were found and therefore need to calculate total flux during this period
Haverigg	All species	2019	Correction for predation	1.33	1.5	Basic arithmetic error on page 23/24 of Percival (2020)
Goole Fields I	All species	2017	Width of study area	3,200	2,750	Re-measured on Google Earth using maps provided in report
Goole Fields II	All species	2017-18	Correction for efficiency	1	1.1	Only 91% of carcasses found in efficiency trials

Wind farm	Species	Year	Input parameter	Old value	New value	Rationale
Goole Fields I	All species	2017-18	Whole dataset added	Whole dataset added	Whole dataset added	Whole dataset added that was suitable for use within Collision Risk Models
Gneizdzewo	All species	2007	Number of turbines	19	11	States in Zieliński *et al*. (2011) that only 11 turbines were searched for carcasses during most of the study years, except 2011
Gneizdzewo	All species	2008	Number of turbines	19	11	States in Zieliński *et al*. (2011) that only 11 turbines were searched for carcasses during most of the study years, except 2011
Gneizdzewo	All species	2010	Number of turbines	19	11	States in Zieliński *et al*. (2011) that only 11 turbines were searched for carcasses during most of the study years, except 2011
Gneizdzewo	All species	2011	Whole dataset added	Whole dataset added	Whole dataset added	Two carcasses were found by dogs but the species or species grouping of these carcasses were not reported
Gneizdzewo	All species	2012	Number of turbines	19	11	States in Zieliński *et al*. (2011) that only 11 turbines were searched for carcasses during most of the study years, except 2011
Gneizdzewo	All species	2007	Width of survey area	3,700	2,500	Re-measured on Google Earth using maps provided in report
Gneizdzewo	All species	2008	Width of survey area	3,700	2,500	Re-measured on Google Earth using maps provided in report
Gneizdzewo	All species	2010	Width of survey area	3,700	2,500	Re-measured on Google Earth using maps provided in report
Gneizdzewo	All species	2012	Width of survey area	3,700	2,500	Re-measured on Google Earth using maps provided in report
Delfzijl-zuid	All species	2006	Correction for Area	1.14	1.04	Using value used in the report see table 2.3 on p. 12 in Brenninkmeijer (2011)

Wind farm	Species	Year	Input parameter	Old value	New value	Rationale
Delfzijl-zuid	All species	2007	Correction for predation	1	1.64	Using value used in the report see table 2.4 on p. 13 in Brenninkmeijer (2011)
Delfzijl-zuid	All species	2008	Correction for efficiency	1	1.14	Using value used in the report see table 2.2 on p. 11 in Brenninkmeijer (2011)
Slufterdam & Distridam	All species	2012	Width of survey area	3,200	6,250	Re-measured on Google Earth, captures the total length of all the turbines as this was similar to how the data were collected
Zeebrugge	All species	2001	N hours monitoring	16	13	Monitoring was dawn until dusk and in October at the study sites, this is a 13-hour period
Kleine Pathoweg	Black-headed gull	2005	Recorded collisions	17	3	Values corrected for spatial and temporal mismatch. Recorded carcasses multiplied by 0.143 and round up to nearest integer
Kleine Pathoweg	Herring/Lesser black-backed gull	2005	Recorded collisions	57	8	Values corrected for spatial and temporal mismatch. Recorded carcasses multiplied by 0.143 and round up to nearest integer
Oosterbierum	Gulls	1990	Estimated collisions	66	20	Table 12c on p. 93 of Winkleman (1992) contains the correct data and 66 is outside of the possible range
Oosterbierum	Gulls	1991	Estimated collisions	36.5	75	Table 12c on p. 93 of Winkleman (1992) contains the correct data and 36.5 is outside of the possible range
Thanet	Large gulls	All years	Data added	Data added	Data added	Two collisions were definitely large gulls, so these were added to the avoidance rate for large gulls with a passage density of 2.76
Thanet	Gulls	All years	Density	2.76	1.62	Data for large gulls added so this density needed adjusting accordingly

Wind farm	Species	Year	Input parameter	Old value	New value	Rationale
Thanet *	All species	All years	Correction for efficiency	1	1.5	The camera detection rate is 0.67, therefore, a proportion of the birds passing through the monitoring area have unknown fates
Boudwijnkanaal *	All species	2005	+	+	+	+
Boudwijnkanaal *	All species	2001	+	+	+	+
Sabinapolder *	All species	2009-11	Correction for Area	1	1.25	Hard to know what value to use, see table 2.2 on p. 12 in Verbeek *et al*. (2012), variable search area during the year

* These changes were only included for avoidance rates presented in Appendix 3 and not those within section 3.3.
+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

3.3 Avoidance rates for key species and species groups

The within wind farm avoidance rates for all the key species for which data was available and species groups are presented here, the data contributing to each of the avoidance rates can be found in Appendix 2. A full spreadsheet of all Band model parameters can be found in the accompanying csv spreadsheet entitled "Ozsanlav-Harris *et al.* (2022) Collision Data" (Annex 2). The R markdown code which can be used to replicate the generation of avoidance rates can be found in the accompanying file "Ozsanlav-Harris *et al.* (2022) markdown code" (Annex 3). Four changes were recommended (see Table 1) but did not receive wider scientific steering group approval so were not included in the avoidance rates below. These additional changes made little difference to avoidance rates estimated and are presented in Appendix 3. Across all four models the avoidance rates we calculated for large gulls, small gulls, all gulls, and all gulls and terns were higher than those presented in Cook (2021).

3.3.1 Basic Band avoidance rates

Table 2. Seabird avoidance rates calculated here using the basic Band model (data in Appendix 2) are compared to those from Cook (2021). Results are presented as a median rate (standard deviation; 95% confidence interval). The standard deviation and 95% confidence interval were calculated using the delta method (Powell 2007).

Species/ species group	Cook (2021)	Ozsanlav-Harris *et al.* (2022)	% change in rate
Kittiwake	0.997 (0.0015; 0.994 – 1)	0.997 (0.0015; 0.994 – 1)	0
Black-headed gull	0.9873 (0.0009; 0.9856 – 0.989)	0.9922 (0.0005; 0.9911 – 0.9932)	↑ 0.493
Herring gull	0.9953 (0.0002; 0.9948 – 0.9957)	0.9952 (0.0002; 0.9948 – 0.9956)	↓ -0.008
Lesser black-backed gull	0.995 (0.0003; 0.9944 – 0.9956)	0.9954 (0.0003; 0.9948 – 0.9959)	↑ 0.037
Great black-backed gull	0.9991 (0.0002; 0.9986 – 0.9995)	0.9991 (0.0002; 0.9987 – 0.9995)	↑ 0.007
Gull	0.9874 (0.0003; 0.9868 – 0.9879)	0.9924 (0.0001; 0.9921 – 0.9926)	↑ 0.506
Large gull	0.986 (0.0007; 0.9846 – 0.9874)	0.9936 (0.0002; 0.9933 – 0.9939)	↑ 0.771
Small gull	0.9919	0.9948	↑ 0.29

Species/ species group	Cook (2021)	Ozsanlav-Harris *et al.* (2022)	% change in rate
	(0.0004; 0.9911 – 0.9927)	(0.0003; 0.9943 – 0.9953)	
Sandwich tern	0.9722 (0.0016; 0.969 – 0.9753)	0.9722 (0.0016; 0.9691 – 0.9753)	↑ 0.002
Tern	0.9712 (0.0007; 0.9697 – 0.9726)	0.9713 (0.0007; 0.9698 – 0.9727)	↑ 0.009
Gulls & terns	0.9856 (0.0002; 0.986 – 0.9852)	0.9902 (0.0001; 0.9904 – 0.99)	↑ 0.467

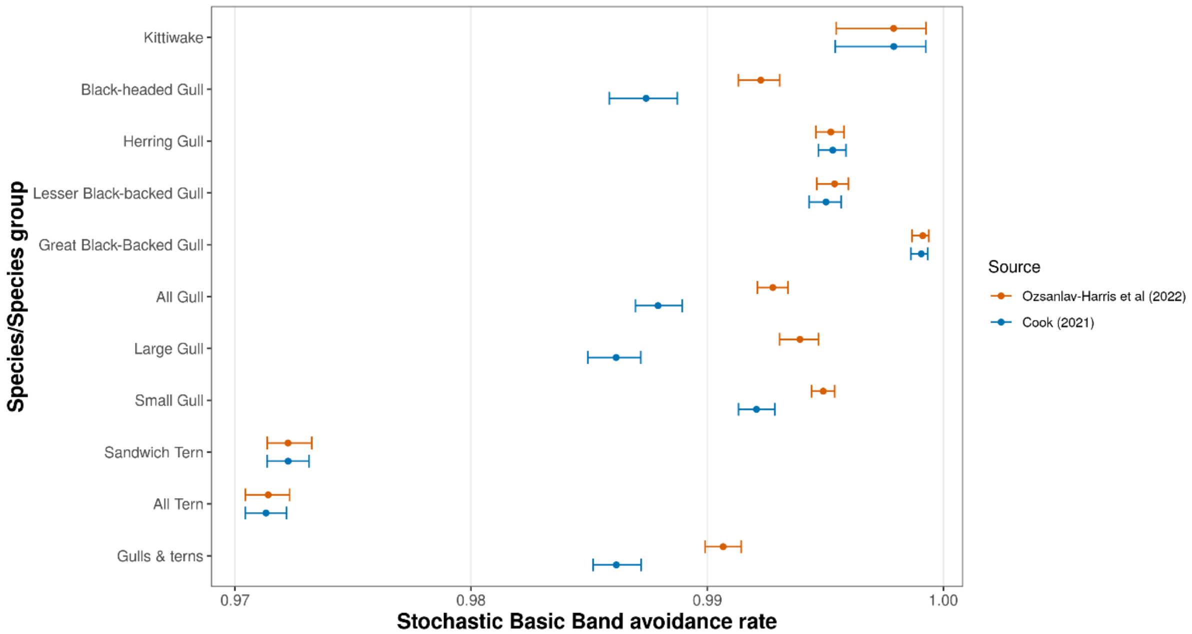

Figure 2. Seabird avoidance rates calculated here using the basic Band model (data in Appendix 2) are compared to those from Cook (2021). Error bars represent the 95% confidence interval calculated using the delta method (Powell 2007).

3.3.2 Extended band avoidance rates

Table 3. Seabird avoidance rates calculated here using the extended Band model (data in Appendix 2) are compared to those from Cook (2021). Results are presented as estimated rate (standard deviation; 95% confidence interval). The standard deviation and 95% confidence interval were calculated using the delta method (Powell 2007).

Species/species group	**Cook (2021)**	**Ozsanlav-Harris *et al.* (2022)**	**% change in rate**
Kittiwake	0.9924 (0.0038; 0.9848 – 0.9999)	0.9924 (0.0038; 0.9848 – 0.9999)	0
Black-headed gull	0.8978 (0.0086; 0.8809 – 0.9147)	0.9151 (0.0047; 0.9058 – 0.9243)	↑ 1.925
Herring gull	0.9825 (0.0008; 0.981 – 0.9841)	0.9825 (0.0008; 0.981 – 0.984)	↓ -0.006
Lesser black-backed gull	0.9789 (0.0012; 0.9766 – 0.9813)	0.9799 (0.0011; 0.9777 – 0.9821)	↑ 0.1
Great black-backed gull	0.9965 (0.0009; 0.9948 – 0.9983)	0.9966 (0.0008; 0.995 – 0.9983)	↑ 0.009
Gull	0.9532 (0.001; 0.9512 – 0.9953)	0.972 (0.0004; 0.9711 – 0.9729)	↑ 1.971
Large gull	0.9448 (0.0028; 0.9393 – 0.9503)	0.9774 (0.0006; 0.9762 – 0.9786)	↑ 3.45
Small gull	0.9354 (0.0034; 0.9288 – 0.942)	0.9438 (0.0022; 0.9396 – 0.9481)	↑ 0.902
Sandwich tern	0.9645 (0.0019; 0.9609 – 0.9682)	0.9646 (0.0019; 0.9609 – 0.9682)	↑ 0.001
Tern	0.9344 (0.0016; 0.9313 – 0.9375)	0.9347 (0.0016; 0.9316 – 0.9378)	↑ 0.034
Gulls & terns	0.9501 (0.0007; 0.9515 – 0.9486)	0.9662 (0.0004; 0.9669 – 0.9655)	↑ 1.696

