BERWICK BANK WIND FARM
OFFSHORE ENVIRONMENTAL IMPACT ASSESSMENT

APPENDIX 11.4, ANNEX D: APPLICATION OF SEABORD

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CONTENT

TABLES

1. INTRODUCTION

1. SeabORD was created by the UK Centre for Ecology & Hydrology (CEH), McArthur Green and Biomathematics & Statistics Scotland (BioSS) to attempt to quantify the fate of displaced and barrier-affected seabirds during the chick-rearing portion of the breeding season for a selected colony (Searle *et al.,* 2014, 2018). It is an individual-based modelling method which predicts the energetic consequences to seabirds due to any changes in their flight paths and foraging areas in the presence of offshore wind farms.

2. The method simulates the flightpaths of individual birds from each of the Special Protection Areas sub-sites (or colonies) to potential foraging areas in scenarios with and without wind farms present (Searle *et al.,* 2018). The information from these simulations is then used in a combination of bioenergetic equations to estimate the percentage body mass loss of the birds and therefore their survival and productivity during the breeding season. Estimate of theoretical annual mortalities can then be predicted based on the predicted masses of each individual by the end of the breeding season.

3. Currently the software is intended to be used to predict the impact of potential wind farms on four key species, each of which is of concern in the ornithological impact assessment for the Offshore Development:

   - Kittiwake
   - Guillemot
   - Razorbill*;* and
   - Puffin.

4. In their Scoping Opinion representation of November 2020, Marine Scotland Science, NatureScot and RSPB Scotland advised that the SeabORD tool should be used to assess displacement and barrier effects for guillemot, razorbill and puffin during the breeding season, assuming that sufficient data were available to parameterise the model. It was advised that the matrix method should be used for all displacement susceptible species and for relevant seasons to enable direct comparisons across species/seasons and provide context for the calculated displacement mortality rates emerging from SeabORD.

5. The current publicly available version of the SeabORD model (Searle *et al.,* 2018) is parameterised for the Forth and Tay region. However, colonies of interest outside of this region were identified as requiring assessment in the 2020 Scoping representations.

6. SSER subsequently contacted the SeabORD model authors at UKCEH to determine how the model could be implemented to include colonies outside of the Forth and Tay region.

7. In their response (F.Daunt, email 27/10/2021), UKCEH stated that running the published version of SeabORD with new input data involves a manual calibration step to ensure that prey levels are set at appropriate levels to represent poor, moderate and good conditions for the birds. This calibration step is required whenever a new set of bird distribution maps and/or set of colonies are being used. UKCEH stated that they believed that currently this manual calibration step could only be undertaken by themselves, but that they had no capacity to undertake this work.

8. They also stated that a key development in the new version of SeabORD for the Cumulative Effects Framework (CEF) is that this calibration step will be automated. This would mean that users could run SeabORD based on any distribution data or set of colonies independently. The only way that users can realistically run SeabORD is to use the distribution maps and colonies in the Marine Scotland SEANSE project (Searle et al., 2020), where calibration has already been undertaken. However, the distribution maps in SEANSE were based on data from 2010-2014, and new GPS tracking data have been collected from 2018-2021 inclusive. UKCEH stated that it would be their strong recommendation that any new analysis should make use of these data, but this would require new calibration for SeabORD because of the resulting changes to the input data on bird and prey distributions. The addition of new colonies would also require a new calibration procedure, because each new colony requires its own bird distribution map. Furthermore, even if such updates were not done i.e. if SeabORD was run based on new footprints but using the SEANSE distribution maps and colonies, UKCEH stated that this would still require their support.

9. Their preference was that SeabORD should be implemented once the new version is available within the CEF.

10. Email correspondence with UKCEH was subsequently shared with Marine Scotland Science, NatureScot and RSPB Scotland in December 2021 following Road Map Meeting 4 (volume 3, appendix 11.8). In their Scoping Opinion representation of November 2020, Marine Scotland Science advised that the updated version of the SeabORD tool within the CEF should be available from April 2022 onwards. To date (November 2022) the CEF and the associated revised SeabORD model have not been published.

11. In the absence of the updated version of SeabORD, and following discussions during Road Map Meeting 5 (volume 3, appendix 11.8), the current publicly available version of the SeabORD (Searle et al., 2018) was run using a “simplistic” method which does not utilize GPS tracking data but instead employs a ‘distance decay’ method: this was subsequently clarified at Road Map 6 that the outputs would be presented for context (volume 3, appendix 11.8), however the matrix method results would be taken forward into the PVA modelling.

12. Here, HiDef Aerial Surveying Limited (HiDef) use the Searle et al., (2018) model to present the potential impacts from the Proposed Development array area. Due to the run times of SeabORD (see Section 4), there was insufficient time to undertake an assessment in combination with other Forth and Tay projects. The outputs of SeabORD have been presented to provide further context to the results presented in volume 3, appendix 11.4.

13. Separately, a sensitivity analysis of the SeabORD model was carried out by Natural Power (Vallejo et al., 2022 (volume 3, appendix 11.4, annex H)). The sensitivity of outputs to the values used for 81 parameters and assumptions, including those fixed within the model code and those that can be altered by the user, were explored. Implications from this sensitivity analysis for this report are discussed in Section 5.

2. METHODS

14. A list of terms used throughout the annex and their definitions are provided in Table 2.1.

Table 2.1: Definitions of terms used through the description of the methods and results.

Term	Definition
Additional mortality (%)	Additional mortality (%) is the increase in the mortality rates caused by the presence of the wind farm. For example, if a 5% mortality rate was expected without the wind farm present and a 10% mortality rate was expected with the wind farm present, the additional mortality would be 5%.
Barrier effect	Birds suffering barrier effects will no longer be able to travel through the wind farm footprint or buffer area, this will impact individuals by increasing their travel time.

Term	Definition
Border	The border is an area surrounding the wind farm footprint that barrier effected birds will not enter due to disturbance from the wind farm.
Buffer	The buffer area surrounds the border, individuals that are susceptible to displacement will be assigned a foraging location in the buffer if their original randomly selected foraging location is within the wind farm footprint.
Displacement	Individuals that are not able to forage within the wind farm footprint and must find a new foraging location are classified as suffering from displacement.
Impacted individuals	Impacted individuals experience barrier effects or displacement at least once during the simulation, impacts do not have to result in mortality for an individual to be classed as 'impacted'.
Paired simulation	Paired simulations simulate two breeding seasons. The only difference between the two simulations is the presence of the wind farm. If multiple pairs are run in the same simulation, each pair of simulations will have a unique prey quantity value selected.
Single simulation	A single simulation only simulates one chick-rearing period in one scenario (with or without wind farm present). These are used to calibrate the SeabORD model.
Year type	The year type can be 'poor', 'moderate' or 'good', these classifications represent the environmental conditions during the year and classifications use values expected during moderate environmental conditions. 'Poor' classifications occur when the % body mass loss of adults is higher and % chick survival is lower than those observed during a typical year. 'Good' years are only classified based on the % body mass loss of adults.

