BTO RESEARCH REPORT 739

Additional analysis to inform SNCB recommendations regarding collision risk modelling

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Report to Natural England.

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Looking out for birds

EXECUTIVE SUMMARY

Collision Risk Models are widely used in order to predict potential impact of collisions with turbines on bird populations but, are known to be sensitive to the parameter referred to as the avoidance rate. The most widely used Collision Risk Model is the Band Model, updated in 2012 for use in the offshore environment. Previous studies have estimated suitable avoidance rates for use in the Band model. However, given ongoing data collection, there is a need to update these estimates to ensure they reflect the best available evidence. Drawing from the data presented in Cook et al. (2014) and more recent studies, notably the ORJIP Bird Collision Avoidance study, this report presents updated estimates of avoidance rates for gulls and terns and makes recommendations about suitable avoidance rates for gannets. It further sets out recommendations and considerations for future revisions to avoidance rates as more data become available.

BACKGROUND

Collision Risk Models are widely used in order to predict the potential impact of collisions with turbines in both the onshore and offshore environments on bird populations (Masden & Cook, 2016). However, these models are known to be sensitive to the parameter referred to as the avoidance rate (Chamberlain *et al*., 2006). The avoidance rate is assumed to reflect the proportion of birds that take action in order to avoid collision with turbines. However, it is typically calculated by comparing estimates of the number of birds colliding to those that would be expected to collide in the absence of avoidance action (Band, 2012; Chamberlain *et al.*, 2006; Cook *et al.*, 2018; Cook *et al*., 2014) (Eq. 1)

Eq. 1

$$\textit{Avoidance Rate} = 1 - \left(\frac{\textit{Observed Collision Rate}}{\textit{Collision Rate Predicted In Absence Of Avoidance}}\right)$$

The collision rate predicted in the absence of avoidance is a function of i) the number of birds estimated to pass through the turbine rotor swept areas of a wind farm over any given time period (referred to as the flux rate), and ii the probability of a bird passing through the turbine rotor swept area and colliding with a blade (referred to as the Probability of Collision or, PColl). This means that, in addition to capturing the rate at which birds may take action to avoid collision, the avoidance rate also incorporates error in the estimates of both PColl and the flux rate. However, the estimation of both of these parameters is based on a simplified set of assumptions relating to the movement and behaviour of the birds, and the operation of the turbines. This means that estimates of avoidance rates are sensitive to many of the parameters that CRMs are sensitive to, including flight height, flight speed and turbine rotation speed (Cook *et al*., 2014; Masden *et al*., in review).

Flight speed and turbine rotation speed contribute to the estimation of PColl. An increase in turbine rotation speed will result in an increase in the probability of collision and, hence, the collision rate predicted in the absence of avoidance. An increase in flight speed will result in a decrease in PColl as it reduces the probability that the bird and turbine blade will occupy the same point at the same time. However, as flight speed is also used in the estimation of the flux rate, this does not translate to a reduction in the collision rate predicted in the absence of avoidance. The model guidance suggests that whilst the impact of flight speed on the two parameters may act in opposite directions, the error associated with each should cancel this effect out (Band, 2012). However, subsequent analysis suggests this may not be the case, and that the influence of flight speed on the flux rate swamps its influence on PColl (Masden *et al.* in review). Similarly, an increase in the proportion of birds at collision risk height will increase the number of birds available to collide and, hence, the collision rate predicted in the absence of avoidance. Following Eq. 1, an increase in turbine rotation speed, flight height or flight speed will all result in an increase in the collision rate predicted in the absence of avoidance and, therefore, also increase the avoidance rate. This highlights the importance of ensuring that robust estimates of these parameters are used when calculating avoidance rates.

Related to the above point, there are differences in the approaches used by models in order to estimate the number of birds predicted to collide in the absence of avoidance. For example, the basic Band model (options 1 & 2) assumes a uniform distribution across the turbine rotor swept area, whilst the extended Band model (option 3) accounts for variation in this distribution. This allows a more precise estimate of predicted collisions, given that for most species birds will be much more likely to be present at the lower edges of the rotor sweep, where they are less likely to collide, than at higher altitudes within the rotor sweep. As a result, the number of birds predicted to collide in the absence of avoidance using the extended Band model will be lower than that for the basic Band model. This means that, following Eq. 1, the avoidance rate estimated using the extended Band model will be lower than is the case for the basic Band model. This example highlights that avoidance rates are not transferable between different models.

Given the sensitivity of CRMs to avoidance rates and, the challenges posed to industry by current estimates of collisions (Brabant *et al*., 2015; Broadbent & Nixon, 2019; Busch & Garthe, 2017), there has been considerable interest in generating more accurate estimates of avoidance rates. This has resulted in a number of reviews of the topic (Cook *et al*., 2018; Cook *et al.*, 2014; Cook *et al*., 2012) and large-scale, industry-funded projects in order to quantify avoidance behaviour (Skov, *et al.*, 2018). As our understanding of collision risk improves as a result of more projects being built, and an increased appreciation for the scale of potential cumulative impacts, it is necessary to update past estimates of avoidance rates. As part of this, key changes will include the incorporation of data from new studies (including Skov *et al*. 2018), accounting for the imperfect detection of corpses, and incorporating data from sites at which bird activity was recorded but no collisions detected. As a consequence of these changes, the recommended avoidance rates for key species are also likely to be changed.

An important additional data set is likely to be that collected as part of the Offshore Renewables Joint Industry Programme (ORJIP) funded Bird Collision Avoidance (BCA) project. Previous analysis, reported in Bowgen & Cook (2018), considered how the data collected could be used to parameterise avoidance rates for CRMs. Bowgen & Cook (2018) estimated avoidance rates for use in the deterministic Band model as follows:

0.990 for Black-legged Kittiwake (option 1)

0.995 for Northern Gannet and large gulls (option 1)

0.980 for Black-legged Kittiwake (option 3)

0.993 for large gulls (option 3)

Bowgen & Cook (2018) also undertook further analyses in order to derive median avoidance rates suitable for use in the stochastic collision risk model i.e.

0.994 (95% CIs 0.976 – 0.998) for Black-legged Kittiwake (option 1)

0.997 (95% CIs 0.992 – 0.999) for large gulls (option 1)

0.970 (95% CIs 0.871 – 0.989) for Black-legged Kittiwake (option 3)

0.990 (95% CIs 0.974 – 0.995) for large gulls (option 3)

The median values were recommended for use in the stochastic collision risk models and these differ from the values estimated by Bowgen & Cook (2018) for use in the deterministic model, due to differences in the way in which flight height distributions are incorporated into the avoidance rate calculations (which are based on comparing expected with observed collisions). These rates were not adopted into guidance as they were based on the outputs from a single study and lacked the contemporary density data required in order to give more context to the observed collision rates. To support the development of SNCB advice in relation to CRMs, there is a need to consider how the data collected as part of the ORJIP BCA project and analysed by Bowgen & Cook (2018) should be combined with existing estimates of avoidance rates (e.g. Cook *et al.*, 2018; Cook *et al.*, 2014). There is a further need to consider the extent to which avoidance rates may differ according to the model used, with particular reference to the basic and extended Band (2012) model and, the basic and extended stochastic CRM (sCRM) (McGregor *et al*., 2018).

This report will:

1. Combine ARs from various sites as presented in Cook et al. (2014) where appropriate, with those derived from the ORJIP study (Bowgen & Cook, 2018), and any additional sites where the appropriate data are available, to provide avoidance rates based on data across a range of sites where possible. These would be species-specific ARs where data allow, but in some cases these may need to be based on data across functional groups (e.g. gulls) or informed by rates for other species (e.g. Northern Gannet). Where data allow, provide a SD for the recommended avoidance rates.

2. Where a meaningful SD estimated across sites (or from other appropriate source of variability) this should incorporate variation between sites (for the deterministic Band model) and variability in the input parameters (for the sCRM).

3. Production of a set of principles that could be used when making decisions on which avoidance rate is most appropriate in different circumstances. This would need to consider species-specific data availability (for example Cook *et al*. 2014 recommend avoidance rates (with SD) for Gannet which is based on all gulls data because no Northern Gannet data were available) and how variability is estimated and can be applied to both the Band (2012) spreadsheet and the McGregor *et al*. (2018) sCRM tool.

4. Advise on appropriate Avoidance rate and SD to use for Sandwich Tern, given available data.

METHODS

Data

In order to estimate avoidance rates suitable for use in collision risk models we need information describing the number of collisions recorded, and a passage rate for birds through the study area over the period in which collision data were recorded. Ideally, information on the flight heights of birds within the study area, and any corrections applied to account for imperfect detection of corpses, should also be reported. In addition to the data collated as part of Cook *et al.* (2014) and collected by Skov *et al.* (2018), I identified reports from seven additional sites (Bloodgate Hill, Blyth Harbour, Deflzijl-Zuid, Goole Fields, Red House Farm, Sabinapolder and Slufterdam and Distridam) which included the necessary data to estimate avoidance rates (Figure 1).

Collision data presented in Skov *et al*. (2018) were collected using a combined camera-radar system mounted on two offshore wind turbines; all other data were collected during carcass searches as part of post-construction monitoring at onshore wind farms. Bird and wind farm parameters used in this analysis are presented in tables 1 and 2.

Figure 1 Location of windfarms from which data were obtained in order to calculate avoidance rates. 1. Bloodgate Hill; 2. Blyth Harbour; 3. Goole Field; 4. Haverigg; 5. Hellrigg; 6. Red House Farm; 7. Avonmouth; 8. Kessingland; 9. Gneizdzewo; 10. Bouin; 11. Ooseterbierum; 12. Thanet; 13. Zeebrugge; 14. Boudwijnkanaal; 15. Kleine Pathoweg; 16. De Put; 17. Delfzijl-zuid; 18. Sabinapolder; 19. Slufterdam & Distridam.

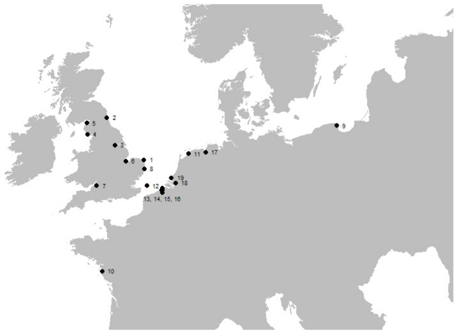


Table 1 Values for bird parameters (± standard deviation) used to estimate avoidance rates

	Length (m)[1]	Wingspan (m)[1]	Flight speed (m/s)	Flight mode	Nocturnal activity[2]
Common Gull	0.36 (0.005)	1.05 (0.04)	11.9 (1.6)[3]	Flapping	0.25
Black-headed Gull	0.41 (0.005)	1.20 (0.04)	13.4 (2.9)[3]	Flapping	0.25
Black-legged Kittiwake	0.39 (0.005)	1.08 (0.04)	13.1 (0.4)[3]	Flapping	0.25
Lesser Black-backed Gull	0.58 (0.005)	1.42 (0.04)	13.1 (1.8)[3]	Flapping	0.25
Herring Gull	0.60 (0.005)	1.44 (0.04)	12.8 (1.8)[3]	Flapping	0.25
Great Black-backed Gull	0.71 (0.005)	1.58 (0.04)	13.7 (1.8)[3]	Flapping	0.25
Sandwich Tern	0.38 (0.005)	1.00 (0.04)	12.9 (0.9)[4]	Flapping	0
Common Tern	0.33 (0.005)	0.88 (0.04)	10.9 (0.9)[5]	Flapping	0
Little Tern	0.23 (0.005)	0.52 (0.04)	10.9 (0.9)[5]	Flapping	0

[1](Robinson, 2017), SDs based on guidance issued alongside (McGregor *et al.,* 2018). The default values in the sCRM have subsequently been updated. However, these changes do not have an impact on the estimated avoidance rates. [2](Garthe & Hüppop, 2004) [3](Alerstam *et al*., 2007) [4](Wakeling & Hodgson, 1992) [5]Flight speed for Arctic Tern presented in (Alerstam *et al*., 2007).

Table 2 Values for wind farm (± standard deviation) parameters used to estimate avoidance rates

	Location	Latitude	Turbine Model (MW)	Number of Turbines	Hub Height (m)	Blades	Rotor Diameter (m)	Blade Width (m)	Rotor Speed (rpm)	Rotor Pitch (°)	Width Survey window (m)	Height Survey Window (m)	References
Bloodgate Hill	Coastal	52.87	0.225	10	30	3	27	0.66	43 (0.05)	10 (0.01)	1500	43.5	(Percival *et al.*, 2008)
Blyth Harbour	Coastal	55.13	3.4	1	76	3	104	4.3	13.8 (0.05)	15 (0.01)	400	128	(Percival *et al.*, 2017)
Goole Fields	Inland	53.66	2.05	16	79	3	92	4.4	17.5 (0.05)	10 (0.01)	3200	150	(Percival *et al.*, 2018b, 2018a, 2018c)
Haverigg	Coastal	54.23	0.6	8	41.5	3	42	2.2	13.7 (0.05	15 (0.01)	1800	62.5	(Arcus Consultancy Services, 2019; Percival, 2020)
Hellrigg	Coastal	54.84	2.3	4	80	3	82	4.4	18 (0.05)	10 (0.01)	4000	121	(Percival, n.d., 2015)
Red House Farm	Coastal	52.81	2	6	59	3	82	4.4	18 (0.05)	10 (0.01)	3000	59	(Percival *et al.*, 2015)
Avonmouth	Coastal	51.50	2.05	2	80	3	92	4.4	17.5 (0.05)	10 (0.01)	1300	160	(The Landmark Practice, 2013)
Kessingland	Coastal	52.41		2	80	3	92	2.5	15 (0.05)	10 (0.01)	92	92	(Wild Frontier Ecology, 2013)
Gneizdzewo	Coastal	54.70	2	19	80	3	80	4.4	18 (0.05)	10 (0.01)	3700	120	(Zielinski *et al.*, 2008, 2010, 2011, 2012)
Bouin	Coastal	46.95	2.5	8	60	3	80	4.4	18 (0.05)	10 (0.01)	4000	100	(Dulac, 2008)
Oosterbierum	Coastal	53.20	0.3	18	35	3	30	0.66	43 (0.05)	10 (0.01)	1430	60	(Winkelman, 1992)
Thanet	Offshore	51.50	3	8	70	3	90	3.5	16.1 (0.05)	15 (0.01)	2709	115	(Skov, Heinänen, *et al.*, 2018)
Zeebrugge	Coastal	51.36	0.4	6	34	3	34	0.66	43 (0.05)	10 (0.01)	720	80	(J. Everaert, 2008; J. Everaert *et al.*, 2002; Joris Everaert & Stienen, 2007)
Boudwijnkanaal	Coastal	51.28	0.6	7	55	3	48	1.1	43 (0.05)	10 (0.01)	1539	79	(J. Everaert, 2008; J. Everaert *et al.*, 2002; Joris Everaert & Stienen, 2007)
Kleine Pathoweg	Coastal	51.28	1.8	7	85	3	70	4.4	18 (0.05)	10 (0.01)	1820	120	(J. Everaert, 2008; J. Everaert *et al.*, 2002; Joris Everaert & Stienen, 2007)
De Put	Coastal	51.15	0.8	2	75	3	48	1.1	43 (0.05)	10 (0.01)	300	100	(J. Everaert, 2008; J. Everaert *et al.*, 2002; Joris Everaert & Stienen, 2007)
Delfzijl-Zuid	Coastal	53.28	2	34	85	3	70	4.4	18 (0.05	10 (0.01)	2700	120	(Brenninkmeijer & van der Weyde, 2011)
Sabinapolder	Coastal	51.66	0.85	6	48	3	52	1.1	43 (0.05)	10 (0.01)	1500	84	(Verbeek *et al.*, 2012)
Slufterdam & Distridam	Coastal	51.92	1.5	21	67	3	83	4.4	18 (0.05)	10 (0.01)	3200	500	(Prinsen *et al.*, 2013)