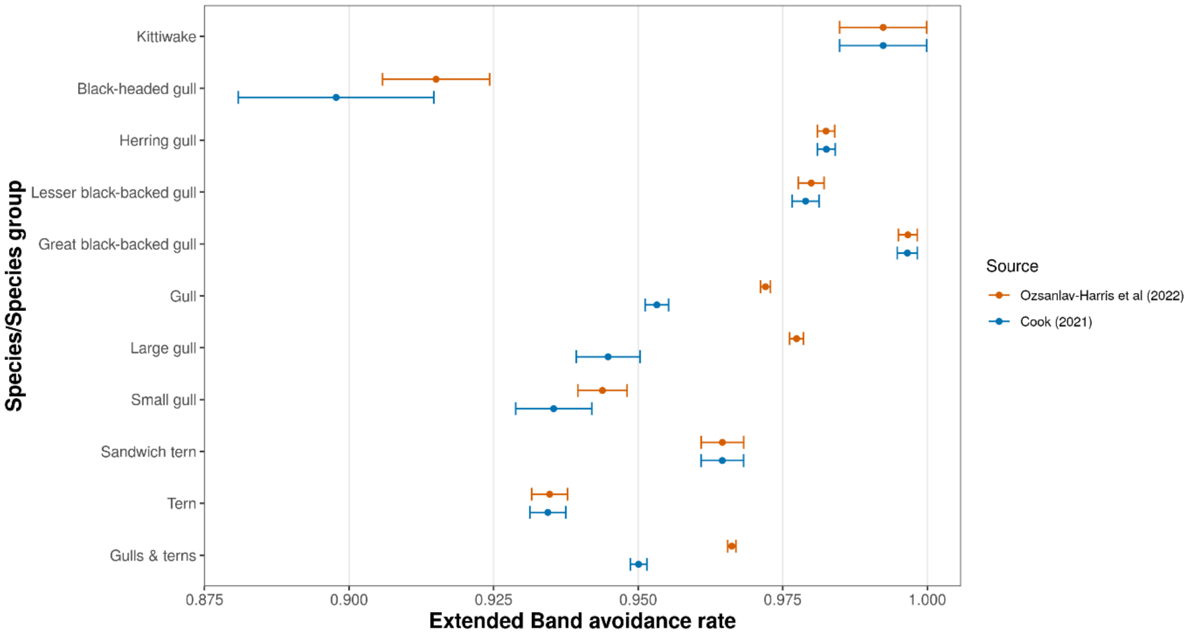

Figure 3. Seabird avoidance rates calculated here using the extended Band model (data in Appendix 2) are compared to those from Cook (2021). Error bars represent the 95% confidence interval calculated using the delta method (Powell 2007)

3.3.3 Basic stochastic collision risk model avoidance rates

Table 4. Seabird avoidance rates calculated here using the basic stochastic collision risk model (data in Appendix 2) are compared to those from Cook (2021). Results are presented as estimated rate (standard deviation; 95% confidence interval). The standard deviation and 95% confidence interval were calculated from 1,000 random iterations where input parameter values were varied.

Species/species group	Cook (2021)	Ozsanlav-Harris *et al.* (2022)	% change in rate
Kittiwake	0.9979 (0.0013; 0.9954 – 0.9993)	0.9979 (0.0013; 0.9955 – 0.9993)	0
Black-headed gull	0.9874 (0.0007; 0.9859 – 0.9887)	0.9923 (0.0005; 0.9913 – 0.9931)	↑ 0.492
Herring gull	0.9953 (0.0003; 0.9947 – 0.9959)	0.9952 (0.0003; 0.9946 – 0.9958)	↓ -0.008
Lesser black-backed gull	0.995 (0.0003; 0.9943 – 0.9957)	0.9954 (0.0003; 0.9946 – 0.996)	↑ 0.036
Great black-backed gull	0.9991 (0.0002; 0.9986 – 0.9993)	0.9991 (0.0002; 0.9987 – 0.9994)	↑ 0.006
Gull	0.9879 (0.0005; 0.987 – 0.9889)	0.9928 (0.0003; 0.9921 – 0.9934)	↑ 0.492

Species/species group	Cook (2021)	Ozsanlav-Harris *et al.* (2022)	% change in rate
Large gull	0.9861 (0.0006; 0.9849 – 0.9872)	0.9939 (0.0004; 0.9931 – 0.9947)	↑ 0.789
Small gull	0.9921 (0.0004; 0.9913 – 0.9929)	0.9949 (0.0002; 0.9944 – 0.9954)	↑ 0.285
Sandwich tern	0.9723 (0.0004; 0.9714 – 0.9731)	0.9722 (0.0005; 0.9714 – 0.9733)	↓ -0.001
Tern	0.9713 (0.0004; 0.9704 – 0.9722)	0.9714 (0.0005; 0.9704 – 0.9723)	↑ 0.01
Gulls & terns	0.9862 (0.0005; 0.9852 – 0.9872)	0.9907 (0.0004; 0.9899 – 0.9914)	↑ 0.459

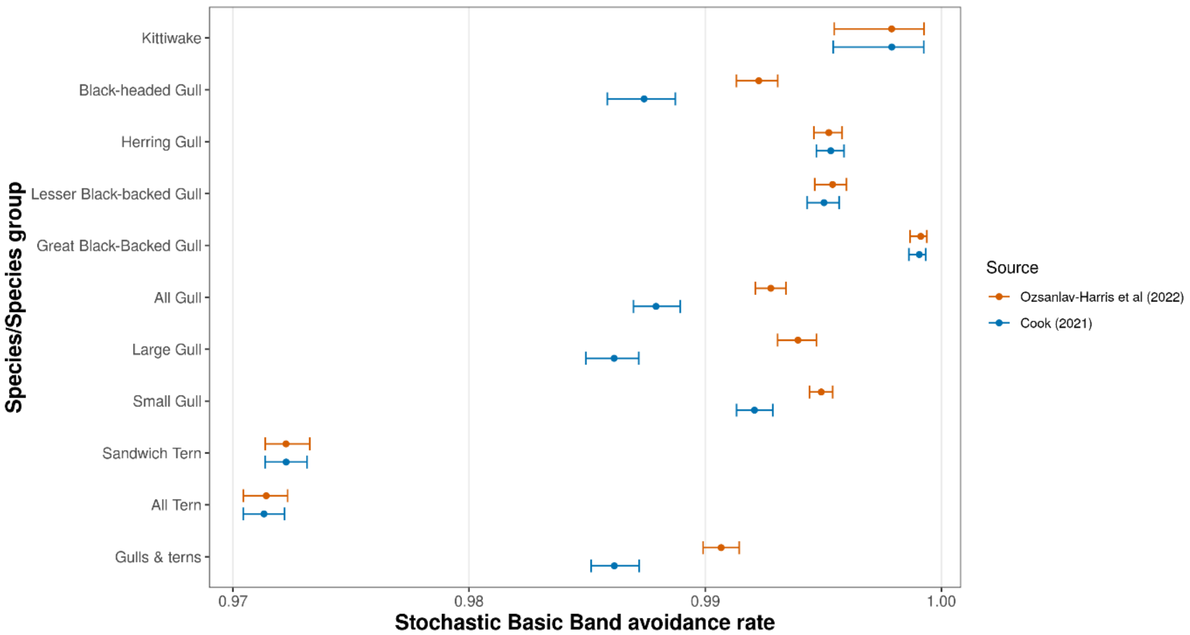

Figure 4. Seabird avoidance rates calculated here using the basic stochastic collision risk model (data in Appendix 2) are compared to those from Cook (2021). Error bars represent the 95% confidence interval calculated from 1,000 random iterations were input parameter values where varied.

3.3.4 Extended stochastic collision risk model avoidance rates

Table 5. Seabird avoidance rates calculated here using the extended stochastic collision risk model (data in Appendix 2) are compared to those from Cook (2021). Results are presented as estimated rate (standard deviation; 95% confidence interval). The standard deviation and 95% confidence interval were calculated from 1,000 random iterations where input parameter values where varied.

Species/species group	Cook (2021)	Ozsanlav-Harris *et al.* (2022)	% change in rate
Kittiwake	0.9947 (0.1455; 0.39–0.9981)	0.9947 (0.1295; 0.466–0.9981)	↓ -0.001
Black-headed gull	0.9043 (0.0202; 0.8543–0.9348)	0.9222 (0.0175; 0.8822–0.9499)	↑ 1.982
Herring gull	0.9498 (0.0091; 0.929–0.9649)	0.9504 (0.0085; 0.9323–0.9645)	↑ 0.064
Lesser black-backed gull	0.98 (0.0022; 0.976–0.9843)	0.981 (0.0022; 0.9768–0.9854)	↑ 0.105
Great black-backed gull	0.997 (0.0008; 0.995–0.9982)	0.997 (0.0008; 0.995–0.9982)	↑ 0.003
Gull	0.9258 (0.0067; 0.9129–0.9393)	0.9533 (0.0047; 0.9439–0.962)	↑ 2.969
Large gull	0.9104 (0.0083; 0.894–0.9265)	0.9614 (0.0047; 0.9525–0.971)	↑ 5.599
Small gull	0.9427 (0.008; 0.925–0.9562)	0.9512 (0.0078; 0.9343–0.9645)	↑ 0.902
Sandwich tern	0.9705 (0.0028; 0.9652–0.9758)	0.9705 (0.0029; 0.9645–0.976)	↑ 0.002
Tern	0.94 (0.0032; 0.9338–0.9464)	0.9401 (0.0033; 0.9341–0.9465)	↑ 0.005
Gulls & terns	0.9295 (0.0049; 0.9204–0.9395)	0.95 (0.0038; 0.9427–0.9574)	↑ 2.202

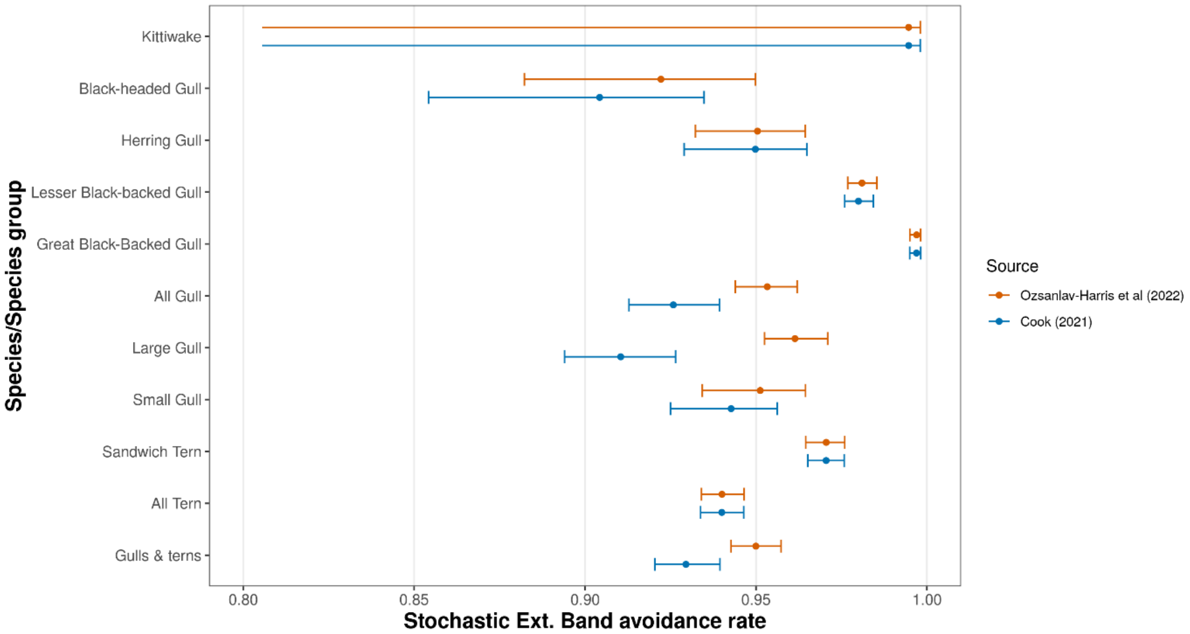

Figure 5. Seabird avoidance rates calculated here using the extended stochastic collision risk model (data in Appendix 2) are compared to those from Cook (2021). Error bars represent the 95% confidence interval calculated from 1,000 random iterations where input parameter values were varied. Note: the lower confidence interval for kittiwake has been removed to assist interpreting the plot. The values were 0.466 and 0.390 for Ozsanlav-Harris *et al.* (2022) and Cook (2022), respectively.

3.4 Sensitivity analysis 1: Amalgamating Zeebrugge and Slufterdam & Distridam

Amalgamating the data across the whole turbine array for Zeebrugge and Slufterdam & Distridam made minor differences to avoidance rate estimates but did increase the 95% confidence interval in almost all instances for the non-stochastic models (Figures 6 & 7). For the stochastic models, the 95% confidence interval only increased for terns (Figures 8 & 9). The increase in the confidence intervals for non-stochastic models could be due to how standard deviations are calculated using the delta method (Powell 2007). The delta method calculates the avoidance rate for each row in the dataset and then captures the variability between rows. When the data for Zeebrugge and Slufterdam & Distridam are amalgamated our uncertainty in the mean avoidance rate increases as fewer data points are contributing to its estimation, this is then reflected in a larger standard deviation and 95% confidence interval. This is perhaps a truer reflection of the 95% confidence interval as data at the individual turbine level would not have constituted truly independent samples and no effort was made to account for that pseudo-replication. It should also be noted that the data structure in Cook (2021) would be unsuitable to estimate individual avoidance rates per turbine at Zeebrugge and Slufterdam & Distridam as the passage rates are not reflective of the true passage rate at the turbine level.

