Joint advice note from the Statutory Nature Conservation Bodies (SNCBs) regarding bird collision risk modelling for offshore wind developments

JNCC, Natural England, Natural Resources Wales, NatureScot

August 2024

For further information please contact:
JNCC, Quay House, 2 East Station Road, Fletton Quays, Peterborough PE2 8YY
https://jncc.gov.uk/
Communications@jncc.gov.uk

This resource was produced by the Statutory Nature Conservation Bodies JNCC, Natural England, Natural Resources Wales and NatureScot.

This document should be cited as:
JNCC, Natural England, Natural Resources Wales, NatureScot. 2024. *Joint advice note from the Statutory Nature Conservation Bodies (SNCBs) regarding bird collision risk modelling for offshore wind developments*. JNCC, Peterborough. https://hub.jncc.gov.uk/f7892820-0f84-4e96-9eff-168f93bd343d.

Acknowledgments:

Individuals from JNCC, Natural England, Natural Resources Wales and NatureScot have contributed to this note.

This document is compliant with JNCC's Evidence Quality Assurance Policy.

Contents

1. Summary and recommendations

This guidance from the Statutory Nature Conservation Bodies (SNCBs – comprising JNCC, Natural England, Natural Resources Wales and NatureScot) provides recommendations on how the Offshore Wind Farm (OWF) industry should apply the available evidence on turbine collision risk to the impact assessment process. This is an updated advice note that covers the input parameters required for collision risk modelling (CRM), including updated avoidance rates. The guidance incorporates new collision data from terrestrial wind farms and the Offshore Renewables Joint Industry Programme (ORJIP) Bird Collision Avoidance study presented in Skov *et al*. (2018). This data was initially presented in the recent work on recalculating Avoidance Rates undertaken by the British Trust for Ornithology (BTO) (Cook 2021) and has been revised and further updated by Ozsanlav-Harris *et al*. (2023)

Recommended bird parameter values, including avoidance rates, are presented for use within the context of both the deterministic Band Collision Risk Model (CRM) (Band 2012) and the stochastic Collision Risk Model (sCRM) (Caneco & Humphries 2022 – note that, at the time of writing, this was at Beta release stage and therefore requiring, and undergoing, testing). The recommended values to use in each CRM scenario for each parameter for each key species are provided in Section 9.

The recommendations (further described in the main body of this guidance note) are:

- For all collision risk modelling, we recommend variability is incorporated. This can be implemented using the sCRM for seabird species (Caneco & Humphries 2022)
- The avoidance rates detailed in Tables 1, 2 and 3 of this note should be used, based on work presented in Cook (2021) and Ozsanlav-Harris *et al*. (2023).
- Tables 2 and 3 provide SNCB recommended biometric and other input parameters which should be used.
- Mean collision estimates and associated 95% confidence limits should be presented in tabular form, as generated by the sCRM tool (Caneco & Humphries 2022).
- We recommend that Option 2 of the Basic Band model is always presented, with other options presented if appropriate. Where robust and appropriate site-specific flight height data relevant to the proposed development is available, Option 1 can be presented. We do not recommend that the Extended model is used.
- All output files generated by the sCRM tool should be provided, including Excel (xlsx) worksheets with the monthly collision statistics for each model option, as well as the annual overall collisions. When presenting outputs from the sCRM tool, the input and output log files should be presented. Input parameters should include if Highest Astronomical Tide (HAT) or Lowest Astronomical Tide (LAT) was used, pitch, and rotor speed in addition to bird parameters.

2. Background

The SNCBs welcome recent initiatives which have improved the evidence base around input parameters for use within collision risk modelling. In response to this improved evidence base, this note constitutes revised SNCB advice (replacing the 2014 SNCB advice note), advising appropriate avoidance rates and other key bird parameters for use within Band (2012) and Caneco & Humphries (2022) CRM. We welcome the body of evidence that constitutes the ORJIP-funded Bird Collision Avoidance study (Skov *et al*. 2018), the development of stochastic approaches to CRM (Masden 2015; McGregor *et al*. 2018), the recent review of avoidance rates (Cook 2021) and the further work and sensitivity analysis by Ozsanlav-Harris *et al*. (2023).