2.2. MODELLED SPAS

15. The choice of SPAs to model in SeabORD (version 1.3) was based on the outputs of the apportioning assessment (volume 3, appendix 11.5). As the model only simulates the chick-rearing phase of the breeding season, the SPAs simulated were chosen where modelled breeding season impacts exceeded the threshold to determine the need for further population modelling (volume 3, appendix 11.6).

16. SeabORD allows for a maximum of six SPAs to be modelled during each simulation, with the model being calibrated to one of these colonies (see Section 2.3). Six SPAs were included in the model for kittiwake and guillemot simulations, five for razorbill simulations and three SPAs were included for puffin simulations. For kittiwake and guillemot simulations, the SPAs included in each simulation were chosen based on consideration of the apportioning outputs (previous paragraph). The SPAs included for each species are shown in Table 2.2.

17. In order to produce accurate results for each colony, the model must be calibrated to the colony of interest before running the simulation. These simulations are hereby referred to as the 'final' simulations and those colonies for which final simulations were successfully carried out are highlighted by asterisks in Table 2.2.

18. Each colony modelled must be represented by a single geographical reference point as close to the midpoint of its coastline as possible (Table 2.2). For island colonies, the midpoint was selected to be on the side of the island closest to the Proposed Development.

19. SeabORD requires the number of breeding pairs at each colony as an input parameter. The most recent available population counts from the Seabird Monitoring Programme (SMP) were provided to HiDef from the Joint Nature Conservation Committee (JNCC) in January 2022.

20. Correction factors were applied to the counts provided by JNCC to calculate the estimated number of breeding pairs for the relevant colonies for guillemots, razorbills and puffins. The counts for all the colonies shown in Table 2.2 for guillemots were provided in individuals. To correct these counts a factor of 0.67 was applied to estimate the number of breeding pairs.

21. Razorbill counts for Farne Islands, Fowlsheugh, St Abb's Head to Fast Castle and Troup, Pennan and Lion's Head were also provided in individuals, and the same correction factor of 0.67 was applied. The counts provided for the Forth Islands were provided as a combination of Apparently Occupied Sites (AOS) and individuals. The correction factor was applied to the individual counts and then added to the number of AOS, the latter already a measure of breeding pairs. Puffin counts for Coquet Island and Farne Islands were provided as Apparently Occupied Burrows (AOB) (a measure of breeding pairs) and so no correction factor was applied. The counts for the Forth Islands were provided as a combination of AOB and individuals. The same method used for razorbills at Forth Islands was applied.

22. Kittiwake counts were measured in Apparently Occupied Nests (AON) for all the colonies included in the simulation, meaning that no correction factor was applied to the counts provided.

Table 2.2: The coordinates for the reference point and the number of breeding pairs included in the model for each colony. Final simulations were only carried out for the colonies highlighted with an asterisk (*).

SPA	Latitude	Longitude	Kittiwake pairs	Guillemot pairs	Razorbill pairs	Puffin pairs
Buchan Ness to Collieston Coast	57.68208	-2.25110	11295	19776	-	-
Coquet Island	55.33676	-1.53920	-	-	-	25029*
Farne Islands	55.64048	-1.63080	4402	42908*	286*	43752
Forth Islands	56.18330	-2.55670	4517*	17290*	3939*	43620*
Fowlsheugh	56.92005	-2.20027	13271*	45679*	8908*	-
St. Abb's Head to Fast Castle	55.92210	-2.19142	5452*	30704*	1964*	-
Troup, Pennan and Lion's Heads	57.68208	-2.25110	10616	15947	3027*	-

2.3. CALIBRATION OF THE MODEL

23. It is recommended to use GPS data to determine the foraging ranges and prey distribution of populations during SeabORD simulations (Mobbs *et al.*, 2018). When GPS data are available, the relative density of each seabird species can be calculated and the foraging range, proportion of individuals and distribution of prey can be inferred directly within the model to provide site-specific values instead of relying on estimates from the literature. It also allows for the inclusion of heterogenous prey distributions. However, as appropriate GPS data were unavailable the distance decay method was selected to determine foraging locations (Section 2.3) and the prey distribution was assumed to be uniform. This assumption does not mirror prey distributions in reality which are heterogeneous nor how central place foragers exploit resources e.g. Ashmole's halo effect (Ashmole, 1963). Thus, prey distribution did not impact the results of simulations as each foraging location is assumed the same level of prey available.

24. To determine the prey quantity range (g per unit volume) used in the final simulations, SeabORD was calibrated to each species, at each colony using 'single' simulations. Single simulations run a single scenario, in this case a breeding season with no wind farm present. The outputs for each single simulation can then be compared to determine the prey quantity range which is expected to occur in a year meeting the criteria for a moderate year (see paragraph 16). During single simulations the proportion of the population at each colony included in the population was set to 10%. The only input value altered was the prey quantity, with the rest of the values for each species being shown in Table 2.3.

25. Calibrating the model is important as the breeding season outputs in the final paired simulations (with and without wind farm) will only use values from the prey quantity (g per unit volume) range selected. Therefore, to produce realistic results the prey range in the final simulations should be set to values expected during typical or 'moderate' breeding seasons. This allows for the outputs relating to the chick-rearing period to be associated to moderate years and annual mortalities for poor and good years to be calculated correctly, calibrating to poor or good years would potentially overestimate or underestimate the predicted impacts of the wind farm (see section 4).

Table 2.3: Input values used for running 'single' and the final 'paired' simulations.

Variable	Kittiwake	Guillemot	Razorbill	Puffin
% of populations susceptible to displacement (following the Scoping Approach (see volume 3, appendix 11.4)	30	60	60	60
% of those susceptible to displacement barriered	100	100	100	100
Maximum foraging range (km)[1]	300.6	153.7	164.6	265.4
Proportion of individuals within range	0.975	0.975	0.975	0.975
Wind farm footprint border (km) based on the default value available examples	0.5	0.5	0.5	0.5
Wind farm footprint buffer (km) based on the default value in available examples	5	5	5	5
Starting random number seed	39173	39173	39173	39173

[1] Values taken from Woodward *et al.,* (2019) are the mean-maximum + 1 standard deviation (SD).

26. To determine which prey levels resulted in a chick-rearing period during 'moderate' environmental conditions, SeabORD's outputs from single simulations were compared to existing literature. Firstly, the average percentage body mass loss of adults across the breeding season must fall between the species' respective upper and lower boundaries shown in Table 2.4. Therefore, the upper prey quantity used in the simulation was the highest prey quantity which gave results where the adult mass loss (%) was still greater than the lower boundary. To determine the lower prey quantity used in the final simulations a second condition was added so that the prey quantity was the smallest prey quantity that gave an adult mass loss (%) lower than the upper boundary and a chick survival (%) greater than the lower boundary.