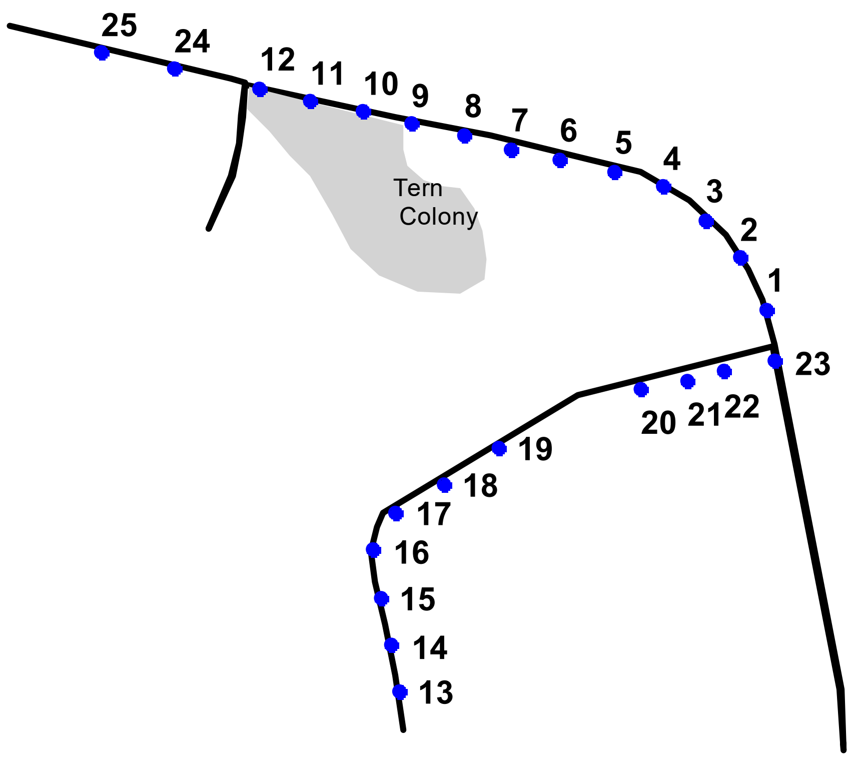
Estimation of avoidance rates

As highlighted above (Eq. 1), avoidance rates can be estimated by comparing predicted and observed collision rates. The predicted collision rate can be estimated by multiplying the number of birds passing through the turbine rotor sweeps by the probability of any individual bird colliding. The number of birds estimated to pass through the rotor sweep is estimated by scaling up the flight activity recorded during surveys to cover the total period over which searches for collision victims were carried out. However, as a result, the final estimated avoidance rate is highly sensitive to the number of flights estimated to occur during the period over which carcass searches are carried out (see p101 of Cook *et al.* (2014) for example).

In some instances, flight activity may not be spread evenly across a site. For example, at Zeebrugge flight activity is likely to be greatest around the turbines closest to the tern breeding colony (Figure 2). As part of monitoring at this site, searches for collision victims were carried out on a weekly or twice weekly basis around all turbines between 2001 and 2007 (Everaert, 2008). Reflecting likely spatial patterns in flight activity, the greatest number of corpses were recovered from beneath the turbines closest to the breeding colony (Everaert, 2008; Everaert & Stienen, 2007). To complement the monitoring of corpses, flight activity surveys were carried out to assess the number of birds passing through the turbine lines in June 2001, September 2001, June 2002, June 2004, and June 2005. In 2001 and 2002, birds were counted passing turbines 9–12, and in 2004 and 2005 birds were counted passing turbines 7–12 (Fig. 2). Extrapolating activity levels from these turbines to turbines elsewhere in the wind farm may lead to an overestimate of the flux rate across the wind farm as a whole and, in turn, the predicted collision rate. Given equation 1, where the predicted collision rate is overestimated, this will lead to an overestimate of the final avoidance rate. Consequently, where possible I assessed avoidance rates in relation to individual turbines (Zeebrugge, Slufterdam and Distridam, Kessingland) before summarising these across the wind farm concerned. Elsewhere, I restricted analyses to carcasses collected from the areas in which flight activity surveys were carried out; though, in the majority of cases, this reflected the wind farm as a whole.

In addition to estimates of flight activity and mortality, estimating avoidance rates requires information describing turbine size (hub height and rotor diameter) and operational parameters (rotor speed and pitch), together with bird flight speed, flight height and nocturnal activity. Turbine information was described within the monitoring reports reviewed or inferred from turbines of a similar size and capacity, following Cook

Figure 2 Turbines on Zeebrugge harbour wall with location of Tern breeding colony shown (recreated from Everaert & Stienen, 2007).



et al. (2014). Data describing bird flight speed and nocturnal activity were drawn from standard references (Alerstam *et al.*, 2007; Garthe & Hüppop, 2004; Pennycuick *et al*., 2013). Where available, estimates of the number or proportion of birds at collision risk height were extracted from the monitoring reports. Where these data were not available, or were felt to be unreliable (e.g. subject to unknown biases), flight height estimates from Johnston *et al*. (2014) were used. The resulting data were used to estimate avoidance rates suitable for use in the basic and extended Band (2012) Model, and the basic and extended sCRM (McGregor *et al.*, 2018).

Basic Band Model

To estimate an avoidance rate for the Basic Band model I followed the approach set out in Cook *et al.* (2014) using the following steps:

Firstly, estimate the passage rate of birds through turbine rotor sweeps:

1. As a first step, I estimated the hourly number of birds passing through the wind farm. In most cases, this was achieved by dividing the total number of birds recorded during surveys by the total duration of these surveys. However, in the case of Skov *et al.* (2018) data were available as density estimates rather than counts – though it is important to note that, in contrast to the data from onshore sites, these estimates were not contemporaneous with the collection of collision estimates. These were converted into an hourly passage rate following the approach set out in Band (2012).

2. I then estimated the total number of birds passing through the wind farm over the duration of each survey: multiplying the hourly passage rate by the total number of hours covered by each survey period and correcting for nocturnal activity (Eq. 2). I estimated the total number of hours daylight and night over each survey period following the approach of Forsythe *et al.* (1995).

Eq. 2

N Birds passing through wind farm = (hourly passage rate × n hours daylight) + (hourly passage rate × n hours night × correction for nocturnal activity)

3. This was then corrected by an estimate of the proportion of birds at collision risk height.

4. I then estimated the area of the total survey frontal area at collision risk height by multiplying the width of the survey window by the rotor diameter (table 2).

5. This was then multiplied by the total turbine frontal area as a proportion of the total survey frontal area at collision risk height (Eq. 3) to give an estimate of the total number of birds passing through the turbine rot or swept area.

Eq. 3

Avoidance Rate =

$$\left(\frac{N\ turbines \times (\pi \times (0.5 \times rotor\ diameter)^2)}{width\ survey\ window \times rotor\ diameter}\right)$$

To get the number of collisions expected in the absence of avoidance, this figure was multiplied by the probability of collision estimated following Band (2012). For each species and species group ('terns', 'large gulls', 'small gulls' and 'all gulls') I followed the process set out in Cook *et al.* (2014) using ratio estimators (Cochran, 1977) to estimate an avoidance rate across all years and sites, and the Delta method (Powell, 2007) to estimate the standard deviation and 95% confidence intervals around this figure, reflecting variability in the avoidance rates between sites and years. The resulting values reflect within-wind farm avoidance; **in order to estimate total avoidance, macro-avoidance must also be incorporated.**

Extended Band Model

A first step in estimating an avoidance rate for the extended Band model is to estimate the proportion of birds passing through the turbine rotors. This follows steps 1–4 (above) but does not include a correction for the proportion of birds at collision risk height (step 5). That is because species flight height distributions are accounted for in the estimation of the collision integral, which I applied following the approach set out in Band (2012). I based flight height distributions on the values presented in Johnston *et al.* (2014). I then multiplied the number of birds passing through the turbine rotor swept areas by the collision integral to get an estimate of the number of collisions in the absence of avoidance. As above, avoidance rates were then estimated across all sites and years using Eq. 1, and combined using ratio estimators and the Delta method (Cochran, 1977; Powell, 2007). As above, the reported standard deviations reflect variability in the avoidance rates between sites.

Basic Stochastic Collision Risk Model

In contrast to the approach for the Basic Band model, where I estimated a single avoidance rate for each site in each year during which data collection had taken place and then combined these to give an overall avoidance rate with associated uncertainty, for the basic sCRM I used a Monte Carlo simulation approach to estimate avoidance rates. This approach means that I was able to estimate a mean, median, standard deviation and 95% CIs for each year, and for all years and sites combined. Using this approach, avoidance rates were estimated over 1,000 iterations. Within each iteration, the steps set out above for the basic Band model were followed with random values for turbine rotor speed and pitch, bird flight speed, wingspan and length drawn from a normal distribution based on the mean and standard deviations presented in Table 2, and average hourly passage rates drawn from a Poisson distribution based on the mean average hourly passage rates estimated following steps 1–4 above. As above, I then estimated avoidance rates across each site and year, and combined these using ratio estimators (Cochran, 1977). Following these simulations, I had 1,000 estimated avoidance rates for each species and group. From these, I extracted the median values, standard deviations and 95% CIs. In addition to reflecting variability between sites and years, as with the basic and extended Band model, the standard deviations reported here reflect variability in the input parameters.

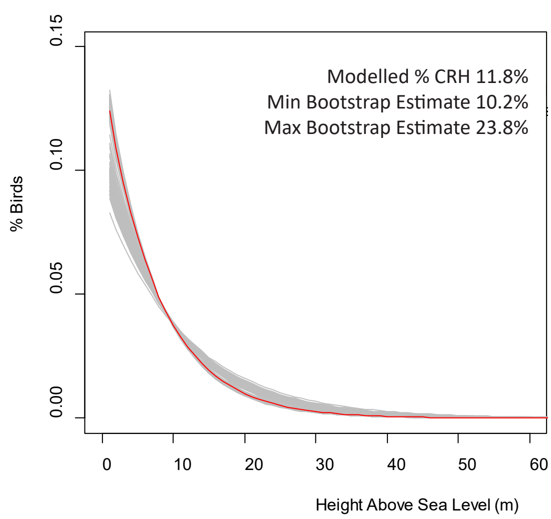
Extended Stochastic Collision Risk Model

The approach to estimating an avoidance rate for use with the extended stochastic collision risk model broadly entailed a Monte Carlo simulation approach, as described for the basic stochastic collision risk model, applied to the steps set out for the extended Band model. However, there is a key difference in relation to how flight height distributions are accounted for.

The extended stochastic collision risk model makes use of 200 random realisations of flight height distributions generated when estimating the distributions presented in (Johnston *et al.*, 2014). Each of these random realisations will have a slightly different shape, reflecting different proportions of birds at any given height. Logically, a difference in the proportion of birds at any given height between distributions will lead to differences in the proportion of birds at other heights. We can examine this more closely by plotting the 200 bootstrapped random realisations of Sandwich Tern flight height distributions and comparing these to the maximum likelihood "best fit" distribution (Figure 3). Here we can see that the "best fit" line does not pass perfectly through the middle of the random realisations. At lower heights, the "best fit" distribution reflects some of the higher proportions of birds at any given height. However, around 10 m above sea level this switches and the "best fit" distribution now has some of the lower proportions of birds at any given heights. We can see this reflected in the minimum and maximum proportions of birds predicted to be flying at collision risk height in relation to turbines of the dimensions present at Zeebrugge.

The proportion of birds at collision risk height is a key component of the number of collisions expected in the absence of avoidance behaviour, and hence the final estimated avoidance rate. Given the range of estimated proportions of birds at collision risk height from these random realisations and the proportion of birds at collision risk height in the "best fit" modelled distribution, it is clear that the mean and median estimates of the number of collisions expected in the absence of avoidance behaviour from the bootstrap data will exceed that estimated using the best fit data within the extended Band model. As a consequence of this the avoidance rates will differ between the extended Band model and, the extended sCRM.

Figure 3 Bootstrapped estimates (grey lines) of the proportion of Sandwich Terns at collision risk height from the data underpinning (Johnston *et al.*, 2014) in comparison to the maximum likelihood distribution (red line).



Northern Gannet Avoidance Rate

Whilst corpses of Northern Gannets which have apparently collided with offshore wind farms have been recovered (Rothery *et al*., 2009), concerns over the imperfect detection of these corpses mean that it is not possible to estimate an avoidance rate for this species following the methodologies described above. Instead, we must rely on comparison with other species and make inferences based on our knowledge of the species' ecology. Unlike the other species considered in this analysis, Northern Gannets are known to strongly avoid wind farms (V. Dierschke *et al*., 2016). We can use this information to estimate a range of potential total avoidance rates by combining plausible macro-avoidance rates with plausible within-wind farm avoidance rates following Eq. 4.

Eq. 4

$$\text{Total Avoidance} = 1-((1-\text{macro avoidance}) \times (1-\text{within wind farm avoidance}))$$

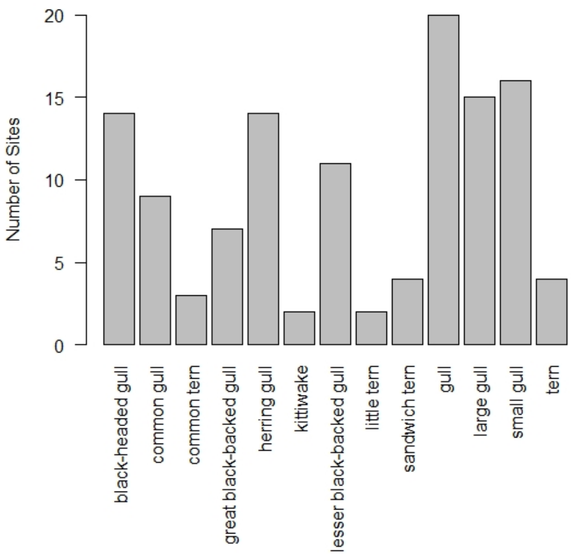
To achieve this, I simulate a range of total avoidance rates based on macro avoidance rates ranging from 0.5–1.0 and within-wind farm avoidance rates ranging from 0.9–1.0. I then compare these to the values of within-wind farm avoidance estimated for the species above, and published estimates of Northern Gannet macro-avoidance, in order to make inferences about plausible values for Northern Gannet total avoidance.