As SNCBs provide advice based on the best available evidence, our position on avoidance rates and other CRM parameters is subject to change as new empirical data become available.

We acknowledge that the European Offshore Wind Deployment Centre (EOWDC) bird collision avoidance study has reported (Tjørnløv *et al*. 2023) since the work undertaken by Ozsanlav-Harris *et al*. (2023). It has not been possible to incorporate data from Tjørnløv *et al*. (2023) into our advice on avoidance rates at this stage as it was not available in a suitable format at the time of the analysis by Ozsanlav-Harris *et al*. (2023). The SNCBs would not recommend avoidance rates based on evidence from single/individual windfarms are used. Our recommended avoidance rates use all available evidence across windfarms and locations. Any future updates would consider this evidence (alongside other relevant evidence that may emerge).

2.1. Collision Models

Band (2012) describes four options, based on either the Basic Band model (which assumes a uniform distribution of flight heights within the collision risk height range), or the Extended Band model (which uses flight height distribution data in calculating the probability of collision at different distances from the rotor hub).

- Option 1: Basic Band model using site-specific data for proportion of birds at risk height.
- Option 2: Basic Band model using generic data for proportion of birds at risk height.
- Option 3: Extended Band model using generic data for flight height distributions.
- Option 4: Extended Band model using site-specific data for flight height distributions.

There have been several implementations of a stochastic Band (2012) CRM. McGregor *et al*. (2018) provided a user interface which was based on the stochastic version of Band (2012) initially developed in Masden 2015. Support for this has now been withdrawn, and it has been replaced by Caneco & Humphries (2022) interface which is termed the sCRM tool, and is based on stochLAB R package (which can also be used directly). This is intended to improve the user experience, and the efficiency and ease of undertaking multiple CRMs. The sCRM tool uses essentially the same modelling process and formulae as in Band (2012) but implemented so as to consider stochasticity around input parameters and provide as output a distribution of likely collision rates reflecting that stochasticity rather than a single predicted collision rate such as the Band (2012) spreadsheet provides. The sCRM can also be used to run a deterministic Band (2012) analysis exactly as in the Band (2012) spreadsheet.

We do not recommend that the Extended model is used and hence do not provide any parameter recommendations for the Extended model (see Section 4).

2.2. Avoidance rates

This note updates the SNCB advice note on avoidance rates from 2014 and provides more comprehensive guidance on CRM parameterisation. The SNCB 2014 note was based on work in Cook *et al*. (2014) to calculate collision avoidance rates, based on empirical collision data available at that time, which noted a distinct lack of data available from OWFs. Skov et al. (2018) provided empirical evidence of avoidance behaviour at different scales at an OWF but none of these alone, or combined, compare directly with avoidance rates that can be applied within Band (2012) nor McGregor *et al*. (2018) collision risk models. The calculated avoidance rates recommended (e.g. Cook *et al*. 2014; Cook 2021; Ozsanlav-Harris *et al*. 2023; and previous SNCB advice) incorporate elements of error in relation to both the data used and the model itself (Band 2012). The incorporation of this error means that the avoidance rates used by Band (2012) or McGregor *et al*. (2018) are likely to be lower than those measured empirically such as in Skov *et al*. (2018). For this reason, we do not recommend that the avoidance rates presented in Skov *et al*. (2018) are applied directly to collision risk modelling using Band (2012) nor McGregor *et al*. (2018).

To address this issue, JNCC commissioned the BTO to undertake follow-on work to consider how best to make use of the data collected by the ORJIP Bird Collision Avoidance project at Thanet OWF in order to estimate improved avoidance rates suitable for use within Band (2012) and/or McGregor *et al*. (2018). This work, presented in Bowgen & Cook (2018), used data from the ORJIP study, along with publicly available pre- and post-construction density information from the OWF site, to assess the number of collisions observed in the ORJIP study compared to those that would be predicted in the absence of any avoidance behaviour using Band (2012), and to calculate avoidance rates based on the differences between observed and predicted collisions. Bowgen & Cook (2018) looked at other parameters within Band (2012) to identify those for which it is most important to have accurate information and for which differences either in the way the parameter is measured/calculated, or between sites, can markedly influence the predicted number of collisions.