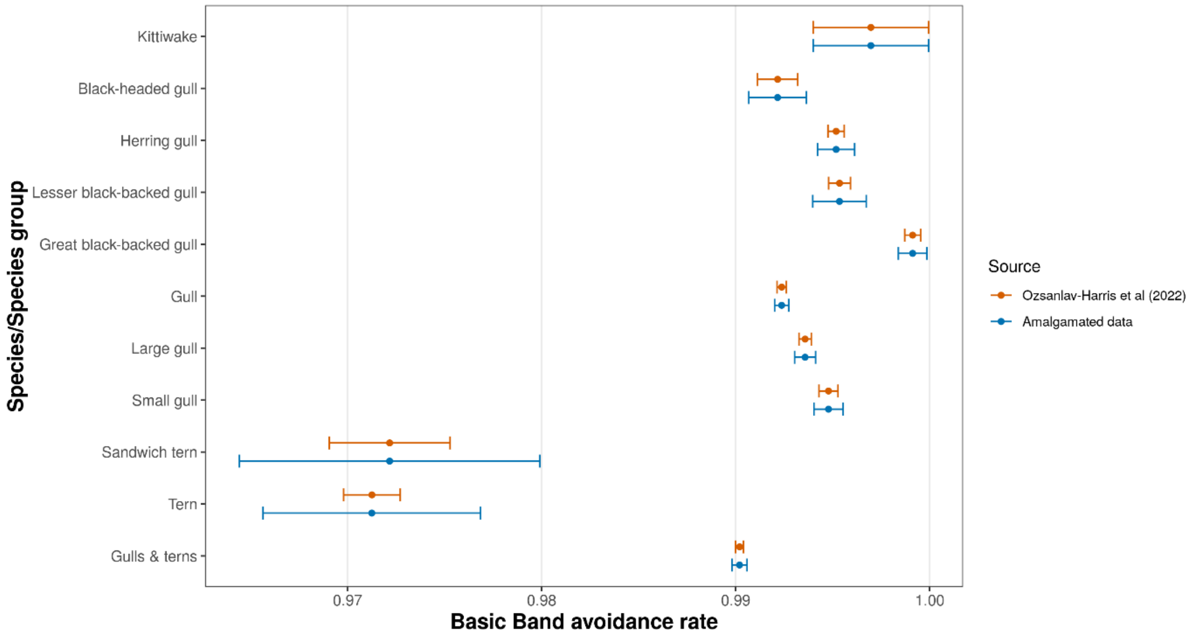

Figure 6. Seabird avoidance rates calculated using the basic Band model to determine the influence of amalgamating the data across the whole turbine array for Zeebrugge and Slufterdam & Distridam. Error bars represent the 95% confidence interval calculated using the delta method (Powell 2007).

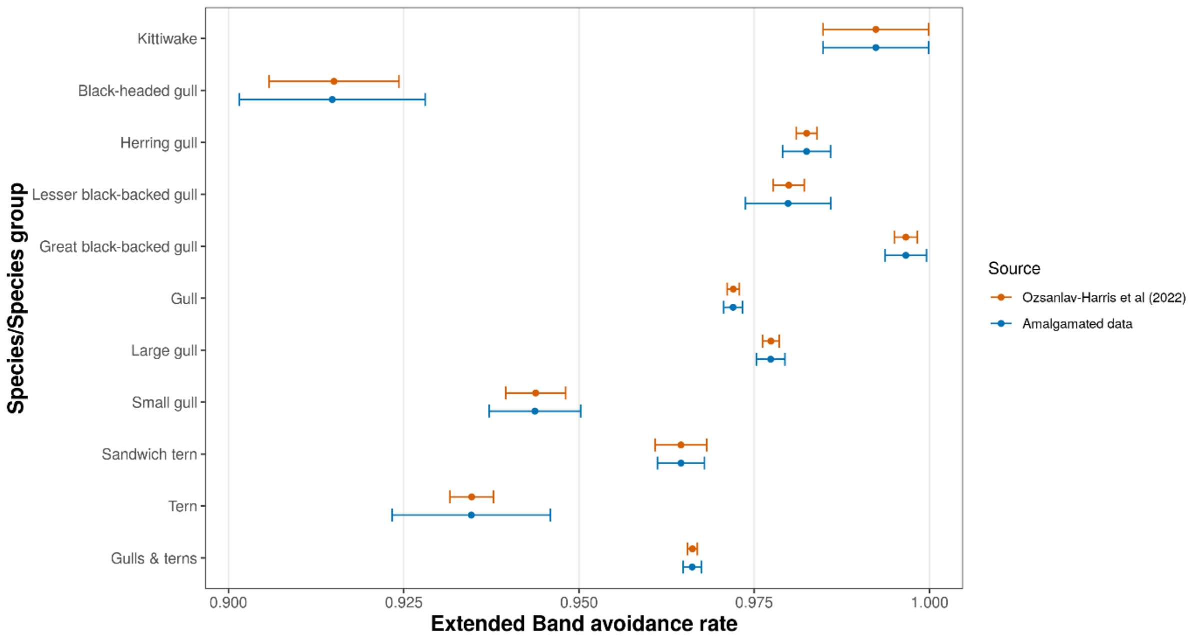

Figure 7. Seabird avoidance rates calculated using the extended Band model to determine the influence of amalgamating the data across the whole turbine array for Zeebrugge and Slufterdam & Distridam. Error bars represent the 95% confidence interval calculated using the delta method (Powell 2007).

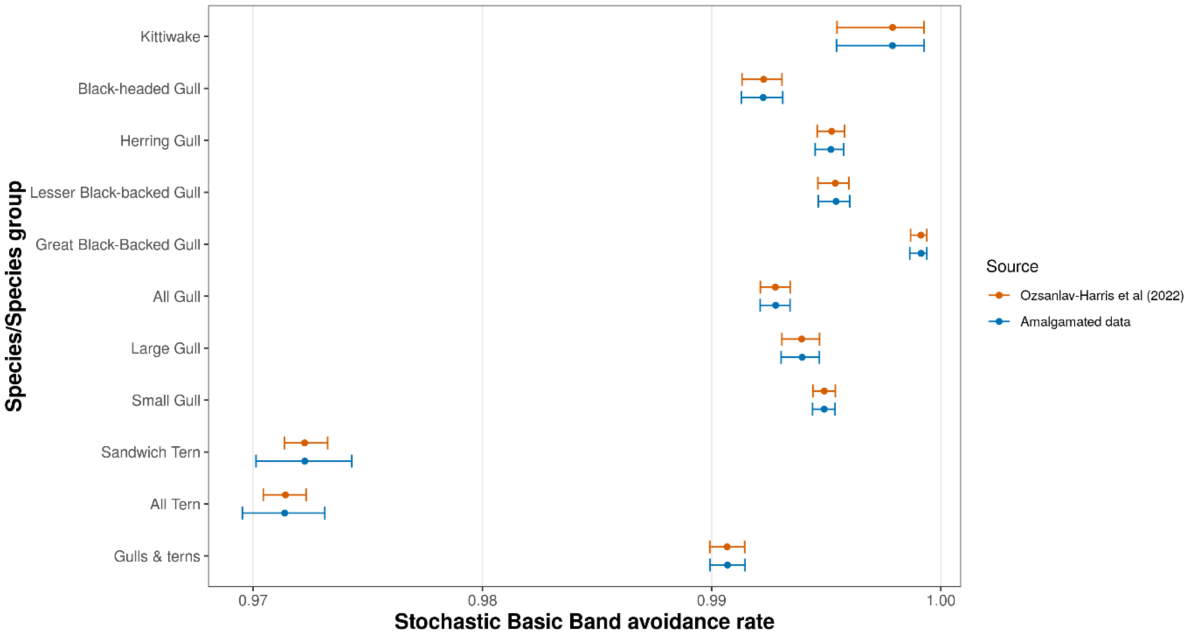

Figure 8. Seabird avoidance rates calculated using the basic stochastic collision risk model to determine the influence of amalgamating the data across the whole turbine array for Zeebrugge and Slufterdam & Distridam. Error bars represent the 95% confidence interval calculated from 1,000 random iterations where input parameter values were varied.

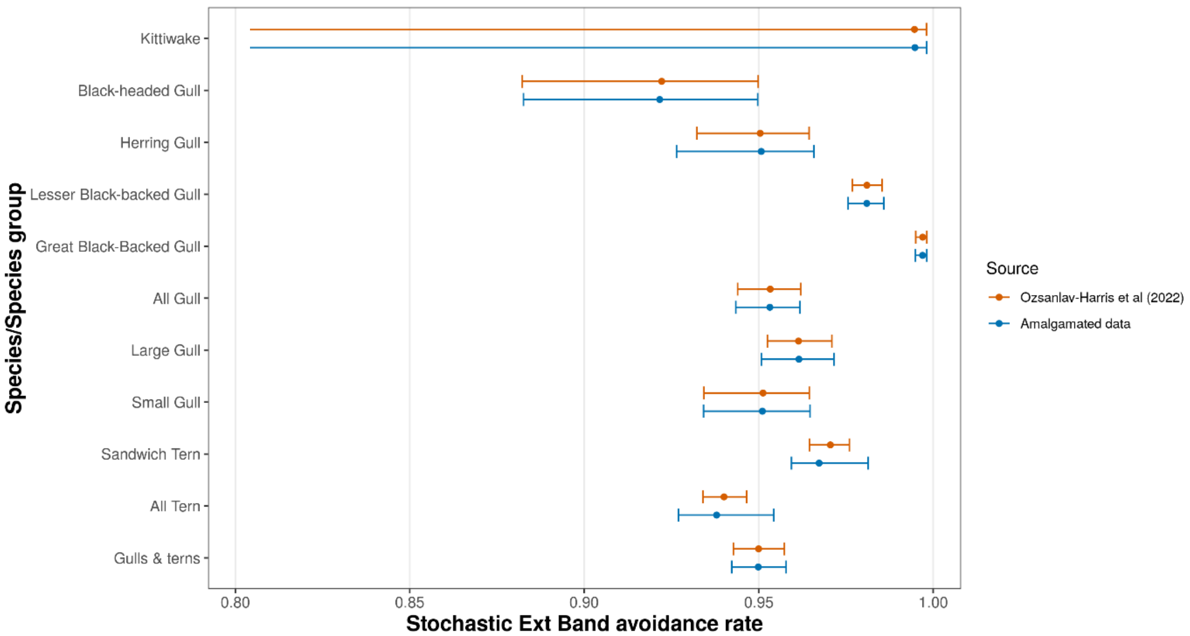

Figure 9. Seabird avoidance rates calculated using the extended stochastic collision risk model to determine the influence of amalgamating the data across the whole turbine array for Zeebrugge and Slufterdam & Distridam. Error bars represent the 95% confidence interval calculated from 1,000 random iterations where input parameter values were varied. Note: the lower confidence interval for kittiwake has been removed to assist interpreting the plot. The values were 0.466 and 0.382 for Ozsanlav-Harris *et al*. (2022) and the amalgamated data, respectively.

3.5 Sensitivity analysis 2: Nocturnal passage rate correction

Only small decreases in avoidance rates for gulls were observed when changing the nocturnal correction factors for Boudwijnkanaal and Kleine Pathoweg from 0.25 to 0 (Figures 10, 11, 12 & 13). In all instances the new avoidance rate estimate was within the 95% confidence interval of the previous rate calculated using the data in Appendix 2. The avoidance rate estimate decreases as the *total flux* decreases, which in turn decreases the predicted number of collisions in the absence of avoidance causing the fraction in equation 1 to increase.

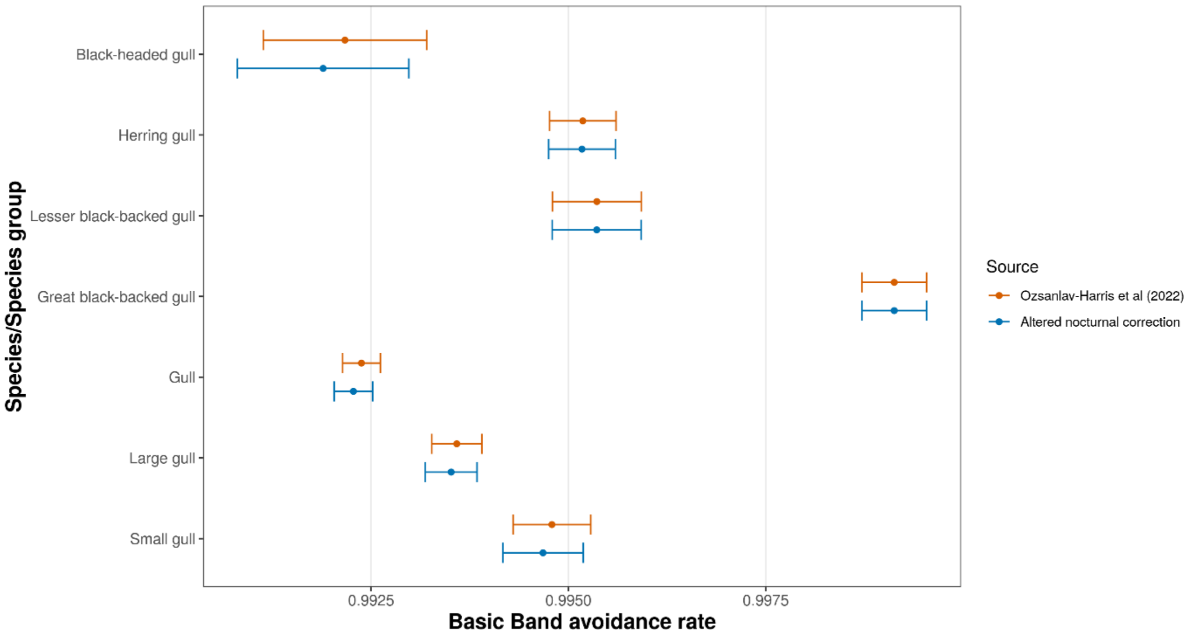

Figure 10. Seabird avoidance rates calculated using the basic Band model to determine the influence of setting nocturnal correction factor to 0 for Boudwijnkanaal and Kleine Pathoweg datasets. Error bars represent the 95% confidence interval calculated using the delta method (Powell 2007). Note: only gulls were recorded at both these sites so avoidance rates for terns are not shown.

