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Brims Tidal Array Ltd

Supporting Document 14B

Collision Risk to Diving Seabirds

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Abbreviations

The following abbreviations are used in this report:

- AfL – Agreement for Lease (effectively the Brims offshore development site)
- BTAL - Brims Tidal Array Limited
- CEH – Centre for Ecology and Hydrology
- CRM – Collision Rate Modelling ('Band' model)
- ERM – Encounter Rate Modelling
- ESAS – European Seabirds at Sea (survey method)
- JNCC - Joint Nature Conservation Committee
- MMFR - Mean Maximum Foraging Range
- SAMS – Scottish Association for Marine Science
- SNH – Scottish Natural Heritage
- TEC – Tidal Energy Converter (rotor and nacelle)

INTRODUCTION

1. This supporting document to Chapter 14 – Ornithology of the Brims ES examines in detail the potential for Brims tidal devices to kill or injure diving birds through collision.

2. Tidal energy converters (TECSs) such as tidal stream turbines pose a theoretical risk to some diving bird species (McCluskie *et al*., 2012; Furness *et al*., 2012). The risk is theoretical because any effect has yet to be empirically demonstrated. Furthermore there is uncertainty as to whether: animals of relatively small size such as diving seabirds would be struck by a rotor blade or would be swept past the blade while entrained within the tidal stream; and whether, were birds to be struck, the strike force would result in a trauma sufficient to cause injury or death (Wilson *et al*., 2007). For the purposes of impact assessment it is cautiously assumed that Brims tidal devices do pose a collision risk to diving birds and that the strike force could be sufficient to cause injury or death, and therefore this subject merits detailed evaluation.

3. Although the encounter and collision rate model outputs are quantitative, they should be regarded as only indicative of the level of additional mortality/injury that may result. This is because the models used have not been validated empirically and several of the model parameters are only known approximately. While actual rates of behavioural avoidance and evasion and mortality/injury are unknown, model outputs are considered useful in terms of giving a first order and, most likely, cautious estimate of the absolute magnitude of the potential collision risk. Model outputs are also potentially useful for comparing different scenarios, e.g., different types and combinations of tidal devices and in aiding the understanding of which aspects of tidal devices and array design have greatest bearing on collision risk to diving birds. Encounter and collision rate modelling are recommended by SNH to better understand the potential for collision risk to diving seabirds from tidal stream turbines (SNH, 2015). Elsewhere similar modelling methods have been used to examine the risk to diving seabirds at the European Marine Energy Centre Fall of Warness test site, Orkney (EMEC, 2014) and for the proposed Perpetuus Tidal Energy Centre test facility off the Isle of Wight, England (PTEC, 2014).

4. In response to a draft version of this report, SNH (letter to Marine Scotland, 14 December 2015) stated that although they recognised the uncertainty regarding avoidance they advised the use of 98% avoidance as this value has been used for assessment of tidal projects elsewhere. They also advised that results for other avoidance rates should also be presented to provide context.

Aims

5. The modelling presented here has three aims:

- to examine the potential for collisions between TECs and diving birds;
- to identify the worst-case scenario, in terms of the combination of turbine depth and turbine type, to use in the project's impact assessment;

- to examine how bird mortality (or serious injury) caused by such collision could impact on the adult annual mortality rate of the regional breeding population of a species.

6. Through consultation with MS and SNH (SNH, letter 17 January 2014), it was agreed that collision risk should be examined for diving seabird species that regularly occur in the vicinity of the Brims development, namely common guillemot, razorbill, puffin, black guillemot, shag and gannet. These are the diving species that the baseline ornithology surveys (**Supporting Document 14A: Bird Surveys Technical Report**) showed to regularly use the Brims ESAS survey area. Since agreeing these species with MS and SNH the range of devices being considered and footprint of the tidal array (**ES Chapter 4: Project Description**) has changed. The project's design envelope now only includes devices that will be seabed mounted and that will operate with a minimum surface clearance of 30m below LAT. The proposed array footprint is now restricted to an area where the seabed is at least 65m depth in all parts and mostly 70-90m deep, beyond the depth limit for energetically profitable foraging by diving seabirds that target the seabed for foraging.

7. As a consequence of the above changes to the project's design and footprint the two species at Brims that specialise in foraging at or near the seabed, black guillemot and shag, are no longer likely to be exposed to a collision risk because the seabed throughout the AfL is effectively beyond their diving range and therefore the AfL is not expected to provide suitable foraging area for these species. This is borne out by the results of the baseline surveys. The 18 surveys of the Brims Survey Area recorded no black guillemots or shags on the sea surface inside the AfL. Both species were only recorded on the sea close to Hoy/South Walls coast, where the depth is less than approx. 40m (**Supporting Document 14A**, Bird Surveys Technical Report). Based on this empirical survey evidence and also taking into consideration the expected habitat selection based on foraging profitability considerations it is concluded that any collision risk to black guillemot and shag is negligible and therefore no collision risk modelling is undertaken for these two species.

METHODS

Model choice

8. Two models have been developed and published to predict the number of occasions that swimming animals may encounter operating TECs and thereby giving rise to the potential for harmful collision events (SNH, 2015). Neither model *per se* takes into account avoidance or evasion behaviour by animals, nor do they consider whether the collision strike force is sufficient to result in harm to the animal. However, these things can be accounted for, post-modelling, by applying 'avoidance rate' adjustment factors to model predictions.

9. The first model considered is the encounter rate model (ERM) developed by SAMS and CEH (Wilson *et al.*, 2007), and further elaborated by Band (Annex 3 in EMEC, 2014; SNH, 2015), to predict the potential for swimming animals to be harmed by open rotor tidal device types. This model adapts a predator-prey encounter rate model initially developed for jellyfish preying on plankton (Gerritsen and Strickler, 1977). ERM estimates the number of encounter events per unit time per device based on the relative velocities

(i.e., closing velocity) of the 'predator' (a rotating turbine) and the 'prey' (a swimming animal), and their sizes.

10. The second model is the 'Band' collision rate model (CRM). This model was initially developed to estimate the risk of collision to flying birds from wind turbines (Band *et al.*, 2007). The model has two stages. The first stage estimates the number of transits by a species through the rotor swept area per unit time (typically a season or a year) for the location under investigation. The second stage estimates the likelihood that a flying bird travelling through the rotor swept area will make contact with (i.e., encounter) a rotor. The encounter risk (or collision risk as referred to by the authors), before taking into account avoidance or evasion, is the product of the output from the two model stages.

11. The approach used in the Band CRM can also be used to estimate collision risk to diving birds from tidal devices. However, there are a number of differences between flying birds and swimming birds. The main difference is that for wind farms it is assumed that a bird passing through a rotor swept area is in level flight (a reasonable assumption based on observing flying birds) and that they pass at right angles to the plane of rotation i.e. at 90 degrees to a rotor blade (this assumption is unlikely to be always met, however the model output has low sensitivity to varying the angle of approach). For diving birds, swim trajectories are likely to be inclined to the horizontal or be approximately vertical, as they typically have v-shaped or u-shaped dive paths starting at and returning to the water surface. Indeed trajectories relative to a TEC could be orientated at any angle between horizontal and vertical.

12. A comparison of the outputs from the Band and ERM models for an open (i.e. unshrouded) 3-bladed turbine using the same input parameters has recently been undertaken (Appendix 3 in EMEC 2014). This concluded that for the range of scenarios tested, the two models gave broadly similar output values but with a relatively consistent difference, such that the average number of encounter events predicted by the ERM exceeded the number of collisions predicted by the Band model by a factor of approximately 1.4.

13. It was further agreed through consultation with MS and SNH (SNH, Scoping Opinion, 31 October 2013) that the Encounter Rate Model (ERM) (Wilson *et al*., 2007; SNH, 2015) was a suitable approach to investigate the potential for collision mortality. This method has the advantage that it makes no assumptions about an animal's swimming direction relative to a rotor. Although ERM was initially considered to be the preferred method to examine the potential for collision to diving birds from Brims, SNH subsequently recommended the use of CRM for the open-centred turbines (SNH, letter 21 August 2014). This model has been used for two species (common guillemot and razorbill) for comparison.

Avoidance rate

14. The potential number of harmful collisions is estimated by first undertaking predictive modelling of the number of encounters between TECs and diving birds and then adjusting this number by an 'avoidance rate'.

Although not part of the models *per se*, the greatest uncertainty in terms of the practical application of the model outputs is the lack of information on the effectiveness of avoidance and evasion behaviour by diving birds (and all other taxa) and the consequences to individual birds of a collision event.

15. An 'avoidance rate' is commonly used in collision risk modelling to adjust predictions to take account of animals response behaviour, however this is not an entirely appropriate term within the context of tidal turbines and can be confusing. In wider practice, and as used here, the avoidance rate term is a catch-all adjustment factor that combines far field avoidance behaviour, near field evasion behaviour and an allowance for non-harmful collisions, which may be more likely for collisions of swimming birds with tidal turbines than for flying birds with wind turbines (see below). The avoidance rate as used here is defined as the percentage of predicted encounters that are assumed not to translate into harmful collisions. Despite its name, the term 'avoidance rate' as used in this document makes no inference as to the reason why some predicted encounters do not translate into a harmful collisions and covers all types of contributing factors such as avoidance behaviour, evasion behaviour and low impact strikes.