RESULTS

Gull and tern avoidance rates

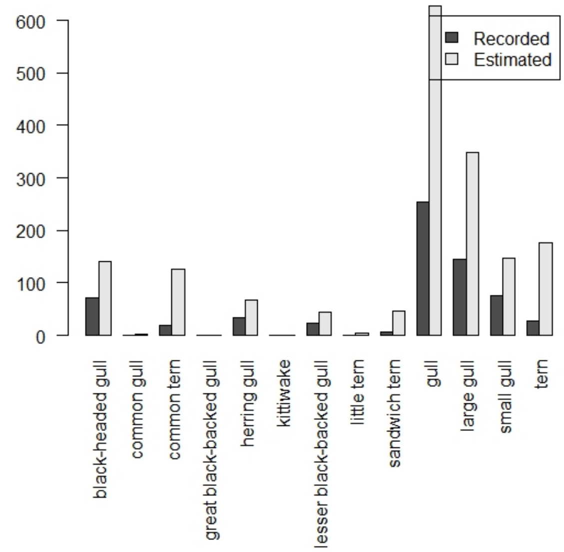
Data were obtained from 19 sites (Table 2, Figure 1). The number of sites from which data were available to estimate avoidance rates varied from two for Little Tern and Black-legged Kittiwake, to 13 for Black-headed Gull and Herring Gull (Figure 4). There were also data from a significant number of sites for Lesser Black-backed Gull (10) and Common Gull (9). Across groups, data were available from 19 sites for all gulls, buT only four sites for terns.

Figure 4 The number of sites from which data were available to estimate avoidance rates for each species and species group.



Across the studies, a total of 282 collisions involving gulls and terns was recorded. However, once corrections were applied to account for the proportion of the search area covered, observer efficiency and scavenger activity, this number increased to 805 estimated collisions. Black-headed Gulls were the most commonly reported victims with 71 recorded collisions, increasing to 140 once correction factors were applied (Figure 5). In total 255 gull collision victims were reported (628 after applying correction factors) and 27 tern collision victims (176 after applying correction factors).

Figure 5 The number of collision victims recorded during collision monitoring and estimated once corrections had been applied for corpse detection and scavenger activity



Generally, estimated avoidance rates for use with the basic sCRM are consistent with those estimated for use with the basic Band model. However, there are noticeable differences for a number of species in the rates estimated using the two extended Band models. As highlighted above, this relates to differences in the way that flight height distributions are considered by the two models.

Table 3 Estimated rates (Standard deviations; 95% Confidence Intervals) for use with different Collision Risk Models

	Basic Band (2012) Model	Extended Band (2012) Model	Basic sCRM	Extended sCRM
Sandwich Tern	0.9722 (0.0016; 0.969–0.9753)	0.9645 (0.0019; 0.9609–0.9682)	0.9723 (0.0005; 0.9714–0.9732)	0.9706 (0.0028; 0.9644–0.9753)
Common Tern	0.9201 (0.0036; 0.9129–0.9272)	0.8558 (0.0074; 0.8413–0.8703)	0.9204 (0.0016; 0.9174–0.9236)	0.8538 (0.0076; 0.839–0.8683)
Little Tern	0.9982 (0.0003; 0.9977–0.9987)	0.9901 (0.0014; 0.9874–0.9929)	0.9982 (0.0001; 0.9981–0.9983)	0.99 (0.0006; 0.9888–0.9911)
All Terns	0.9712 (0.0007; 0.9697–0.9726)	0.9344 (0.0016; 0.9313–0.9375)	0.9713 (0.0004; 0.9704–0.9722)	0.9399 (0.0033; 0.9333–0.946)
Black-legged Kittiwake	0.9970 (0.0015; 0.994–1)	0.9924 (0.0038; 0.9848–0.9999)	0.9979 (0.0013; 0.9954–0.9993)	0.9947 (0.1316; 0.4098–0.998)
Black-headed Gull	0.9873 (0.0009; 0.9856–0.989)	0.8978 (0.0086; 0.8809–0.9147)	0.9874 (0.0008; 0.9859–0.9888)	0.9047 (0.0204; 0.8536–0.9351)
Common Gull	0.9997 (0.0001; 0.9996–0.9998)	0.9976 (0.0005; 0.9967–0.9985)	0.9997 (0; 0.9997–0.9998)	0.9979 (0.0003; 0.9973–0.9984)
Lesser Black-backed Gull	0.995 (0.0003; 0.9944–0.9956)	0.9789 (0.0012; 0.9766–0.9813)	0.995 (0.0003; 0.9943–0.9956)	0.9801 (0.0022; 0.9762–0.9847)
Herring Gull	0.9953 (0.0002; 0.9948–0.9957)	0.9825 (0.0008; 0.981–0.9841)	0.9953 (0.0003; 0.9947–0.9959)	0.9497 (0.0088; 0.9317–0.9651)
Great Black-backed Gull	0.9991 (0.0002; 0.9986–0.9995)	0.9965 (0.0009; 0.9948–0.9983)	0.9991 (0.0002; 0.9985–0.9993)	0.9969 (0.0009; 0.9946–0.9982)
Small gulls	0.9919 (0.0004; 0.9911–0.9927)	0.9354 (0.0034; 0.9288–0.942)	0.9921 (0.0004; 0.9913–0.9928)	0.9426 (0.0081; 0.9229–0.9559)
Large gulls	0.9860 (0.0007; 0.9846–0.9874)	0.9448 (0.0028; 0.9393–0.9503)	0.9861 (0.0006; 0.9849–0.9873)	0.9104 (0.0082; 0.8935–0.9259)
All gulls	0.9874 (0.0003; 0.9868–0.9879)	0.9532 (0.001; 0.9512–0.9553)	0.9879 (0.0005; 0.987–0.9889)	0.9261 (0.0066; 0.9128–0.9382)
All gulls & terns	0.9856 (0.0002; 0.9852–0.9860)	0.9501 (0.0007; 0.9486–0.9515)	0.9861 (0.0005; 0.9851–0.9871)	0.9295 (0.0047; 0.9204–0.9387)

Sandwich Tern Avoidance Rate

Data to estimate avoidance rates for Sandwich Terns came from four sites (Blyth Harbour, Bouin, Zeebrugge and Slufterdam & Distridam). Across these four sites, recorded activity levels varied from 0.004 birds hour^{-1} to 884 birds hour^{-1}, with 45 collisions estimated across these sites once corrections for search area, searcher efficiency and predator activity had been applied. However, the majority of these collisions occurred within the wind farm in Zeebrugge (Table 4). The avoidance rates estimated here differ from those estimated previously (Cook *et al*., 2014 and Natural England guidance note). In part this is due to the inclusion of data from additional sites. However, restricting analyses to data collected from Zeebrugge in 2004 and 2005 only also highlights differences that must be accounted for. For these data, the analysis presented here generates an avoidance rate of 0.952 in 2004 and 0.984 in 2005. For reference, the equivalent values in Cook *et al.* (2014) were 0.989 and 0.994, while the previous Natural England guidance estimated an average of 0.989 across both years. These differences highlight the role that seemingly minor decisions in how to treat the data can have in the estimation of avoidance rates, and the importance of transparency in these calculations. In Cook *et al.* (2014) a decision was made to base calculations on observed rather than recorded collisions to ensure consistency with the analyses for other species. In relation to Eq. 1, this meant a lower observed collision rate than was included here, resulting in a higher avoidance rate. In relation to the previous Natural England guidance, a collision risk factor (presumed to be equivalent to PColl) of 0.253 was used. In contrast, the estimate of PColl for this study was 0.097. It is unclear how the collision risk factor used in the previous analysis was derived. However, in the context of Eq 1., the higher value would result in a higher estimate of the number of collisions expected in the absence of avoidance and, consequently, a higher avoidance rate.

Table 4 Summary of bird data contributing to avoidance rates for Sandwich Tern

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Blyth Harbour	01/09/2016	31/03/2017	4	54	0.07	0.50	0.00	1.00	1.00	1.00	0.00
Bouin	01/01/2003	31/12/2006	2	370	0.00	0.20*	0.00	1.23	1.32	1.00	0.00
Slufterdam & Distridam	13/06/2012	04/07/2012	18	15	1.20	0.12	1.00	1.00	1.00	1.00–3.23	1.00
Zeebrugge**	01/06/2000	31/07/2000	11	16	0.69	0.18	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge**	01/06/2001	31/07/2001	11	16	0.69	0.18	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/09/2001	31/10/2001	24	16	1.50	0.38	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/06/2004	30/06/2004	15032	17	884.24	0.06	3.00	1.10	1.16	4.17–9.09	28.52
Zeebrugge	01/06/2005	30/06/2005	12320	17	724.71	0.13	3.00	1.10	1.16	4.17–9.09	15.96

*20% of all birds recorded at rotor height; **Data are averaged across the 2000 and 2001 breeding seasons

The low activity levels at the remaining sites mean that if the Zeebrugge data are excluded from the analysis then the estimated avoidance rates are substantially reduced (Table 5), indicating that that these data are exerting a strong influence on the final estimated avoidance rates. For the extended models this includes negative avoidance rates, which would imply a higher number of collisions recorded than would have been expected given activity levels at the site. However, this is likely to be an artefact of incorporating data from Slufterdam & Distridam, where a single collision was recorded despite low levels of activity. Whilst counter-intuitive, this highlights the importance of incorporating data from a range of sites in the analysis. Collisions are chance events and can occur at sites with low levels of activity. Indeed, past analyses have highlighted that recorded collisions do not always correlate with activity levels (Manuela de Lucas *et al*., 2008; Ferrer *et al*., 2012). To ensure that the variation in avoidance rates is accurately captured, it is important to include data from high and low activity sites where available. However, it is also important to consider how well the available data reflect variation in the sites where the species occurs. In this instance there is a strong influence of data from Zeebrugge on the final estimated rate.

Table 5 Estimated rates (Standard deviations; 95% Confidence Intervals) for use with different Collision Risk Models for Sandwich Tern excluding data from Zeebrugge

Basic Band (2012) Model	Extended Band (2012) Model	Basic sCRM	Extended sCRM
0.7144 (0.0631; 0.5907 – 0.8382)	-3.3669 (0.9245; -1.5548 – -5.1790)	0.5477 (0.1557; 0.2744 – 0.9460)	-2.6516 (1.3098; -5.8493 – -0.6090)

Common Tern Avoidance Rate

Data to estimate avoidance rates for Common Terns came from three sites (Bouin, Zeebrugge and Slufterdam & Distridam). Across these three sites, recorded activity levels varied from 0.065 birds hour^{1} to 599 birds hour^{1}, with 126 collisions estimated across these sites once corrections for search area, searcher efficiency and predator activity had been applied (Table 6).

As with Sandwich terns, the majority of these collisions occurred within the wind farm in Zeebrugge. However, in this instance, the exclusion of data from Zeebrugge led to an increase in the estimated avoidance rate for the basic Band Model and basic sCRM and, a reduced avoidance rate for the extended models (Table 7). These changes were not as extreme as those recorded for Sandwich tern and, confidence intervals around the reported rates were smaller, indicating that these data may better reflect a realistic range of behaviour than is the case for Sandwich tern. However, estimated avoidance rates are still based on limited sample size and, an all tern rate may better reflect the variation expected for common terns.

Table 6 Summary of bird data contributing to avoidance rates for Common Tern

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Bouin	01/01/2003	31/12/2006	24	370	0.06	0.20*	0.00	1.23	1.32	1.00	0.00
Slufterdam & Distridam	13/06/2012	04/07/2012	2564	15	170.93	0.12	4.00	1.00	1.00	1.00–3.23	8.10
Zeebrugge**	01/06/2000	31/07/2000	498	16	31.13	0.07	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge**	01/06/2001	31/07/2001	498	16	31.13	0.07	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/09/2001	31/10/2001	86	16	5.38	0.21	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/06/2004	30/06/2004	10198	17	599.88	0.06	6.00	1.10	1.16	4.17–9.09	44.88
Zeebrugge	01/06/2005	30/06/2005	4216	17	248.00	0.27	9.00	1.10	1.16	4.17–9.09	73.57

*20% of all birds recorded at rotor height; **Data are averaged across the 2000 and 2001 breeding seasons

Table 7 Estimated rates (Standard deviations; 95% Confidence Intervals) for use with different Collision Risk Models for Common Tern excluding data from Zeebrugge

Basic Band (2012) Model	Extended Band (2012) Model	Basic sCRM	Extended sCRM
0.9738 (0.0038; 0.9663 – 0.9813)	0.7263 (0.0400; 0.6479 – 0.8048)	0.9737 (0.0009; 0.9727 – 0.9770)	0.7231 (0.0222; 0.6822 – 0.7280)

Little Tern Avoidance Rate

Data to estimate avoidance rates for Little Terns came from two sites (Zeebrugge and Slufterdam & Distridam). Across these three sites, recorded activity levels varied from 0.333 birds hour[1] to 116 birds hour[1] with five collisions estimated across these sites once corrections for search area, searcher efficiency and predator activity had been applied, all at Zeebrugge (Table 8).

Table 8 Summary of bird data contributing to avoidance rates for Little Tern

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Slufterdam & Distridam	13/06/2012	04/07/2012	5	15	0.33	0.12	0.00	1.00	1.00	1.00–3.23	0.00
Zeebrugge*	01/06/2000	31/07/2000	1860	16	116.25	0.45	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge*	01/06/2001	31/07/2001	1860	16	116.25	0.45	1.00	1.10	1.16	4.17–9.09	5.32
Zeebrugge	01/09/2001	31/10/2001	1605	16	100.31	0.50	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/06/2004	30/06/2004	1724	17	101.41	0.13	0.00	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/06/2005	30/06/2005	370	17	21.76	0.65	0.00	1.10	1.16	4.17–9.09	0.00

*Flight Activity Data are averaged across the 2000 and 2001 breeding seasons

All terns Avoidance Rate

Data to estimate avoidance rates for terns came from four sites (Blyth Harbour, Bouin, Zeebrugge and Slufterdam & Distridam). Across these four sites, recorded activity levels varied from 0.07 birds hour[1] to 1585 birds hour[1] with 176 collisions estimated across these sites once corrections for search area, searcher efficiency and predator activity had been applied (Table 9).

Excluding data from Zeebrugge from the analysis resulted in avoidance rate for the basic models that were broadly in line with those estimated using all the data, but substantially reduced estimates for the extended models (Table 10).

Table 9 Summary of bird data contributing to avoidance rates for all terns

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	Observed Collisions	Correction Factor			Corrected Collisions
							Predation	Efficiency	Area	
Blyth Harbour	01/09/2016	31/03/2017	4	54	0.07	0	1.00	1.00	1.00	0.00
Bouin	01/01/2003	31/12/2006	26	370	0.07	0	1.23	1.32	1.00	0.00
Slufterdam & Distridam	13/06/2012	04/07/2012	2587	15	172.47	5	1.00	1.00	1.00–3.23	9.10
Zeebrugge*	01/06/2000	31/07/2000	2369	16	148.06	0	1.10	1.16	4.17–9.09	0.00
Zeebrugge*	01/06/2001	31/07/2001	2369	16	148.06	1	1.10	1.16	4.17–9.09	5.32
Zeebrugge	01/09/2001	31/10/2001	1715	16	107.19	0	1.10	1.16	4.17–9.09	0.00
Zeebrugge	01/06/2004	30/06/2004	26954	17	1585.53	9	1.10	1.16	4.17–9.09	73.00
Zeebrugge	01/06/2005	30/06/2005	16906	17	994.47	12	1.10	1.16	4.17–9.09	89.54

Table 10 Estimated rates (Standard deviations; 95% Confidence Intervals) for use with different Collision Risk Models for all terns excluding data from Zeebrugge

Basic Band (2012) Model	Extended Band (2012) Model	Basic sCRM	Extended sCRM
0.9709 (0.0021; 0.9666 – 0.9752)	0.6954 (0.0229; 0.6505 – -0.7404)	0.9707 (0.0011; 0.9696 – 0.9744)	0.6933 (0.0248; 0.6470 – 0.7469)

Black-legged Kittiwake Avoidance Rate

Data to estimate Black-legged Kittiwake avoidance rates come from two sites, Thanet, and Blyth Harbour, with a single collision recorded at Thanet. An additional collision was noted at Zeebrugge in September 2001, but without an estimate of the species' activity levels, it was not possible to use this to estimate an avoidance rate (Everaert *et al*., 2002).