Table 2.4: Adult percentage body mass loss and percentage chick survival used to determine prey values used in the final paired simulations. Values taken from Mobbs *et al.,* (2018).

Species	Adult Mass Loss (%)		Chick Survival (%)
	Lower boundary	Upper boundary	Lower boundary
Kittiwake	5.0	15.0	11
Guillemot	3.5	10.5	49
Razorbill	3.5	10.5	50
Puffin	3.5	10.5	50

2.4. INPUT PARAMETERS AND ASSUMPTIONS

27. The input parameters (Table 2.3) come from various sources. The percentage of population for each species susceptible to displacement was in line with Scoping Opinion (volume 3, appendix 11.8).

28. As GPS data were unavailable for all of the SPAs modelled, the model was run using the distance decay option to determine the foraging location of individuals. This method assigns foraging locations with the assumption that as the distance from the colony (the reference point in Table 2.2) increases, the density of birds will decrease. For each species, the foraging range was set to the mean maximum foraging plus 1 SD reported in Woodward *et al.,* (2019). The proportion of individuals foraging within each species foraging range was set to 0.975 to account for the inclusion of SD.

29. It was assumed that all individuals susceptible to displacement would be barriered. This means that all of the individuals subject to displacement (e.g. 60% of guillemots) would be unable to travel within the wind farm footprint and border. This is assumed to occur due to disturbance caused by the wind farm. The wind farm was also assumed to have a border of 0.5 km and a buffer of 5 km, following the available examples of the application of SeabORD (Searle *et al.*, 2018; Mobbs *et al.*, 2018). The buffer does not affect the flightpaths for birds but will affect competition by changing the density of birds foraging within the buffer. Whereas the border will affect the flightpaths of birds that experience barrier effects.

2.5. PAIRED SIMULATIONS

30. Once the prey quantity ranges were determined using single simulations, they could then be used to run the final simulations. The final simulations consisted of 10 paired simulations where 10 prey quantities were selected from within the inputted ranges using random stratification. This method of prey level selection allows for uncertainty to be incorporated into model outputs as effects across a range of

moderate prey levels are generated (Searle *et al*., 2018). For each prey quantity, a breeding season with and without the wind farm was simulated. Thus, the model was run for 20 unique breeding seasons. The final outputs are the average of the 10 simulations with and without the wind farm respectively. The only values which differed from those used in the single simulations were the prey quantity ranges and proportions of the populations included.

31. The proportion of the population used in the final paired simulations varied by species. As SeabORD uses an individual based model, the time taken to carry out a simulation is directly related to the number of individuals within the model as the calculations must be carried out for each individual separately. The entire population was included for razorbill simulations due to smaller colony sizes. However, due to the size of kittiwake, guillemot and puffin colonies entire populations could not be modelled.

32. The final paired simulations were not carried out for all colonies included in the model due to time constraints. For example, to carry out the paired simulation for guillemots, using 50% of the population, took approximately 4 days. The colonies simulated for kittiwake, guillemot and puffins were selected due to the results of apportioning. The colonies included in the final simulations, proportion of populations simulated and prey quantity ranges used as inputs can be found in Table 2.5.

Table 2.5: Prey quantity ranges and proportion of populations used as input values during the final paired simulations.

Colony	Proportion of population included in simulation	Lower prey quantity (g per unit volume)	Upper prey quantity (g per unit volume)
Kittiwake			
Forth Islands	0.2	147	189
Fowlsheugh	0.2	126	158
St. Abb's Head to Fast Castle	0.2	154	192
Guillemot			
Farne Islands	0.2	328	407
Forth Islands	0.2	330	413
Fowlsheugh	0.2	292	377
St. Abb's Head to Fast Castle	0.	366	452
Razorbill			
Farne Islands	1.0	205	254
Forth Islands	1.0	209	267
Fowlsheugh	1.0	184	241
St. Abb's Head to Fast Castle	1.0	224	288
Troup, Pennan and Lion's Heads	1.0	219	269
Puffin			
Coquet Island	0.2	192	236
Forth Islands	0.2	190	231

33. For simulated seasons where wind farms are present, if individuals that are susceptible to displacement are assigned a foraging location within the wind farm footprint a new foraging location within the buffer will be selected. As SeabORD assigns each foraging location randomly, this process does not take into account the level of intraspecific competition during selection.

34. Barrier navigation was set to 'Perimeter' following the examples available (Searle *et al*., 2018; Mobbs *et al*., 2018). This means that any barrier-affected birds (all those susceptible to displacement) would be unable to travel within the wind farm border. Instead, each individual affected would travel in a straight line until they meet the border, where they would then follow the perimeter of the border until they can travel in a straight line again. This also occurs when any bird encounters land.

2.6. BIOENERGETICS OF THE MODEL

35. Each individual was assigned a Daily Energetic Expenditure (DEE) for each timestep by the model. The DEE assigned for chicks were constant throughout the simulation and values associated with chicks' mass towards the end of the chick-rearing period were used. For adults, the DEE for the initial timestep was selected from a species-specific range of values stored in SeabORD following a normal distribution. For the following timesteps adult DEE used was calculated using the activity budget of individuals in the previous timestep.

36. The activity budget consisted of four behaviours; flying, staying on the sea surface, foraging and time spent at the colony. The time spent flying was calculated using the flightpaths generated and the foraging and sea surface time was calculated by SeabORD. It was assumed that individuals must spend at least one hour on the sea surface during each timestep. Each timestep lasts 24 hours, apart from kittiwake where each timestep is set to 36 hours. Any remaining time after these three activities were carried out is assigned to spending time at the colony.

37. The Daily Energetic Requirement (DER) of each individual could then be calculated by dividing the DEE by an assimilation efficiency stored in SeabORD and adding half of the chicks DEE. Half of the chicks DEE was added as it is assumed that each parent contributes equally to the chick's survival. If the DEE was greater than the DER, then the adults would lose body mass. During the simulation, individuals are unable to gain mass during each timestep, even if an individual's mass is less than their initial mass at the beginning of the chick-rearing period. This assumption is based on chick-rearing being one of the most energetically expensive periods of an adults life cycle.

At the end of each timestep the percentage mass loss by each individual was then used to select a behaviour carried out by adults and chicks during the next time step (

38. Table 2.6).

39. A full list of the default parameters used by SeabORD are provided in the Appendix Section 6.1.

Table 2.6: Behaviours of each individual determined by body mass.

Species	Age	% of initial mass	Behaviour for next timestep
All	Adult	>90	Stays at nest.
All	Adult	80-90	Leaves chick unattended to reach DER. This results in an increase in the likelihood of death of the chick due to predation or harsh environmental conditions. A linear relationship between time left unattended and risk of chick death is assumed until a threshold is met where chick death is assumed (kittiwake, guillemot and razorbill only).
All	Adult	<80	Abandon chick[1]
All	Adult	<60	Assumed to have died.
Puffin	Chick	60 - 80	Chick will go to the opening of the burrow, increasing the likelihood of death due to predation or harsh environmental conditions. A linear relationship between time spent at the burrow opening and chick death is assumed.
All	Chick	<60	Assumed to have died.