16. It is reasonable to assume that, based on the behavioural abilities and physical robustness of diving seabirds, not all encounters with a TEC will result in harmful collisions. For example, the authors of the SAMS model point out that diving birds have a moderately fast burst speed which, although considerably slower than the speed of the outer tips of blades (Fraenkel, 2006), would enable a bird to successfully take evasive action under many situations (Wilson *et al*., 2007). Furthermore, tidal devices are generally relatively small (for example compared to large wind turbines) and are likely to spend a relatively high proportion of time rotating below their maximum rotation speed (i.e., during the part of the tide cycle around slack water); together these things will mean that at certain times, especially in the inner parts of the rotor swept area, the collision strike force may be below that required to cause injury.

17. The indicative number of harmful collisions that would occur for avoidance rates of 50%, 90%, 95%, 98% and 99% were calculated. This range is considered by Scottish Natural Heritage as being appropriate for presenting and assessing diving bird collision modelling results for tidal stream arrays (EMEC, 2014; SNH, 2015). These avoidance rates reflect the general view of many biologists working in the field that the actual number of harmful collisions will be substantially lower than the predicted number of encounters (EIMR Conference collision workshop, 2 May 2014[1]).

18. Following advice from SNH (letter to Marine Scotland 14 December 2015), a 98% avoidance rate was chosen as the focus for assessing the impacts of collision on diving bird populations.

[1] Environmental Interactions of Marine Renewable Energy Technologies, 2014

19. The question of which avoidance rate is most appropriate for the assessment of a particular device type is considered in the Discussion.

Model input parameter and assumptions

20. ERM and CRM require information on the physical dimensions and rotation speed of the moving parts of TECs (i.e., the rotor blades), together with data on the size, swimming speed and density at rotor depths of the species being assessed.

21. Model outputs are in terms of encounter events per second per device. The encounter rate value is then scaled up by multiplying it by risk exposure time of interest (e.g., breeding season, non-breeding season, etc.) and total number of TEC devices in the array being assessed.

22. The density of a diving bird species at device depths is estimated from the average density of birds on the sea surface (e.g., as determined from ESAS surveys), combined with information on dive frequency, duration and depth from published behaviour studies.

23. The derivation of the device-specific and species-specific parameters that are required for ERM and CRM are discussed in more detail in the sections below. A worked example of the ERM calculation for one species is presented in Annex 1, together with copies of the spreadsheets for common guillemot and razorbill. Copies of the CRM spreadsheets for the 23m 3-bladed turbine and the 16m shrouded open-centred turbine are presented in Annex 2 and Annex 3 respectively.

Tidal device parameters

24. The models consider two device types as set out in Table 1. In all cases the devices would be mounted on the seabed and have no surface piercing elements. These devices are described in full in **ES Chapter 5: Project Description**.

25. The models require input parameters for rotor number, rotor blade length, rotor blade width (for ERM only, i.e., blade thickness front to back) and rotation velocity of rotors (Table 1). These parameters are known for all device types considered for the BTA development.

26. ERM also requires a value for the mean rotor velocity relative to the water (the mean tangential velocity to the axis). Current speed will vary with a sinusoidal pattern with the tide cycle. Wilson *et al*. (2007) and Band (SNH, 2015) assume that the mean velocity relative to the water will approximate to the root mean square velocity of the mean component and the current velocities; this is also assumed for the modelling undertaken here.

27. For turbines with an annular design like the OpenHydro shrouded turbine, SNH recommend that for Stage 2 of CRM (likelihood of collision for a single bird transiting through the turbine diameter) it is assumed that, taking into consideration a bird's width (its wing span), all transits through the rotor swept area result in

collision and that all birds that transit through the central hole pass through unharmed. This approach is adopted here. It is precautionary because there is a small possibility that a diving bird of the size of a guillemot could pass through the rotor swept area without encountering a turbine blade. Adopting this method for estimating the Stage 2 collision probability has the advantage that the turbine parameters for the number of blades, blade chord width and blade pitch are not required and therefore the calculation is simplified.

Table 1. Turbine parameters used for impact assessment

Parameter	Open-centred 10-blade shrouded turbine	3-blade unshrouded turbine	Comment
Number of rotors per device	1	1	
Device rotor diameter (m)	12.8 (16m including shroud)	23	
Rotor blade length (m)	4.35	11.5	For the open-centre turbine the maximum blade length will be 4.35m with an open centre of 4.1m diameter.
Maximum blade chord width (m)	2.4*	1.8	
Mean blade thickness (front to back) (m)	0.10	0.30	0.30 is value used in EMEC 2014 report for a 25m diameter 3-blade turbine.
Mean blade pitch	30*	5	
No. rotor blades	10	3	
Mean rotation period (RPM)	8.00	6.95	
Mean rotor velocity (m/s)	3.5	4.2	
Mean current speed during operation (m/s)	1.56	1.56	
Mean blade speed relative to water (m/s)	3.9	4.5	
% of time operational	85.60%	85.60%	

* not used in models

28. The models consider three depth scenarios for turbine placement in the water column in relation to seabed clearance and surface clearance, as set out in Table 2. A seabed depth of 70 m below LAT is assumed for all scenarios. This assumption provides for a cautious assessment because the actual depth where turbines will be located within the development site is on average greater, ranging from approximately 68 to 90 m below LAT (see Figure 2 in **ES Chapter 5: Project Description**), and for most of the time the actual depth will be up to a few metres greater than during LAT conditions.

29. The species considered show different patterns in the proportion of underwater time spent within different depth bands (Table 3). For the two species that forage on the seabed (shag and black guillemot) the time spent in each depth band above the seabed will be equal, and therefore the ERM predictions for these two species are not sensitive to where in the water column a turbine operates. For razorbill, puffin and gannet, the time spent in each depth band decreases sharply with increasing depth. Therefore the ERM predictions for these species are very sensitive to the where in the water column a turbine operates; predicted encounters are highest when turbines are positioned relatively close to the surface. Common guillemots spend the highest proportion of their underwater time in intermediate depth bands, especially between 40 and 60m depth. Therefore the ERM predictions for this species have moderate sensitivity to where in the water column a turbine operates; the predicted encounter are highest when turbines are positioned in a depth range of approximately 40-60 m below the surface. In light of the above the three turbine depth scenarios considered for each device type are as follow:

- Scenario 1 - deepest turbine depth. The minimum sea bed clearance and maximum surface clearance that might be installed.
- Scenario 2 -intermediate turbine depth. The sea bed and surface clearance that results in the highest encounter rate for common guillemot.
- Scenario 3 - shallowest turbine depth. The maximum seabed clearance and minimum surface clearance that might be installed.

Table 2. Turbine depth scenarios modelled by ERM. Note for the Open Hydro devices the clearance specified is measured to the outer edge of the shroud.

Turbine type	Turbine operating depth scenario	Seabed clearance (m)	Surface clearance (m below LAT)
Open Hydro 16m shrouded device with a 12.8m diameter open-centred rotor	Shallowest	34	30
	Intermediate	10	44
	Deepest	4	50
3-bladed 23m diameter rotor	Shallowest	27	30
	Intermediate	7	40
	Deepest	4	43

Seabird parameters

30. The ERM requires input parameters about the diving bird species being examined, namely: the size of the bird (body length and wing span), average swimming speed, average density at rotor depth and the length of time that birds are exposed to a collision risk (exposure time).

31. Information on bird size is sourced from BTO Bird Facts website (http://www.bto.org/about-birds/birdfacts) which in turn is based on published information on biometrics (e.g. Cramp, 1985) (Tables 2 to 5).

32. For the auk species the mean on-sea areal density (birds/km^2) for the time of year of interest, as determined from the baseline ESAS surveys, is used as a starting point for calculating underwater density (**Supporting Document 14A**). For gannet the areal density of all birds recorded in the baseline surveys is used (i.e., birds on the sea plus birds in flight). This is then combined with published information on time budget to give an estimate of underwater areal density. Even though collision risk is limited to the AfL, the mean seasonal density values used are those derived from data for the AfL + 1km as these are considered a more robust measure of density because of the tighter confidence limits. Examination of the baseline survey species distribution map for these species shows that there are no obvious differences in the use of the AfL and AFL + 1km.

33. Information on time spent at different depths (Table 3) is then used to estimate proportion of underwater time spent at rotor depth by summing the %-underwater-time value for all 1m-depth bands occupied by the rotors. These estimates were then combined to give the estimated density (birds/m^3) at rotor depth, the density parameter required for ERM. Consideration was given to the methods suggested in SNH 2015 for estimating density at rotor depth, however this was considered to be less appropriate than the method described below on account of the relatively large water depth at the site.

Time spent under water and time at rotor depth

34. Estimates of the proportion of at-sea time spent underwater and the proportion of this time assumed to be at rotor depth for the Brims site were derived from published literature. From these data the % of underwater time spent at each depth was calculated (Table 3) and this is also shown graphically in term of estimated percentage of underwater time each depth is exceeded (Figure 1) to show the species-specific pattern of depths use .

35. Although there are numerous studies reporting diving behaviour for the species examined few of them provide the detailed information on depth-specific time spent underwater (i.e., time *vs* depth) that is required to parameterise the models of the species that routinely forage in the within the water column (as opposed to foraging at or close to the seabed). Data on maximum/ mean diving depth and maximum/ mean dive duration are not sufficient to reasonably establish the underwater time *vs* depth relationship. In any

case care needs to be exercised in interpreting reported results as there are inconsistency in terminology, for example sometimes means or medians refer to the sample of dives recorded and at other time they refer to the sample of birds tagged.