With no birds recorded at collision risk height and no collisions recorded at Blyth Harbour, estimates of Black-legged Kittiwake avoidance rate rely on the data collected as part of the ORJIP BCA study at Thanet (Bowgen & Cook, 2018). In contrast to the other studies considered in this analysis, these data were collected in the offshore environment and consequently make use of density estimates, rather than passage rates derived from visual surveys, in order to estimate the total flux through the wind farm. Estimated avoidance rates presented here are based on generic values for speed rather than the straight line and actual speed values used in those derived as part of Bowgen and Cook (2018). This is because a single generic value for speed better reflects how collision risk models are used at present. The analysis in Bowgen & Cook (2018) highlights the step-by-step process used to estimate avoidance rates from studies such as that carried out at Thanet, and the decisions that need to be taken at each step in the process and the implications those decisions can have on the final estimated values.

The data collected as part of the ORJIP BCA study offer a valuable insight into bird behaviour in and around offshore windfarms (Skov *et al.* 2018) and the analysis set out in Bowgen & Cook (2018) demonstrates how such data can be used in order to estimate avoidance rates for use in the Band Model. However, for a number of reasons, the avoidance rates estimated in Bowgen & Cook (2018) are unlikely to be as representative as those for other species or groups presented in this report. Firstly, data were collected from an area with relatively low densities of Black-legged Kittiwake, and were restricted to winter only. This means that these data are unlikely to be reflective of the full range of conditions experienced by Black-legged Kittiwakes on an annual basis. Secondly, there is some uncertainty over estimates of the proportion of birds at collision risk height within Thanet wind farm. Data collected as part of monitoring carried out during the ORJIP BCA study suggest a far higher proportion of birds at collision risk height than has been estimated elsewhere. It is unclear as to whether this is a genuine effect or may be the result of some bias in data collection. For example, Borkenhagen *et al.* (2018) found that flight heights estimated using laser-rangefinders may be biased against lower flying birds, which could result in an overestimate of the proportion of birds at risk height. Following Eq. 1, such an overestimate would result in an increase in the estimated avoidance rate. If it is a genuine effect, this may indicate site-specific variations in behaviour, e.g., related to how the birds use the site or the time of year at which they are present (and compounding the need to have data from several sites). For these reasons, a more precautionary and generically applicable approach would be to use the generic values estimated by Johnston *et al.* 2014. Finally, and most importantly, contemporaneous density estimates were not available, meaning total flux had to be estimated using the mean of post-construction density estimates. As a result, the extent to which the avoidance rates here reflect activity levels within the windfarm over the time period in which collision rates were monitored is unclear.

Table 11 Summary of bird data contributing to avoidance rates for Black-legged Kittiwake

Site	Surveys Start Date	Surveys End Date	Density (birds km^{1})	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
									Predation	Efficiency	Area	
Blyth Harbour	01/09/2016	31/03/2017	NA	74	54	1.37	**0.00**	0.00	1.00	1.00	1.00	0.00
Thanet	01/10/2014	31/03/2015	1.1	Na	NA	NA	*0.10*	1.00	1.00	1.00	1.00	1.00
Thanet	01/10/2014	31/03/2016	1.1	NA	NA	NA	*0.10*	0.00	1.00	1.00	1.00	0.00

Black-headed Gull Avoidance Rate

Data to estimate avoidance rates for Black-headed Gulls came from 13 sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Hellrigg, Red House Farm, Avonmouth, Kessingland, Gneizdzewo, Bouin, Boudwijnkanaal, Kleine Pathoweg, Zeebrugge, Slufterdam & Distridam) with passage rates ranging from 0.50 birds hour^{-1} to 174 birds hour^{-1} and a total of 140 collisions estimated following corrections for search area, searcher efficiency and predator behaviour. These data have been collected across a range of sites reflecting different habitat types, over a number of different years (Table 12).

Table 12 Summary of bird data contributing to avoidance rates for Black-headed Gull

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Avonmouth	01/10/2007	31/03/2008	NA	NA	4.40	**0.32**	1.00	1.00	1.00	1.00	1.00
Avonmouth	01/10/2008	31/03/2009	NA	NA	7.10	**0.65**	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2009	31/03/2010	NA	NA	2.90	**0.33**	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2011	31/03/2012	NA	NA	12.80	**0.75**	0.00	1.00	1.00	1.00	0.00
Bloodgate Hill	01/10/2007	27/02/2008	4503	36	125.08	**0.18**	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	520	54	9.63	**0.07**	2.00	1.00	1.00	1.00	2.00
Boudwijnkanaal	01/05/2001	31/05/2001	49	17	2.88	**0.12**	0.00	1.00	1.00	1.00	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	2960	17	174.12	**0.32**	0.00	1.00	1.00	1.00	0.00
Boudwijnkanaal	01/09/2005	31/12/2005	696	17	40.94	**0.69**	12.00	1.00	1.00	1.00	15.96
Bouin	01/01/2003	31/12/2006	5815	370	15.72	**0.20***	28.00	1.23	1.32	1.00	45.46
Gneizdzewo	15/09/2010	15/11/2010	38	68	0.56	*0.02*	1.00	1.00	1.00	1.00	1.00
Gneizdzewo	15/09/2011	15/11/2011	212	57	3.72	*0.02*	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2012	15/11/2012	32	63	0.51	*0.02*	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	1187	45	26.38	**0.20**	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	72	62.10	**0.33**	2.00	1.14	1.00	1.00	2.76
Hellrigg	01/12/2011	31/03/2012	182	38	4.79	**0.25**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2012	31/03/2013	4799	36.5	131.48	**0.81**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	2501	36	69.47	**0.68**	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	215	18	11.94	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	104	18	5.78	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	58	18	3.22	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	117	18	6.50	**1.00**	1.00	1.79	1.00	1.00	1.79
Kleine Pathoweg	01/09/2005	31/12/2005	345	16	21.56	**0.57**	17.00	1.00	1.00	1.00	59.50
Red House Farm	01/04/2009	31/08/2009	NA	36	54.50	**0.24**	3.00	1.00	1.00	1.00	3.00
Slufterdam & Distridam	13/06/2012	04/07/2012	1659	15	110.60	**0.26**	4.00	1.00	1.00	1.00–3.23	7.56
Zeebrugge	01/06/2000	31/07/2000	17	16	1.06	**0.12**	0.00	1.00	1.00	4.17–9.09	0.00
Zeebrugge	01/06/2001	31/07/2001	17	16	1.06	**0.12**	0.00	1.00	1.00	4.17–9.09	0.00
Zeebrugge	01/09/2001	31/10/2001	94	16	5.88	**0.87**	0.00	1.00	1.00	4.17–9.09	0.00

*20% of all birds estimated to be at collision risk height

Common Gull Avoidance Rate

Data to estimate avoidance rates for common gulls came from nine sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Hellrigg, Red House Farm, Kessingland, Gneizdzewo, Bouin, Slufterdam & Distridam) with passage rates ranging from 0.03 birds hour^{1} to 507 birds hour^{1} and 2 collisions estimated following corrections for search area, searcher efficiency and predator behaviour (Table 13). Whilst there are some sites with significant activity levels, in most cases the number of birds recorded is much lower at 1-5 birds hour^{1}.

Table 13 Summary of bird data contributing to avoidance rates for Common Gull

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Bloodgate Hill	01/10/2007	27/02/2008	2207	36	61.31	**0.17**	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	470	54	8.70	**0.02**	0.00	1.00	1.00	1.00	0.00
Bouin	01/01/2003	31/12/2006	12	370	0.03	**0.20***	0.00	1.23	1.32	1.00	0.00
Gneizdzewo	15/09/2010	15/11/2010	39	68	0.57	*0.05*	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2011	15/11/2011	64	57	1.12	*0.05*	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2012	15/11/2012	110	63	1.75	*0.05*	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	89	45	1.98	**0.29**	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	72	17.60	**0.24**	0.00	1.14	1.00	1.00	0.00
Hellrigg	01/12/2011	31/03/2012	322	38	8.47	**0.50**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2012	31/03/2013	18512	36.5	507.18	**0.88**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	3315	36	92.08	**0.75**	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	24	18	1.33	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	29	18	1.61	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	27	18	1.50	**1.00**	1.00	1.79	1.00	1.00	1.79
Kessingland	01/11/2012	31/03/2013	43	18	2.39	**1.00**	0.00	1.79	1.00	1.00	0.00
Red House Farm	01/04/2009	31/08/2009	NA	36	2.90	**0.06**	0.00	1.00	1.00	1.00	0.00
Slufterdam & Distridam	13/06/2012	04/07/2012	66	15	4.40	**0.26**	0.00	1.00	1.00	1.00–3.23	0.00

*20% of all birds recorded at collision risk height

Lesser Black-backed Gull Avoidance Rate

Data to estimate avoidance rates for lesser black-backed gulls came from 10 sites (Bloodgate Hill, Goole Fields, Haverigg, Hellrigg, Red House Farm, Avonmouth, Kessingland, Bouin, Boudwijnkanaal, Zeebrugge, Slufterdam & Distridam) with passage rates ranging from 0.03 birds hour^{1} to 125 birds hour^{1} and a total of 43 collisions estimated following corrections for search area, searcher efficiency and predator behaviour. These data have been collected across a range of sites reflecting different habitat types, over a number of different years.

Table 14 Summary of bird data contributing to avoidance rates for Lesser Black-backed Gull

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Bloodgate Hill	01/10/2007	27/02/2008	7	36	0.19	**0.60**	0.00	1.00	1.00	1.00	0.00
Boudwijnkanaal	01/05/2001	31/05/2001	45	17	2.65	**0.76**	0.00	1.00	1.00	1.00	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	9	17	0.53	**0.89**	0.00	1.00	1.00	1.00	0.00
Bouin	01/01/2003	31/12/2006	63	370	0.17	**0.20***	0.00	1.23	1.32	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	851	45	18.91	**0.61**	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	72	45.30	**0.49**	1.00	1.14	1.00	1.00	1.38
Haverigg	01/04/2014	31/07/2014	1411	36	39.19	**0.34**	2.00	1.07	1.12	1.00	2.40
Haverigg	01/05/2019	31/07/2019	1016	36	28.22	**0.89**	1.00	1.07	1.33	1.00	1.42
Hellrigg	01/12/2011	31/03/2012	1	38	0.03	**1.00**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2012	31/03/2013	15	36.5	0.41	**0.88**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	54	36	1.50	**0.85**	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	15	18	0.83	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	25	18	1.39	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	17	18	0.94	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	57	18	3.17	**1.00**	0.00	1.79	1.00	1.00	0.00
Red House Farm	01/04/2009	31/08/2009	NA	36	3.60	**0.74**	0.00	1.00	1.00	1.00	0.00
Slufterdam & Distridam	13/06/2012	04/07/2012	1876	15	125.07	**0.62**	17.00	1.00	1.00	1.00–3.23	29.74
Zeebrugge	01/06/2000	31/07/2000	81	16	5.06	**0.32**	0.00	1.00	1.00	4.17–9.09	0.00
Zeebrugge	01/06/2001	31/07/2001	81	16	5.06	**0.32**	1.00	1.00	1.00	4.17–9.09	4.17
Zeebrugge	01/09/2001	31/10/2001	1025	16	64.06	**0.69**	1.00	1.00	1.00	4.17–9.09	4.17

*20% of all birds recorded at collision risk height

Herring Gull Avoidance Rate

Data to estimate avoidance rates for Herring Gulls came from 12 sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Haverigg, Hellrigg, Red House Farm, Avonmouth, Kessingland, Gneizdzewo, Bouin, Boudwijnkanaal, Zeebrugge, Slufterdam & Distridam) with passage rates ranging from 0.20 birds hour^{1} to 90 birds hour^{1} and a total of 66 collisions estimated following corrections for search area, searcher efficiency and predator behaviour (Table 15). These data have been collected across a range of sites reflecting different habitat types, over a number of different years.

Table 15 Summary of bird data contributing to avoidance rates for Herring Gull

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Avonmouth	01/10/2007	31/03/2008	NA	NA	6.80	**0.81**	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2008	31/03/2009	NA	NA	13.00	**0.82**	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2009	31/03/2010	NA	NA	18.80	**0.67**	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2011	31/03/2012	NA	NA	38.20	**0.79**	0.00	1.00	1.00	1.00	0.00
Bloodgate Hill	01/10/2007	27/02/2008	49	36	1.36	**0.90**	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	4358	54	80.70	**0.56**	1.00	1.00	1.00	1.00	1.00
Boudwijnkanaal	01/05/2001	31/05/2001	154	17	9.06	**0.25**	0.00	1.00	1.00	1.00	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	812	17	47.76	**0.34**	1.00	1.00	1.00	1.00	1.33
Bouin	01/01/2003	31/12/2006	807	370	2.18	**0.20***	0.00	1.23	1.32	1.00	0.00
Gneizdzewo	15/09/2011	15/11/2011	32	57	0.56	*0.11*	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	34	45	0.76	**0.44**	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	72	2.50	**0.66**	0.00	1.14	1.00	1.00	0.00
Haverigg	01/04/2014	31/07/2014	3273	36	90.92	**0.24**	3.00	1.07	1.12	1.00	3.60
Haverigg	01/05/2019	31/07/2019	1757	36	48.81	**0.89**	5.00	1.07	1.33	1.00	7.12
Hellrigg	01/12/2011	31/03/2012	141	38	3.71	**0.44**	1.00	1.00	1.00	1.00	1.00
Hellrigg	01/12/2012	31/03/2013	2646	36.5	72.49	**0.94**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	1028	36	28.56	**0.86**	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	355	18	19.75	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	98	18	5.44	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	203	18	11.28	**1.00**	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	93	18	5.17	**1.00**	1.00	1.79	1.00	1.00	1.79
Red House Farm	01/04/2009	31/08/2009	NA	36	0.20	**1.00**	0.00	1.00	1.00	1.00	0.00
Slufterdam & Distridam	13/06/2012	04/07/2012	403	15	26.87	**0.39**	17.00	1.00	1.00	1.00–3.23	29.34
Zeebrugge	01/06/2000	31/07/2000	136	16	8.50	**0.25**	1.00	1.00	1.00	4.17–9.09	4.17
Zeebrugge	01/06/2001	31/07/2001	136	16	8.50	**0.25**	2.00	1.00	1.00	4.17–9.09	8.79
Zeebrugge	01/09/2001	31/10/2001	1032	16	64.50	**0.53**	2.00	1.00	1.00	4.17–9.09	8.34

*20% of all birds recorded at collision risk height

Great Black-backed Gull Avoidance Rate

Data to estimate avoidance rates for great black-backed gulls came from 7 sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Hellrigg, Red House Farm, Bouin, Slufterdam & Distridam) with passage rates ranging from 0.05 birds hour^{-1} to 31 birds hour^{-1} and just 1 collision estimated following corrections for search area, searcher efficiency and predator behaviour (Table 16). Activity levels at most sites were low with <1 bird hour^{-1} recorded.