[1] If one parent abandons the chick, the other parent will also abandon the chick despite its own body mass.

40. Chick mortality can also occur during a timestep if the time an adult spends away from the nest is greater than the threshold of 18 hours for kittiwake, guillemot and razorbill. This was determined by expert judgment (Searle *et al*., 2018). Predation risk and environmental risks were modelled to increase as the time left unattended increased until this threshold was met.

2.7. ANNUAL MORTALITY OUTPUTS

41. The annual mortality of adults is calculated using the body mass of each individual. The model assumes that there is a logistic relationship between body mass at the end of the breeding season and the likelihood of the individual to survive the winter (Searle *et al*., 2018). This relationship requires two parameters: a 'baseline' survival rate and the shape of the curve.

42. The 'baseline' survival used was based on the mean value of sites with observed data on annual adult survival, curated by the creators of SeabORD. The shape of the curve was also set by SeabORD and determines the strength of the relationship between body mass and survival. This was based on previous studies by Oro and Furness (2002) and Erikstad *et al*., (2009).

The mortality rates for simulations with no wind farm present were calculated using SeabORD outputs and compared to those used from the literature and used for the Population Viability Analysis (PVA) for this development to sense-check the results (

43. Table 2.7).

Table 2.7: Baseline adult survival rates used during Population Viability Analysis for the SPAs modelled.

Species	Survival estimate (%)	Calculated mortality estimate (%)[1]	Reference
Kittiwake	85.5	14.5	Jitlal *et al.*, (2017)
Guillemot	92.7	7.3	Jitlal *et al.*, (2017)
Razorbill	91.0	9.0	Jitlal *et al.*, (2017)
Puffin	90.1	9.9	Lahoz-Monfort *et al.*, (2011)

[1] Calculated using 100 – survival estimate.

44. For simulations using less than 100% of the population, mortalities were scaled using a scaling factor of 1/proportion of the population modelled. This was discussed and agreed with by Dr. Kate Searle, one of the developers of SeabORD. However, it was noted that the results may not scale linearly. Using the scaling factor means if you were to scale the results of a simulation using 50% of the population, the scaled number of mortalities would double. However, as the model includes stochasticity it is not guaranteed that running a simulation with 50% and 100% of the population would follow this trend and this has not been investigated. Thus, scaled values can only exist as an estimate of those produced by simulations using the full population as they may not produce the exact same values as running the full population in the simulation (Searle, K. 2022, pers. comm., 21 June). This could lead to small under or overestimations of mortalities and mortality rates.

45. The additional mortality (%) expected due to the Proposed Development for each colony was calculated using the scaled adult mortality values for kittiwake, guillemot and puffin, or the mortalities from running a full simulation for razorbill. Additional mortality represents the increase in mortalities between the baseline scenario with no wind farm and the scenario with the wind farm present i.e. a 1% additional mortality would mean that 1% more of the adult population is expected to not survive the year in the presence of the wind farm. These values were calculated using the following equation:

$$Additional\ mortality\ (\%) = \left(\frac{(Annual\ mortalities\ (wind\ farm) - annual\ mortalites\ (baseline))}{Population\ size}\right) * 100$$

46. Scaled values were used to calculate additional mortality rates as it was found that the use of a scaling factor did not impact mortality rates for baseline or scenarios with the wind farm present (see Section 6.2).

3. RESULTS

47. The results of the paired simulations are presented below, the mean values represent the mean of the 10 chick-rearing periods simulated for each scenario are reported alongside the standard deviation (SD). Table 3.1, Table 3.3, Table 3.5 and Table 3.7 present the annual adult mortalities predicted by SeabORD, the scaled mortalities where necessary and additional mortality (%) caused by the presence of the Proposed Development using the scaled mortality estimates. Additional mortality in the following tables refers to the percentage of the whole adult population expected to survive the year during baseline simulations but not survive the year in simulations where the wind farm is present within the simulation.

48. A full table of metrics produced by SeabORD such as body mass, distance travelled and number of trips travelled during the paired simulations are presented for each species in Table 3.2, Table 3.4,Table 3.6 and Table 3.8.The results presented are for moderate years. The mortality rates predicted by SeabORD for poor and good years can be found in Section 6.2

3.2. KITTIWAKE

Table 3.1 : Modelled impacts of the Proposed Development on adult kittiwake during the year, at the three SPAs simulated. Additional mortality was calculated using scaled mortality values.

Year Type	Proportion of population used in the simulation	Adults not surviving the year						Difference in mortalities between scenarios (scaled mortalities)	Additional mortality (%)
		Baseline (no wind farm)			Wind farm present				
		Mean	SD	Scaled mortalities	Mean	SD	Scaled mortalities		
Forth Islands									
Poor	0.2	762.900	12.862	3814.500	768.100	13.270	3840.500	26.000	0.288
Moderate	0.2	514.300	7.469	2571.500	517.200	7.598	2586.000	14.500	0.161
Good	0.2	311.700	11.615	1558.500	314.800	11.641	1574.000	15.500	0.172
Fowlsheugh									
Poor	0.2	1854.500	134.489	9272.500	1895.300	104.834	9476.500	204.000	0.769
Moderate	0.2	1226.900	112.704	6134.500	1267.200	82.931	6336.000	201.500	0.759
Good	0.2	699.100	66.313	3495.500	716.100	51.602	3580.500	85.000	0.320
St. Abb’s Head to Fast Castle									
Poor	0.2	909.600	17.475	4548.000	911.900	18.114	4548.000	11.500	0.054
Moderate	0.2	644.800	13.710	3224.500	650.100	15.051	3224.000	26.500	0.125
Good	0.2	393.700	12.936	1968.500	397.700	15.116	1968.500	20.000	0.094

Table 3.2: SeabORD outputs for kittiwake at each of the three sites simulated during a moderate chick-rearing period.