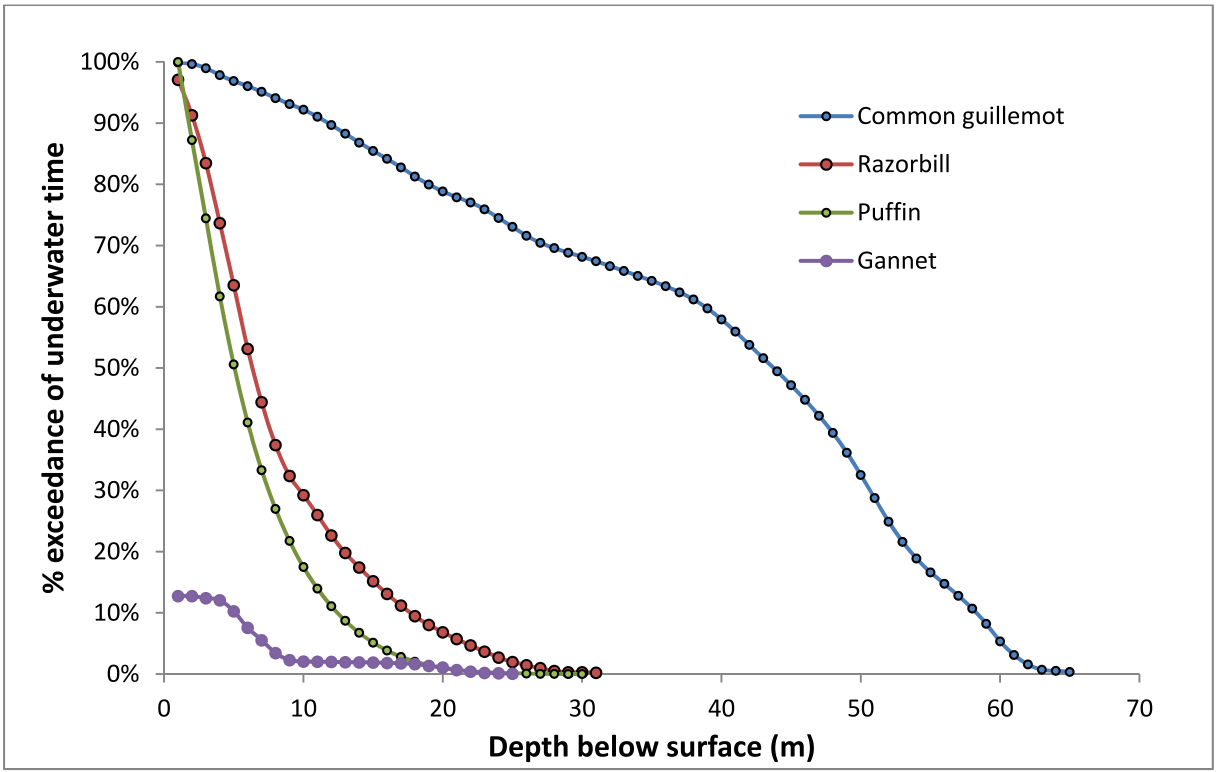

Figure 1. The estimated % of underwater time plotted against depth (based on various sources as detailed in text).

Common guillemot, razorbill and puffin

36. For common guillemot and razorbill the study by Thaxter *et al*. (2010) conducted in SE Scotland provides the information required and this is used here to estimate the likely percentage of time spent at rotor depth Table 3).

37. The maximum dive depth reported by Thaxter *et al*. 2010 for common guillemot, 62m, (these authors do not calculate a median maximum depth) was in line with the median (across birds) maximum approximately 50m reported by Barrett and Furness (1990). However these studies contrast with results reported by Tremblay *et al.* (2003) for common guillemot at another site in Norway where dive depth was appreciably lower with maximum depth was 37m, and mean dive depth of just 10m compared to a corresponding mean of approximately 31m in the Thaxter *et al*. study. This suggests that the pattern of dive depths recorded by Thaxter *et al.* is towards the upper (deeper) end of the depth range targeted by this species. The use of time-at-depth data from a study where the birds choose to dive to relatively deep (such as the Thaxter et al. study) will lead to more conservative (higher) predictions of encounter rate from the modelling.

38. In the case of razorbill Thaxter *et al*. (2010) report a maximum dive depth of 32m, and this compares to a median (across birds) maximum depth of 25-30 m reported by Barret and Furness (1990). Other studies of razorbill diving behaviour also report this species diving to relatively shallow depths compared to common guillemot. For example, chick-rearing razorbills off Iceland were observed foraging at depths rarely greater than 35m (maximum 41m) (Dall'Antonia *et al.*, 2001) and the mean dive depth attained in a Baltic study was below 15m. Thus all studies are in line with the results of Thaxter *et al*. study in indicating that razorbills spend only a very small proportion of underwater time below 30 m.

39. The study by Thaxter *et al.* was undertaken at the Isle of May, SE Scotland, and approximately 290 km south of the Brims project site. The range of sea depths within 50 km of the Isle of May (i.e. the areas likely to be most targeted for foraging by common guillemot and razorbill) are similar to those found in the Pentland Firth; with most areas being below 50m, extensive areas between 60m and 100m, and a negligible area deeper than 100m (http://www.doggerbank.nl/index-old.htm).

40. An important feature of the % time *versus* depth exceedance plot for common guillemot (Figure 1) is that it is not linear but shows that disproportionately more time is spent at intermediate depths, which causes the notable bulge in the plotted line. The worst case scenario for collision risk is positioning turbines at the depth range that corresponds to the steepest gradient of the plot (i.e. the right hand side of the bulge).

41. For puffin no estimate of the proportion of time at sea spent under water was found in the literature. This figure was therefore derived from information on time adults are absent from the colony (Creelman and Storey, 1991) and information on the daily time spent underwater (Spencer, 2012). Creelman and Storey (1991) showed that during the breeding season adult puffins are absent from the colony for approximately 67% of daylight hours (derived as follows: 75% of hours in during 30-day pre-laying period; 45% of hours during incubation and brooding, a 50-day period; and, 87% of hours during remainder of chick rearing, a 40-day period). Assuming that 10% of the time away is spent in flight (in absence of flight time budget data for puffin, the value from Thaxter *et al*. (2010) for common guillemot used), then this suggests that during the breeding season puffins spend approximately 60% of daylight hours on or below the sea surface. For Brims, this translates to approximately 10 hours per day. Spencer (2012) showed that breeding puffins undertook an average of 256 dives per day of mean duration 48.7 seconds, giving a daily time below water of 3.46 hours. Combining the two figures gives an estimate of 34.6% of at-sea daylight time spent underwater during the breeding season. For the non-breeding season it is assumed that the daily time spent underwater is the same as during the breeding season, and that a reasonable estimate of the percent of time underwater is given by this figure divided by mean day length (3.46 hours/ 9.75 hrs). This gives a value of 35.5%. For the models a more precautionary figure of 40% is used for both periods of the year.

42. For puffin the time-depth logger results for over 8000 dives recorded by Spencer were used to derive the time-at-depth relationship required for the models (Table 3), though this turned out to be not to be strictly required following an increase to 30m in the value for the proposed minimum surface clearance (sea surface

to device at LAT) for the Project. As a result none of the Brims rotor depth scenarios are anticipated to be within the depth range regularly attained by this species. The Spencer study recorded a mean maximum dive depth of 28m. Results from Barrett and Furness, 1990 also show that puffin rarely exceed 25-30m depth. Therefore it is a reasonable assumption that only a negligible proportion of underwater time is spent below 30 m.

43. The time spent at different depths was estimated from data on dive-depth frequency to different depths (Spencer, 2012) and the relationship between dive duration and dive depth. Spencer does not detail the exact relationship between duration and depth, but states that dive duration increased linearly with depth. For the purposes of estimating time spent at each depth it was assumed that dive time increases by two seconds for every additional metre of attained. This figure is consistent with a mean descent/ascent rate of 1 m/s underwater and is used as the basis for estimating the assumed time spent at different depths (Table 3).

44. Note the reports of these auk species exceptionally attaining much greater dive depths off Newfoundland (approx. 180m for common guillemot, approx. 140m for razorbill and approx. 60m for puffin) are based on incidental captures in fisheries gill nets (Piatt and Nettleship, 1985) and therefore may not be reliable; the data from studies using modern time-depth loggers are considered to be much more reliable.

<u>Gannet</u>

45. For gannet it is assumed that 2% of the daylight time is spent foraging underwater (Table 3). This figure is based on a study of tagged birds that demonstrated that <2% of the time away from the colony was spent underwater (Ropert-Coudert *et al.,* 2008).

46. The approximate proportion underwater time spent by gannets in each 1m-depth band was derived from the time-depth information reported by Ropert-Coudert *et al*., (2008).

Accounting for age

47. As the aim of the modelling is to predict impact of collisions on adult mortality rate, an adjustment is made to the density figure to discount for the proportion of immature birds present. During the Brims ESAS surveys, 76% of gannets that were aged in the breeding season, and 61% during the non-breeding period, were in adult plumage; these figures are used in the models. The other species examined here could not be reliably aged in the field. For these species the proportion of adults assumed to be present at Brims is informed by the analysis of population age-structure presented by Furness (2014).

Exposure time

48. Exposure time is the amount of time the bird population being investigated is potentially exposed to a collision risk. This is required in terms of exposure time per year as the aim is to estimate the impact collision mortality might have on a population's annual mortality rate. Potential exposure time in hours was

calculated for each seasonal period examined for daylight using the model developed by Forsythe *et al*. (1995) for calculating latitude specific estimates of day length.

49. All species were assumed to be exposed to a collision risk throughout the daylight period. No evidence was found in published literature that any of the species examined dive at night, nor is this to be expected as all species considered here locate prey visually. Tagging studies on black guillemot in the Pentland Firth (Masden *et al*., 2013) and Atlantic puffin in Maine (USA) (Spencer, 2012) found no evidence of diving during the hours of darkness. Similarly, tagging studies of shag by Daunt *et al*. (2006) and of gannet by Ropert-Coudert *et al*. (2009) found no evidence of foraging at night.