Table 16 Summary of bird data contributing to avoidance rates for Great Black-backed Gull

Site	Surveys Start Date	Surveys End Date	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	% Flights At Rotor Height (Site Specific Or Generic)	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Bloodgate Hill	01/10/2007	27/02/2008	13	36	0.36	**0.77**	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	1704	54	31.56	**0.56**	0.00	1.00	1.00	1.00	0.00
Bouin	01/01/2003	31/12/2006	18	370	0.05	**0.20***	0.00	1.23	1.32	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	72	1.30	**0.69**	0.00	1.14	1.00	1.00	0.00
Hellrigg	01/12/2011	31/03/2012	2	38	0.05	**1.00**	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2012	31/03/2013	18	36.5	0.49	**0.93**	0.0	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	2	36	0.06	**0.50**	0.00	1.00	1.00	1.00	0.00
Red House Farm	01/04/2009	31/08/2009	NA	36	0.06	**1.00**	1.00	1.00	1.00	1.00	1.00
Slufterdam & Distridam	13/06/2012	04/07/2012	4	15	0.27	**0.62**	0.00	1.00	1.00	1.00–3.23	0.00

*20% of all birds recorded at collision risk height

Small Gull Avoidance Rate

Data to estimate avoidance rates for small gulls (Black-headed Gull, Common Gull, Black-legged Kittiwake) came from 15 sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Hellrigg, Red House Farm, Avonmouth, Kessingland, Gneizdzewo, Bouin, Thanet, Boudwijnkanaal, Kleine Pathoweg, Dr Put, Zeebrugge, Slufterdam & Distridam) with passage rates ranging from 1.13 birds hour^{1} to 638 birds hour^{1} and a total of 146 collisions estimated following corrections for search area, searcher efficiency and predator behaviour.

Table 17 Summary of bird data contributing to avoidance rates for small gulls

Site	Surveys Start Date	Surveys End Date	Density (Birds km^{-1})	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Avonmouth	01/10/2007	31/03/2008	NA	NA	NA	4.40	1.00	1.00	1.00	1.00	1.00
Avonmouth	01/10/2008	31/03/2009	NA	NA	NA	7.10	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2009	31/03/2010	NA	NA	NA	2.90	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2011	31/03/2012	NA	NA	NA	12.80	0.00	1.00	1.00	1.00	0.00
Bloodgate Hill	01/10/2007	27/02/2008	NA	6710	36	186.39	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	NA	1067	54	19.76	2.00	1.00	1.00	1.00	2.00
Boudwijnkanaal	01/05/2001	31/05/2001	NA	49	17	2.88	0.00	1.00	1.00	1.33	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	NA	2960	17	174.12	0.00	1.00	1.00	1.33	0.00
Boudwijnkanaal	01/09/2005	31/12/2005	NA	696	17	40.94	12.00	1.00	1.00	1.33	15.96
Bouin	01/01/2003	31/12/2006	NA	5894	370	15.93	29.00	1.23	1.32	1.00	47.08
De Put	01/01/2006	28/02/2006	NA	160	18	8.89	2.00	1.00	1.00	1.00	2.00
Gneizdzewo	15/09/2010	15/11/2010	NA	77	68	1.13	1.00	1.00	1.00	1.00	1.00
Gneizdzewo	15/09/2011	15/11/2011	NA	289	57	5.07	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2012	15/11/2012	NA	142	63	2.25	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	NA	1276	45	28.36	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	NA	72	79.70	2.00	1.14	1.00	1.21	2.76
Hellrigg	01/12/2011	31/03/2012	NA	504	38	13.26	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2012	31/03/2013	NA	23311	36.5	638.66	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	NA	5816	36	161.56	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	NA	372	18	20.67	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	NA	245	18	13.61	2.00	1.79	1.00	1.00	3.58
Kleine Pathoweg	01/09/2005	31/12/2005	NA	345	16	21.56	17.00	1.00	1.00	3.50	59.50
Red House Farm	01/04/2009	31/08/2009	NA	NA	36	57.40	3.00	1.00	1.00	1.00	3.00
Slufterdam & Distridam	13/06/2012	04/07/2012	NA	1751	15	116.73	4.00	1.00	1.00	1.00–3.23	7.56
Thanet	01/10/2014	31/03/2015	1.1	NA	NA	NA	1.00	1.00	1.00	1.00	1.00
Thanet	01/10/2015	31/03/2016	1.1	NA	NA	NA	0.00	1.00	1.00	1.00	0.00
Zeebrugge	01/06/2000	31/07/2000	NA	17	16	1.06	0.00	1.00	1.00	4.17–9.09	0.00
Zeebrugge	01/06/2001	31/07/2001	NA	17	16	1.06	0.00	1.00	1.00	4.17–9.09	0.00
Zeebrugge	01/09/2001	31/10/2001	NA	94	16	5.88	0.0	1.00	1.00	4.17–9.09	0.00

Large Gull Avoidance Rate

Data to estimate avoidance rates for large gulls (Herring Gull, Lesser Black-backed Gull, Great Black-backed Gull) came from 15 sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Haverigg, Hellrigg, Red House Farm, Avonmouth, Kessingland, Gneizdzewo, Bouin, Thanet, Kleine Pathoweg, Boudwijnkanaal, Zeebrugge, Slufterdam & Distridam) with passage rates ranging from 0.06 birds hour^{1} to 152 birds hour^{1} and a total of 349 collisions estimated following corrections for search area, searcher efficiency and predator behaviour. The estimated large gull avoidance rate is lower than those estimated for Lesser Black-backed, Herring and Great Black backed Gulls as it includes data from surveys in which the data used to estimate activity levels were drawn from birds identified as large gulls rather than to species level. This includes the data collected at Thanet and the data collected at Boudwijnkanaal and Kleine Pathoweg in autumn/winter 2005.

Table 18 Summary of bird data contributing to avoidance rates for small gulls

Site	Surveys Start Date	Surveys End Date	Density (Birds km^{-1})	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Avonmouth	01/10/2007	31/03/2008	NA	NA	NA	6.80	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2008	31/03/2009	NA	NA	NA	13.00	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2009	31/03/2010	NA	NA	NA	18.80	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2011	31/03/2012	NA	NA	NA	38.20	0.00	1.00	1.00	1.00	0.00
Bloodgate Hill	01/10/2007	27/02/2008	NA	69	36	1.92	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	NA	6070	54	112.41	1.00	1.00	1.00	1.00	1.00
Boudwijnkanaal	01/05/2001	31/05/2001	NA	199	17	11.71	0.00	1.00	1.00	1.33	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	NA	821	17	48.29	1.00	1.00	1.00	1.33	1.33
Boudwijnkanaal	01/09/2005	31/12/2005	NA	339	17	19.94	28.00	1.00	1.00	1.33	37.24
Bouin	01/01/2003	31/12/2006	NA	891	370	2.41	1.00	1.23	1.32	1.00	1.62
Gneizdzewo	18/08/2008	16/11/2008	NA	15	216	0.07	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2010	15/11/2010	NA	117	68	1.72	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2011	15/11/2011	NA	32	57	0.56	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2012	15/11/2012	NA	67	63	1.06	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	NA	924	45	20.53	0.00	1.00	1.00	1.00	0.0
Goole Fields	01/09/2017	31/03/2018	NA	NA	72	50.84	1.00	1.14	1.00	1.21	1.38
Haverigg	01/04/2014	31/07/2014	NA	4684	36	130.11	5.00	1.07	1.12	1.00	5.99
Haverigg	01/05/2019	31/07/2019	NA	2773	36	77.03	6.00	1.07	1.33	1.00	8.54
Hellrigg	01/12/2011	31/03/2012	NA	144	38	3.79	1.00	1.00	1.00	1.00	1.00
Hellrigg	01/12/2012	31/03/2013	NA	2679	36.5	73.40	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	NA	1084	36	30.11	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	NA	493	18	27.39	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	NA	370	18	20.56	1.00	1.79	1.00	1.00	1.79
Kleine Pathoweg	01/09/2005	31/12/2005	NA	327	16	20.44	57.00	1.00	1.00	3.50	199.50
Red House Farm	01/04/2009	31/08/2009	NA	NA	36	3.86	1.00	1.00	1.00	1.00	1.00
Slufterdam & Distridam	13/06/2012	04/07/2012	NA	2283	15	152.20	34.00	1.00	1.00	1.00–3.23	59.08
Thanet	01/10/2014	31/03/2015	2.76	NA	NA	NA	2.00	1.00	1.00	1.00	2.00
Thanet	01/10/2015	31/03/2016	2.76	NA	NA	NA	2.00	1.00	1.00	1.00	2.00
Zeebrugge	01/06/2000	31/07/2000	NA	217	16	13.56	1.00	1.00	1.00	4.17–9.09	4.17
Zeebrugge	01/06/2001	31/07/2001	NA	217	16	13.56	3.00	1.00	1.00	4.17–9.09	12.96
Zeebrugge	01/09/2001	31/10/2001	NA	2057	16	128.56	3.00	1.00	1.00	4.17–9.09	12.51

All Gull Avoidance Rate

Data to estimate avoidance rates for all gulls came from 19 sites (Bloodgate Hill, Blyth Harbour, Goole Fields, Haverigg, Hellrigg, Red House Farm, Avonmouth, Kessingland, Gneizdzewo, Bouin, Oosterbierum, Thanet, Kleine Pathoweg, De Put, Delfzijl-Zuid, Sabinapolder, Boudwijnkanaal, Zeebrugge, Slufterdam & Distridam) with passage rates ranging from 1.4 birds hour^{-1} to 712 birds hour^{-1} and a total of 628 collisions estimated following corrections for search area, searcher efficiency and predator behaviour.

Table 19 Summary of bird data contributing to avoidance rates for all gulls

Site	Surveys Start Date	Surveys End Date	Density (Birds km^{-1})	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Avonmouth	01/10/2007	31/03/2008	NA	NA	NA	11.20	1.00	1.00	1.00	1.00	1.00
Avonmouth	01/10/2008	31/03/2009	NA	NA	NA	20.10	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2009	31/03/2010	NA	NA	NA	21.70	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2011	31/03/2012	NA	NA	NA	51.00	0.00	1.00	1.00	1.00	0.00
Bloodgate Hill	01/10/2007	27/02/2008	NA	6779	36	188.31	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	NA	7137	54	132.17	3.00	1.00	1.00	1.00	3.00
Boudwijnkanaal	01/05/2001	31/05/2001	NA	248	17	14.59	0.00	1.00	1.00	1.33	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	NA	3781	17	222.41	1.00	1.00	1.00	1.33	1.33
Boudwijnkanaal	01/09/2005	31/12/2005	NA	1035	17	60.88	40.00	1.00	1.00	1.33	53.20
Bouin	01/01/2003	31/12/2006	NA	6785	370	18.34	30.00	1.23	1.32	1.00	48.71
De Put	01/01/2006	28/02/2006	NA	160	18	8.89	2.00	1.00	1.00	1.00	2.00
Delfzijl-Zuid	01/08/2006	30/10/2006	NA	1496	33	45.33	8.00	1.00	1.00	1.14	9.12
Gneizdzewo	15/09/2007	15/11/2007	NA	894	216	4.14	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	18/08/2008	16/11/2008	NA	311	216	1.44	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2010	15/11/2010	NA	223	68	3.28	1.00	1.00	1.00	1.00	1.00
Gneizdzewo	15/09/2011	15/11/2011	NA	1018	57	17.86	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2012	15/11/2012	NA	1839	63	29.19	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	NA	2200	45	48.89	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	NA	72	130.54	3.00	1.14	1.00	1.21	4.14
Haverigg	01/04/2014	31/07/2014	NA	4684	36	130.11	5.00	1.07	1.12	1.00	5.99
Haverigg	01/05/2019	31/07/2019	NA	2773	36	77.03	6.00	1.07	1.33	1.00	8.54
Hellrigg	01/12/2011	31/03/2012	NA	648	38	17.05	1.00	1.00	1.00	1.00	1.00
Hellrigg	01/12/2012	31/03/2013	NA	25990	36.5	712.05	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	NA	6900	36	191.67	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	NA	865	18	48.06	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	NA	615	18	34.17	3.00	1.79	1.00	1.00	5.37
Kleine Pathoweg	01/09/2005	31/12/2005	NA	672	16	42.00	74.00	1.00	1.00	3.50	259.00
Oosterbierum	NA	NA	NA	NA	NA	NA	NA	2.40	5.50	NA	NA
Oosterbierum	NA	NA	NA	NA	NA	NA	NA	36.50	1.00	NA	NA
Red House Farm	01/04/2009	31/08/2009	NA	NA	36	61.26	4.00	1.00	1.00	1.00	4.00
Sabinapolder	13/11/2209	03/12/2010	NA	NA	NA	30.00	17.00	1.00	1.00	1.00	17.00
Slufterdam & Distridam	13/06/2012	04/07/2012	NA	4034	15	268.93	38.00	1.00	1.00	1.00–3.23	66.64
Thanet	01/10/2014	31/03/2015	3.86	NA	NA	NA	3.00	1.00	1.00	1.00	3.00
Thanet	01/10/2015	31/03/2016	3.86	NA	NA	NA	2.00	1.00	1.00	1.00	2.00
Zeebrugge	01/06/2000	31/07/2000	NA	234	16	14.63	1.00	1.00	1.00	4.17–9.09	4.17
Zeebrugge	01/06/2001	31/07/2001	NA	234	16	14.63	3.00	1.00	1.00	4.17–9.09	12.96
Zeebrugge	01/09/2001	31/10/2001	NA	2151	16	134.44	3.00	1.00	1.00	4.17–9.09	12.51

All Gulls and Tern Avoidance Rate

Data to estimate avoidance rates for all gulls and terns came from 19 sites (Table 2, Figure 1) with passage rates ranging from 1.4 birds hour[1] to 712 birds hour[1] and a total of 804 collisions estimated following corrections for search area, searcher efficiency and predator behaviour.