Output Variable	Scenario (wind farm present/not present)	Forth Islands		Fowlsheugh		St. Abb's Head to Fast Castle	
		Mean	SD	Mean	SD	Mean	SD
Proportion of population simulated	Both	0.2		0.2		0.2	
Number of adult birds in simulation	Both	1806		13636		4246	
Adult survival at end of breeding season (%)	Not present	100.000	0.000	100.000	0.000	100.000	0.000
	Present	100.000	0.000	100.000	0.000	100.000	0.000
Initial adult body mass (g)	Not present	371.673	0.000	372.607	0.000	372.662	0.000
	Present	371.673	0.000	372.607	0.000	372.662	0.000
Final adult body mass (g)	Not present	342.321	6.464	342.614	6.358	342.591	6.590
	Present	341.941	6.247	341.235	5.362	342.046	6.167
Difference between total distance flown with and without wind farm (km)		14.122	4.141	141.606	5.141	11.501	6.657
Difference in the total number of trips carried out with and without wind farm		-0.217	0.102	-2.233	0.298	-0.363	0.157
Chicks not surviving the season	Not present	324.700	233.805	991.500	724.300	410.300	299.558
	Present	338.100	234.126	1210.900	721.073	433.000	300.656
Additional mortality of chicks with wind farm present (%)		1.484	0.681	8.267	2.587	2.083	0.995
Number of adults directly impacted by the wind farm (displaced or barriered)[1]	Present	481		1421		645	

[1] The number of adults directly impacted includes any adults that were displaced and/or barriered at least once during the chick-rearing period. Direct impacts do not always result in mortality.

3.3. GUILLEMOT

Table 3.3: **Modelled impacts of the Proposed Development (only) on adult guillemot during the year, at the four SPAs simulated.**

Year Type	Proportion of population simulated	Adults not surviving the year						Difference in mortalities between scenarios (scaled mortalities)	Additional mortality (%)
		Baseline (no wind farm)			Wind farm present				
		Mean	SD	Scaled mortalities	Mean	SD	Scaled mortalities		
Farne Islands									
Poor	0.2	3657.200	107.469	18286.000	3676.800	103.742	18384.000	98.000	0.114
Moderate	0.2	1870.000	56.449	9350.000	1885.300	53.691	9426.500	76.500	0.089
Good	0.2	1372.000	41.905	6860.000	1384.800	39.072	6924.00	64.000	0.075
Forth Islands									
Poor	0.2	1544.100	33.713	7720.500	1547.100	29.392	7735.500	15.000	0.043
Moderate	0.2	790.000	21.802	3950.000	792.000	21.802	3960.000	10.000	0.029
Good	0.2	555.300	26.433	2776.500	560.000	22.702	2800.000	23.500	0.068
Fowlsheugh									
Poor	0.2	3238.800	138.696	16192.000	3405.700	119.554	17028.500	836.500	0.916
Moderate	0.2	1586.100	87.646	7930.500	1677.300	80.815	8386.500	456.000	0.499
Good	0.2	1206.800	63.968	6034.000	1287.200	53.410	6436.000	402.000	0.440
St. Abb's Head to Fast Castle									
Poor	0.2	3286.100	77.750	16430.500	3320.300	71.550	16601.500	171.000	0.278
Moderate	0.2	1783.900	38.182	8919.500	1802.500	39.150	9012.500	93.000	0.151
Good	0.2	1413.500	33.534	7067.500	1420.500	33.431	7102.500	35.000	0.057

Table 3.4: SeabORD outputs for guillemot at each of the four sites simulated during a moderate chick-rearing period.

Output Variable	Scenario (wind farm present/not present)	Farne Islands		Forth Islands		Fowlsheugh		St. Abb's Head to Fast Castle	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Proportion of population simulated	Both	0.2		0.2		0.2		0.2	
Number of adult birds in simulation	Both	17164		6916		18272		18272	
Adult survival at end of breeding season (%)	Not present	100.000	0.000	100.000	0.000	100.000	0.000	100.000	0.000
	Present	100.000	0.000	100.000	0.000	100.000	0.000	100.000	0.000
Initial adult body mass (g)	Not present	920.534	0.000	920.027	0.000	920.385	0.000	920.385	0.000
	Present	920.534	0.000	920.027	0.000	920.385	0.000	920.385	0.000
Final adult body mass (g)	Not present	864.238	16.957	864.356	16.909	864.678	16.690	864.678	16.690
	Present	863.780	26.758	864.162	16.779	860.663	16.215	860.663	16.215
Difference between total distance flown with and without wind farm (km)		6.224	0.315	-4.886	0.971	70.036	9.332	70.036	9.332
Difference in the total number of trips carried out with and without wind farm		-0.016	0.005	-0.101	0.005	-0.867	0.048	-0.867	0.048
Chicks not surviving the season	Not present	1459.900	1083.772	615.400	440.294	1642.800	1203.195	1642.800	1203.195
	Present	1508.600	1097.987	624.900	445.035	1980.400	1393.786	1980.400	1393.786
Additional mortality of chicks with wind farm present (%)		0.567	0.228	0.275	0.196	3.695	2.229	3.695	2.229
Number of adults directly impacted by the wind farm (displaced or barriered)[1]	Present	5729		2574		5681		5957	

[1] The number of adults directly impacted includes any adults that were displaced and/or barriered at least once during the chick-rearing period. Direct impacts do not always result in mortality.

3.4. RAZORBILL

Table 3.5: **Modelled impacts of the Proposed Development (only) on adult razorbill during the year, at the five SPAs simulated using 100% of the population.**

Year Type	Adults not surviving the year				Difference in mortalities between the scenarios	Additional mortality (%)
	Baseline (no wind farm)		Wind farm present			
	Mean	SD	Mean	SD		
Farne Islands						
Poor	136.400	7.589	136.100*	7.310	0.300	-0.052
Moderate	78.400	3.239	78.200*	3.795	0.200	-0.035
Good	37.100	2.923	38.200	2.251	1.100	0.192
Forth Islands						
Poor	2077.700	29.766	2091.000	26.175	13.300	0.365
Moderate	1204.500	13.485	1220.500	12.730	16.000	0.288
Good	636.700	11.036	643.700	11.116	7.000	0.224
Fowlsheugh						
Poor	3573.600	169.462	3788.000	123.224	124.400	1.203
Moderate	1976.700	108.130	2127.300	82.110	150.600	0.845
Good	1039.100	55.671	1136.000	41.110	96.900	0.544
St. Abb’s Head to Fast Castle						
Poor	1285.000	45.845	1303.800	52.753	18.800	0.479
Moderate	723.700	23.903	738.400	33.557	14.700	0.374
Good	438.600	21.277	448.400	28.880	9.800	0.249
Troup, Pennan and Lion’s Heads						
Poor	1754.900	69.901	1757.700	68.628	2.800	0.046
Moderate	1082.000	29.269	1082.700	29.352	0.700	0.012
Good	568.200	18.317	569.500	16.946	1.300	0.021

*It is expected that the number of mortalities in scenarios with the wind farm present would be higher than baseline scenarios. The lower number of mortalities in a poor and moderate year in Farne Islands could be due to stochasticity in the model combined with the presence of the wind farm having little impact. This is supported by the low difference in mortalities across all three year types. It is also shown that the wind farm had little impact on travel costs as travel distance increased by only 0.987km and no difference in the number of trips between the scenarios (Table 3.6).

Table 3.6: SeabORD outputs for razorbill at each of the five sites, using 100% of the population during a moderate chick-rearing period.