50. In the model exposure time is considered in seconds per season of the year examined as the model predictions are in terms of encounters per second.

Table 3. Assumed percentage of underwater time spent in each 1-metre depth band. Data are from Thaxter *et al*. (2010) for common guillemot and razorbill, Spencer (2012) for puffin and Ropert-Coudert *et al*. (2008) for gannet. See text for explanation of derivation and information sources.

Depth band (m)	Common guillemot	Razorbill	Puffin	Gannet
0-1	0.2%	5.8%	12.8%	12.9%
1-2	0.5%	11.6%	12.8%	12.9%
2-3	1.4%	15.6%	12.8%	12.6%
3-4	2.3%	19.6%	11.1%	12.2%
4-5	2.0%	20.2%	9.5%	11.6%
5-6	1.7%	20.8%	7.8%	9.0%
6-7	1.9%	17.4%	6.3%	6.2%
7-8	2.1%	14.0%	5.2%	2.1%
8-9	2.0%	10.1%	4.3%	2.1%
9-10	1.9%	6.3%	3.5%	1.9%
10-11	2.3%	6.5%	2.9%	1.9%
11-12	2.7%	6.7%	2.4%	1.8%
12-13	2.8%	5.7%	2.0%	1.8%
13-14	2.9%	4.8%	1.6%	1.7%
14-15	2.7%	4.5%	1.3%	1.5%
15-16	2.6%	4.2%	1.0%	1.4%
16-17	2.8%	3.8%	0.80%	1.2%
17-18	3.0%	3.4%	0.60%	1.1%
18-19	2.6%	2.9%	0.42%	1.0%
19-20	2.3%	2.4%	0.30%	0.8%
20-21	2.0%	2.2%	0.22%	0.7%
21-22	1.7%	2.1%	0.16%	0.6%
22-23	2.3%	2.0%	0.11%	0.4%
23-24	2.8%	1.9%	0.08%	0.3%
24-25	2.9%	1.5%	0.05%	0.1%
25-26	2.9%	1.0%	0.03%	0%
26-27	2.3%	0.97%	0.02%	0%
27-28	1.7%	0.89%	0.02%	0%
28-29	1.5%	0.45%	0.01%	0%
29-30	1.3%	0.00%	0.00%	0%
30-31	1.5%	0.15%	0.0%	0%
31-32	1.6%	0.30%	0.0%	0%
32-33	1.6%	0.15%	0.0%	0%
33-34	1.6%	0.%	0.0%	0%
34-35	1.7%	0.0%	0.0%	0%
35-36	1.7%	0.0%	0.0%	0%
36-37	2.0%	0.0%	0.0%	0%
37-38	2.3%	0.0%	0.0%	0%
38-39	2.9%	0.0%	0.0%	0%
39-40	3.6%	0.0%	0.0%	0%
40-41	4.0%	0.0%	0.0%	0%

Depth band (m)	Common guillemot	Razorbill	Puffin	Gannet
41-42	4.4%	0.0%	0.0%	0%
42-43	4.3%	0.0%	0.0%	0%
43-44	4.3%	0.0%	0.0%	0%
44-45	4.5%	0.0%	0.0%	0%
45-46	4.8%	0.0%	0.0%	0%
46-47	5.2%	0.0%	0.0%	0%
47-48	5.6%	0.0%	0.0%	0%
48-49	6.5%	0.0%	0.0%	0%
49-50	7.3%	0.0%	0.0%	0%
50-51	7.5%	0.0%	0.0%	0%
51-52	7.7%	0.0%	0.0%	0%
52-53	6.6%	0.0%	0.0%	0%
53-54	5.4%	0.0%	0.0%	0%
54-55	4.6%	0.0%	0.0%	0%
55-56	3.7%	0.0%	0.0%	0%
56-57	3.9%	0.0%	0.0%	0%
57-58	4.2%	0.0%	0.0%	0%
58-59	5.0%	0.0%	0.0%	0%
59-60	5.8%	0.0%	0.0%	0%
60-61	4.4%	0.0%	0.0%	0%
61-62	3.1%	0.0%	0.0%	0%
62-63	1.7%	0.0%	0.0%	0%
63-64	0.33%	0.0%	0.0%	0%
64-65	0.40%	0.0%	0.0%	0%
65-66	0.46%	0.0%	0.0%	0%
66-67	0.23%	0.0%	0.0%	0%
68+	0.0%	0.0%	0.0%	0%

Table 4. Input parameters for common guillemot

Parameter	**Units**	**Season**			**Comment/source**
		Colony attendance	**Chicks at sea**	**Winter**	
Months		Mar-Jul	Aug	Sep-Feb	Baseline surveys (Supporting Document 14A)
Exposure period daylight	hours	2415	480	1619	Forsythe *et al*. 1995
Mean surface areal density	birds/ km^2	10.43	0	2.14	From Brims baseline ESAS survey results (AfL+1km) (Supporting Document 14A)
Proportion of at-sea time spent underwater		0.25	0.25	0.25	Thaxter *et al*. 2010, mean dive duration x dive pause ratio, study gives value of 0.238, more precautionary value of 0.25 used.
Proportion of adults		0.76	0.76	0.57	Based on Furness 2014
Assumed swim speed	m/s	1.8			Watanuki *et al*. 2006 (value 1.7 m/s)
Bird length	m	0.40			BTO Bird Facts website
Bird wing length	m	0.67			BTO Bird Facts website
Bird effective radius factor	m	2.55			Band (in EMEC 2014)
Bird effective encounter radius	m	0.26			Band (in EMEC 2014)
Adult annual mortality rate		6.1%			Horswill and Robinson 2015
Biologically relevant receptor population	adults	609,250			Breeding adults in MMFR, derived from Seabird 2000 census data.
Percent of underwater time spent at rotor depth, OH shrouded 12.8m diameter rotor					
Shallowest turbine depth scenario		18.7%			Derived from data in Thaxter *et al*. 2010
Intermediate turbine depth scenario		38.7%			
Deepest turbine depth scenario		24.6%			
Percent of underwater time spent at rotor depth, 3-bladed 23m diameter rotor					
Shallowest turbine depth scenario		43.9%			Derived from data in Thaxter *et al*. 2010
Intermediate turbine depth scenario		58.2%			
Deepest turbine depth scenario		53.4%			

Table 5. Input parameters for razorbill.

Parameter	Units	Season			Comment/source
		Colony attendance	Chicks at sea	Winter	
Months		April -July	Aug	Sep-Mar	Baseline surveys (Supporting Document 14A)
Exposure period daylight	hours	2050	480	1983	Forsythe *et al*. 1995
Mean surface areal density	birds/ km^2	5.70	1.06	0.4	From ESAS survey results (AfL+1km)
Proportion of at-sea time spent underwater		0.20	0.20	0.20	Thaxter *et al*. 2010, mean dive duration x dive pause ratio, study gives value of 0.174, more precautionary value of 0.20 used.
Proportion of adults		0.75	0.75	0.57	Based on Furness 2014
Assumed swim speed	m/s	1.7			Watanuki *et al*. 2006 (value 1.61 m/s)
Bird length	m	0.38			BTO Bird Facts website
Bird wing length	m	0.66			BTO Bird Facts website
Bird effective radius factor	m	2.55			Band (in EMEC 2014)
Bird effective encounter radius	m	0.26			Band (in EMEC 2014)
Adult annual mortality rate		10.5%			Horswill & Robinson 2015
Biologically relevant receptor population	adults	10,739			Breeding adults in MMFR, derived from Seabird 2000 census data.
Percent of underwater time spent at rotor depth, OH shrouded 12.8m diameter rotor					
Shallowest turbine depth scenario		0.3%			Derived from data in Thaxter *et al*. 2010
Intermediate turbine depth scenario		0%			
Deepest turbine depth scenario		0%			
Percent of underwater time spent at rotor depth, 3-bladed 23m diameter rotor					
Shallowest turbine depth scenario		0.3%			Derived from data in Thaxter *et al*. 2010
Intermediate turbine depth scenario		0%			
Deepest turbine depth scenario		0%			

Table 6. Input parameters for puffin.

Parameter	Units	Season		Comment/source
		Breeding	Winter	
Months		April –mid August	Mid-Aug - March	Baseline surveys (Supporting Document 14A)
Exposure period daylight	hours	2050	1983	Forsythe *et al*. 1995
Mean surface areal density	birds/ km^2	4.16	0.38	From ESAS survey results (AfL+1km)
Proportion of at-sea time spent underwater		0.4	0.4	Derived from studies by Creelman and Storey 1991, and Spencer 2012. Actual estimate 0.346 (full details in text).
Proportion of adults		0.75	0.57	Based on Furness 2014
Assumed swim speed	m/s	1.6		Informed by mean values for auk species in Watanuki *et al*. 2006 (mean =1.55m/s)
Bird length	m	0.28		BTO Bird Facts website
Bird wing length	m	0.55		BTO Bird Facts website
Bird effective radius factor	m	2.55		Band (in EMEC 2014)
Bird effective encounter radius	m	0.22		Band (in EMEC 2014)
Adult annual mortality rate		9.4%		Horswill & Robinson 2015
Biologically relevant receptor population	adults	142,670		Breeding adults in MMFR, derived from Seabird 2000 census data.
Percent of underwater time spent at rotor depth, OH shrouded 12.8m diameter rotor				
Shallowest turbine depth scenario		0%		Derived from data in Spencer 2012
Intermediate turbine depth scenario		0%		
Deepest turbine depth scenario		0%		
Percent of underwater time spent at rotor depth, 3-bladed 23m diameter rotor				
Shallowest turbine depth scenario		0%		Derived from data in Spencer 2012
Intermediate turbine depth scenario		0%		
Deepest turbine depth scenario		0%		

Table 7. Input parameters for gannet.