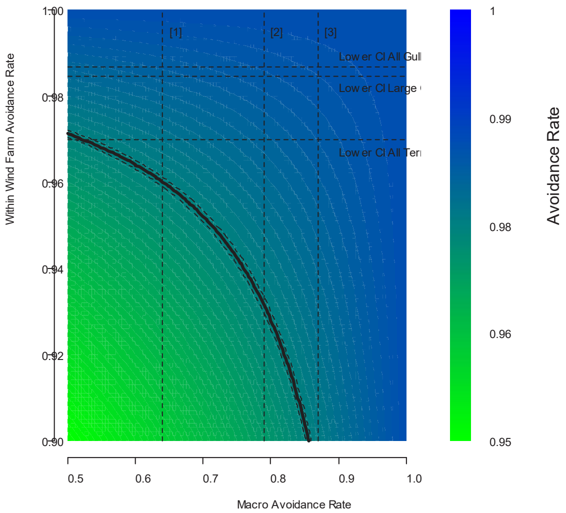
Table 20 Summary of bird data contributing to avoidance rates for all gulls

Site	Surveys Start Date	Surveys End Date	Density (Birds km^{-1})	Total Count	Hours Of Survey	Passage Rate (Birds Hr^{-1})	Observed Collisions	Correction Factor			Corrected Collisions
								Predation	Efficiency	Area	
Avonmouth	01/10/2007	31/03/2008	NA	NA	NA	11.20	1.00	1.00	1.00	1.00	1.00
Avonmouth	01/10/2008	31/03/2009	NA	NA	NA	20.10	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2009	31/03/2010	NA	NA	NA	21.70	0.00	1.00	1.00	1.00	0.00
Avonmouth	01/10/2011	31/03/2012	NA	NA	NA	51.00	0.00	1.00	1.00	1.00	0.00
Bloodgate Hill	01/10/2007	27/02/2008	NA	6779	36	188.31	0.00	1.00	1.00	1.00	0.00
Blyth Harbour	01/09/2016	31/03/2017	NA	7141	54	132.24	3.00	1.00	1.00	1.00	3.00
Boudwijnkanaal	01/05/2001	31/05/2001	NA	248	17	14.59	0.00	1.00	1.00	1.33	0.00
Boudwijnkanaal	01/10/2001	31/10/2001	NA	3781	17	222.41	1.00	1.00	1.00	1.33	1.33
Boudwijnkanaal	01/09/2005	31/12/2005	NA	1035	17	60.88	40.00	1.00	1.00	1.33	53.20
Bouin	01/01/2003	31/12/2006	NA	6811	370	18.41	30.00	1.23	1.32	1.00	48.71
De Put	01/01/2006	28/02/2006	NA	160	18	8.89	2.00	1.00	1.00	1.00	2.00
Delfzijl-Zuid	01/08/2006	30/10/2006	NA	1496	33	45.33	8.00	1.00	1.00	1.14	9.12
Gneizdzewo	15/09/2007	15/11/2007	NA	894	216	4.14	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	18/08/2008	16/11/2008	NA	311	216	1.44	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2010	15/11/2010	NA	223	68	3.28	1.00	1.00	1.00	1.00	1.00
Gneizdzewo	15/09/2011	15/11/2011	NA	1018	57	17.86	0.00	1.00	1.00	1.00	0.00
Gneizdzewo	15/09/2012	15/11/2012	NA	1839	63	29.19	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/04/2017	31/08/2017	NA	2200	45	48.89	0.00	1.00	1.00	1.00	0.00
Goole Fields	01/09/2017	31/03/2018	NA	NA	72	130.54	3.00	1.14	1.00	1.21	4.14
Haverigg	01/04/2014	31/07/2014	NA	4684	36	130.11	5.00	1.07	1.12	1.00	5.99
Haverigg	01/05/2019	31/07/2019	NA	2773	36	77.03	6.00	1.07	1.33	1.00	8.54
Hellrigg	01/12/2011	31/03/2012	NA	648	38	17.05	1.00	1.00	1.00	1.00	1.00
Hellrigg	01/12/2012	31/03/2013	NA	25990	36.5	712.05	0.00	1.00	1.00	1.00	0.00
Hellrigg	01/12/2014	31/03/2015	NA	6900	36	191.67	0.00	1.00	1.00	1.00	0.00
Kessingland	01/11/2011	31/03/2012	NA	865	18	48.06	0.00	1.79	1.00	1.00	0.00
Kessingland	01/11/2012	31/03/2013	NA	615	18	34.17	3.00	1.79	1.00	1.00	5.37
Kleine Pathoweg	01/09/2005	31/12/2005	NA	672	16	42.00	74.00	1.00	1.00	3.50	259.00
Oosterbierum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Red House Farm	01/04/2009	31/08/2009	NA	NA	36	61.26	4.00	1.00	1.00	1.00	4.00
Sabinapolder	13/11/2209	03/12/2010	NA	NA	NA	30.00	17.00	1.00	1.00	1.00	17.00
Slufterdam & Distridam	13/06/2012	04/07/2012	NA	6621	15	441.40	43.00	1.00	1.00	1.00–3.23	75.74
Thanet	01/10/2014	31/03/2015	3.86	NA	NA	NA	3.00	1.00	1.00	1.00	3.00
Thanet	01/10/2015	31/03/2016	3.86	NA	NA	NA	2.00	1.00	1.00	1.00	2.00
Zeebrugge	01/06/2000	31/07/2000	NA	2603	16	162.69	1.00	1–1.1	1–1.16	4.17–9.09	4.17
Zeebrugge	01/06/2001	31/07/2001	NA	2603	16	162.69	4.00	1–1.1	1–1.16	4.17–9.09	18.28
Zeebrugge	01/09/2001	31/10/2001	NA	3866	16	241.63	3.00	1–1.1	1–1.16	4.17–9.09	12.51
Zeebrugge	01/06/2004	30/06/2004	NA	26954	17	1585.53	9.00	1.10	1.16	4.17–9.09	73.00
Zeebrugge	01/06/2005	30/06/2005	NA	16906	17	994.47	12.00	1.10	1.16	4.17–9.09	89.54

Northern Gannet Avoidance Rates

Whilst evidence for macro-avoidance in gulls and terns is equivocal, there is evidence of strong macro-avoidance in Northern Gannet (Dierschke *et al*., 2016). By combining published estimates of macro-avoidance with a range of plausible values for within-windfarm avoidance informed by the above analyses, it is possible to estimate a realistic, precautionary avoidance rate for gannets. A previous review of macro-avoidance in gannets found macro-avoidance rates in excess of 0.5 (Dierschke *et al*., 2016), with several values significantly greater than this reported. Based on this review and subsequent research, we can consider scenarios with low, medium and high levels of macro-avoidance of 0.64, 0.79 and 0.87 (Krijgsveld *et al*., 2011; Vanermen, Onkelinx, Verschelde, *et al*., 2015; Welcker & Nehls, 2016).

Figure 6 Simulations of total avoidance rates for northern gannet in comparison to the published macro-avoidance rates from [1] (Krijgsveld et al., 2011), [2] (Vanermen, Onkelinx, Courtens, et al., 2015) and [3] (Welcker & Nehls, 2016) and, the lower confidence interval surrounding the avoidance rates for use in the basic Band (2012) model for large gulls, all gulls and all terns. Curved line indicates the within-windfarm avoidance rate for all gulls and terns (and 95% Cis) as a proxy for total avoidance.



We can then combine these with the avoidance rates estimated above in order to get an indication of the potential range of overall avoidance. To be precautionary, these calculations can be based on the lower confidence interval estimated for each rate. If we consider that within-windfarm avoidance by Northern Gannets is likely to at least equal to the lower CI of the all terns rate, we can see that, as long as macro-avoidance is greater than 0.535, total avoidance for Northern Gannets is likely to exceed the within-windfarm avoidance rate for all gulls and terns (Figure 6). This figure is well below the low macro-avoidance scenario from Krijgsveld *et al.*, (2011) highlighted above.

Having combined estimates of with-windfarm avoidance from gulls and terns with low, medium, and high estimates of macro-avoidance recorded in Northern Gannets, we can estimate a range of total avoidance of between 0.9891 and 0.9982 (Table 21). Given that avoidance behaviour is likely to reflect a continuum, it is also worth considering whether the all gulls and terns avoidance rate may be a suitable proxy for total avoidance in Northern Gannets. In selecting between these figures there are a number of important factors to consider. Firstly, while it is clear that macro-avoidance in Northern Gannets is likely to be high, data from GPS tracking highlights that there are clear differences between individuals in relation to their response to wind farms (Peschko *et al.*, 2021). Secondly, whilst it is true that no Northern Gannets have been directly observed colliding, collisions are rare events and, to date, studies have been carried out in areas where Northern Gannet densities are relatively low, particularly during the breeding season. Furthermore, it is clear that Northern Gannet collisions do occur, with the recovery of corpses with injuries consistent with having been struck by turbine blades at Blyth (Rothery *et al*., 2009) and in Belgium (E. Stienen pers. comm.). Consequently, a precautionary value is likely to be appropriate.

Sensitivty of Avoidance Rates

Accounting for the imperfect detection of corpses can have a significant impact on the avoidance rates estimated from these data (Figure 7). Generally, the imperfect detection of corpses can have three causes:

- Scavenger or predator activity;
- Searcher efficiency;
- Restricted access to the area around the base of the turbines.

There are a variety of approaches for estimating correction factors to account for this imperfect detection, and the values used are often site-specific and cannot be transferred to other sites (Bernardino *et al.*, 2013; Costantini *et al*., 2017). All studies included in this analysis explicitly state that they have considered imperfect detection in their estimates of mortality. This has been achieved through searcher efficiency trials

Table 21 Avoidance rates for the basic Band (2012) model (and 95% CIs) estimated for Northern Gannet through combining low, medium, and high macro-avoidance rates with the estimated avoidance rates for all terns, small gulls, large gulls, all gulls, and all gulls and terns.

	Low macro-avoidance	Mediun macro-avoidance	High macro-avoidance
All Terns Avoidance Rate	0.9896 (0.9891 – 0.9901)	0.994 (0.9936 – 0.9942)	0.9963 (0.9961 – 0.9964)
Small Gulls Avoidance Rate	0.9971 (0.9968 – 0.9974)	0.9983 (0.9981 – 0.9985)	0.9989 (0.9988 – 0.9991)
Large Gulls Avoidance Rate	0.995 (0.9945 – 0.9955)	0.9971 (0.9968 – 0.9974)	0.9982 (0.998 – 0.9984)
All Gull Avoidance Rate	0.9955 (0.9952 – 0.9956)	0.9974 (0.9972 – 0.9975)	0.9984 (0.9983 – 0.9984)
All Gulls and Terns Avoidance Rate	0.9948 (0.9947 – 0.995)	0.997 (0.9969 – 0.9971)	0.9981 (0.9981 – 0.9982)

Table 22 Avoidance rates for the extended Band (2012) model(and 95% CIs) estimated for Northern Gannet through combining low, medium, and high macro-avoidance rates with the estimated avoidance rates for all terns, small gulls, large gulls, all gulls, and all gulls and terns.

	Low macro-avoidance	Mediun macro-avoidance	High macro-avoidance
All Terns Avoidance Rate	0.9764 (0.9753 – 0.9775)	0.9862 (0.9856 – 0.9869)	0.9915 (0.9911 – 0.9919)
Small Gulls Avoidance Rate	0.9767 (0.9744 – 0.9791)	0.9864 (0.985 – 0.9878)	0.9916 (0.9907 – 0.9925)
Large Gulls Avoidance Rate	0.9801 (0.9781 – 0.9821)	0.9884 (0.9873 – 0.9896)	0.9928 (0.9921 – 0.9935)
All Gull Avoidance Rate	0.9832 (0.9824 – 0.9839)	0.9902 (0.9898 – 0.9906)	0.9939 (0.9937 – 0.9942)
All Gulls and Terns Avoidance Rate	0.982 (0.9815 – 0.9825)	0.9895 (0.9892 – 0.9898)	0.9935 (0.9933 – 0.9937)

Table 23 Avoidance rates for the basic sCRM (and 95% CIs) estimated for Northern Gannet through combining low, medium, and high macro-avoidance rates with the estimated avoidance rates for all terns, small gulls, large gulls, all gulls, and all gulls and terns.

	Low macro-avoidance	Mediun macro-avoidance	High macro-avoidance
All Terns Avoidance Rate	0.9897 (0.9893 – 0.99)	0.994 (0.9938 – 0.9942)	0.9963 (0.9962 – 0.9964)
Small Gulls Avoidance Rate	0.9972 (0.9969 – 0.9974)	0.9983 (0.9982 – 0.9985)	0.999 (0.9989 – 0.9991)
Large Gulls Avoidance Rate	0.995 (0.9946 – 0.9954)	0.9971 (0.9968 – 0.9973)	0.9982 (0.998 – 0.9983)
All Gull Avoidance Rate	0.9956 (0.9953 – 0.996)	0.9975 (0.9973 – 0.9977)	0.9984 (0.9983 – 0.9986)
All Gulls and Terns Avoidance Rate	0.995 (0.9946 – 0.9954)	0.9971 (0.9969 – 0.9973)	0.9982 (0.9981 – 0.9983)

Table 24 Avoidance rates for the extended sCRM (and 95% CIs) estimated for Northern Gannet through combining low, medium, and high macro-avoidance rates with the estimated avoidance rates for all terns, small gulls, large gulls, all gulls, and all gulls and terns.

	Low macro-avoidance	Mediun macro-avoidance	High macro-avoidance
All Terns Avoidance Rate	0.9784 (0.976 – 0.9806)	0.9874 (0.986 – 0.9887)	0.9922 (0.9913 – 0.993)
Small Gulls Avoidance Rate	0.9793 (0.9722 – 0.9841)	0.9879 (0.9838 – 0.9907)	0.9925 (0.990 – 0.9943)
Large Gulls Avoidance Rate	0.9677 (0.9617 – 0.9733)	0.9812 (0.9776 – 0.9844)	0.9884 (0.9862 – 0.9904)
All Gull Avoidance Rate	0.9734 (0.9686 – 0.9778)	0.9845 (0.9817 – 0.987)	0.9904 (0.9887 – 0.992)
All Gulls and Terns Avoidance Rate	0.9746 (0.9713 – 0.9779)	0.9852 (0.9833 – 0.9871)	0.9908 (0.9897 – 0.992)

Figure 7 Avoidance rates estimated for use with the basic Band model with (blue) and without (red) application of correction factors for corpse detection.