Output Variable	Scenario (wind farm present/not present)	Farne Island		Forth Island		Fowlsheugh		St. Abb's Head to Fast Castle		Troup-Pennan-Lions Heads	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number of adult birds in simulation	Both	527		7878		17816		3928		6054	
Adult survival at end of breeding season (%)	Not present	100.000	0.000	100.000	0.000	100.000	0.000	100.000	0.000	100.000	0.000
	Present	100.000	0.000	100.000	0.000	100.000	0.000	100.000	0.000	100.000	0.000
Initial adult body mass (g)	Not present	582.913	0.000	582.761	0.000	582.913	0.000	582.679	0.000	583.223	0.000
	Present	582.913	0.000	582.761	0.000	582.913	0.000	582.679	0.000	583.223	0.000
Final adult body mass (g)	Not present	548.058	10.278	549.008	11.074	548.341	11.628	533.145	9.137	546.519	10.744
	Present	547.793	10.247	548.651	10.967	545.518	11.197	532.281	8.710	546.471	10.734
Difference between total distance flown with and without wind farm (km)		5.214	1.247	5.402	1.466	75.611	9.665	16.017	9.781	0.987	0.155
Difference in the total number of trips carried out with and without wind farm		-0.030	0.017	-0.119	0.009	-0.982	0.030	-0.175	0.043	0.000	0.003
Chicks not surviving the season	Not present	34.500	27.200	519.300	378.909	1196.500	1018.492	784.100	496.098	487.100	348.875
	Present	35.700	27.047	530.100	384.438	1610.000	1216.577	831.000	499.400	489.200	349.821
Additional mortality of chicks with wind farm present (%)		0.420	0.676	0.274	0.193	3.519	2.355	2.338	0.774	0.069	0.059
Number of adults directly impacted by the wind farm (displaced or barriered)[1]	Present	194		3063		5793		2187		245	

[1] The number of adults directly impacted includes any adults that were displaced and/or barriered at least once during the chick-rearing period. Direct impacts do not always result in mortality

3.5. PUFFIN

Table 3.7: Modelled impacts of the Proposed Development (only) on adult puffin during the year, at the two SPAs simulated.

Year Type	Proportion of population included in simulation	Adults not surviving the year						Difference in mortalities between scenarios (scaled mortalities)	Additional mortality (%)
		Baseline (no wind farm)			Wind farm present				
		Mean	SD	Scaled mortalities	Mean	SD	Scaled mortalities		
Coquet Island									
Poor	0.2	2088.600	39.192	10443.000	2151.100	40.154	10755.500	62.500	0.624
Moderate	0.2	1471.000	20.747	7355.000	1523.200	24.476	7615.000	52.200	0.519
Good	0.2	855.500	16.775	4277.500	904.000	27.051	4520.000	48.500	0.484
Forth Islands									
Poor	0.2	3377.900	7.370	16889.500	3442.800	16.171	17214.000	324.500	0.372
Moderate	0.2	2407.800	7.005	12039.000	2459.500	18.362	12297.500	258.500	0.296
Good	0.2	1364.300	8.795	6821.500	1406.900	14.896	7034.500	213.000	0.244

Table 3.8: SeabORD outputs for puffin at each of the two sites simulated during a moderate chick-rearing period.

Output Variable	Scenario (wind farm present/not present)	Coquet Island		Forth Islands	
		Mean	SD	Mean	SD
Proportion of population simulated	Both	0.2		0.2	
Number of adult birds in simulation	Both	10012		17448	
Adult survival at end of breeding season (%)	Not present	100.000	0.000	100.000	0.000
	Present	99.997	0.005	100.000	0.000
Initial adult body mass (g)	Not present	393.016	0.000	392.700	0.000
	Present	393.016	0.000	392.700	0.000
Final adult body mass (g)	Not present	368.542	8.185	368.798	7.803
	Present	367.428	8.415	368.086	8.003
Difference between total distance flown with and without wind farm (km)		29.901	2.420	53.837	8.307
Difference in the total number of trips carried out with and without wind farm		-0.062	0.066	0.046	0.091
Chicks not surviving the season	Not present	419.600	184.516	655.100	252.071
	Present	461.400	216.573	688.600	283.492
Additional mortality of chicks with wind farm present (%)		0.835	0.679	0.384	0.370
Number of adults directly impacted by the wind farm (displaced or barriered)[1]	Present	5147		9826	

[1] The number of adults directly impacted includes any adults that were displaced and/or barriered at least once during the chick-rearing period. Direct impacts do not always result in mortality

4. CONCLUSION

4.1. OVERVIEW OF OUTPUTS OF THE MODELLING EXERCISE

49. The results produced by SeabORD indicate that the Proposed Development array area will have little impact on kittiwake, guillemot, razorbill and puffin SPA populations. The main parameter produced by SeabORD that indicates this is the additional mortality caused by the wind farm under moderate conditions. This is due to the simulations being calibrated to these conditions and the resulting outputs from Table 3.2, Table 3.4, Table 3.6 and Table 3.8 only being true for moderate year types. The additional mortality is also represented by the difference in mortalities between scenarios.

50. The number of mortalities predicted to be caused by displacement and barrier effects following the introduction of the wind farm ranged from 14.5 – 201.5, 10.0 – 456.0, -0.2 – 150.6 and 52.2 – 258.5 for kittiwakes, guillemots, razorbill and puffins respectively (Table 3.1, Table 3.3, Table 3.5 & Table 3.7).

51. It would be expected that the predicted impact on an SPA would decrease as the distance from the development area increases. However, simulations for Fowlsheugh SPA resulted in the highest increase in mortalities for kittiwake, guillemot and razorbill despite not being the closest SPA to the Proposed Development. This could potentially be due to the location of the reference point selected for the SPA as the mid-point of the coastline occurred within an indent along the UK coastline. As the model uses the perimeter pathfinding method to travel around land masses as well as the development area, this means that more foraging sites could be susceptible to increased travel distances than in reality where individuals would be departing the colony from various locations. Moreover, Fowlsheugh SPA was found to have the largest decrease in the average number of trips when the wind farm is present. This could indicate that individuals at this SPA could have higher rates of abandonment as adults need to carry out less trips to only provide for themselves, or it could indicate low levels of body mass loss leading to adults staying at the nest with their chicks. Due to the higher increases in mortalities compared to other SPAs, the former could be assumed.

52. Another factor that could influence this is that the reference point for the Forth Islands SPA was set to the Isle of May. There were multiple foraging sites available for this colony in the opposite direction to the wind farm due to the uniform prey distribution assumption.

53. The SeabORD authors advised HiDef not to rely on the additional mortality of chicks to interpret the impact of wind farms, as the corresponding results for adults have been found to be more accurate (K. Searle meeting with HiDef 21 July 2022). However, the results have been included to provide the full picture of how the model operates.

4.2. DISCUSSION OF THE SEABORD MODEL

54. The model determines abandonment by adults using the % body mass loss over the breeding season and assumes that when one adult abandons a chick, the other adult will do so too and these individuals are removed from further timesteps. In addition to this, individuals are not able to gain mass during the chick-rearing period.