Parameter	Units	Season		Comment/source
		Breeding	Winter	
Months		March – Sep	Oct – Feb.	Baseline surveys (Supporting Document 14A)
Exposure period daylight	hours	3282	1231	Forsythe *et al*. 1995
Mean surface areal density	birds/ km^2	0.32	0.12	Baseline surveys (Supporting Document 14A), includes flying birds (whole Survey Area).
Proportion of at-sea time spent underwater		0.02		Ropert-Coudert *et al*. (2008) demonstrate that <2% of time away from colony is spent underwater, so a precautionary value of 0.02 is used.
Proportion of adults		0.74	0.55	Based on Furness 2014
Assumed swim speed	m/s	1.0		Ropert-Coudert *et al*. (2008) value is for wing-beat diving (actual value 0.81m/s). (Note, the vertical descent rate during plunge diving is approx. 6m/s, but this only occurs up to a depth of ca. 10m, well above rotor depth)
Bird length	m	0.94		BTO Bird Facts website
Bird wing length	m	1.72		BTO Bird Facts website
Bird effective radius factor	m	2.55		Band (in EMEC 2014)
Bird effective encounter radius	m	0.67		Band (in EMEC 2014)
Adult annual mortality rate		8.1%		Horswill & Robinson 2015
Biologically relevant receptor population	adults	75,870		Breeding adults in MMFR, derived from Seabird 2000 census data.
Percent of underwater time spent at rotor depth, OH shrouded 12.8m diameter rotor				
Shallowest turbine depth scenario		0%		Derived from data in Ropert-Coudert *et al*. (2008)
Intermediate turbine depth scenario		0%		
Deepest turbine depth scenario		0%		
Percent of underwater time spent at rotor depth, 3-bladed 23m diameter rotor				
Shallowest turbine depth scenario		0%		Derived from data in Ropert-Coudert *et al*. (2008)
Intermediate turbine depth scenario		0%		
Deepest turbine depth scenario		0%		

RESULTS

Model outputs

All species

52. The model outputs predict that of the four species examined only two are likely to be exposed to a collision risk, namely common guillemot and razorbill.

53. Puffin and gannet are not predicted to be exposed to any collision risk. This is because the maximum diving depth typically attained by these species (approximately 25m for puffin and approximately 20 m for gannet, Table 3) is less than the upper reach of the turbine rotor blades under all turbine depth scenarios, i.e. these species are not expected to attain depth of operating rotors.

54. For common guillemot and razorbill the percentage of predicted encounters in each period of the year is presented in Tables 8 and 11.

55. The number of encounters predicted for a single device of each design for each operating depth scenario examined is presented in Tables 9 and 12. This information identifies which turbine depth scenario and turbine design combination is predicted to pose the greatest collision risk to a species; this is considered to be the worst case scenario.

56. The effects of potential collision mortality resulting from 30 (Stage 1) and 200 (Stages 1 and 2 combined) devices operating at the worst case depth scenario on the adult mortality rate of the regional breeding populations of common guillemot and razorbill is examined in Tables 10 and 13. This is undertaken for indicative avoidance rates of 50%, 90%, 95%, 98% and 99%.

57. The numbers of adult deaths per year would be expected to change with time through the operational life of the project directly in line with changes in population size, however the percentage effect on the mortality rate would be expected to remain the same irrespective of population change provided the relative importance to a species of the Brims AfL for foraging remained the same.

Common guillemot

58. Common guillemots occur very commonly throughout the year in the Brims AfL, especially during the colony-attendance part of the breeding season (March to July) (**Supporting Document 14A**). This species forages in mid-water depths, with dives typically attaining depths of between 10 and 60m below the surface (Thaxter *et al*., 2010). The combination of high abundance and the potential to dive to rotor depths means that there is greater potential for collision risk to common guillemots than any of the other species examined.

59. Common guillemots typically disperse widely away from breeding areas during the non-breeding period, and at this time there is extensive mixing of breeding populations (Wernham *et al*., 2002). However, some adults

return to breeding colonies during the winter (Harris & Wanless, 1990). It is assumed that all collisions during the breeding season and half the collisions during the non-breeding period of the year (September to February) involve individuals from the regional breeding population.

60. The great majority (88%) of the predicted encounters (by both ERM and CRM) occur during the colony-attendance part of the breeding season (Table 8), reflecting the much higher density typically present at this time of year. The lack of predicted encounters during the chicks-at-sea part of the breeding season results from recording no common guillemots at this time of year in the baseline ESAS surveys.

Table 8. The percentage of predicted common guillemot encounters occurring in each season.

Season	% of predicted encounters (all adults)	% of adults assumed to be from regional breeding population	% of predicted encounters involving regional breeding adults
Colony attendance (March to July)	85.7%	100%	92.3%
Chick-at-sea period (August)	0.0%	100%	0.0%
Non-breeding (Sept. to Feb.)	14.3%	50%	7.7%

61. The model predictions for common guillemot showed moderate sensitivity to the turbine operation depth (Table 9). The worst case for collision risk is for the intermediate depth scenario and therefore the predictions for this scenario are of most relevance for assessment.

62. A comparison of the outputs from ERM and CRM (Table 9) shows that number of encounters the predicted by the two methods are broadly similar, particularly for the 23 m diameter 3-bladed turbine.

Table 9. Comparisons of predicted number of 'no avoidance' encounters with adult common guillemot per device per annum from ERM and CRM modelling.

Turbine	Operating depth scenario	Predicted number of adults encounters per annum		CRM as % of ERM
		ERM	CRM	
OH, shrouded, 12.8m rotor	Shallowest	27.9	44.6	160%
	Intermediate (worst case)	57.7	92.4	
	Deepest	36.5	58.5	
Unshrouded, 23m rotor	Shallowest	41.7	38.4	92%
	Intermediate (worst case)	55.2	50.9	
	Deepest	50.7	46.7	

Stage 1

63. Under the worst case depth scenario (intermediate), for an array of 30 devices, and for the assumed parameter values described with no avoidance rate adjustment, the ERM predicts that there will be approximately 1,538 and 1,607 encounter events annually involving adult common guillemots from the regional breeding population for the unshrouded and shrouded turbine design respectively (Table 10). This compares to equivalent CRM predictions of 1,449 and 2,632 encounter events per annum for the unshrouded and shrouded turbine design respectively.

64. Taking the worst case prediction of 2,632 encounter events per annum and using a 98% avoidance rate, it is predicted that approximately 53 adult common guillemots of the regional breeding population would be killed each year (Table 10). Assuming a regional breeding population of 609,250 adults (**Supporting Document 14A**) and an adult mortality rate of 6.10% (Horswill and Robinson, 2015), the baseline number of adult deaths in the population is estimated at 37,164 birds per annum. The additional mortality caused by 53 collisions would cause the adult annual mortality rate to increase by 0.14%, i.e., a change from 6.10% to 6.11%. Different avoidance rates (e.g., rates of 90%, 95% and 99%) result in correspondingly proportionate changes to the predicted adult mortality rate (Table 10).

Stage 1 & 2

65. Under the worst case depth scenario (intermediate), for an array of 200 devices, and for the assumed parameter values described with no avoidance rate adjustment, the ERM predicts that there will be approximately 10,256 and 10,713 encounter events annually involving adult common guillemots from the regional breeding population for the unshrouded and shrouded turbine design respectively (Table 10). This

compares to equivalent CRM predictions of 9,663 and 17,549 encounter events per annum for the unshrouded and shrouded turbine design respectively.

66. Taking the worst case prediction of 17,549 encounter events per annum and using a 98% avoidance rate, it is predicted that approximately 351 adult common guillemots would be killed each year from the regional breeding population (Table 10). Assuming the same population size and baseline mortality rate as above, the additional mortality from these collisions would cause the adult annual mortality rate to increase by 0.94%, i.e., a change from 6.10% to 6.16%. Different avoidance rates (e.g., rates of 90%, 95% and 99%) result in correspondingly proportionate changes to the predicted adult mortality rate (Table 10).

Table 10. The predicted number of encounters with adult common guillemot predicted by ERM and CRM models and the indicative adult mortality and changes to baseline adult mortality rate of the regional breeding population for avoidance rates of 50%, 90%, 95%, 98% and 99%. The worst case prediction is highlighted.

Turbine	Model	Predicted adult encounters per year (no avoidance)		50% Avoidance		90% Avoidance		95% Avoidance		98% Avoidance		99% Avoidance	
		All adults	Adults from regional breeding population	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality
Stage 1, 30 devices													
OH, shrouded, 12.8m rotor	ERM	1730	1607	803	2.2%	161	0.43%	80	0.22%	32	0.09%	16	0.04%
	CRM	2771	2632	1316	3.5%	263	0.71%	132	0.35%	53	0.14%	26	0.07%
Unshrouded, 23m rotor	ERM	1656	1538	769	2.1%	154	0.41%	77	0.21%	31	0.08%	15	0.04%
	CRM	1526	1449	725	2.0%	145	0.39%	72	0.20%	29	0.08%	14	0.04%
Stage 1 & 2, 200 devices													
OH, shrouded, 12.8m rotor	ERM	11535	10713	5356	14.4%	1071	2.88%	536	1.44%	214	0.58%	107	0.29%
	CRM	18475	17549	8774	23.6%	1755	4.72%	877	2.36%	351	0.94%	175	0.47%
Unshrouded, 23m rotor	ERM	11042	10256	5128	13.8%	1026	2.76%	513	1.38%	205	0.55%	103	0.28%
	CRM	10173	9663	4832	13.0%	966	2.60%	483	1.30%	193	0.52%	97	0.26%

Razorbill

67. Razorbills occur commonly throughout the year in the Brims AfL, especially during the colony-attendance part of the breeding season (April to July) (**Supporting Document 14A**). This species forages relatively close to the surface; dives seldom (<1% of dives) exceed 30m below the surface and most underwater time is spent within 15m of the surface (Table 3, based on Thaxter *et al*., 2010).