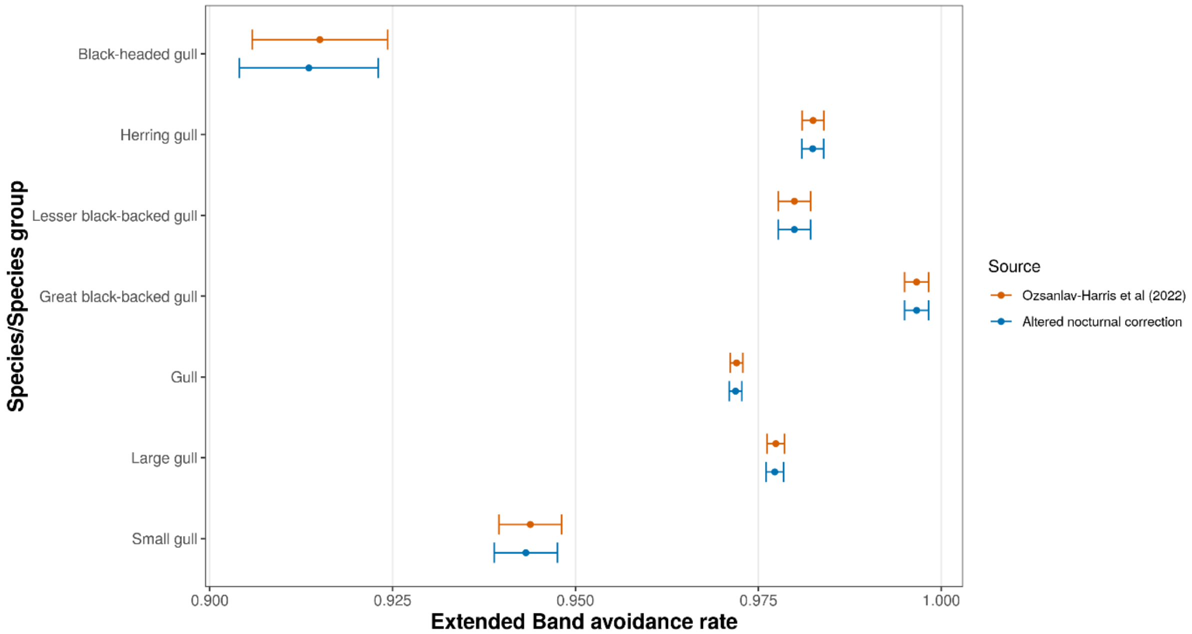

Figure 11. Seabird avoidance rates calculated using the extended Band model to determine the influence of setting nocturnal correction factor to 0 for Boudwijnkanaal and Kleine Pathoweg datasets. Error bars represent the 95% confidence interval calculated using the delta method (Powell 2007). Note: only gulls were recorded at both these sites so avoidance rates for terns are not shown.

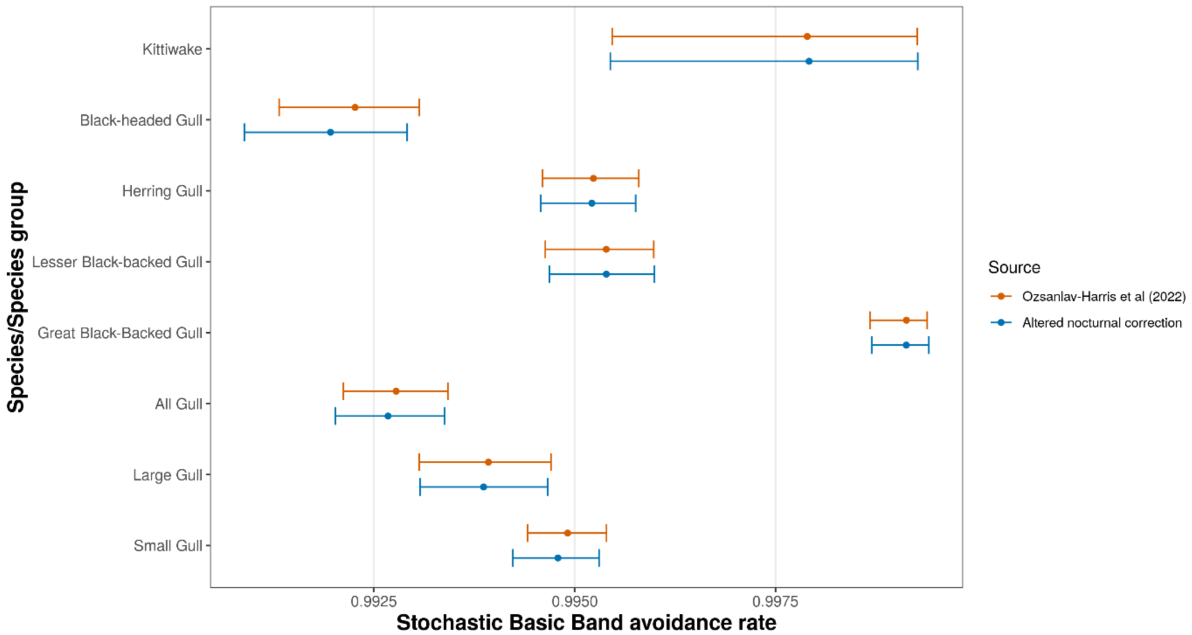

Figure 12. Seabird avoidance rates calculated using the basic stochastic collision risk model to determine the influence of setting nocturnal correction factor to 0 for Boudwijnkanaal and Kleine Pathoweg datasets. Error bars represent the 95% confidence interval calculated from 1,000 random iterations were input parameter values were varied. Note: only gulls were recorded at both these sites so avoidance rates for terns are not shown.

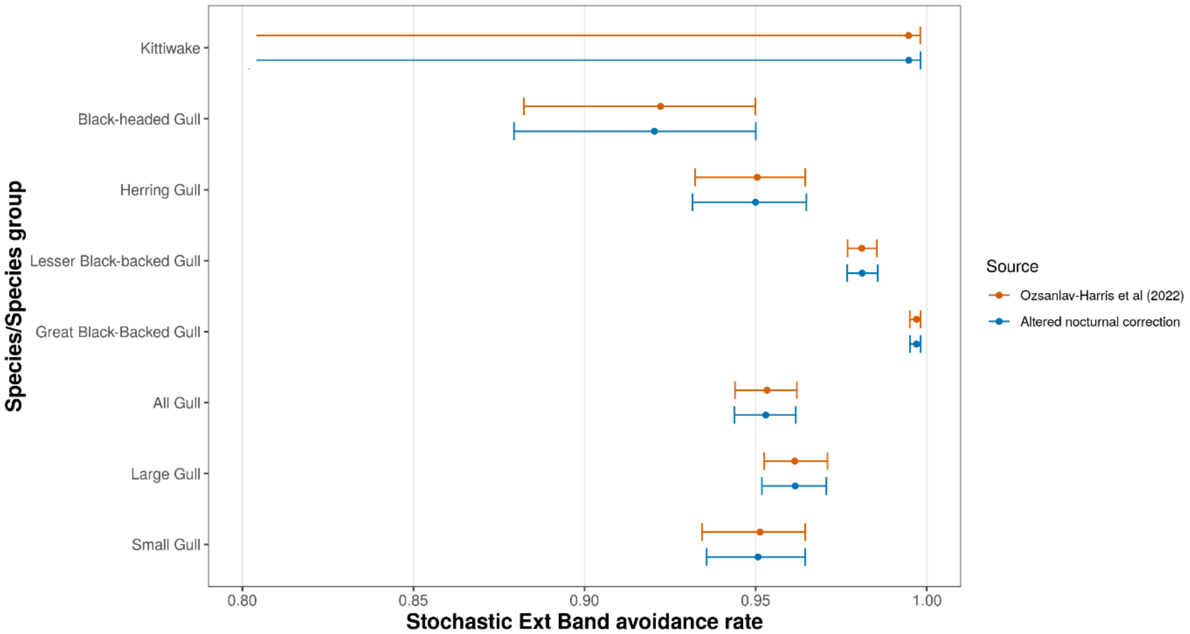

Figure 13. Seabird avoidance rates calculated using the extended stochastic collision risk model to determine the influence of setting nocturnal correction factor to 0 for Boudwijnkanaal and Kleine Pathoweg datasets. Error bars represent the 95% confidence interval calculated from 1,000 random iterations were input parameter values were varied. Note: only gulls were recorded at both these sites so avoidance rates for terns are not shown. Note: the lower confidence interval for kittiwake has been removed to assist interpreting the plot. The values were 0.466 and 0.401 for Ozsanlav-Harris *et al.* (2022) and the altered nocturnal correction dataset, respectively

4 Conclusions

- The avoidance rates presented here are higher than those in Cook (2021). There were significant increases, due to non-overlapping 95% confidence intervals in the avoidance rates for large gulls, all gulls, and gulls and terns across all four models, and for small gull and black-headed gull for basic models.
- The increase in avoidance rates was largely driven by a large reduction in the estimated number of carcasses for Kleine Pathoweg when accounting for a spatiotemporal mismatch between the carcass searches and passage data.
- Many of the species-specific avoidance rates did not change significantly, besides the increase in avoidance rate for black-headed gull in the basic model variants. This was due to many of the altered values (see Table 1) relating to species groupings instead of specific species. The increase in black-headed gull avoidance rate was caused by the observed collisions for Kleine Pathoweg changing from 17 to 3.
- The avoidance rates were consistently lower for extended model variants. This was due to the use of generic species-specific flight height distribution in the stochastic models which consistently estimated a lower flux at collision risk height compared to the site-specific proportion of flux at collision risk height in the non-stochastic variants. This difference is likely caused by birds flying higher on land due to topography and man-made structures than over water, which is where the species-specific flight height distributions are derived from.
- The large 95% confidence interval for kittiwake in the stochastic extended band model is likely due to the small amount of data for this species (only one observed collision). Therefore, it likely represents a more truthful measure of model error.
- The error around avoidance rates was sensitive to how the data were amalgamated for Zeebrugge and Slufterdam & Distridam. When the data from Zeebrugge and Slufterdam & Distridam were amalgamated 95% confidence intervals increased, especially for the non-stochastic models. This is perhaps a truer reflection of the 95%

confidence interval as data at the individual turbine level would not have constituted truly independent samples and no effort was made to account for that pseudo-replication.
- Changing the nocturnal correction factor from 0.25 to 0 for Boudwijnkanaal and Kleine Pathoweg only leads to a very small decrease in avoidance rates for all gulls grouping and black-headed gull.
- Overall, these findings alter the avoidance rate of all gulls by up to 3.0% (0.926 to 0.953), large gulls by up to 5.6% (0.910 to 0.961), and gulls & terns by up to 2.2% (0.930 to 0.950) depending on the model variant used but the changes were largest for the stochastic extended Band model. This will decrease the predicted level of seabird mortality in environmental impact assessments due to higher rates of avoidance behaviour.

5 Limitations and Recommendations

- The data is still primarily collected at onshore and coastal sites with very little offshore data therefore these avoidance rates may not fully capture the offshore behaviour of seabirds.
- The proportion of birds flying at rotor height systematically differs between the site-specific onshore data and those derived from the offshore flight height distributions in Johnston *et al*. (2014). Since the passage and collision data used in this report is largely from onshore wind farms this would lead to avoidance rates being underestimated for the extended model variants that use the offshore flight height distributions. Therefore, we recommend using the basic variants of the models over the extended variants.
- Incorporating more data from more offshore wind farms, as it becomes available, will increase the suitability of avoidance rates for offshore applications. It will also increase the accuracy of the extended model variants as the modelled flight height distributions used will more accurately reflect bird flight height as they are also collected offshore.
- Any future meta-analysis should ensure that all data are at the same spatial level (i.e. all at the turbine array level). If values for individual turbines within arrays are incorporated this could lead to unrealistically small confidence intervals unless the pseudo-replication is accounted for (e.g. in a mixed effects model).
- Any future field studies that may be suitable for the calculation of avoidance rate should ensure that passage rates, carcass searches and correction factors are calculated over the same number of turbines and during the same time periods. The buffer zone within which passage rates are calculated should be more consistent between studies. We would suggest that the buffer should not exceed the maximum distance between turbines within the array. This would ensure that avoidance rates will mainly incorporate micro- and meso-avoidance instead of macro-avoidance. Correction factors for predation, search area, and search efficiency should be provided separately as well as methodology detailing how they were calculated so their suitability can be fully assessed.
- The review of data and suggested alterations to data used to calculate avoidance rates adds to confidence and transparency in the resulting recommended avoidance rates. The principles applied to this review should carry over into future updates to the recommended avoidance rates as further data becomes available.