55. This could have consequences on the number of mortalities predicted by SeabORD when compared to reality. It would be assumed that once individuals abandon their chicks they would then be able to prioritise meeting their own DER and possibly even exceed the energy required resulting in increases in body mass if chicks are abandoned earlier during the breeding season. This would then have knock-on effects to the predicted annual mortalities which use body mass as an indicator of survival during the remainder of the year.

56. It was also found that the baseline mortality rates produced by SeabORD were much higher than those in the literature provided for the PVA carried out for this project (

57. Table 2.7), highlighting likely inaccuracies within the results provided by SeabORD. This could be attributed to the value of the slope parameter in the mass-survival relationship used to predict adult mortalities, with Vallejo *et al*., (2022) (volume 3, appendix 11.4, annex H) highlighting that the slope in the current publicly available model issteeper than that produced using more geographically relevant data (e.g. Daunt *et al*., 2018).

58. It was also assumed that there was a uniform prey distribution as appropriate GPS data were unavailable for all SPA colonies. This means that every SPA within the simulation area had the same level of prey quantity despite differences in location. This does not occur in reality, with theories such as Ashmole's Halo documenting areas of low prey abundance surrounding seabird colonies due to predation from breeding colonies (Ashmole, 1963). Currently, SeabORD only allows for the inclusion of non-uniform prey distributions if GPS data for the species and colony of interest are available. These data must include the density of birds for locations within the simulation area for each of the SPA colonies under consideration, which was unavailable for Proposed Development.

59. The outputs produced by SeabORD are particularly sensitive to prey distribution type. The analysis carried out by Natural Power found using the uniform prey option as opposed to prey distributions based on GPS data led to increased additional mortality for kittiwake adults in a 'good' year and additional chick mortality during the chick-rearing period (Vallejo *et al*., 2022; volume 3, appendix 11.4, annex H).

60. The use of the distance decay function was also investigated as part of the sensitivity analysis (Vallejo *et al*., 2022 (volume 3, appendix 11.4, annex H)). When compared to distribution maps created using GPS data, it was found that the distance decay approach did not produce similar maps for the Forth and Tay area. This is most likely due to the distance decay method not accounting for patchy prey distributions, which would influence foraging seabird distributions in real life scenarios.

61. Foraging sites are also selected at random which is unlikely to occur in reality when individuals will determine their foraging location using factors such as the level of competition and prey abundance or quality.

62. The results presented in this annex include the use of a scaling factor of 1/proportion of population simulated to generate the number of scaled mortalities. However, it is not clear whether the number of mortalities produced by SeabORD scales linearly as you increase the proportion of the population. This could have impacts on the final estimates; it is unknown what the scale or direction of any changes this assumption could cause to the final results. This is also coupled with minimal guidance on how large of a proportion you must use in scaled simulations to produce reliable results.

63. The model was also found to operate using many parameters based on expert judgement as opposed to previous datasets or evidence, leading to oversimplification in some parts of the model. The uncertainty around these individual parameters is not always clearly stated. Thus, it is likely that the true level of uncertainty is unaccounted for by the model (Vallejo *et al*., 2022 (volume 3, appendix 11.4, annex H; Searle *et al*., 2022).

64. Planned expansions and developments of the SeabORD model including some of the points mentioned, such as the issues surrounding uncertainty, have been described in Searle *et al*., (2022).

4.3. ISSUES WITH IMPLEMENTATION OF SEABORD

65. HiDef encountered some difficulties in running the simulations, particularly due to the large size of SPA populations being modelled. Issues with the use of SeabORD were discussed with the creators of SeabORD directly where possible.

66. **Calibration:** HiDef required clarification of the methods used to calibrate the model to generate the correct prey quantity ranges for the final paired simulations (Table 2.5) (Searle, K. 2022, personal communication, 5 May).

67. **Estimated breeding pairs**: SeabORD requires the number of breeding pairs rather than individuals, leading to complications over correction factors and lack of advice on how they should be applied. Moreover, the calculation of estimated breeding pairs is known to have a large scope for error.

68. **Run time:** Due to the large population sizes required in modelling, the run time for SeabORD simulations meant that the number of paired simulations carried out had to be limited. For example, the guidance for using the software states that 10 paired runs with 30,000 individuals would be expected to take approximately 20 hours. Moreover, this meant that some final paired simulations for certain species (guillemot, puffin and kittiwake) were reduced to using 20% of the population rather than the planned 50% and final simulations could not be run for all colonies included in the model. The full time taken to run the simulations included in this report are shown in Table 4.1. Due to technical issues with the SeabORD software there were multiple incomplete simulation runs with the time for failed runs included in Table 4.1. The estimated run time for running all colonies using the originally proposed proportion of populations and full list of SPAs is shown in Table 4.2.

69. **Scaling factors:** as simulations for the same species used different proportions of the population, a scaling factor was applied to the results to estimate the outputs of running the simulation with 100%. This was discussed with the creators of SeabORD and it was decided to use 1/proportion of the population simulated. However, it was noted by the creators of SeabORD that the outputs may not scale linearly, meaning that scaled values can only provide an estimate of running the model with the full population (Searle, K. 2022, pers. comm., 21 June).

70. **Troubleshooting:** while running the simulations errors were encountered which we were unable to troubleshoot due to error messages referring to code which is not publicly available. This led to rerunning simulations and further time costs.

71. **Model processes:** some of the specifics of the model have not been made clear in the supporting documents, for example how the annual mortalities for ‘poor’ or ‘good’ years are generated, leading to initial uncertainty when interpreting results.

Table 4.1: **Run time of SeabORD final paired simulations reported and unsuccess simulation runs. One simulation provides the results for one SPA (i.e. to get the results for three different kittiwake SPAs, three simulations must be run with the respective prey quantity ranges).**

Species	Number ran successfully	Number ran unsuccessfully	Proportion of SPA birds	Average time for simulations	Total time per successful/ unsuccessful simulations (days)
Kittiwake	3	1	0.2	1.85 days	5.55 / 1.85
Guillemot	4	3	0.2	1.25 days	5.00 / 3.75
Guillemot	0	2	0.5	4.67 days	0.00 / 9.34
Razorbill	5	1	1.0	9.67 hours	2.01 / 0.40
Puffin	2	1	0.2	1.38 days	2.76 / 1.38
				Run time	**26.83 / 16.72**
				Combined run time	**43.55**

Table 4.2 **Expected run time to produced results for all SPAs using the originally planned proportion of the individuals simulated.**

Species	Number of colonies requiring simulations	Proportion of SPA birds	Average time for simulations	Total time per simulation (days)
Kittiwake	6	0.5	4.63 days[1]	27.78
Guillemot	5	0.5	4.67 days	23.35
Razorbill	5	1.0	9.67 hours	2.01
Puffin	3	0.5	3.45 days[1]	10.35
			Total simulation time	**63.49**

[1] Run times are estimated by multiplying the values from Table 4.1 by 2.5 as no successful or unsuccessful simulations were run using the initially planned proportion of individuals

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6. APPENDIX

6.1. DEFAULT SEABORD PARAMETERS

Table 6.1: Default parameters used within the bioenergetic equations carried out by SeabORD.