68. Razorbills disperse widely away from breeding areas during the non-breeding period, mainly to more southerly areas such as the seas off France and Spain (Wernham *et al*., 2002). During the non-breeding season most of the razorbills using the Brims site are likely to originate from more northern breeding areas especially Iceland (Wernham *et al*., 2002).

69. It is assumed that all collisions during the breeding season (including the chick-at-sea period) and half the collisions during the non-breeding period (September to March) of the year involve individuals from the regional breeding population.

70. The great majority (95%) of the predicted encounters (both CRM and ERM) occur during the breeding season (including the chick-at-sea period) (Table 12), reflecting the much higher density typically present at this time of year.

Table 11. The percentage of predicted razorbill encounters occurring in each season.

Season	% of predicted encounters (all adults)	% of adults assumed to be from regional breeding population	% of predicted encounters involving regional breeding adults
Colony attendance (April to July)	80.4%	100%	82.3%
Chick-at-sea period (August)	15.0%	100%	15.3%
Non-breeding (Sept. to March)	4.6%	50%	2.4%

71. The model predictions for razorbill showed very high sensitivity to the turbine depth (Table 12). The deepest and intermediate depth scenarios predict no encounters; this is because under these scenarios no dives would be expected to reach the turbine depths. The worst case for collision risk is for the shallowest depth scenario (surface clearance of 30m) and therefore the predictions for this scenario are of most relevance for assessment.

72. A comparison of the outputs from ERM and CRM (Table 12) shows that the numbers of encounters predicted by the two methods are broadly similar, particularly for the 23 m diameter 3-bladed turbine.

Table 12. Comparisons of predicted number of 'no avoidance' encounters with adult razorbill per device per annum from ERM and CRM modelling.

Turbine	Operating depth scenario	Predicted number of adults encounters per annum		CRM as % of ERM
		ERM	CRM	
OH, shrouded, 12.8m rotor	Shallowest (worst case)	0.17	0.26	150%
	Intermediate	0	0	
	Deepest	0	0	
Unshrouded, 23m rotor	Shallowest (worst case)	0.11	0.09	85%
	Intermediate	0	0	
	Deepest	0	0	

<u>Stage 1</u>

73. Under the worst case depth scenario (shallowest), for an array of 30 devices, and for the assumed parameter values described with no avoidance rate adjustment, the ERM predicts that there will be approximately 3 and 5 encounter events annually involving adult razorbills from of the regional breeding population for the unshrouded and shrouded turbine design respectively (Tables 13). This compares to equivalent CRM predictions of approximately 3 and 8 encounter events per annum for the unshrouded and shrouded turbine design respectively.

74. Taking the worst case prediction of an average of 7.5 encounter events per annum and using a 98% avoidance rate, it is predicted that on average one adult razorbill from the regional breeding population would be killed approximately once every seven years (the prediction is 0.1 deaths per year) (Table 13). Assuming a regional breeding population of 10,739 adults (**Supporting Document 14A**) and an adult mortality rate of 10.5% (Horswill and Robinson, 2015), the baseline number of adult deaths in the population is estimated at 1,128 birds per annum. This additional mortality from collisions would cause the adult annual mortality rate to increase by 0.01%, i.e., a change from 10.500% to 10.501%. Different avoidance rates (e.g., rates of 90%, 95% and 99%) result in correspondingly proportionate changes to the predicted adult mortality rate (Table 13).

Stage 1 & 2

75. Under the worst case depth scenario (shallowest), for an array of 200 devices, and for the assumed parameter values described with no avoidance rate adjustment, the ERM predicts that there will be approximately 21 and 33 encounter events annually involving adult razorbills from of the regional breeding population for the unshrouded and shrouded turbine design respectively (Tables 13). This compares to

equivalent CRM predictions of approximately 18 and 50 encounter events per annum for the unshrouded and shrouded turbine design respectively.

76. Taking the worst case prediction of 50 encounter events per annum and using a 98% avoidance rate, it is predicted that approximately one adult razorbill from the regional breeding population would be killed each year (Table 13). Assuming the same population size and baseline mortality rate as above, the additional mortality from these collisions would cause the adult annual mortality rate to increase by 0.1%, i.e., a change from 10.50% to 10.51%. Different avoidance rates (e.g., rates of 90%, 95% and 99%) result in correspondingly proportionate changes to the predicted adult mortality rate (Table 13).

Table 13. The predicted number of encounters with adult razorbill predicted by ERM and CRM models and the indicative adult mortality and changes to baseline adult mortality rate of the regional breeding population for avoidance rates of 50%, 90%, 95%, 98% and 99%. The worst case prediction is highlighted.

Turbine	Model	Predicted adult encounters per year (no avoidance)		50% Avoidance		90% Avoidance		95% Avoidance		98% Avoidance		99% Avoidance	
		All adults	Adults from regional breeding population	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality	Predicted adults deaths	Change to baseline mortality
Stage 1, 30 devices													
OH, shrouded, 12.8m rotor	ERM	5.1	5.0	2.5	0.22%	0.5	0.04%	0.3	0.02%	0.10	<0.01%	0.05	<0.01%
	CRM	7.7	7.5	3.7	0.33%	0.7	0.07%	0.4	0.03%	0.15	0.01%	0.07	<0.01%
Unshrouded, 23m rotor	ERM	3.3	3.2	1.6	0.14%	0.3	0.03%	0.2	0.01%	0.06	<0.01%	0.03	<0.01%
	CRM	2.8	2.7	1.4	0.12%	0.3	0.02%	0.1	0.01%	0.05	<0.01%	0.03	<0.01%
Stage 1 & 2, 200 devices													
OH, shrouded, 12.8m rotor	ERM	34.2	33.4	16.7	1.48%	3.3	0.30%	1.7	0.15%	0.7	0.06%	0.3	0.03%
	CRM	51.3	50.0	25.0	2.22%	5.0	0.44%	2.5	0.22%	1.0	0.09%	0.5	0.04%
Unshrouded, 23m rotor	ERM	21.9	21.4	10.7	0.95%	2.1	0.19%	1.1	0.09%	0.4	0.04%	0.2	0.02%
	CRM	18.6	18.1	9.1	0.80%	1.8	0.16%	0.9	0.08%	0.4	0.03%	0.2	0.02%

DISCUSSION

77. It should be noted that the worst case collision risk predictions presented are for the worst possible case, in which turbines are positioned in the water column where they would pose the greatest potential collision risk to a species assuming a sea bed depth of 65 m throughout the deployment site. However, the worst possible case is unlikely to be the same as what will transpire for the built array. This is because in many parts of the deployment area the seabed depth is greater than 65 m and it is likely that engineering considerations will limit how far above the seabed turbines can be operated. Thus, the actual surface clearance is likely to be greater than assumed for the worst case scenarios and, as a consequence, collision risk could be substantially lower. The 'worst-case' approach adopted provides Open Hydro the greatest scope in possible engineering designs (such as turbine deployment height above the seabed); as the design details are narrowed further modelling can be undertaken to examine how the predicted collision risk to diving birds decreases.

78. There are several uncertainties that affect the accuracy of the model predictions, but by choosing conservative parameter values for the assessment it is considered that the outputs are likely to overestimate rather than underestimate the number of harmful collisions. Nevertheless, an obvious criticism of the ERM and CRM methods is that they have not been empirically validated for diving birds. This will not be possible until tidal device arrays are built and there are appropriate monitoring data that measure if, and how many, collision fatalities actually occur.

79. Aside from the uncertainty over the most appropriate avoidance rate, the model outputs are sensitive to the bird and device parameter values and the uncertainty over some of these has potential to affect the model outputs, in particular, the proportion of a bird's at-sea time spent underwater at rotor depth and mean rotor velocities.

80. The time budget data for the species examined comes from tagging studies undertaken in the breeding season, especially the chick-rearing period when birds are easiest to catch. The extra feeding demands placed on adults provisioning young will inevitably mean additional time spent foraging. Thus, all else being equal, using a value for proportion of time spent underwater derived from provisioning adults is likely to be an overestimate the actual value of this parameter for other times of year (which would result in ERM predictions being a biased high). Of course, there are many reasons why all else may not be equal, (e.g. day length and differences in prey availability and value) and this means there is potential for this parameter values to be higher as well as lower than assumed. Nevertheless there is only limited potential for the value of this time underwater parameter to be greater. This is because diving birds cannot spend all their time underwater; at minimum they need time on the surface to recover from dives and time for preening, and in the breeding season for all the activities associated with breeding.

81. For the four species considered, no information was found to indicate that diving behaviour was influenced by state of the tide or current speed. Although neither can be ruled out it is assumed that diving activity by these species occurs at all states of the tide and current speeds. It is possible that, at least towards the upper end of the spectrum of current speeds experienced at Brims, current speed may be sufficient to reduce foraging efficiency and therefore birds may dive less frequently when current speed is greatest. If this was so this would be expected to reduce the overall likelihood of collision events.