Glossary

- **Micro-avoidance:** bird behavioural response to a single blade of a turbine.
- **Meso-avoidance:** bird behavioural response within the footprint of the wind farm to avoid individual turbines.
- **Macro-avoidance:** bird behavioural response to the presence of a wind farm that are outside the footprint of the wind farm resulting in the redistribution of birds inside and outside the wind farm.
- **Passage rate:** the number of birds passing through the turbine array per hour.
- **Carcass searches:** periodic searches conducted for the carcass of collision victims, the results of these searches are referred to as collision data.
- **Proportion at rotor height** (*proportion of birds at rotor height*): the proportion of birds passing through the turbine array that fly at the same height as the sweep zone of the rotor blades.
- **Correction factor:** the number of carcasses found is multiplied by these factors to correct for the imperfect detection of carcasses. These include corrections for predation, search efficiency and the proportion of the search area accessible.
- **Nocturnal correction:** for gulls the passage rate between sunrise and sunset (daytime) is multiplied by 0.25 to determine the passage rate between sunset and sunrise (night-time). A nocturnal correction factor is not applied to terns as the passage rate between sunset and sunrise is considered to be negligible.
- **Width of survey window:** the maximum width of the turbine array over which passage rates were measured.
- **Spatiotemporal mismatch:** when the passage rates, carcass searches and/or correction factors were calculated over a different number of turbines or for a different time period.
- ***Total flux***: the total number of birds passing through the footprint of the turbine array and buffer zone during the study period, based on observational data.
- ***Flux through sweep zone***: the total number of birds predicted to pass through the turbine sweep zones in the absence of avoidance behaviour during the study period.
- ***Predicted collisions***: the number of collisions expected to occur during the study period in the absence of any avoidance behaviour.
- ***Pcol***: probability a bird collides with a turbine blade as it passes through the rotor sweep zone.
- **Amalgamating data:** when in reference to passage/collision data it means when data was provided at the individual turbine level it was combined to give a single value for the whole turbine array.

References

Band, B. (2012) 'Using a collision risk model to assess bird collision risks for offshore windfarms', 02(March), p. 62. Available at: https://www.bto.org/sites/default/files/u28/downloads/Projects/Final_Report_SOSS02_Band1ModelGuidance.pdf.

Barthelmie, R.J. & Pryor, S.C. (2021) 'Climate change mitigation potential of wind energy', Climate, 9(136), pp. 1–22. doi: 10.3390/cli9090136.

Black, J., Cook, A.S.P.C. & Anderson, O.R. 2019. Better estimates of collision mortality to black-legged kittiwakes at offshore windfarms. JNCC Report No. 644, JNCC, Peterborough, ISSN 0963-8091. https://hub.jncc.gov.uk/assets/bbe5e9fa-0ef2-4cb7-a34a-a9c87960bb75.

Cook, A.S.C.P. (2021) Additional analysis to inform SNCB recommendations regarding collision risk modelling.

Cook, A.S.C.P., Humphreys, E.M., Masden, E.A., Band, W. & Burton, N.H.K. (2014) 'The Avoidance Rates of Collision Between Birds and Offshore Turbines', Scottish Marine and Freshwater Science, 5(16), pp. 1–263.

Desholm, M. & Kahlert, J. (2005) 'Avian collision risk at an offshore wind farm', Biology Letters, 1(3), pp. 296–298. doi: 10.1098/rsbl.2005.0336.

Dierschke, V., Furness, R.W. & Garthe, S. (2016) 'Seabirds and offshore wind farms in European waters: Avoidance and attraction', Biological Conservation. Elsevier Ltd, 202, pp. 59–68. doi: 10.1016/j.biocon.2016.08.016.

Everaert, J. (2003) 'Wind turbines and birds in Flanders: preliminary study results and recommendations', Oriolus, 69, pp. 145–155.

Everaert, J. (2008) Effecten van windturbines op de fauna in Vlaanderen. Onderzoeksresultaten, discussie en aanbevelingen. Brussels.

Everaert, J. & Stienen, E.W.M. (2007) 'Impact of wind turbines on birds in Zeebrugge (Belgium) Significant effect on breeding tern colony due to collisions', Biodiversity and Conservation i, 16, pp. 3345–3359. doi: 10.1007/978-1-4020-6865-2.

Higgins, P. & Foley, A. (2014) 'The evolution of offshore wind power in the United Kingdom', Renewable and Sustainable Energy Reviews. Elsevier, 37, pp. 599–612. doi: 10.1016/j.rser.2014.05.058.

Johnston, A., Cook, A.S.C.P., Wright, L.J., Humphreys, E.M. & Burton, N.K. (2014) 'Modelling flight heights of marine birds to more accurately assess collision risk with offshore wind turbines', Journal of Applied Ecology, 51(1), pp. 31–41. doi: 10.1111/1365-2664.12191.

Masden, E.A. & Cook, A.S.C.P. (2016) 'Avian collision risk models for wind energy impact assessments', Environmental Impact Assessment Review. Elsevier Inc., 56, pp. 43–49. doi: 10.1016/j.eiar.2015.09.001.

McGregor, R.M., King, S., Donovan, C.R., Caneco, B. & Webb, A. (2018) A Stochastic Collision Risk Model for Seabirds in Flight. Marine Scotland.

Percival, S. (2015) Hellrigg Wind Farm: Goose Refuge Monitoring Report Winter 2014-15. Durham.

Percival, S., Percival, T. & Lowe, T. (2018a) Goole Fields II Wind Farm, East Yorkshire Post-construction Year 1 Bird Surveys 2017-18. Durham.

Percival, S., Percival, T. & Lowe, T. (2018b) Goole Fields Wind Farm, East Yorkshire: Post-construction Phase Bird Surveys Autumn/Winter 2015/16 to 2017/18. Durham.

Powell, L. (2007) 'Approximating variance of demographic parameters using the delta method: A reference for avian biologists', Condor, 109(4), pp. 949–954. doi: 10.1525/cond.2012.114.3.678.

Prinsen, H.A.M., Hartman, J.C., Beuker, D. & Anema, L.S.A. (2013) Vliegbewegingen van meeuwen en sterns bij twee windparken op de Eerste Maasvlatke. Veldonderzoek naar flux, vlieghoogtes en aanvaringsslachtoffers. Rapport 13-023. Bureau Waardenburg, Culemborg.

Zieliński, P., Bela, G. & Marchlewski, A. (2011) Report on monitoring of the wind farm impact on birds in the vicinity of Gnieżdżewo (gmina Puck, woj. pomorskie).

Appendix 1: Report list

1. Arcus Consultancy Services. (2019). Winter Ornithology Report 2018-19 Haverigg III Wind Farm Life Extension North Lane, Haverigg, Cumbria. York.
2. Brenninkmeijer, A., & van der Weyde, C. (2011). Monitoring vogelaanvaringen Windpark Delfzijl-Zuid 2006-2011. Feanwalden.
3. Dulac, P. (2008). Evaluation de l'impact du parc eolian de Bouin (Vendee) sur l'avifaune et les chauves-souris. Bilan de 5 anness de suivi. Nantes.
4. Everaert, J., Devos, K., & Kuijken, E. (2002). Windturbines en vogels in Vlaanderen: Voorlopige onderzoeksresultaten en buitenlandse bevindingen.
5. Everaert, Joris. (2003). Wind turbines and birds in Flanders: preliminary study results and recommendations. Oriolus, 69, 145–155.
6. Everaert, Joris. (2008). Effecten van windturbines op de fauna in Vlaanderen. Onderzoeksresultaten, discussie en aanbevelingen. Brussels.
7. Everaert, Joris, & Stienen, E. W. M. (2007). Impact of wind turbines on birds in Zeebrugge (Belgium) Significant effect on breeding tern colony due to collisions. Biodiversity and Conservation I, 16, 3345–3359. doi:10.1007/978-1-4020-6865-2
8. Percival, S. (2015). Hellrigg Wind Farm: Goose Refuge Monitoring Report Winter 2014-15. Durham.
9. Percival, S. (2020). Haverigg II Windfarm Lifetime Extension Report to Inform a Habitats Regulations Assessment. Durham.
10. Percival, S., Percival, T., & Lowe, T. (2017). Wansbeck Blyth Harbour Wind Farm Ornithological Monitoring Programme: Wintering Bird Surveys 2016-17. Durham.
11. Percival, S., Percival, T., & Lowe, T. (2018a). Goole Fields II Wind Farm, East Yorkshire Post-construction Year 1 Bird Surveys 2017-18. Durham.
12. Percival, S., Percival, T., & Lowe, T. (2018b). Goole Fields Wind Farm, East Yorkshire: Post-construction Phase Bird Surveys Autumn/Winter 2015/16 to 2017/18. Durham.
13. Percival, S., Percival, T., & Lowe, T. (2018c). Goole Fields Wind Farm, East Yorkshire: Post-Construction Phase Bird Surveys Breeding Season 2017. Durham.
14. Percival, Steve, Percival, T., & Hoit, M. (2015). Red House Farm Wind Cluster, Lincolnshire collision monitoring 2009. Durham.
15. Percival, Steve, Percival, T., Hoit, M., & Lowe, T. (2008). Blood Hill Wind Farm, Norfolk Post-construction wintering bird surveys 2006-07 and 2007-08. Durham.
16. Prinsen, H. A. M., Hartman, J. C., Beuker, D., & Anema, L. S. A. (2013). Vliegbewegingen van meeuwen en sterns bij twee windparked op de Eerste Maasvlatke. Culemborg.
17. Skov, H., Heinänen, S., Norman, T., Ward, R., Méndez-Roldán, S., & Ellis, I. (2018). ORJIP Bird Collision and Avoidance Study. Final report - April 2018.
18. The Landmark Practice. (2013). Birds and wind turbines at Avonmouth docks year 5 monitoring report. Bristol.
19. Verbeek, R. G., Beuker, D., Hartman, J. C., & Krijgsveld, K. L. (2012). Monitoring vogels Windpark Sabinapolder Onderzoek naar aanvaringsslachtoffers.
20. Wild frontier ecology. (2013). Kessingland Wind Farm Annual Post-construction Monitoring Report Year 2.
21. Winkleman, J. E. (1992). De invloed van de Sep-proefwindcentrale te Oosterbierum (Fr.) op vogels. Arnheim.
22. Zieliński, P., Bela, G., & Kwitowski, K. (2007). Report on monitoring influence of wind farm operating near Gnieżdżewo (gmina of Puck, pomorskie voivodeship) on birds., (December).
23. Zieliński, P., Bela, G., & Marchlewski, A. (2008). Report on monitoring of the wind farm impact on birds in the vicinity of Gnieżdżewo (gmina Puck, woj. pomorskie) part 1.

24. Zieliński, P., Bela, G., & Marchlewski, A. (2010). Report on monitoring of the wind farm impact on birds in the vicinity of Gnieżdżewo (gmina Puck, woj. pomorskie) part 1.
25. Zieliński, P., Bela, G., & Marchlewski, A. (2011). Report on monitoring of the wind farm impact on birds in the vicinity of Gnieżdżewo (gmina Puck, woj. pomorskie).
26. Zieliński, P., Bela, G., & Marchlewski, A. (2012). Report on monitoring of the wind farm near Gnieżdżewo impact on birds (gmina Puck, pomorskie voivodeship).

Appendix 2: Avoidance rate contributing data

Table S1: Summary of bird data contributing to avoidance rates for black-legged kittiwake.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Blyth harbour	01/09/2016	31/03/2017	0	2.2	1	1	0	74	54	1.37	0.0	0.00
Thanet	01/10/2014	31/03/2015	1	1	1	1	1	NA	NA	NA	0.1	2,133.94
Thanet	01/10/2015	31/03/2016	0	1	1	1	0	NA	NA	NA	0.1	2,149.64

Table S2: Summary of bird data contributing to avoidance rates for black-headed gull.