The analysis of Bowgen & Cook (2018) only considered data from a single site and may not be transferable to other sites where birds may behave differently. To address this, in 2020 Natural England commissioned the BTO to undertake a review of all available studies with the aim of combining data from the sites presented in Cook *et al*. (2014), with those derived from the ORJIP study (Bowgen & Cook 2018), and any additional sites with appropriate data, to derive avoidance rates based on data across a range of sites (Cook 2021). MacArthur Green undertook a critical review of Cook (2021), which highlighted some concerns with the way the data was used to calculate avoidance rates, in particular the influence of one particular wind farm on overall avoidance rates. In response to these concerns, JNCC commissioned further review and sensitivity analysis (Ozsanlav-Harris *et al*. 2023). The SNCBs recommend the use of avoidance rates in Ozsanlav-Harris *et al*. (2023) and these are presented in Tables 1, 2 and 3 below.

3. Recommended Avoidance Rates

The SNCB recommended avoidance rates are those presented in Annex 4 of Ozsanlav-Harris *et al*. (2023) which ensures that the avoidance rates are consistent with Caneco & Humphries (2022) sCRM and associated stochLAB R package. This work incorporates collision data from all suitable terrestrial, coastal and offshore wind farms that was available at the time of the analyses.

The previous 2014 advice note provided avoidance rate advice on five key species (lesser black-backed gull *Larus fuscus*, herring gull *Larus argentatus*, great black-backed gull *Larus marinus*, black-legged kittiwake *Rissa tridactyla* and northern gannet *Morus bassanus*). Aside from herring gull, all recommended avoidance rates were derived from a species group dataset (e.g. ‘all gull’ for kittiwake and gannet) or a species sub-group (‘large gull’ for lesser black-backed gull and great black-backed gull) and for all other species (e.g. terns, skuas) a default rate of 98% was advised.

This current guidance seeks to simplify this further, acknowledging that the paucity of offshore, species-specific data undermines the confidence we can place in species-specific rates at this stage.

3.1. Lesser black-backed, great black-backed, and herring gull

We recommend the ‘large gull’ rate for these species.

Whilst individually, these species had data to estimate avoidance rates from up to 12 sites, data quality is variable. Individual species avoidance rates are similar (Tables 2 to 5 and Annex 4 from Ozsanlav-Harris *et al*. 2023) as expected from these biologically similar species, particularly for the Basic Band model. We therefore recommend an amalgamated ‘large gull’ rate for each of these species.

3.2. Kittiwake

We recommend that the ‘all gull’ rate is used for black-legged kittiwake.

There was data with which to estimate avoidance rates for this species from only two sites. Whilst kittiwake are a small gull, behaviourally they may be considered as not very similar to the other small gull species for which we have data to estimate avoidance rates, insofar as kittiwake are considered more marine in nature and forage much further offshore than other small species for which we have data (e.g. Woodward *et al*. 2019). We therefore recommend an amalgamated ‘all gull’ rate for this species.

3.3. Common and black headed gulls

We recommend the ‘small gull’ rate for these species.

Whilst individually, these species had data to estimate avoidance rates from up to 13 sites, data quality is variable. We therefore recommend an amalgamated ‘small gull’ rate for each of these species.

3.4. All other gulls and skuas

We recommend the ‘all gull’ rate is used for all other gull species, and for skuas.

Given the lack of data for other gull species, we recommend using the ‘all gull’ rate for any gull species not already covered. Given the lack of data for skua species and the fact that skuas are behaviourally similar to gulls, we recommend using the ‘all gull’ rate for any skua species.

3.5. Gannet

We recommend the ‘all gull’ rate is used for gannet.

There is extremely limited species-specific data to estimate an avoidance rate for this species. Whilst we might consider the most biologically similar species for which we do have data to be the larger gull species, given the uncertainties around gannet avoidance behaviours in vicinity of turbines and manoeuvrability, we have chosen to use an amalgamation of data across all gulls to reflect this uncertainty.

The avoidance rates calculated in Ozsanlav-Harris *et al*. (2023), as with previously estimated avoidance rates, are within-windfarm avoidance rates. Whilst this is sufficient to capture avoidance for most species, studies have consistently shown that gannet exhibit macro-avoidance (similar to displacement but affects flying birds only; reduces the number of birds entering an OWF footprint compared to what might be expected in the absence of the OWF).