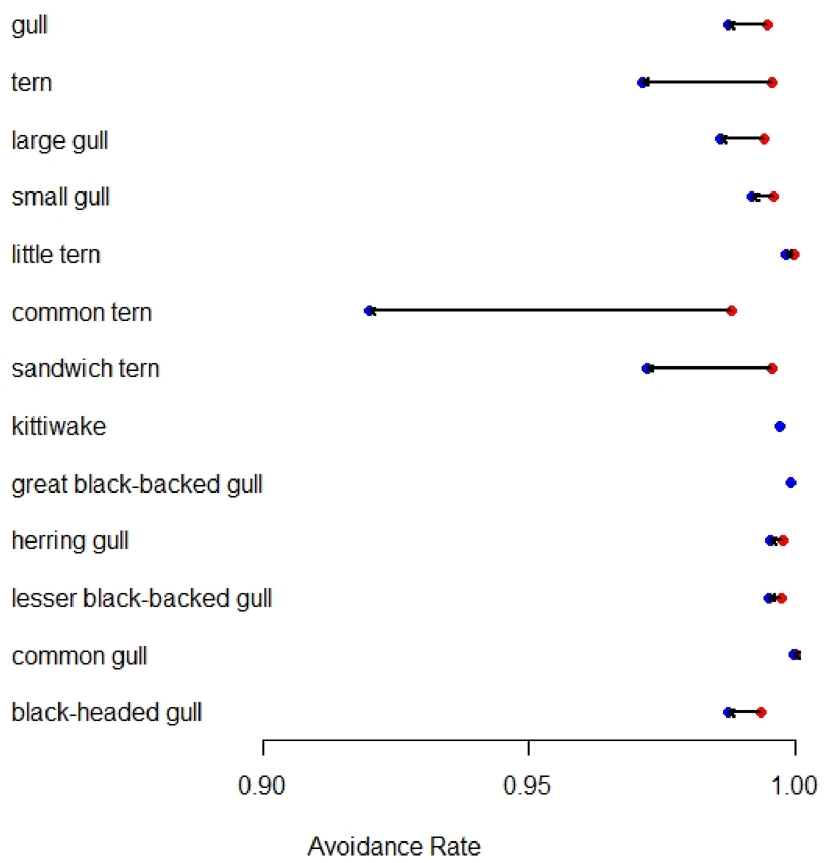
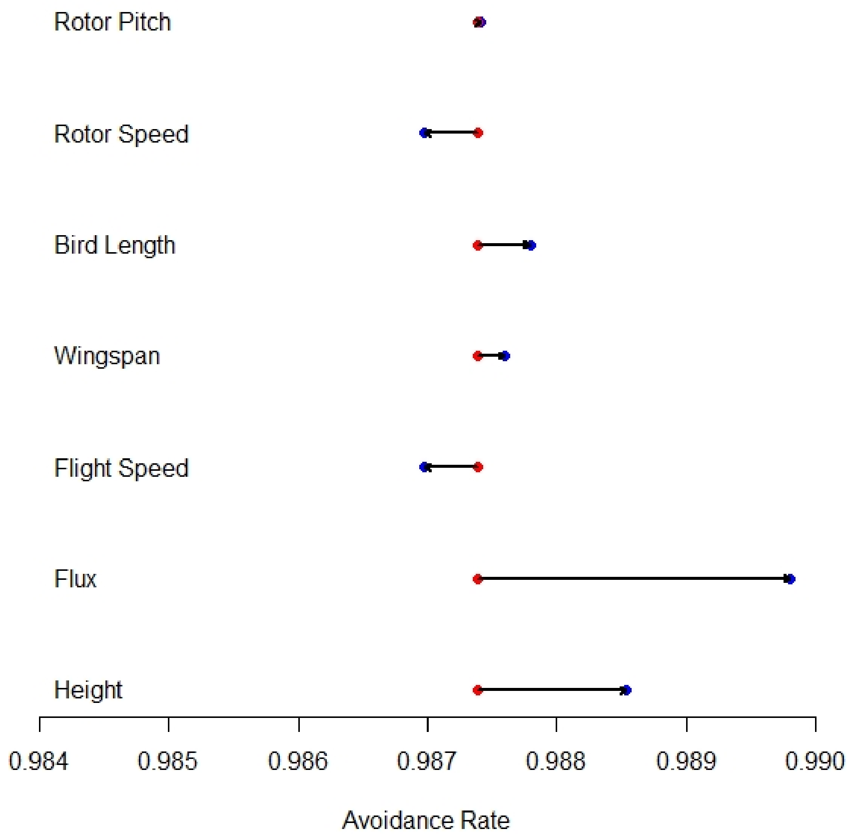


Figure 8 Impact of a 10% error in each parameter used to estimated avoidance rates for gulls using the basic Band model.



and corpse persistence trials. Generally, for the terns and gulls considered here, corrections for these factors have been close to 1 (i.e., there is perfect detection of collision victims, tables 4–20), reflecting both the size of the species concerned and the regularity of searches over the study period. However, in some cases a more significant correction has been applied to account for the area available to search. Where possible we have applied these corrections on a turbine-specific basis. For example, at Zeebrugge, where turbines are on the seawall, in some cases these are adjacent to water and only a small strip either side of the turbine is available to search (Figure 2). The avoidance rates calculated here are based on the collision rates estimated once the corrections for search area, predator activity and searcher efficiency reported in each study have been applied. The impact of applying these correction factors is particularly pronounced in relation to terns, with an estimated avoidance rate for use with the basic Band model of 0.995 reduced to 0.971 after corrections have been applied to account for the imperfect detection of corpses (Figure 7). This is likely to reflect the influence of data from Zeebrugge and Slufterdam & Distridam on the calculated avoidance rates, as both sites applied substantial corrections to account for the area available to search. However, even with gulls we can see a significant reduction in the avoidance rate once imperfect detection of corpses has been accounted for, from 0.994 to 0.987 (Figure 7). Whilst estimates of avoidance rates are sensitive to error in other parameters, notably the flux rate and the proportion of birds at risk height, this sensitivity is not as great as the sensitivity to whether a correction has been applied to account for imperfect corpse detection (Figure 8).

Having applied corrections for corpse detections, in many cases avoidance rates are lower than previous estimates (Table 3) (e.g. Cook *et al*., 2018; Cook *et al.*, 2014). This is particularly noticeable in relation to terns. However, entering the collision rate with corrections applied for corpse detection into the electronic appendix supplied alongside Cook *et al*. (2014) yields a similar estimated avoidance rate for sandwich terns at Zeebrugge to that reported here.

Alternative approaches to estimating avoidance rates

The avoidance rates estimated within this report are based on data collected within the windfarms concerned by comparing predicted and observed collision rates. As such, they account for meso-avoidance, micro-avoidance and error in the model that is used to estimate the predicted collision rates. Given the uncertainty over how applicable avoidance rates derived from onshore sites are to offshore windfarms, and the challenges in collecting collision data in the offshore environment, there is growing interest in approaches to directly measure avoidance behaviour and collision rates. Approaches which have been used to date include boat or digital aerial surveys (APEM Ltd., 2014; Harwood *et al.*, 2018), GPS or boat-based visual tracking (Harwood *et al.,* 2018; Thaxter *et al.*, 2018), radar (Krijgsveld *et al.*, 2011; Plonczkier & Simms, 2012; Skov, Heinanen, *et al*., 2018) and camera systems (Desholm *et al*., 2006; Skov, Heinanen, *et al*., 2018). These studies all provide valuable insights into the behaviour of birds in the offshore environment and context about collision and avoidance rates.

The variability of the marine environment makes it challenging to draw conclusions about the response of birds to windfarms based on changes in their distribution (Maclean *et al*., 2013; Vanermen, Onkelinx, Verschelde, *et al.*, 2015). However, given the expansion of offshore windfarms and the monitoring carried out at these sites, we are in a position to make general inferences about the likely response of different species to a windfarm at a macro scale. For example, species like gannets and divers show a consistent, negative response to windfarms, while gulls may not show any avoidance response (Dierschke *et al*., 2016). Whilst some studies (e.g. Desholm & Kahlert, 2005) show birds strongly responding to the presence of turbines, translating data from these studies into an avoidance rate is challenging as they do not account for birds whose flightpaths would not have intersected with turbines. However, such challenges can be overcome.

Harwood *et al*. (2018) use a data set based on visual tracking of Sandwich Terns from boats in order to investigate their avoidance response to turbines within Sheringham Shoal Windfarm. As data were available from the pre- and post-construction phases, it was possible to analyse how distance to turbine locations changed once the windfarm had been completed. Similarly, (Thaxter *et al.,* 2018) used GPS tracking data in order to analyse the proximity of Lesser Black-backed Gulls to windfarms within the Irish Sea. In this instance no pre-construction data were available, but this challenge was overcome by simulating a series of random tracks and comparing these to the observed distribution. Both of these studies highlighted a strong avoidance response to the presence of turbines. Such responses reflect meso-avoidance, given that they relate to data collected within the windfarms concerned. The resolution of the GPS data and the rarity of birds entering turbine rotor-swept areas mean that it is not possible to make inferences about last-second micro-avoidance from these data. However, the strength of the response to the presence of turbine implies that meso-avoidance rates are likely to be very high.

Such studies highlight how macro- and meso-avoidance rates can be derived as part of ongoing studies. However, in order to estimate an avoidance rate suitable for use in collision risk models it would be necessary to combine these with estimates of micro-avoidance, and account for model error (the term avoidance rates may be misleading, but the avoidance rate as specified in Band 2012 is a way of accounting for error in predicted collisions, widely assumed to be largely due to avoidance behaviour taken by birds). The deployment of camera systems will help with the estimation of last-second micro-avoidance rates. However, the rarity of such events (e.g. Skov, Heinanen, *et al*., 2018) will make it challenging to robustly quantify these rates. Incorporating other sources of model error is likely to be more challenging still.

Principals to guide the selection of appropriate avoidance rates

The sensitivity of collision risk models to the assumed avoidance rates means that it is important that the best available evidence is used in order to select appropriate values. Ideally, we would be able to recommend a series of seasonal-, species-, age-, and activity-specific rates. In practice we lack the data to do so. Given the data available at present we must consider where it is appropriate to use species-specific values and, where we must use generic values. I outline some key considerations below to guide current recommendations about avoidance rates and, the incorporation of additional data in the future.

Has imperfect corpse correction been accounted for?

Estimated avoidance rates are highly sensitive to whether or not corpse corrections have been applied (Figure 5). In incorporating future data into estimates of avoidance rates, it is important to consider whether these have been applied. Even in cases where the correction for imperfect detection is 1 (i.e., perfect detection of collision victims), it is important that this is stated explicitly. Monitoring of collision rates using camera systems is becoming increasingly widespread. It is important to develop methodologies that can account for imperfect detection of collisions (e.g. due to camera malfunctions or limits on the number of birds that can be tracked at any time) with these systems.

Null records

The fact that no collisions have been recorded at a site should not be a reason to exclude data from that site when estimating avoidance rates. Where flight activity for a species of interest has been recorded at a site, it is important that these data are incorporated into analyses. A failure to incorporate these data is likely to result in an underestimate of avoidance rate. Incorporating these data will also help to ensure avoidance rates are based on data from a more representative range of sites; the variability and uncertainty surrounding these estimates will also be better reflected.

Avoidance rates are model specific

A key part of estimating avoidance rates is estimating the number of collisions that would have been expected in the absence of avoidance. Each model does this differently and, hence, each requires the use of a different avoidance rate. The most obvious example of this relates to the basic and extended Band models. By accounting for the vertical distribution of birds, the extended model results in a reduced estimate of the total number of birds at risk of collision. Consequently, the avoidance rate used with the extended model is typically lower than that used with the basic model. A similar logic applies to the Christie & Urquhart (2015) extension to the Band model. However, it also applies to the extended sCRM, and may apply to the basic sCRM. As set out above (Figure 3), the way bootstrapped estimates of species flight height distributions are used by the extended sCRM means that median estimated collision rates in the absence of avoidance may differ from those estimated using the extended Band model. A similar issue is likely to arise for the basic sCRM if site specific estimates of the proportion of birds at collision risk height are not available and must be derived from the generic Johnston *et al.* (2014) distributions.

Avoidance rates for the extended models

At present, the extended models make use of the continuous flight height distributions developed by Johnston *et al.* (2014) in order to account for variation in collision risk across a turbine's rotor-swept area. Where the proportions of birds at risk height were reported by the studies included in the analyses reported above, these were not correlated with the proportion that would be predicted to be at risk height from the Johnston *et al.* (2014) data ($r = 0.3$). This introduces another source of error into the collision rates predicted using the extended models. However, the proportion of birds at risk height were not systematically over or underestimated from the Johnston *et al.* (2014) data. This suggests that, where these generic flight height distributions are used, the avoidance rates estimated here are suitable for use with the extended models. This is because the error in estimating the proportion of birds at risk height will be present in the avoidance rates and the data feeding into the collision risk model. However, where site-specific flight height distributions are available, this error will not be present in both sources of data, meaning the avoidance rates estimated here should not be used.

Species-specific or group-specific values?

The avoidance rates estimated above are derived from a broad range of sites with varying levels of bird activity. In determining whether to use species-specific or group-specific values, it is useful to consider whether data have been collected across a range of sites that capture variability in bird activity levels. In relation to offshore windfarms, there may be a desire to focus on data that have been collected from offshore sites. However, this should be balanced against consideration of how representative those data are, particularly in circumstances when monitoring of bird movements is not concurrent with monitoring of collisions. It may be useful to consider rules of thumb (e.g. data from a minimum of 10 sites) when considering whether to use species-specific avoidance rates in preference to group-specific estimates.

Site specific and generic values for bird parameters

At present, the avoidance rate captures both the avoidance behaviour of the bird and error arising as a result of simplifications of the models. A key part of this is the estimate of the total number of birds likely to pass turbine rotor swept areas and being exposed to the risk of collision. This is a product of the total number of birds in the windfarm at any given time (in the case of an offshore windfarm, the density of birds), the speed at which each bird moves through the windfarm, and the proportion of birds at collision risk height. The total number of birds within the windfarm and the proportion at collision risk height are both estimated using site-specific values, and are consequently representative of the sites under consideration. This means that elements of model error associated with site-specific estimates of these parameters are accounted for in the calculation of avoidance rates. In contrast, flight speed is usually based on generic values (e.g. Alerstam *et al.*, 2007). Flight speed is used to estimate the total number of birds likely to pass through a windfarm over any given time period. A higher flight speed means that a greater number of birds will pass through a windfarm and be at risk of collision.

If we consider an example whereby the generic estimate of speed is greater than the site-specific estimate, the generic speed would estimate a greater number of birds moving through the windfarm than the site-specific speed and, consequently, the collision rate predicted in the absence of avoidance would be greater using the generic speed. When compared to the observed number of collisions, this would lead to a higher avoidance rate than if the site-specific value was used. In such an example, the error associated with assumptions around flight speed would not be properly accounted for. As more robust estimates of parameters, such as flight speed, become available (e.g. through GPS tracking), careful consideration is needed in relation to how these should be incorporated into analyses of collision risk and avoidance.

Avoidance rates for species or groups for which collision data are unavailable

Estimating avoidance rates following the approach set out above relies on data describing both collisions and the movements of birds through a windfarm. For some species, such as Northern Gannet, whilst we know collisions do occur, despite extensive monitoring, we lack the necessary data to estimate avoidance in this way. As an alternative, we could consider a gradient of values drawing from published estimates of macro-avoidance behaviour and a plausible range of within windfarm avoidance rates, as set out above (Figure 8). Based on our understanding of macro-avoidance behaviour of the species concerned, and its ecology relative to other species, we could make inferences about suitable total avoidance rates for use in collision risk models.

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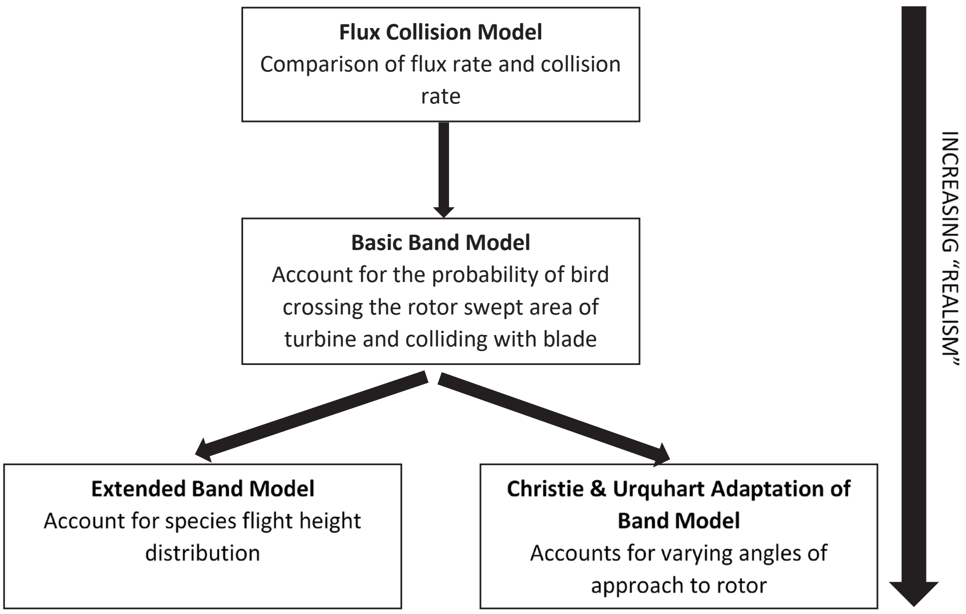
Appendix 1 Alternative Collision Risk Models

There are a number of CRMs available but, the starting point for most is to estimate the total number of birds likely to pass through the turbine rotor sweeps (Masden & Cook, 2016). The Flux Collision Model (Kleyheeg-Hartman *et al.*, 2018) simply compares this figure to the number of recorded collision victims in order to estimate a collision rate for use in future analyses. The basic Band (2012) model takes this a step further and estimates the probability of a bird colliding with a turbine blade. Further developments of this model then incorporate additional complexity in order to more accurately reflect the movement and behaviour of birds through accounting for the flight height distribution of the species concerned (Band, 2012), or allowing different angles of approach to turbine blades (Christie & Urquhart, 2015). Each of these steps increases the realism of the model (Figure A1) but also alters the number of collisions expected in the absence of avoidance behaviour and, hence, the avoidance rate to be used.