Site	Start date	End date	Observed carcasses	Area Correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	1,938	36.0	53.83	0.18	2,620.43
Blyth Harbour	01/09/2016	31/03/2017	2	2.2	1	1	2.40	520	54.0	9.63	0.07	387.82
Goole Fields I	01/04/2017	31/08/2017	0	1	1	1	0.00	1,187	45.0	26.38	0.20	6,015.51
Goole Fields II	01/09/2017	31/03/2018	2	1.21	1.14	1.1	3.03	NA	72.0	62.10	0.33	21,054.41
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	2501	36.0	69.47	0.68	4,734.96
Red house farm	01/04/2009	31/08/2009	3	1	1	1	3.00	NA	36.0	54.50	0.24	4,546.36
Avonmouth	01/10/2007	31/03/2008	1	1	1	1	1.00	NA	NA	4.40	0.32	379.03
Avonmouth	01/10/2008	31/03/2009	0	1	1	1	0.00	NA	NA	7.10	0.65	1,232.86
Avonmouth	01/10/2009	31/03/2010	0	1	1	1	0.00	NA	NA	2.90	0.33	255.96
Avonmouth	01/10/2011	31/03/2012	0	1	1	1	0.00	NA	NA	12.80	0.75	2,584.32
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	215	18.0	11.94	1.00	18,530.27
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	104	18.0	5.78	1.00	8,963.48
Kessingland	01/11/2012	31/03/2013	1	1	1.79	1	1.79	117	18.0	6.50	1.00	9,996.56

Site	Start date	End date	Observed carcasses	Area Correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Kessingland	01/11/2012	31/03/2013	0	1	1.79	1	0.00	58	18.0	3.22	1.00	4,955.56
Gneizdzewo	15/09/2010	15/11/2010	1	1	1	1	1.00	38	68.0	0.56	0.02	2.96
Gneizdzewo	15/09/2012	15/11/2012	0	1	1	1	0.00	32	63.0	0.51	0.02	2.68
Hellrigg	01/12/2011	31/03/2012	0	1	1	1	0.00	182	38.0	4.79	0.25	121.23
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	4,799	36.5	131.48	0.81	10,672.36
Bouin	01/01/2003	31/12/2006	28	1	1.23	1.32	45.46	5,815	370.0	15.72	0.20	8,759.63
Boudwijnkanaal	01/09/2005	31/12/2005	+	+	+	+	+	+	+	+	+	+
Kleine Pathoweg	01/09/2005	31/12/2005	3	3.5	1	1	10.50	345	16.0	21.56	0.57	4,329.38
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Goole Fields I	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	38.10	0.30	13,664.73
Slufterdam & Distridam	13/06/2012	04/07/2012	4	1 – 3.23	1	1	7.56	34,839	315.0	110.60	0.26	2,542.87
Zeebrugge	01/06/2000	31/07/2000	0	4.17 – 9.09	1	1	0.00	68	64.0	1.06	0.12	37.11
Zeebrugge	01/06/2000	31/07/2001	0	4.17 – 9.09	1	1	0.00	68	64.0	1.06	0.12	37.13

Site	Start date	End date	Observed carcasses	Area Correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Zeebrugge	01/09/2001	31/10/2001	0	4.17 – 9.09	1	1	0.00	376	52.0	7.23	0.87	1,518.50

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Table S3: Summary of bird data contributing to avoidance rates for herring gull.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	15	36.0	0.42	0.90	101.41
Blyth Harbour	01/09/2016	31/03/2017	1	2.2	1	1	2.20	4,358	54.0	80.70	0.56	26,002.10
Goole Fields I	01/04/2017	31/08/2017	0	1	1	1	0.00	34	45.0	0.76	0.44	379.07
Goole Fields II	01/09/2017	31/03/2018	0	1.21	1.14	1.1	0.00	NA	72.0	2.50	0.66	1,695.20
Haverigg	01/04/2014	31/07/2014	3	1	1.07	1.12	3.60	3,273	36.0	90.92	0.24	7,004.62
Haverigg	01/05/2019	31/07/2019	5	1	1.5	1.07	8.03	1,757	36.0	48.81	0.89	10,789.84
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	1,028	36.0	28.56	0.86	2,461.42
Red house farm	01/04/2009	31/08/2009	0	1	1	1	0.00	NA	36.0	0.20	1.00	69.52
Avonmouth	01/10/2007	31/03/2008	0	1	1	1	0.00	NA	NA	6.80	0.81	1,482.76
Avonmouth	01/10/2008	31/03/2009	0	1	1	1	0.00	NA	NA	13.00	0.82	2,847.74
Avonmouth	01/10/2009	31/03/2010	0	1	1	1	0.00	NA	NA	18.80	0.67	3,368.91
Avonmouth	01/10/2011	31/03/2012	0	1	1	1	0.00	NA	NA	38.20	0.79	8,123.93
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	355	18.0	19.72	1.00	30,596.49

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	98	18.0	5.44	1.00	8,446.36
Kessingland	01/11/2012	31/03/2013	0	1	1.79	1	0.00	203	18.0	11.28	1.00	17,344.46
Kessingland	01/11/2012	31/03/2013	1	1	1.79	1	1.79	93	18.0	5.17	1.00	7,945.98
Hellrigg	01/12/2011	31/03/2012	1	1	1	1	1.00	141	38.0	3.71	0.44	165.29
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	2,646	36.5	72.49	0.94	6,828.77
Bouin	01/01/2003	31/12/2006	0	1	1.23	1.32	0.00	807	370.0	2.18	0.20	1,215.65
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Goole Fields I	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	0.80	0.68	650.36
Slufterdam & Distridam	13/06/2012	04/07/2012	17	1 – 3.23	1	1	29.34	8,463	315.0	26.87	0.39	926.56
Zeebrugge	01/06/2000	31/07/2000	1	4.17 – 9.09	1	1	4.17	544	64.0	8.50	0.25	630.82
Zeebrugge	01/06/2000	31/07/2001	2	4.17 – 9.09	1	1	8.79	544	64.0	8.50	0.25	631.16
Zeebrugge	01/09/2001	31/10/2001	2	4.17 – 9.09	1	1	8.34	4,128	52.0	79.38	0.53	10,166.54

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Table S4: Summary of bird data contributing to avoidance rates for lesser black-backed gull.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	1	36.0	0.03	0.60	4.51
Goole Fields I	01/04/2017	31/08/2017	0	1	1	1	0.00	851	45.0	18.91	0.61	13153.79
Goole Fields II	01/09/2017	31/03/2018	1	1.21	1.14	1.1	1.52	NA	72.0	45.30	0.49	22805.09
Haverigg	01/04/2014	31/07/2014	2	1	1.07	1.12	2.40	1411	36.0	39.19	0.34	4277.93
Haverigg	01/05/2019	31/07/2019	1	1	1.5	1.07	1.60	1016	36.0	28.22	0.89	6239.31
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	54	36.0	1.50	0.85	127.79
Red house farm	01/04/2009	31/08/2009	0	1	1	1	0.00	NA	36.0	3.60	0.74	925.96
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	15	18.0	0.83	1.00	1292.81
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	25	18.0	1.39	1.00	2154.68
Kessingland	01/11/2012	31/03/2013	0	1	1.79	1	0.00	57	18.0	3.17	1.00	4870.12
Kessingland	01/11/2012	31/03/2013	0	1	1.79	1	0.00	17	18.0	0.94	1.00	1452.49
Hellrigg	01/12/2011	31/03/2012	0	1	1	1	0.00	1	38.0	0.03	1.00	2.66
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	15	36.5	0.41	0.88	36.24

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Bouin	01/01/2003	31/12/2006	0	1	1.23	1.32	0.00	63	370.0	0.17	0.20	94.90
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Goole Fields I	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	12.30	0.64	9411.09
Slufterdam & Distridam	13/06/2012	04/07/2012	17	1 – 3.23	1	1	29.74	39396	315.0	125.07	0.62	6856.91
Zeebrugge	01/06/2000	31/07/2000	0	4.17 – 9.09	1	1	0.00	324	64.0	5.06	0.32	482.39
Zeebrugge	01/06/2000	31/07/2001	1	4.17 – 9.09	1	1	4.17	324	64.0	5.06	0.32	482.65
Zeebrugge	01/09/2001	31/10/2001	1	4.17 – 9.09	1	1	4.17	4100	52.0	78.85	0.69	13092.43

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Table S5: Summary of bird data contributing to avoidance rates for great black-backed gull.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0	5	36.0	0.14	0.77	28.92
Blyth Harbour	01/09/2016	31/03/2017	0	2.2	1	1	0	1704	54.0	31.56	0.56	10166.95
Goole Fields II	01/09/2017	31/03/2018	0	1.21	1.14	1.1	0	NA	72.0	1.30	0.69	921.57
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0	2	36.0	0.06	0.50	2.78
Red house farm	01/04/2009	31/08/2009	1	1	1	1	1	NA	36.0	0.06	1.00	20.85
Hellrigg	01/12/2011	31/03/2012	0	1	1	1	0	2	38.0	0.05	1.00	5.33
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0	18	36.5	0.49	0.93	45.96
Bouin	01/01/2003	31/12/2006	0	1	1.23	1.32	0	18	370.0	0.05	0.20	27.11
Goole Fields I	01/09/2017	31/03/2018	0	0	0	0	0	NA	NA	0.80	0.93	889.46
Slufterdam & Distridam	13/06/2012	04/07/2012	0	1 – 3.23	1	1	0	84	315.0	0.27	0.62	14.62

Table S6: Summary of bird data contributing to avoidance rates for all gulls.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Avonmouth	01/10/2007	31/03/2008	1	1	1	1	1.00	NA	NA	5.60	0.57	1861.79
Avonmouth	01/10/2008	31/03/2009	0	1	1	1	0.00	NA	NA	10.05	0.74	4,080.60
Avonmouth	01/10/2009	31/03/2010	0	1	1	1	0.00	NA	NA	10.85	0.50	3,624.87
Avonmouth	01/10/2011	31/03/2012	0	1	1	1	0.00	NA	NA	25.50	0.77	10,709.25
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	2738	180.0	15.21	0.52	3,750.06
Blyth harbour	01/09/2016	31/03/2017	3	2.2	1	1	4.60	7137	432.0	16.52	0.28	36,689.00
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/09/2005	31/12/2005	+	+	+	+	+	+	+	+	+	+
Bouin	01/01/2003	31/12/2006	30	1	1.23	1.32	48.71	6785	2590.0	2.62	0.20	10,219.95
De Put	01/01/2006	28/02/2006	2	1	1	1	2.00	160	18.0	8.89	0.62	1,060.54
Delfzijl-zuid	01/08/2006	30/10/2006	8	1.04	1.64	1.14	15.56	1496	33.0	45.33	0.12	5,336.86
Gneizdzewo	15/09/2007	15/11/2007	0	1	1	1	0.00	894	216.0	4.14	0.11	105.28

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Gneizdzewo	18/08/2008	16/11/2008	0	1	1	1	0.00	311	432.0	0.72	0.11	56.37
Gneizdzewo	15/09/2010	15/11/2010	1	1	1	1	1.00	223	272.0	0.82	0.07	64.72
Gneizdzewo	15/09/2012	15/11/2012	0	1	1	1	0.00	1839	252.0	7.30	0.07	706.96
Goole Fields I	01/04/2017	31/08/2017	0	1	1	1	0.00	2200	225.0	9.78	0.33	20,280.82
Goole Fields I	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	11.02	0.56	28,054.12
Goole Fields II	01/09/2017	31/03/2018	3	1.21	1.14	1.1	4.55	NA	504.0	18.65	0.47	51,524.59
Haverigg	01/04/2014	31/07/2014	5	1	1.07	1.12	5.99	4684	72.0	65.06	0.29	11,282.55
Haverigg	01/05/2019	31/07/2019	6	1	1.5	1.07	9.63	2773	72.0	38.51	0.89	17,029.15
Hellrigg	01/12/2011	31/03/2012	1	1	1	1	1.00	648	190.0	3.41	0.64	723.47
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	25990	182.5	142.41	0.89	62,309.40
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	6900	180.0	38.33	0.73	14,249.06
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	865	144.0	6.01	1.00	74,552.01
Kessingland	01/11/2012	31/03/2013	3	1	1.79	1	5.37	615	144.0	4.27	1.00	52,546.02

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Kleine Pathoweg	01/09/2005	31/12/2005	11	3.5	1	1	38.50	672	32.0	21.00	0.57	8,308.91
Oosterbierum	NA	NA	6	1	2.4 – 36.5	1 – 5.5	95.00	NA	NA	NA	0.28	16,977.78
Red house farm	01/04/2009	31/08/2009	4	1	1	1	4.00	NA	180.0	12.25	0.61	5,623.17
Sabinapolder	13/11/2009	03/09/2011	17	1	1	1	17.00	NA	NA	30.00	0.29	14,299.99
Slufterdam & Distridam	13/06/2012	04/07/2012	38	1 – 3.23	1	1	66.64	84,714	1,890.0	44.82	0.40	10,481.98
Thanet	01/10/2014	31/03/2015	3	1	1	1	3.00	NA	NA	NA	0.20	22,741.97
Thanet	01/10/2015	31/03/2016	2	1	1	1	2.00	NA	NA	NA	0.20	22,909.31
Zeebrugge	01/06/2000	31/07/2000	1	4.17 – 9.09	1	1	4.17	936	192.0	4.88	0.23	1,150.32
Zeebrugge	01/06/2000	31/07/2001	3	4.17 – 9.09	1	1	12.96	936	192.0	4.88	0.23	1,150.94
Zeebrugge	01/09/2001	31/10/2001	3	4.17 – 9.09	1	1	12.51	8,604	156.0	55.15	0.70	24,777.47