We recommend that the ‘all gull’ within-windfarm avoidance rate is used for gannet. Consideration should be given to applying a macro-avoidance rate in addition to this. This may be achieved in practice by reducing the density of gannet in flight going into the CRM by an appropriate macro-avoidance rate. Natural England have commissioned a review of gannet macro-avoidance rates which can inform this. Potential application of macro-avoidance rates to gannet may differ between countries and therefore should be discussed with the relevant SNCB.

3.6. Terns

We recommend that the ‘all gulls and terns’ rate is used for all tern species.

Individually, and collectively, tern species had data to estimate avoidance rates from only two sites. The data set is heavily influenced by one of these sites, Zeebrugge, where the turbine locations relative to the colony are not considered representative; the Zeebrugge turbines are positioned on a breakwater between the tern colony and the sea and account for 44 of the 45 sandwich tern collisions.

In the absence of a more balanced set of data for tern behaviour we consider it more appropriate to recommend that the ‘all gulls and terns’ rate is used for terns at this time.

3.7. Other marine species

For any species not covered above, we recommend discussion with the relevant SNCB. The ‘all gulls and terns’ rate is likely to be the default for most species not already covered.

Table 1: Recommended Avoidance Rates (AR) for Collision Risk Modelling.

Species	Basic Band (2012) Model AR (standard deviation) [Note 1]	Basic sCRM AR (standard deviations)
Northern gannet [Note 2] **Black-legged kittiwake** **All other gulls and skuas** (All gull rate)	0.9923 (± 0.0001)	0.9929 (± 0.0003)
Lesser black-backed gull **Herring gull** **Great black-backed gull** (Large gull rate)	0.9936 (± 0.0002)	0.9940 (± 0.0004)
Common gull **Black-headed gull** (Small gull rate)	0.9947 (± 0.0003)	0.9949 (± 0.0003)
Sandwich tern **All other tern species** All gulls and terns rate)	0.9902 (± 0.0001)	0.9908 (± 0.0004)

Note 1: Ozsanlav-Harris *et al*. (2023) calculated SDs for all avoidance rates and they are reproduced here for completeness, though they are not an input used in the Band model.

Note 2: Macro-avoidance should also be considered for this species and accounted for by a reduction of density of birds in flight to account for macro-avoidance displayed by this species. This should be discussed with the appropriate SNCB.

4. Recommended flight height data

Cook *et al*. (2014) demonstrated the importance of having robust estimates of the proportion of birds at Potential Collision Height (PCH). They found, for small gulls in particular, a consistent mismatch between generic modelled flight height distributions and the observed proportion of birds flying at PCH in empirical studies. This may be because the empirical studies used by Cook *et al*. (2014) to derive avoidance rates were all onshore, while the suite of studies used to model generic flight height distributions included more offshore data. These discrepancies mean that avoidance rates are likely to be underestimated for the Extended model using the generic offshore flight height distributions (Ozsanlav-Harris *et al*. 2023). Therefore, we do not recommend use of the Extended variants.

We recommend that robust site-specific flight height data is utilised for proposed offshore wind developments, if available. Agreement with the relevant SNCB regarding flight height data collection technique will be required. Largey *et al*. (2021) provides a recent review of possible methods.

Outputs from Option 2 of the Basic Band model should always be presented alongside any Option 1 outputs if presented, for comparison. This should use the generic flight height information in Johnston *et al*. (2014).

5. Recommended flight speed data

Work is currently being undertaken using tracking data for a number of species at a range of sites, which will provide further information on flight speeds. Whilst this may lead to updated flight speed recommendations, in the meantime we recommend the use of flight speeds presented in Tables 2 and 3. However, where there is site or region-specific evidence that may be appropriate to use, please consult with the relevant SNCB.

6. Recommended Nocturnal Activity Rates

We advise that nocturnal activity factor (NAF) for gannet, kittiwake and lesser black-backed gull are based on Cook *et al*. 2023. For other species we advise a range of NAFs which remains based on Garthe & Hüppop (2004).

When using the deterministic Band model, for species other than gannet, kittiwake and lesser black-backed gull the model should be run twice using the lower and upper nocturnal activity levels. When using the sCRM we suggest using a mean and SD that reflects the likely nocturnal activity range.