Code	Description	Units	Species Values			
			Kittiwake	Guillemot	Razorbill	Puffin
BM_adult_mn	Initial adult body mass mean	g	372.69	920.34	582.9	392.8
BM_adult_sd	Initial adult body mass standard deviation	g	33.62	57.44	26	21.95
BM_adult_mortf	Critical mass below which adult is assumed dead	proportion of mean mass	0.6	0.6	0.6	0.6
BM_adult_abdn	Critical mass below which adult abandons chick	proportion of mean mass	0.8	0.8	0.8	0.8
BM_chick_mn	Initial chick body mass mean	g	36	75.8	64.9	42.2
BM_chick_sd	Initial chick body mass standard deviation	g	2.2	1	6.3	3.7
BM_Chick_mortif	Critical mass below which chick is dead	proportion of initial mass	0.6	0.6	0.6	0.6
daylength	Number of hours per timestep	hours	36	24	24	24
seasonlength	Number of timesteps per season		30	21	21	40
unattend_max_hrs	Critical time threshold for unattendance at nest above which a chick is assumed to die through exposure or predation		18	18	18	0
adult_DEE_mn	Adult daily energy expenditure mean	kJ	802	1489.1	1231.89	871.5
adult_DEE_sd	Adult daily energy expenditure standard deviation	kJ	196	169.9	95.3	80
chick_DER	Chick energy requirement	kJ per day	525.71	221.71	195.67	325
IR_max	Maximum prey intake rate	g per minute	4.369	2.95	3.066	3.293
IR_half_a	Intake rate parameter		900	700	600	1000
IR_half_b	Intake rate parameter		0.02	0.02	0.02	0.02
Adult_priority	Adult priority when food is scarce		0	0	0	0
flight_msec	Average speed in flight	metre per second	13.1	19.1	16	17.6
pelagic	Fraction of dives assumed to be pelagic (not to sea bed)		1	0.5	1	1
forage_depth_mn	Diving depth mean (set to 0 for non-diving species)	m	0	11.71	6.5	4.15
forage_depth_sd	Diving depth standard deviation (set to 0 for non-diving species)	m	0	8.07	5.2	2.1
assim_eff	Assimilation efficiency		0.74	0.78	0.79	0.78
energy_prey	Energy gained from prey	kJ per gram	6.1	6.1	6.1	6.1
energy_nest	Energy cost of nesting at colony	kJ per day	427.75	1168.91	932.17	665.41
energy_flight	Energy cost of flight	kJ per day	1400.74	7361.72	3581.34	3113.85
energy_searest	Energy cost of resting at sea	kJ per day	400.57	810.28	646.15	461.24
energy_forage	Energy cost of foraging	kJ per day	1400.74	1894.9	1421.45	974.97
energy_warming	Energy cost of warming food	kJ per day	34.15	65.07	47.317	35.84
chick_mass_a	maximum chick mass gain per day	g	11	9	7	6

Code	Description	Units	Species Values			
			Kittiwake	Guillemot	Razorbill	Puffin
adult_mass_KG	Energy density of the adult bird’s tissue	kj per gram	38	38	38	38

6.2. MORTALITY RATES

Table 6.2: **Mortality rates calculated using SeabORD simulations (non-scaled) and using scaled mortality estimates for kittiwake.**

Year Type	Non-scaled annual mortalities (%)		Scaled annual mortalities (%)	
	Baseline (no wind farm)	Wind farm present	Baseline (no wind farm)	Wind farm present
Forth Islands				
Poor	42.243	42.530	42.243	42.530
Moderate	28.477	28.638	28.477	28.637
Good	17.259	17.431	17.259	17.431
Fowlsheugh				
Poor	34.938	35.706	34.938	35.706
Moderate	23.114	23.873	23.114	23.873
Good	13.171	13.491	13.171	13.491
St. Abb’s Head to Fast Castle				
Poor	21.423	21.477	21.423	21.477
Moderate	15.186	15.311	15.186	15.311
Good	9.272	9.366	9.272	9.366

Table 6.3: **Mortality rates calculated using SeabORD simulations (non-scaled) and using scaled mortality estimates for guillemot.**

Year Type	Non-scaled annual mortalities (%)		Scaled annual mortalities (%)	
	Baseline (no wind farm)	Wind farm present	Baseline (no wind farm)	Wind farm present
Farne Islands				
Poor	21.307	21.422	21.307	21.422
Moderate	10.895	10.984	10.895	10.984
Good	7.993	8.068	7.993	8.068
Forth Islands				
Poor	22.326	22.370	22.326	22.370
Moderate	11.423	11.452	11.423	11.452
Good	8.029	8.097	8.029	8.097
Fowlsheugh				
Poor	17.723	18.639	17.723	18.639
Moderate	8.680	9.180	8.680	9.180
Good	6.605	7.045	6.605	7.045
St. Abb’s Head to Fast Castle				
Poor	26.755	27.034	26.755	27.034
Moderate	14.525	14.676	14.525	14.676
Good	11.509	11.566	11.509	11.566

Table 6.4: **Mortality rates calculated using SeabORD simulations (non-scaled) and using scaled mortality estimates for razorbill.**

Year Type	Non-scaled annual mortalities (%)	
	Baseline (no wind farm)	Wind farm present
Farne Islands		
Poor	23.846	23.794
Moderate	13.706	13.671
Good	6.486	6.678
Forth Islands		
Poor	26.373	26.542
Moderate	15.289	15.493
Good	8.082	8.171
Fowlsheugh		
Poor	20.058	21.262
Moderate	11.095	11.940
Good	5.832	6.376
St. Abb's Head to Fast Castle		
Poor	32.714	33.192
Moderate	18.424	18.798
Good	11.166	11.415
Troup, Pennan and Lion's Heads		
Poor	28.987	29.034
Moderate	17.872	17.884
Good	9.386	9.407

Table 6.5: **Mortality rates calculated using SeabORD simulations (non-scaled) and using scaled mortality estimates for puffin.**

Year type	Non-scaled annual mortalities (%)		Scaled annual mortalities (%)	
	Baseline (no wind farm)	Wind farm present	Baseline (no wind farm)	Wind farm present
Coquet Island				
Poor	20.861	21.485	20.861	21.485
Moderate	14.692	15.214	14.692	15.212
Good	8.545	9.029	8.545	9.029
Forth Islands				
Poor	19.360	19.732	19.360	19.732
Moderate	13.800	14.096	13.800	14.096
Good	7.819	8.063	7.819	8.063

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