82. Local conditions governing the vertical distribution of fish prey at the Brims site may result in differences to the common guillemot time-at-depth profile to that observed at Thaxter *et al*.'s SE Scotland study area (Figure 1) and this would have a knock on effect on the detail of the time *vs* depth exceedance plot. However it is likely that the overall shape of the plot, i.e. with a bulge at intermediate depths, would remain the same but that the depth range corresponding to the bulge might be somewhat shallower or deeper. This would not be expected to change the encounter rate prediction for the worst-case scenario because the collision rate prediction is not greatly affected by exactly where in water column the bulge in the % time *vs* depth exceedance plot occurs (provided that it is somewhere between the extremes of the shallowest and deepest depth scenarios examined, which is likely.) So the worst case scenario predictions for common guillemot based on the Thaxter *et al*. time-at-depth information is considered to be realistic, however the actual turbine depth range at which the worst case occurs may differ slightly to that described in Table 2.

Avoidance rate

83. In the absence of validation studies on actual avoidance rates (in the wider meaning of this term), the choice of avoidance rate for impact assessment will be semi-arbitrary. Nevertheless, it is known that common guillemot and razorbill have excellent underwater vision (they seek their prey visually), only dive during daylight (so there is a reasonable expectation they can see their surrounding some way ahead), and would be expected to have evolved good avoidance abilities to cope with predators and obstacles whilst diving. On this basis it is judged that these species are likely to show effective avoidance most of the time. Furthermore, as discussed earlier, it is reasonable to assume that the strike force of some collision events will be too small to result in injury. Taking all these factors into consideration it is judged that avoidance rates appropriate for assessing the impacts are likely to be at least 90%. In response to a draft version of this report, SNH (letter to Marine Scotland 14 December 2015) stated that although they recognised the uncertainty regarding avoidance they advise the use of 98% avoidance as this value has been used for assessment of tidal projects elsewhere. They also advised that results for other avoidance rates should also be presented to provide context.

84. In the case of the Open Hydro open-centred shrouded turbines, the ERM and CRM method makes no allowance for the beneficial effects that might accrue from the shrouding or the potential for the open-centre to be used as an escape route, yet common-sense suggests that both of these will reduce collision risk, possibly substantially so. For the reasons set out in the following paragraphs, it is considered likely that a substantially smaller proportion of predicted encounters with an open-centred shrouded turbine will

translate into to collisions compared to the proportion for open-bladed turbine. Taken together, the advantages of shrouding the blades and having a central 'escape' hole would appear to justify the use of a higher avoidance rate when assessing the impact of open-centred shrouded turbines.

85. ERM assumes that bird density 'inside' the shrouded volume of the OH devices will be the same as the density outside in the wider environment. However, because the shrouding will act as a barrier that intercepts swim paths that are orientated downwards/upwards and at right angles to the direction of the current, average bird density inside the shroud would expected to be substantially reduced.

86. For seabed foraging species (e.g., black guillemot and shag) the expectation is that birds travel almost vertically down to and up from the seabed, with little lateral component to their travelling away from the seabed. In such cases the shrouding would be expected to largely eliminate the risk of collision by preventing birds swimming down (or up) into the rotors. For the other species, (common guillemot, razorbill and puffin) dive orientation at rotor depth is expected to be oblique to the horizontal and thus the shrouding will be only partly effective, nevertheless it would be expected to intercept (and thus prevent any potential for collision) some dive paths that would otherwise take a bird into the rotor swept area.

87. The shrouding will not only block a proportion of the potential dive paths that would otherwise go through the rotor swept area, but will also mean that there are no exposed outer rotor tips – the part of a rotor blade that is expected to pose the greatest potential risk to birds because it has the greatest velocity and because it occupies proportionately highest amount of the rotor swept area.

88. It is a reasonable assumption that the effectiveness of a diving bird's behavioural evasion will be negatively correlated with the distance it has to travel to reach risk free water. The hole in the centre of the rotor swept area potentially gives a bird a convenient (i.e., close by) and risk-free escape route should it find itself approaching a rotor and choose to take evasive behaviour. For the Open Hydro turbine design the combination of short rotor blade length (approx. 4 m) and open centre means that at worst a bird approaching the rotor swept area has only to take a maximum evasive movement of approximately 2m to reach safety (i.e., the maximum distance to either the central hole or the outer edge of the shroud). In contrast, for an equivalent non-shrouded closed-centre turbine with relatively long rotor blades (e.g., a 23m diameter conventional turbine), the maximum evasion swim distance a bird may have to travel to reach the risk free water is 12.5m in comparison, six times greater. Bearing in mind that underwater visibility is likely to be <10m at times and therefore that a bird may not detect a turbine until it is within a few metres of it, it is likely that the time difference between a bird first detecting an approaching rotor and the moment when collision would occur will be a few seconds only. At a typical swim speed of approximately 2m/s the distance a swimming bird could potentially travel in in the time it has available to take an evasive movement is likely to be a in the order of a few metres only. On the basis of this reasoning it is concluded that it is likely that evasion behaviour will be more successful for turbine designs where the average distance to safety is smaller.

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ANNEX 1: ERM WORKED EXAMPLE AND COPIES OF ERM SPREADSHEETS

1. Copies of the ERM spreadsheets for common guillemot (all three depth scenarios) and razorbill (shallowest depth scenario only as no encounters predicted for other scenarios) are presented after the worked example below.

2. The ERM calculations undertaken for common guillemot for the 23m diameter 3-bladed turbine during the breeding season are illustrated below by way of an example. The main text of this document describes the basis to the approach and provides the justifications for the values assigned to the various parameters.

3. The equations below, taken from Band 2014 (Annex 3 in EMEC 2014), are used to predict the encounter rate per second of exposure time between birds and the rotor blades of the device (note these are essentially the same equations presented in Wilson *et al*. 2007 and make good a small error made by these authors in the method used to calculate encounter area):

   Z = A * V* D

   Where:

   Z = Encounter rate (encounters per second)

   A = the cross-sectional encounter area (m^2)

   V = the average encounter velocity (m/s)

   D = the density of adult birds at turbine depth (birds/m^3)

4. The value of the cross-sectional encounter area (***A***) is calculated as follows:

   A = (W + 2r) * (R + r) * N

   Where:

   W = the turbine blade width.

   r = the bird's effective encounter radius - i.e. maximum length /effective radius factor (see EMEC (2014) for derivation)

   R = the turbine blade length

   N = the number of rotor blades

For this common guillemot ERM example the assumed values are:

W = 0.3m

r = 0.26m

R = 11.5m

N = 3

Thus, ***A*** = 29.13m^2

5. The value the average encounter velocity function (***V***) is calculated as follows:

$$V = 1 + (u^2/3v^2)$$

u = bird swimming velocity (m/s)

v = the mean rotor velocity (m/s)

6. The value for the density of adult birds at rotor depth (***D***) is calculated from the at-sea areal density of the species multiplied by the assumed proportion of adults in the population then multiplied by the proportion of at-sea time spent underwater and then multiplied by the proportion of underwater time spent at rotor depth. The methods for estimating these three proportions varied between species according to the information available and the nature of the species' diving behaviour, as explained in the Methods section of the text.

7. For the worse case turbine depth scenario during the colony-attendance part of the breeding season the estimated average value of ***D*** for common guillemot = 0.0000000464 adults/m^3.

8. Based upon the above figures, the ERM for common guillemot predicts an encounter rate (***Z)*** of 0.00000636 encounters per second for one turbine. This is the same as one encounter every 157,233 seconds, or one encounter every 43.67 hours of exposure time.

9. To give a measure of how many encounters there will be, the encounter rate is multiplied by the proportion of time the rotors are expected to be operational (85.6%) and the length of time birds are exposed to the risk. In this case the length of exposure time is the daylight hours of the breeding season (for 2415 hours). Thus the estimated number of adult encounters per breeding season (colony-attendance period) is 47.3 ((2415/63.67) x 0.856). To estimate the total number of encounters that may take place over a whole year, separate calculations are made for each season and the season-specific values summed.

Annex 1 continued: copies of ERM spreadsheets for common guillemot for shallowest and intermediate turbine depth scenarios.

COMMON GUILLEMOT Turbine Scenario: SHALLOWEST DEPTH							Bird scenario				X-sectional Encounter Area per rotor							Velocity function	Encounter rate		
									D_s	D	$(W+2r)$	x	$(R+r)$	x	b	=	A	$v\ (1+(u^2/3v^2))$	$=Z$	% time operational	Total encounters per season per rotor
Turbine	Seabed depth (m)	Diameter (m)	rotor length (m)	Seabed clearance (m)	Surface clearance (m)	Pptn UW time at rotor depths	Sp.	Season	Adult areal underwater density (birds/km^2)	Density at rotor depth (birds/m3)	Blade width + Animal's encounter radius	x	Blade length (m) + Animal's encounter radius	x	No. blades	=	Cross-sectional encounter area		Encounter rate (per second)		
OH, shrouded, 12.8m rotor	70	12.8	4.35	25.6	31.6	18.7%	GU	Breeding	1.83	2.68252E-08	0.625	x	4.61	x	10	=	28.85	4.147	0.0000032	85.6%	23.88
	70	12.8	4.35	25.6	31.6	18.7%	GU	Chick rearing	0.00	0	0.625	x	4.61	x	10	=	28.85	4.147	0.000E+00	85.6%	0.00
	70	12.8	4.35	25.6	31.6	18.7%	GU	Non-breedin	0.30	4.45817E-09	0.625	x	4.61	x	10	=	28.85	4.147	5.335E-07	85.6%	3.97
Unshrouded, 23m rotor	70	23	11.50	17	30	43.9%	GU	Breeding	1.83	3.50E-08	0.825	x	11.76	x	3	=	29.13	4.708	4.81E-06	85.6%	35.76
	70	23	11.50	17	30	43.9%	GU	Chick rearing	0.00	0	0.825	x	11.76	x	3	=	29.13	4.708	0.000E+00	85.6%	0.00
	70	23	11.50	17	30	43.9%	GU	Non-breedin	0.30	5.82426E-09	0.825	x	11.76	x	3	=	29.13	4.708	7.988E-07	85.6%	5.94