The nocturnal activity levels that the SNCBs recommend are provided in Tables 2 and 3.

7. Recommended bird density data

Both Band (2012) and McGregor *et al*. (2018) require monthly bird density data to be provided as an input. For the deterministic (Band) model we advise that mean species densities for each month with the corresponding upper and lower 95% Confidence Intervals (CIs) are used.

When running the sCRM (McGregor *et al*. 2018), the uncertainty/variability around the monthly density estimates should be specified. There are three options in the sCRM tool for providing the bird density inputs with uncertainty measures in the sCRM:

1. Mean species densities with standard deviations
2. Maximum (max), minimum (min), and selected percentiles from a distribution of mean density estimates
3. 1,000 samples from a distribution of mean densities (e.g. from a bootstrapped sample)

Use of mean densities with standard deviations is not recommended for use with the sCRM as the model samples from a truncated normal distribution and this may not reflect the distribution of the bird density data from the site (Trinder 2017).

The second option requires a set of reference points for the site density data to be provided to generate a distribution to sample from. As a minimum this should include a minimum, maximum, and median (50th centile) density value. Other centiles can also be added. This option may be used if a model-based approach to generate density estimates is used (e.g. MRSea).

The third option is to upload 1,000 samples from a distribution of mean density values (e.g. as generated by bootstrapping). If this option is used, then the bootstrapped data should be provided to enable the modelling to be re-run and the outputs checked.

We recommend that option 3 is used, with option 2 acceptable in some cases.

8. Recommendations for undertaking collision assessment in-combination with other OWFs

The advice presented in this note applies equally to assessments of a proposed OWF alone and in-combination with other existing and planned OWFs. Insofar as is possible, attempts should be made to calculate predicted collisions at relevant existing and planned OWFs using tools and parameters that we would advise (Tables 2 and 3).

It is outside the scope of this note to provide detailed discussion or advise on undertaking in-combination assessments, but we are aware of the cumulative effects framework (CEF) tool (led by the UK Centre for Ecology & Hydrology). The SNCBs are working together to develop a collective knowledge and experience of the tool and will provide further information on conducting in-combination assessments and use of the CEF tool in due course. In the meantime, please discuss in-combination assessments with the relevant SNCBs.

9. Recommended parameters by species

Table 2: SNCB recommended parameters for the Basic Band model – Option 1 or 2 (Band 2012).

Species	**Avoidance rate (AR)**	**Flight speed (m/s) [note 1]**	**Nocturnal Activity Factor (NAF) [note 2]**	**Body length (m) [note 3]**	**Wingspan (m) [note 3]**	**Flight type**	**% of flights upwind**
Northern gannet [note 4]	0.9923	14.9	14% 1.56	0.94	1.72	Flapping [note 5]	50
Black-legged kittiwake	0.9923	13.1	40% 2.60	0.39	1.08	Flapping	50
Lesser black-backed gull	0.9936	13.1	30% 2.20	0.58	1.42	Flapping	50
Herring gull	0.9936	12.8	25–50% 2–3	0.60	1.44	Flapping	50
Great black-backed gull	0.9936	13.7	25–50% 2–3	0.71	1.58	Flapping	50
Sandwich tern	0.9902	10.3	Defer to Garthe and Huppop 2004 or where empirical data is available consult SNCB	0.38	1.00	Flapping	50
Common gull, Black-headed gull	0.9947	Consult SNCB		Consult SNCB	Consult SNCB	Flapping	50
All other gulls and skuas	0.9923	Consult SNCB		Consult SNCB	Consult SNCB	Consult SNCB	Consult SNCB
All other tern species	0.9902	Consult SNCB		Consult SNCB	Consult SNCB	Consult SNCB	Consult SNCB

Note 1: Flight speeds from Alerstam *et al*. (2007) except for gannet from Pennycuick (1997) and Sandwich tern from Fijn & Gyimesi (2018).

Note 2: Based on Garthe & Hüppop (2004) other than gannet, kittiwake and lesser black-backed gull which is based on Cook *et al*. (2023).

Note 3: All named species from Snow & Perrins (1998).

Note 4: See section 3.5 and Table 1 regarding macro-avoidance.