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Table S7: Summary of bird data contributing to avoidance rates for large gulls.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Avonmouth	01/10/2007	31/03/2008	0	1	1	1	0.00	NA	NA	6.80	0.81	1,482.76
Avonmouth	01/10/2008	31/03/2009	0	1	1	1	0.00	NA	NA	13.00	0.82	2,847.74
Avonmouth	01/10/2009	31/03/2010	0	1	1	1	0.00	NA	NA	18.80	0.67	3,368.91
Avonmouth	01/10/2011	31/03/2012	0	1	1	1	0.00	NA	NA	38.20	0.79	8,123.93
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	21	108.0	0.19	0.76	134.84
Blyth harbour	01/09/2016	31/03/2017	1	2.2	1	1	2.20	6,070	216.0	28.10	0.28	36,169.06
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/09/2005	31/12/2005	+	+	+	+	+	+	+	+	+	+
Bouin	01/01/2003	31/12/2006	1	1	1.23	1.32	1.62	891	1480.0	0.60	0.20	1341.31
Gneizdzewo	18/08/2008	16/11/2008	0	1	1	1	0.00	15	216.0	0.07	0.11	2.72
Gneizdzewo	15/09/2010	15/11/2010	0	1	1	1	0.00	117	68.0	1.72	0.11	43.77
Gneizdzewo	15/09/2012	15/11/2012	0	1	1	1	0.00	67	63.0	1.06	0.11	26.95

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Goole fields 1	01/04/2017	31/08/2017	0	1	1	1	0.00	924	135.0	6.84	0.38	13,611.31
Goole fields 1	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	3.65	0.72	11,345.61
Goole fields 2	01/09/2017	31/03/2018	1	1.21	1.14	1.1	1.52	NA	360.0	10.17	0.54	26,130.47
Haverigg	01/04/2014	31/07/2014	5	1	1.07	1.12	5.99	4,684	72.0	65.06	0.29	11,282.55
Haverigg	01/05/2019	31/07/2019	6	1	1.5	1.07	9.63	2,773	72.0	38.51	0.89	17,029.15
Hellrigg	01/12/2011	31/03/2012	1	1	1	1	1.00	144	114.0	1.26	0.81	173.29
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	2,679	109.5	24.47	0.92	6,910.97
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	1,084	108.0	10.04	0.74	2,591.99
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	493	72.0	6.85	1.00	42,490.34
Kessingland	01/11/2012	31/03/2013	1	1	1.79	1	1.79	370	72.0	5.14	1.00	31,613.06
Kleine Pathoweg	01/09/2005	31/12/2005	8	3.5	1	1	28.00	327	16.0	20.44	0.56	3,979.53
Red house farm	01/04/2009	31/08/2009	1	1	1	1	1.00	NA	108.0	1.29	0.91	1,016.33
Slufterdam & Distridam	13/06/2012	07/04/2012	34	1 – 3.23	1	1	59.08	47,943	945.0	50.73	0.54	7,798.10
Thanet	01/10/2014	31/03/2015	1	1	1	1	1.00	NA	NA	NA	0.25	12,985.88

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Thanet	01/10/2015	31/03/2016	1	1	1	1	1.00	NA	NA	NA	0.25	13,081.44
Zeebrugge	01/06/2000	31/07/2000	1	4.17 – 9.09	1	1	4.17	868	128.0	6.78	0.29	1,113.21
Zeebrugge	01/06/2001	31/07/2001	3	4.17 – 9.09	1	1	12.96	868	128.0	6.78	0.29	1,113.82
Zeebrugge	01/09/2001	31/10/2001	3	4.17 – 9.09	1	1	12.51	8,228	104.0	79.12	0.61	23,258.97

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Table S8: Summary of bird data contributing to avoidance rates for small gulls.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Avonmouth	01/10/2007	31/03/2008	1	1	1	1	1.00	NA	NA	4.40	0.32	379.03
Avonmouth	01/10/2008	31/03/2009	0	1	1	1	0.00	NA	NA	7.10	0.65	1,232.86
Avonmouth	01/10/2009	31/03/2010	0	1	1	1	0.00	NA	NA	2.90	0.33	255.96
Avonmouth	01/10/2011	31/03/2012	0	1	1	1	0.00	NA	NA	12.80	0.75	2,584.32
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	2,717	72	37.74	0.18	3,615.22
Blyth harbour	01/09/2016	31/03/2017	2	2.2	1	1	2.40	1,067	216	4.94	0.27	519.94
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/09/2005	31/12/2005	+	+	+	+	+	+	+	+	+	+
Bouin	01/01/2003	31/12/2006	29	1	1.23	1.32	47.08	5,894	1,110	5.31	0.20	8,878.63
De Put	01/01/2006	28/02/2006	2	1	1	1	2.00	160	18	8.89	0.62	1,060.54
Gneizdzewo	15/09/2010	15/11/2010	1	1	1	1	1.00	77	136	0.57	0.04	10.11
Gneizdzewo	15/09/2012	15/11/2012	0	1	1	1	0.00	142	126	1.13	0.04	24.37

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Goole fields 1	01/04/2017	31/08/2017	0	1	1	1	0.00	1,276	90	14.18	0.24	6,669.51
Goole fields 1	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	25.75	0.24	16,708.51
Goole fields 2	01/09/2017	31/03/2018	2	1.21	1.14	1.1	3.03	NA	144	39.85	0.29	25,394.13
Hellrigg	01/12/2011	31/03/2012	0	1	1	1	0.00	504	76	6.63	0.38	550.18
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	23,311	73	319.33	0.84	55,398.43
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	5,816	72	80.78	0.72	11,657.07
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	372	72	5.17	1.00	32,061.67
Kessingland	01/11/2012	31/03/2013	2	1	1.79	1	3.58	245	72	3.40	1.00	20,932.97
Kleine Pathoweg	01/09/2005	31/12/2005	3	3.5	1	1	10.50	345	16	21.56	0.57	4,329.38
Red house farm	01/04/2009	31/08/2009	3	1	1	1	3.00	NA	72	28.70	0.15	4,606.84
Slufterdam & Distridam	13/06/2012	04/07/2012	4	1 – 3.23	1	1	7.56	36,771	945	38.91	0.26	2,683.88
Thanet	01/10/2014	31/03/2015	1	1	1	1	1.00	NA	NA	NA	0.10	2,133.94
Thanet	01/10/2015	31/03/2016	0	1	1	1	0.00	NA	NA	NA	0.10	2,149.64
Zeebrugge	01/06/2000	31/07/2000	0	4.17 – 9.09	1	1	0.00	68	64	1.06	0.12	37.11

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Zeebrugge	01/06/2001	31/07/2001	0	4.17 – 9.09	1	1	0.00	68	64	1.06	0.12	37.13
Zeebrugge	01/09/2001	31/10/2001	0	4.17 – 9.09	1	1	0.00	376	52	7.23	0.87	1,518.5

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Table S9: Summary of bird data contributing to avoidance rates for sandwich tern.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Blyth harbour	01/09/2016	31/03/2017	0	2.2	1	1	0.00	4.0	54	0.07	0.50	15.59
Bouin	01/01/2003	31/12/2006	0	1	1.23	1.32	0.00	1.5	370	0.00	0.20	1.82
Slufterdam & Distridam	13/06/2012	04/07/2012	1	1 – 3.23	1	1	1.00	378.0	315	1.20	0.12	11.48
Zeebrugge	01/06/2000	31/07/2000	0	4.17 – 9.09	1.1	1.16	0.00	44.0	64	0.69	0.69	33.19
Zeebrugge	01/06/2001	31/07/2001	0	4.17 – 9.09	1.1	1.16	0.00	44.0	64	0.69	0.69	33.21
Zeebrugge	01/09/2001	31/10/2001	0	4.17 – 9.09	1.1	1.16	0.00	96.0	52	1.85	1.85	132.00
Zeebrugge	01/06/2004	30/06/2004	3	4.17 – 9.09	1.1	1.16	28.52	90,192.0	102	884.24	884.24	6,114.32
Zeebrugge	01/06/2005	30/06/2005	3	4.17 – 9.09	1.1	1.16	15.96	73,920.0	102	724.71	724.71	10,353.28

Table S10: Summary of bird data contributing to avoidance rates for all terns.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Blyth harbour	01/09/2016	31/03/2017	0	2.2	1	1	0.00	4.0	54	0.07	0.50	15.59
Bouin	01/01/2003	31/12/2006	0	1	1.23	1.32	0.00	25.5	740	0.03	0.20	30.97
Slufterdam & Distridam	13/06/2012	04/07/2012	5	1 – 3.23	1	1	9.10	54,327.0	945	57.49	0.12	1,649.22
Zeebrugge	01/06/2000	31/07/2000	0	4.17 – 9.09	1.1	1.16	0.00	9,476.0	192	49.35	0.23	14,353.27
Zeebrugge	01/06/2001	31/07/2001	1	4.17 – 9.09	1.1	1.16	5.32	9,476.0	192	49.35	0.23	14,364.94
Zeebrugge	01/09/2001	31/10/2001	0	4.17 – 9.09	1.1	1.16	0.00	6,860.0	156	43.97	0.36	12,232.24
Zeebrugge	01/06/2004	30/06/2004	9	4.17 – 9.09	1.1	1.16	73.00	161,724.0	306	528.51	0.08	11,735.33
Zeebrugge	01/06/2005	30/06/2005	12	4.17 – 9.09	1.1	1.16	89.54	101,436.0	306	331.49	0.35	19,396.19

Table S11: Summary of bird data contributing to avoidance rates for all gulls & terns.

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Avonmouth	01/10/2007	31/03/2008	1	1	1	1	1.00	NA	NA	5.60	0.57	1861.79
Avonmouth	01/10/2008	31/03/2009	0	1	1	1	0.00	NA	NA	10.05	0.74	4,080.60
Avonmouth	01/10/2009	31/03/2010	0	1	1	1	0.00	NA	NA	10.85	0.50	3,624.87
Avonmouth	01/10/2011	31/03/2012	0	1	1	1	0.00	NA	NA	25.50	0.77	10,708.25
Bloodgate Hill	01/10/2007	27/02/2008	0	1	1	1	0.00	2,738.0	180.0	15.21	0.52	3,750.06
Blyth harbour	01/09/2016	31/03/2017	3	2.2	1	1	4.60	7,141.0	486.0	14.69	0.30	36,704.58
Boudwijnkanaal	01/05/2001	31/05/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/10/2001	31/10/2001	+	+	+	+	+	+	+	+	+	+
Boudwijnkanaal	01/09/2005	31/12/2005	+	+	+	+	+	+	+	+	+	+
Bouin	01/01/2003	31/12/2006	30	1	1.23	1.32	48.71	6810.5	3330.0	2.05	0.20	10250.92
De Put	01/01/2006	28/02/2006	2	1	1	1	2.00	160.0	18.0	8.89	0.62	1060.54
Delfzijl-zuid	01/08/2006	30/10/2006	8	1.04	1.64	1.14	15.56	1496.0	33.0	45.33	0.12	5336.86
Gneizdzewo	15/09/2007	15/11/2007	0	1	1	1	0.00	894.0	216.0	4.14	0.11	105.28

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Gneizdzewo	18/08/2008	16/11/2008	0	1	1	1	0.00	311.0	432.0	0.72	0.11	56.37
Gneizdzewo	15/09/2010	15/11/2010	1	1	1	1	1.00	223.0	272.0	0.82	0.07	64.72
Gneizdzewo	15/09/2012	15/11/2012	0	1	1	1	0.00	1,839.0	252.0	7.30	0.07	706.96
Goole fields 1	01/04/2017	31/08/2017	0	1	1	1	0.00	2,200.0	225.0	9.78	0.33	20,280.82
Goole fields 1	01/09/2017	31/03/2018	0	0	0	0	0.00	NA	NA	11.02	0.56	28,054.12
Goole fields 2	01/09/2017	31/03/2018	3	1.21	1.14	1.1	4.55	NA	504.0	18.65	0.47	51,524.59
Haverigg	01/04/2014	31/07/2014	5	1	1.07	1.12	5.99	4,684.0	72.0	65.06	0.29	11,282.55
Haverigg	01/05/2019	31/07/2019	6	1	1.5	1.07	9.63	2,773.0	72.0	38.51	0.89	17,029.15
Hellrigg	01/12/2011	31/03/2012	1	1	1	1	1.00	648.0	190.0	3.41	0.64	723.47
Hellrigg	01/12/2012	31/03/2013	0	1	1	1	0.00	25,990.0	182.5	142.41	0.89	62,309.40
Hellrigg	01/12/2014	31/03/2015	0	1	1	1	0.00	6,900.0	180.0	38.33	0.73	14,249.06
Kessingland	01/11/2011	31/03/2012	0	1	1.79	1	0.00	865.0	144.0	6.01	1.00	74,552.01
Kessingland	01/11/2012	31/03/2013	3	1	1.79	1	5.37	615.0	144.0	4.27	1.00	52,546.02