Figure A1 Collision Risk Models vary in their complexity and incorporate different aspects of bird behaviour and turbine operational parameters in order more realistically estimate collision risk



Christie and Urquhart extension to Band Model

At present, the Band (2012) model assumes that birds have a perpendicular angle of approach to the turbine rotor swept area. However, as demonstrated in figure 39 of Everaert (2008), this is unlikely to be a reasonable assumption, and birds are likely to approach from multiple angles. This is important as birds which do not approach at a perpendicular angle may take longer to cross the turbine rotor sweep and, therefore, be at greater risk of collision. Christie & Urquhart (2015) refined the Band *et al.* (2007) Model to account for different angles of approach. However, as with the basic and extended Band models, this refinement will impact the number of birds predicted to be at risk of collision, and hence the appropriate avoidance rates to be used. In addition to allowing for different angles of approach to the turbine, the refinement of Christie & Urquhart (2015) also accounts for the impact of wind speed on bird flight speed and, therefore, the length of time any individual bird is exposed to the risk of collision. To account for this I assumed a mean wind speed of 5 m/s (± 2.5 m/s) at ground level at each site. I then followed the approach described above for the basic stochastic collision risk model to estimate avoidance rates for the (Christie & Urquhart, 2015) refinement to the Band model using Monte Carlo simulation. In addition to the parameters described above, I also drew estimates for wind speed from a normal distribution defined by the mean and standard deviation presented highlighted above.

Flux Collision Model

In contrast to the previous examples, the Flux Collision model (Kleyheeg-Hartman *et al.*, 2018) uses a collision rate rather than an avoidance rate in order to estimate the number of birds at risk of collision. These collision rates are based on observed estimates of collisions and flux rates at operational windfarms and are corrected to account for differences in windfarm layout and turbine design. These collision rates account for both avoidance behaviour within the windfarm (meso- and micro-avoidance) and the probability of a bird which crosses a turbine rotor-swept area colliding with turbine blades. I used Monte Carlo simulation to estimate the total number of birds passing through the turbine rotor sweep as described above for the basic stochastic collision risk model. For each iteration of the simulations, I then estimated a collision rate by dividing the number of collision victims by the number of birds predicted to pass through the turbine rotor sweeps. As previously, mean, and median collision rates with associated standard deviations and 95% CIs were estimated for 2004, 2005 and both years combined.

Table A1 Estimated rates (Standard deviations; 95% Confidence Intervals) for use with different Collision Risk Models

	Christie & Urquhart extension to Band Model	Flux Collision Model
Sandwich Tern	0.9815 (0.0006; 0.9805 – 0.9828)	0.00025494 (0.00000257; 0.00025017 – 0.0002604)
Common Tern	0.9492 (0.0028; 0.945 – 0.9556)	0.00091548 (0.00001197; 0.00089265 – 0.00093957)
Little Tern	0.9988 (0.0001; 0.9986 – 0.999)	0.00005632 (0.0000014; 0.00005384 – 0.00005918)
All Terns	0.981 (0.0008; 0.9798 – 0.983)	0.00043097 (0.00000377; 0.00042347 – 0.00043839)
Black-legged Kittiwake	0.9984 (0.001; 0.9963 – 0.9994)	0.00001672 (0.00037138; 0.00000602 – 0.00173809)
Black-headed Gull	0.9907 (0.0009; 0.9892 – 0.9926)	0.00044743 (0.00002545; 0.00040279 – 0.00050175)
Common Gull	0.9998 (0; 0.9997 – 0.9999)	0.00001553 (0.00000099; 0.0000137 – 0.00001753)
Lesser Black-backed Gull	0.996 (0.0003; 0.9954 – 0.9967)	0.00031671 (0.00002197; 0.00027959 – 0.00036589)
Herring Gull	0.9963 (0.0003; 0.9957 – 0.9971)	0.00030098 (0.00001722; 0.00026849 – 0.00033611)
Great Black-backed Gull	0.9992 (0.0002; 0.9988 – 0.9995)	0.00005016 (0.00001053; 0.00003754 – 0.00007731)
Small gulls	0.994 (0.0006; 0.9932 – 0.9955)	0.00029785 (0.00002827; 0.00024383 – 0.00035169)
Large gulls	0.9891 (0.0007; 0.9879 – 0.9908)	0.00088817 (0.00003622; 0.00082261 – 0.00095754)
All gulls	0.9908 (0.0006; 0.9898 – 0.9921)	0.00052416 (0.0000377; 0.00045444 – 0.00060334)

Appendix 2 Recommended Avoidance Rates

Based on the analyses described above, suggested avoidance rates for key species are presented in Table A2. For terns and gulls, the rates presented below reflect within-windfarm avoidance rates. They do not incorporate macro-avoidance (e.g., any avoidance or attraction that takes place outside the wind farm). When using these values, consideration should be given as to whether, and how, any macro-avoidance should be incorporated. For Northern Gannets, the presented value is presumed to incorporate both macro and within-windfarm avoidance. The increased availability of data, and our increased understanding of how species respond to offshore wind farms mean that it is now possible to extend suggestions about avoidance rates to the extended models for both Northern Gannet and Black-legged Kittiwake. However, it is important to note that the data under-pinning these suggestions is drawn from other species and subject to significant uncertainty. Consequently, if these values are used, they should be treated with caution, and the uncertainty surrounding them should be clearly highlighted.

Following the previous review of avoidance behaviour (Cook *et al.*, 2014), it was not possible to make recommendations about avoidance rates for the extended Band model for Northern Gannet and Black-legged Kittiwake. Since that review was completed, we have gained a much greater understanding of the behaviour of birds in the offshore environment. This has included GPS tacking studies measuring species flight heights (Cleasby *et al.*, 2015; Ross-Smith *et al*., 2016) and species interactions with wind farms and individual turbines (Peschko *et al*., 2020; Thaxter *et al*., 2017), and the ORJIP Bird Collision Avoidance study at Thanet (Skov, Heinänen, *et al*., 2018). These studies give us greater confidence in extrapolating avoidance rates for the extended model to both Northern Gannet and Black-legged Kittiwake. However, in doing so, it is important to note that the data under-pinning these suggestions is drawn from other species and subject to significant uncertainty. Consequently, if these values are used, they should be treated with caution, and the uncertainty surrounding them should be clearly highlighted.

Avoidance rates for these species were previously presented in Cook et al. 2014 and Bowgen and Cook 2018. The inclusion of additional data has enabled the estimation of avoidance rates has resulted in revisions to suggested values and enabled the estimation of avoidance rates suitable for use with the extended Band Model and extended sCRM for a greater range of species. Key changes are set out in table A3.

Table A2 Recommended avoidance rates by species and groups (Standard deviations; 95% Confidence Intervals)

Species & Groups	Suggested Rates	Basic Band (2012) Model	Extended Band (2012) Model	Basic sCRM	Extended sCRM
Sandwich Tern, Common Tern, Little Tern, and other tern species	**All Gulls and Terns rate** Data are only available for a limited number of sites with low levels of activity for some species. Consequently, pooling data across species and sites may better reflect variation in behaviour than relying on species-specific rates. The influence of data collected at Zeebrugge, where the wind farm is present on the edge of a tern breeding colony, means that the all tern rate may not truly reflect behaviour further offshore. Consequently, the all gulls and terns rate is recommended.	0.9856 (0.0002; 0.9852 – 0.9860)	0.9501 (0.0007; 0.9486 – 0.9515)	0.9861 (0.0005; 0.9851 – 0.9871)	0.9295 (0.0047; 0.9204 – 0.9387)
Black-legged Kittiwake and Little Gull	**All gulls rate** Insufficient data to estimate species-specific avoidance rates. Whilst previous reports have recommended the small gulls rate, data collected at Thanet makes reference to collisions involving "unidentified gulls", and it cannot be ruled out that these involved black-legged kittiwakes.	0.9874 (0.0003; 0.9868 – 0.9879)	0.9532 (0.001; 0.9512 – 0.9553)	0.9879 (0.0005; 0.987 – 0.9889)	0.9261 (0.0066; 0.9128 – 0.9382)
Black-headed Gull, Common Gull and other small gulls species	**Small gulls rate** Insufficient data to estimate species-specific rates for these species. Similarities in wingspan, body length and flight speed suggest they may have similar levels of manoeuvrability. Consequently, the pooling data with other small gulls is likely to be appropriate.	0.9919 (0.0004; 0.9911 – 0.9927)	0.9354 (0.0034; 0.9288 – 0.942)	0.9921 (0.0004; 0.9913 – 0.9928)	0.9426 (0.0081; 0.9229 – 0.9559)
Lesser Black-backed Gull, Herring Gull, Great Black-backed Gull and other large gull species	**Large gulls rate** Whilst robust data are available from the onshore environment to estimate avoidance rates for Herring and Lesser Black-backed Gull, uncertainty over the identification of species involved in collisions at Thanet means it may be more appropriate to use the large gulls rate for these species. Similarly, a lack of robust data suggests the large gull avoidance rates should also be used for Great Black-backed Gull and other large gull species.	0.9860 (0.0007; 0.9846 – 0.9874)	0.9448 (0.0028; 0.9393 – 0.9503)	0.9861 (0.0006; 0.9849 – 0.9873)	0.9104 (0.0082; 0.8935 – 0.9259)
Northern Gannet	**All gulls rate** There is significant uncertainty surrounding the behaviour of birds that enter wind farms. However, data collected at Thanet suggests strong avoidance of turbines once birds are inside the wind far, hence the all gulls rate is likely to reflect a realistic within wind farm avoidance rate for gannets. Post-construction data from operational wind farms also suggests strong avoidance of the wind farms themselves. Consequently, prior to assessing collision risk, macro avoidance should be accounted for. There is some uncertainty surrounding macro-avoidance so, it is recommend a range of a 60-80% reduction in pre-construction densities should be considered.	0.9874 (0.0003; 0.9868 – 0.9879) + macro avoid-ance of 60-80%	0.9532 (0.001; 0.9512 – 0.9553) + macro avoid-ance of 60-80%	0.9879 (0.0005; 0.987 – 0.9889) + macro avoidance of 60-80%	0.9261 (0.0066; 0.9128 – 0.9382) + macro avoid-ance of 60-80%

Table A3 Changes from previous recommended avoidance rates

Species	Model	SNCB Guidance (2014)	Bowgen & Cook (2018)	New Rate (Standard deviations; 95% Confidence intervals)	Justification
Sandwich Tern	Basic Band Model	0.98		0.9856 (0.0002; 0.9852 – 0.9860)	This has been revised through the incorporation of additional data. Furthermore, analyses in Cook et al. (2014) did not account for the imperfect detection of corpses and, it is unclear how the collision risk factor used in the previous Natural England guidance was estimated. Given the influence of data from Zeebrugge, which may not be reflective of offshore behaviour, the all gulls and terns rate, as opposed to species specific or tern-specific rates, is suggested.
Black-legged Kittiwake	Basic Band Model	0.989 (± 0.002)	0.99	0.9874 (0.0003; 0.9868 – 0.9879)	The suggested avoidance rate for kittiwake for use in the basic Band model is based on the all gulls rate. The majority of the data relating to kittiwake came from Thanet, and it cannot be ruled out that the collisions involving "unidentified gulls" related to kittiwakes.
Great Black-backed Gull	Basic Band Model	0.995 (± 0.001)	0.995	0.9860 (0.0007; 0.9846 – 0.9874)	In the absence of robust species-specific data, the suggested avoidance rate for great black-backed gulls is based on the large gulls rate. This has been revised following the incorporation of additional data and, through accounting for imperfect detection of corpses.
Lesser Black-backed Gull	Basic Band Model	0.995 (± 0.001)	0.995	0.9860 (0.0007; 0.9846 – 0.9874)	Uncertainty surrounding the identification of species involved in collisions at Thanet mean the large gulls rather than species specific rates are suggested.
Herring Gull	Basic Band Model	0.995 (± 0.001)	0.995	0.9860 (0.0007; 0.9846 – 0.9874)	Uncertainty surrounding the identification of species involved in collisions at Thanet mean the large gulls rather than species specific rates are suggested.
Lesser Black-backed Gull	Extended Band Model	0.989 (± 0.002)	0.993	0.9448 (0.0028; 0.9393 – 0.9503)	The inclusion of additional data and, accounting for imperfect corpse detection has resulted in the suggested avoidance rates for these species for use in the extended Band model being reduced. Uncertainty surrounding the identification of species involved in collisions at Thanet mean the large gulls rather than species specific rates are suggested.
Herring Gull	Extended Band Model	0.990 (± 0.002)	0.993	0.9448 (0.0028; 0.9393 – 0.9503)	The inclusion of additional data and, accounting for imperfect corpse detection has resulted in the suggested avoidance rates for these species for use in the extended Band model being reduced. Uncertainty surrounding the identification of species involved in collisions at Thanet mean the large gulls rather than species specific rates are suggested.
Great Black-backed Gull	Extended Band Model	0.989 (± 0.002)	0.993	0.9448 (0.0028; 0.9393 – 0.9503)	Uncertainty surrounding the identification of species involved in collisions at Thanet mean the large gulls rather than species specific rates are suggested.
Northern Gannet	Basic Band Model	0.989 (± 0.002)	0.995	0.9874 (0.0003; 0.9868 - 0.9879) + macro avoidance of 60-80%	Data collected from Thanet suggest strong avoidance of turbines, and data collected from post-construction studies of operational wind farms suggest strong avoidance of the wind farms themselves.

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Additional analysis to inform SNCB recommendations regarding collision risk modelling

Collision Risk Models are widely used in order to predict potential impact of collisions with turbines on bird populations but, are known to be sensitive to the parameter referred to as the avoidance rate. The most widely used Collision Risk Model is the Band Model, updated in 2012 for use in the offshore environment. Previous studies have estimated suitable avoidance rates for use in the Band model. However, given ongoing data collection, there is a need to update these estimates to ensure they reflect the best available evidence. Drawing from the data presented in Cook et al. (2014) and more recent studies, notably the ORJIP Bird Collision Avoidance study, this report presents updated estimates of avoidance rates for gulls and terns and makes recommendations about suitable avoidance rates for gannets. It further sets out recommendations and considerations for future revisions to avoidance rates as more data become available.

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