Note 5: We acknowledge that in reality, northern gannet display both flapping and gliding flight types.

Table 3: SNCB recommended parameters for the Basic stochastic CRM model (Caneco & Humphries 2022) – Option 1 or 2.

Species	Avoidance rate (AR)	Flight speed (m/s) [note 1]	Nocturnal Activity Factor (NAF) [note 2]	Body length (m) [note 3]	Wingspan (m) [note 3]	Flight type	% of flights upwind
Northern gannet [note 4]	0.9929 (± 0.0003)	14.9 (± 0)	0.14 (± 0.10)	0.94 (± 0.0325)	1.72 (± 0.0375)	Flapping [note 5]	50
Black-legged kittiwake	0.9929 (± 0.0003)	13.1 (± 0.40)	0.40 (± 0.12)	0.39 (± 0.005)	1.08 (± 0.0625)	Flapping	50
Lesser black-backed gull	0.9940 (± 0.0004)	13.1 (± 1.90)	0.30 (± 0.18)	0.58 (± 0.03)	1.42 (± 0.0375)	Flapping	50
Herring gull	0.9940 (± 0.0004)	12.8 (± 1.80)	Use central value 0.375 and SD of (0.0637) that results in 0.25 and 0.5 being captured in the 95% CI	0.60 (± 0.0225)	1.44 (± 0.03)	Flapping	50
Great black-backed gull	0.9940 (± 0.0004)	13.7 (± 1.20)		0.71 (± 0.035)	1.58 (± 0.0375)	Flapping	50
Sandwich tern	0.9908 (± 0.0004)	10.3 (± 3.4)	Defer to Garthe & Hüppop (2004) or where empirical data is available consult SNCB	0.38 (± 0.005)	1.00 (± 0.04)	Flapping	50
Common gull, Black-headed gull	0.9949 (± 0.0003)	Consult SNCB		Consult SNCB	Consult SNCB	Flapping	50
All other gulls and skuas	0.9929 (± 0.0003)	Consult SNCB		Consult SNCB	Consult SNCB	Consult SNCB	Consult SNCB
All other tern species	0.9908 (± 0.0004)	Consult SNCB		Consult SNCB	Consult SNCB	Consult SNCB	Consult SNCB

Note 1: Flight speeds from Alerstam *et al*. (2007) except for gannet from Pennycuick (1997) and Sandwich tern from Fijn & Gyimesi (2018).

Note 2: Based on Garthe & Hüppop (2004) other than gannet, kittiwake and lesser black-backed gull which is based on Cook *et al*. (2023).

Note 3: All named species from Snow & Perrins (1998).

Note 4: See section 3.5 and Table 1 regarding macro-avoidance.

Note 5: We acknowledge that in reality northern gannet display both flapping and gliding flight types.

10. Further work required

This joint SNCB position reflects the obligation on SNCBs to provide advice based on available evidence. Consequently, our advice will evolve as new evidence emerges and this SNCB position statement will be subject to review. The SNCBs suggest that the following work is required. We are aware of several ongoing or planned projects that may provide evidence to progress some of these needs. The SNCBs will collectively review evidence and update our advice as it becomes available:

1. Further monitoring of collisions and avoidance behaviour using camera or other suitable technology, at a wider range of sites, particularly offshore sites, and in all biological seasons.
2. Further data on the probability of collision of birds that pass through the rotor swept zone, to validate Pcol calculations.
3. An updated review of generic flight heights and flight speeds.
4. A review of the validity, suitability and application of different methods of site-specific flight height estimation.

11. References

Alerstam, T., Rosén, M., Bäckman, J., Ericson, P.G.P. and Hellgren, O. 2007. Flight speeds among bird species: Allometric and phylogenetic effects. *PLoS Biology*, **5**(8), e197. https://doi:10.1371/journal.pbio.0050197.

Band, B. 2012. *Using a Collision Risk Model to Assess Bird Collision Risks for Offshore Wind Farms*. Report for The Crown Estate.

Bowgen, K. and Cook, A.S.C.P. 2018. Bird Collision Avoidance: Empirical evidence and impact assessments. *JNCC Report No. 614*, JNCC, Peterborough, ISSN 0963-8091.