Site	Start date	End date	Observed carcasses	Area correction	Predation correction	Efficiency correction	Corrected carcasses	Observed passage	Hours of monitoring	Passage rate (birds/ hour)	% flight at rotor height	Flux in sweep zone
Kleine Pathoweg	01/09/2005	31/12/2005	11	3.5	1	1	38.50	672.0	32.0	21.00	0.57	8,308.91
Oosterbierum	NA	NA	6	1	2.4 – 36.5	1 – 5.5	95.00	NA	NA	NA	0.28	16,977.78
Red house farm	01/04/2009	31/08/2009	4	1	1	1	4.00	NA	180.0	12.25	0.61	5,623.17
Sabinapolder	13/11/2009	03/09/2011	17	1	1	1	17.00	NA	NA	30.00	0.29	14,299.99
Slufterdam & Distridam	13/06/2012	04/07/2012	43	1 – 3.23	1	1	75.74	139,041.0	2835.0	49.04	0.31	12,131.20
Thanet	01/10/2014	31/03/2015	3	1	1	1	3.00	NA	NA	NA	0.20	22,741.97
Thanet	01/10/2015	31/03/2016	2	1	1	1	2.00	NA	NA	NA	0.20	22,909.31
Zeebrugge	01/06/2000	31/07/2000	1	4.17 – 9.09	1 – 1.1	1 – 1.16	4.17	10,412.0	384.0	27.11	0.23	15,503.59
Zeebrugge	01/06/2001	31/07/2001	4	4.17 – 9.09	1 – 1.1	1 – 1.16	18.28	10,412.0	384.0	27.11	0.23	15,515.89
Zeebrugge	01/09/2001	31/10/2001	3	4.17 – 9.09	1 – 1.1	1 – 1.16	12.51	15,464.0	312.0	49.56	0.53	37,009.70
Zeebrugge	01/06/2004	30/06/2004	9	4.17 – 9.09	1.1	1.16	73.00	161,724.0	306.0	528.51	0.08	11,735.33
Zeebrugge	01/06/2005	30/06/2005	12	4.17 – 9.09	1.1	1.16	89.54	101,436.0	306.0	331.49	0.35	19,396.19

+ Data used in the analysis, but the authors do not have permission to make the details public in this report.

Appendix 3: Additional avoidance rates

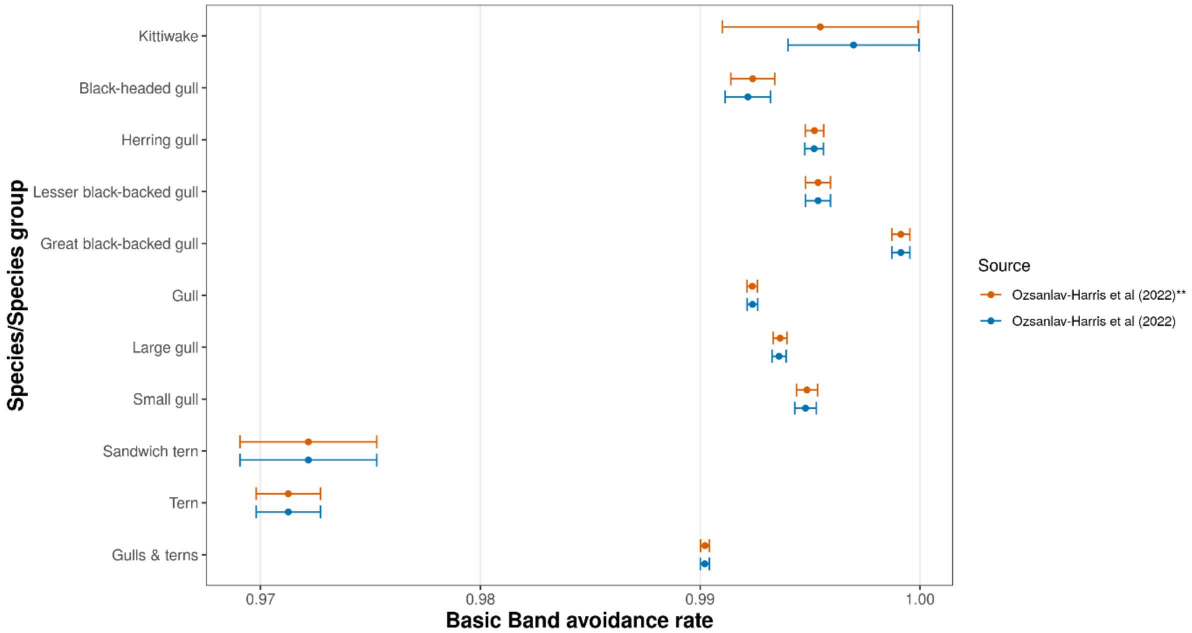

Figure S1. Seabird avoidance rates calculated using the basic Band model, error bars represent the 95% confidence interval calculated using the delta method (Powell 2007). ** are avoidance rates calculated using four additional changes marked with a "*" in Table 1.

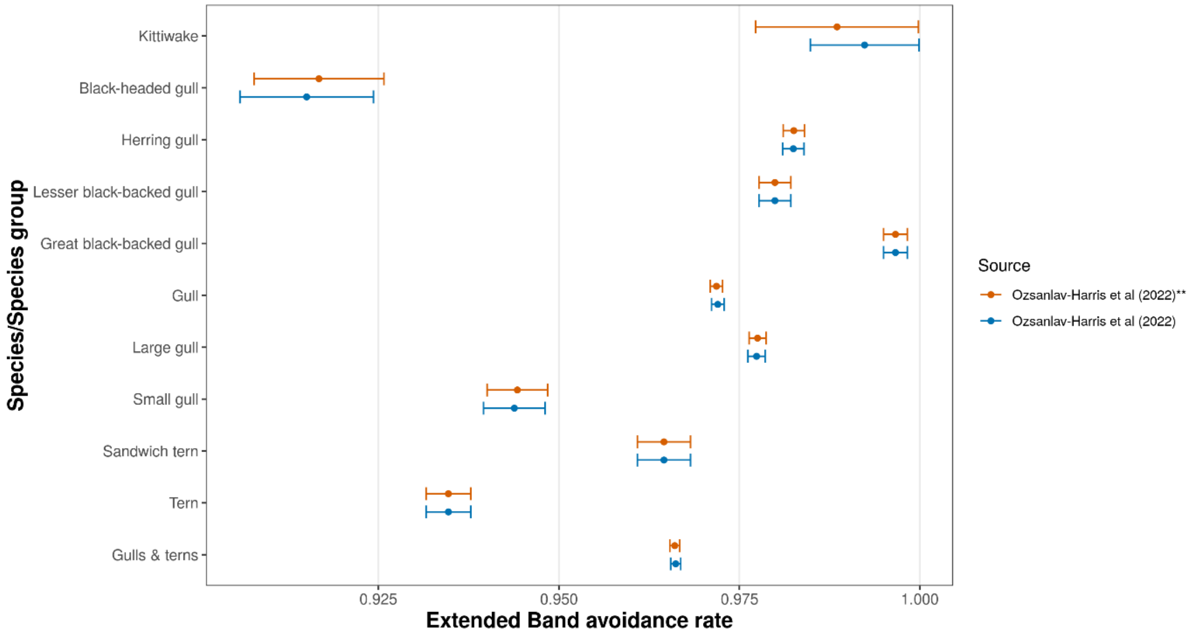

Figure S2. Seabird avoidance rates calculated using the extended Band model, error bars represent the 95% confidence interval calculated using the delta method (Powell 2007). ** are avoidance rates calculated using four additional changes marked with a "*" in Table 1.

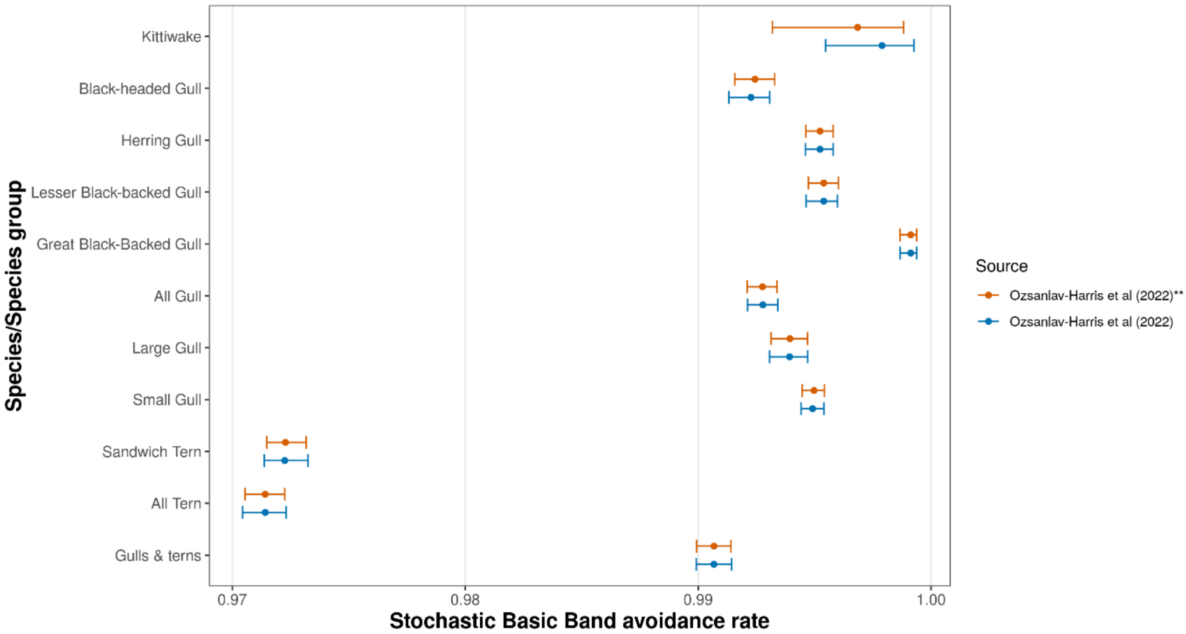

Figure S3. Seabird avoidance rates calculated using the basic stochastic collision risk model, error bars represent the 95% confidence interval calculated from 1,000 random iterations were input parameter values were varied. ** are avoidance rates calculated using four additional changes marked with a "*" in Table 1.

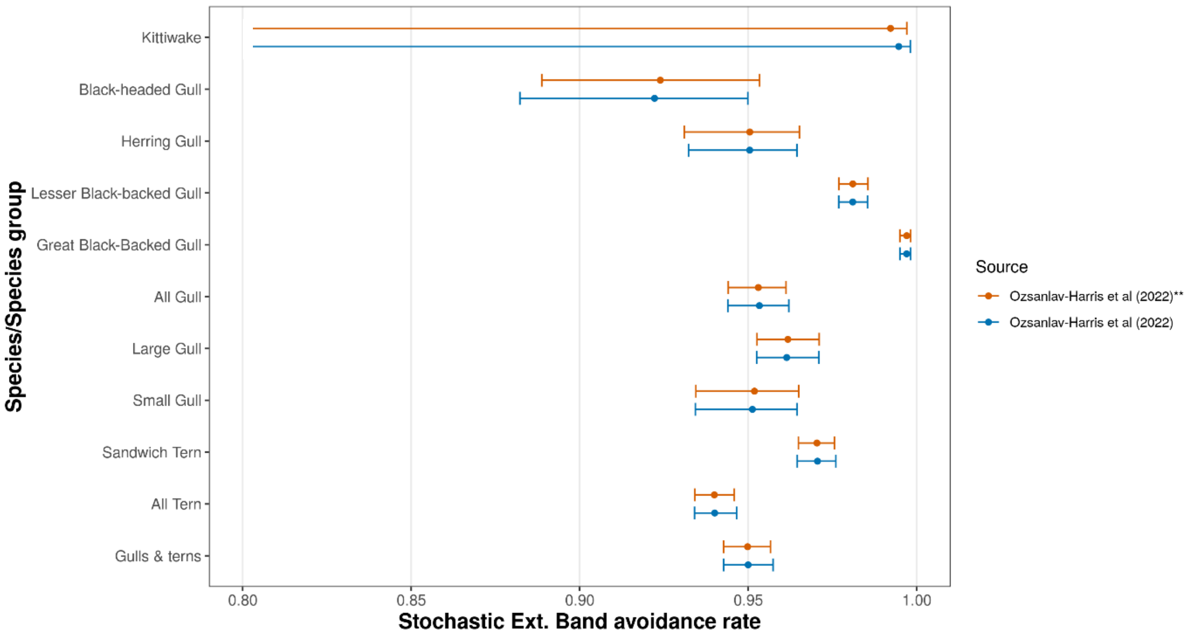

Figure S4. Seabird avoidance rates calculated using the extended stochastic collision risk model, error bars represent the 95% confidence interval calculated from 1,000 random iterations were input parameter values were varied. ** are avoidance rates calculated using four additional changes marked with a "*" in Table 1. Note: the lower confidence interval for Kittiwake has been removed to assist interpreting the plot. The values were 0.262 and 0.413 for Ozsanlav-Harris *et al.* (2022) ** and Ozsanlav-Harris *et al*. (2022), respectively.