Caneco, B. and Humphries, G. 2022. HiDef Aerial Surveying stochLAB. [Online]. https://www.github.com/HiDef-Aerial-Surveying/stochLAB. Accessed 27/01/2023.

Cook, A.S.C.P, Thaxter, C.B., Davies, J., Green, R.M.W., Wischnewski, S. and Boersch-Supan. P. 2023. *Understanding seabird behaviour at sea part 2: improved estimates of collision risk model parameters*. Report to Scottish Government.

Cook, A.S.C.P. 2021. *Additional analysis to inform SNCB recommendations regarding collision risk modelling*. BTO Research Report 739, BTO, Thetford, UK.

Cook, A.S.C.P., Humphries, E.M., Masden, E.A. and Burton, N.H.K. 2014. *The avoidance rates of collision between birds and offshore turbines*. BTO Research Report No 656 to Marine Scotland Science.

Fijn, R.C. and Gyimesi, A. 2018. Behaviour related flight speeds of Sandwich Terns and their implications for wind farm collision rate modelling and impact assessment. *Environmental Impact Assessment Review*, **71**, 12–16. https://doi.org/10.1016/j.eiar.2018.03.007.

Furness, R.W., Garthe, S., Trinder, M., Matthiopoulos, J., Wanless, S. and Jeglinski, J. 2018. Nocturnal flight activity of northern gannets Morus bassanus and implications for modelling collision risk at offshore wind farms. *Environmental Impact Assessment Review*, 73, 1–6. https://doi.org/10.1016/j.eiar.2018.06.006.

Garthe, S. and Hüppop, O. 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. *Journal of Applied Ecology*, **41**, 724–734, 2004. https://doi.org/10.1111/j.0021-8901.2004.00918.x.

Johnston, A. and Cook, A.S.C.P. 2016. How high do birds fly? Development of methods and analysis of digital aerial data of seabird flight heights. BTO Research Report Number 676.

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

Largey, N., Cook, A.S.C.P., Thaxter, C.B., McCluskie, A., Stokke, B.G., Wilson, B. and Masden, E.A. 2021. Methods to quantify avian airspace use in relation to wind energy development. *Ibis*, **163**(3), 747–764. https://doi.org/10.1111/ibi.12913.

Masden, E. 2015. *Developing an avian collision risk model to incorporate variability and uncertainty*. Scottish Marine and Freshwater Science, Vol. 6, No. 14. Edinburgh: Scottish Government, 43 pp. https://doi.org/10.7489/1659-1.

McGregor, R., King, S., Donovan, C., Caneco, B. and Webb, A. 2018. *A Stochastic Collision Risk Model for Seabirds in Flight* (Report No. HC0010-400-001). Report by Marine Scotland Science.

Ozsanlav-Harris, L., Inger, R. and Sherley, R. 2023. *Review of data used to calculate avoidance rates for collision risk modelling of seabirds*. JNCC Report 732, JNCC, Peterborough, ISSN 0963-8091.

Pennycuick, C.J. 1997. Actual and optimum flight speeds: field data reassessed. The *Journal of Experimental Biology*, **200**(17): 2355–2361. https://doi.org/10.1242/jeb.200.17.2355.

Skov, H., Heinänen, S., Norman, T., Ward, R.M., Méndez-Roldán, S. and Ellis, I. 2018. ORJIP Bird Collision and Avoidance Study. Final report – April 2018. The Carbon Trust. United Kingdom. 247 pp.

SNCBs 2014. Joint Response from the Statutory Nature Conservation Bodies to the Marine Scotland Science Avoidance Rate Review.

Snow, D.W. and Perrins, C.M. 1998. The Birds of the Western Palearctic. Non-Passerines. Oxford: Oxford University Press.

Tjørnløv, R.S., Skov, H., Armitage, M., Barker, M., Jørgensen, J.B., Mortensen, L.O., Thomas, K. and Uhrenholdt, T. 2023. Resolving Key Uncertainties of Seabird Flight and Avoidance Behaviours at Offshore Wind Farms; Final Report for the study period 2020-2021. Report by Danish Hydraulic Institute (DHI). Report for Vattenfall.

Trinder, M. 2017 Offshore wind farms and birds: incorporating uncertainty in collision risk models: a test of Masden (2015) Natural England Commissioned Reports, Number 237. York.