COMMON GUILLEMOT Turbine Scenario INTERMEDIATE DEPTH							Bird scenario				X-sectional Encounter Area per rotor							Velocity function	Encounter rate		
									D_s	D	$(W+2r)$	x	$(R+r)$	x	b	=	A	$v\ (1+(u^2/3v^2))$	$=Z$	% time operational	Total encounters per season per rotor
Turbine	Seabed depth (m)	Diameter (m)	rotor length (m)	Seabed clearance (m)	Surface clearance (m)	Pptn UW time at rotor depths	Sp.	Season	Adult areal underwater density (birds/km^2)	Density at rotor depth (birds/m3)	Blade width + Animal's encounter radius	x	Blade length (m) + Animal's encounter radius	x	No. blades	=	Cross-sectional encounter area		Encounter rate (per second)		
OH, shrouded, 12.8m rotor	70	12.8	4.35	11.6	45.6	38.7%	GU	Breeding	1.83	5.55478E-08	0.625	x	4.61	x	10	=	28.85	4.147	0.0000066	85.6%	49.45
	70	12.8	4.35	11.6	45.6	38.7%	GU	Chick rearing	0.00	0	0.625	x	4.61	x	10	=	28.85	4.147	0.000E+00	85.6%	0.00
	70	12.8	4.35	11.6	45.6	38.7%	GU	Non-breeding	0.30	9.23169E-09	0.625	x	4.61	x	10	=	28.85	4.147	1.105E-06	85.6%	8.22
Unshrouded, 23m rotor	70	23	11.50	7	40	58.2%	GU	Breeding	1.83	4.64E-08	0.825	x	11.76	x	3	=	29.13	4.708	6.36E-06	85.6%	47.34
	70	23	11.50	7	40	58.2%	GU	Chick rearing	0.00	0	0.825	x	11.76	x	3	=	29.13	4.708	0.000E+00	85.6%	0.00
	70	23	11.50	7	40	58.2%	GU	Non-breeding	0.30	7.71084E-09	0.825	x	11.76	x	3	=	29.13	4.708	1.057E-06	85.6%	7.87

Annex 1 continued: copies of ERM spreadsheets for common guillemot for deepest turbine depth scenario, and for razorbill for shallowest turbine depth scenario.

COMMON GUILLEMOT Turbine Scenario: DEEPEST DEPTH							Bird scenario				X-sectional Encounter Area per rotor							Velocity function	Encounter rate		
									D_s	D	$(W+2r)$	x	$(R+r)$	x	b	=	A	$v\sqrt{(1+(u^2/3v^2))}$	$=Z$	% time operational	Total encounters per season per rotor
Turbine	Seabed depth (m)	Diameter (m)	rotor length (m)	Seabed clearance (m)	Surface clearance (m)	Pptn UW time at rotor depths	Sp.	Season	Adult areal underwater density (birds/km²)	Density at rotor depth (birds/m3)	Blade width + Animal's encounter radius	x	Blade length (m) + Animal's encounter radius	x	No. blades	=	Cross-sectional encounter area		Encounter rate (per second)		
OH, shrouded, 12.8m rotor	70	12.8	4.35	4	53.2	24.6%	GU	Breeding	1.83	3.51976E-08	0.625	x	4.61	x	10	=	28.85	4.147	0.0000042	85.6%	31.34
	70	12.8	4.35	4	53.2	24.6%	GU	Chick rearing	0.00	0	0.625	x	4.61	x	10	=	28.85	4.147	0.000E+00	85.6%	0.00
	70	12.8	4.35	4	53.2	24.6%	GU	Non-breedin	0.30	5.84963E-09	0.625	x	4.61	x	10	=	28.85	4.147	7.000E-07	85.6%	5.21
Unshrouded, 23m rotor	70	23	11.50	4	43	53.4%	GU	Breeding	1.83	4.26E-08	0.825	x	11.76	x	3	=	29.13	4.708	5.85E-06	85.6%	43.49
	70	23	11.50	4	43	53.4%	GU	Chick rearing	0.00	0	0.825	x	11.76	x	3	=	29.13	4.708	0.000E+00	85.6%	0.00
	70	23	11.50	4	43	53.4%	GU	Non-breedin	0.30	7.08344E-09	0.825	x	11.76	x	3	=	29.13	4.708	9.715E-07	85.6%	7.23

RAZORBILL Turbine Scenario: SHALLOWEST DEPTH							Bird scenario				X-sectional Encounter Area per rotor							Velocity function	Encounter rate		
									D_s	D	$(w+2r)$	x	$(R+r)$	x	b	=	A	$v\sqrt{(1+(u^2/3v^2))}$	$=Z$	% time operational	Total encounters per season per rotor
Turbine	Seabed depth (m)	Dia-meter (m)	rotor length (m)	Seabed clearance (m)	Surface clearance (m)	Pptn UW time at rotor depths	Sp.	Season	Adult areal underwater density (birds/km²)	Density at rotor depth (birds/m3)	Blade width + Animal's encounter radius	x	Blade length (m) + Animal's encounter radius	x	No. blades	=	Cross-sectional encounter area		Encounter rate (per second)		
OH, shrouded, 12.8m rotor	70	12.8	4.35	25.6	31.6	0.3%	RA	Breeding	0.79	1.84254E-10	0.618	x	4.61	x	10	=	28.49	4.147	0.0000000	85.6%	0.138
	70	12.8	4.35	25.6	31.6	0.3%	RA	Chick rearin	0.15	3.42648E-11	0.618	x	4.61	x	10	=	28.49	4.147	4.049E-09	85.6%	0.026
	70	12.8	4.35	25.6	31.6	0.3%	RA	Non-breedi	0.05	1.06027E-11	0.618	x	4.61	x	10	=	28.49	4.147	1.253E-09	85.6%	0.008
Unshrouded, 23m rotor	70	23	11.50	17	30	0.3%	RA	Breeding	0.79	1.03E-10	0.818	x	11.76	x	3	=	28.85	4.708	1.39E-08	85.6%	0.088
	70	23	11.50	17	30	0.3%	RA	Chick rearin	0.15	1.90691E-11	0.818	x	11.76	x	3	=	28.85	4.708	2.590E-09	85.6%	0.016
	70	23	11.50	17	30	0.3%	RA	Non-breedi	0.05	5.90062E-12	0.818	x	11.76	x	3	=	28.85	4.708	8.015E-10	85.6%	0.005

ANNEX 2. COPY OF CRM SPREADSHEET FOR 3-BLADED TURBINE (23M DIAMETER ROTOR)

CRM				blade profile:	r/R	c/C
					0	0.690
					0.050	0.730
					0.100	0.790
					0.150	0.880
					0.200	0.960
Rotor data					0.250	1.000
number of rotors	B	m	1	for Brims	0.300	0.980
rotor diameter (c/f)	2R	m	23	for Brims	0.350	0.920
rotor radius	R	m	11.5	for Brims	0.400	0.850
number of blades	b		3	for Brims	0.450	0.800
maximum blade width	C	m	**1.8**	for Brims	0.500	0.750
blade pitch at blade tip	γ	degrees	5		0.550	0.700
blade profile	c/C			<--	0.600	0.640
rotation speed	Ω	rpm	6.95	for Brims	0.650	0.580
% time not operational	nop		14.4%	for Brims	0.700	0.520
					0.750	0.470
					0.800	0.410
Current data					0.850	0.370
mean current speed ($m\ s^{-1}$)	v_c	$m\ s^{-1}$	1.56	for Brims	0.900	0.300
					0.950	0.240
					1.000	0.000

Animal data				**CRM**			
Species (c/f)				**Common guillemot**			
Rotor depth scenario				**shallowest depth scenario**			
Season				**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	t	s	from ERM spread sheeet (hours x60 x60)	**8,692,095**	**1,727,027**	**5,827,465**	
animal density ar risk depth (c/f)	D	animals m^{-3}	from ERM spread sheeet	**3.50E-08**	**0.00E+00**	**5.82E-09**	
marine animal or diving bird?				diving bird			
length	L	m		0.40			
wingspan / bodywidth	W	m		0.67			
CRM ENCOUNTER RATE							
body length used perp to rotor	L'		swap length & width for diving birds	0.67	0.67	0.67	
body width used in rotor plane	W'		swap length & width for diving birds	0.40	0.40	0.40	
speed of approach used	v_c	$m\ s^{-1}$	v_c	1.56	1.56	1.56	
total frontal area		m^2	$B\pi(R+0.5W')^2$	430	430	430	
encounter probability for single transit	pcoll		pcoll / **Note**	19.76%	19.76%	19.76%	
no of rotor transits per second		s^{-1}	$D\ B\pi(R+0.5W')^2\ v_c$	2.35E-05	0.00E+00	3.91E-06	
encounter rate (per sec) before avoidance	C_{CRM}		$D(B\pi(R+0.5W')^2\ v_c$ pcoll	4.65E-06	0.00E+00	7.72E-07	
no of rotor transits in period			$D\ B\pi(R+0.5W')^2\ v_c(1\text{-nop})t$	**174.9**	**0.0**	**19.5**	
encounters in period before avoidance		animals	C_{CRM} (1-nop) t	**34.6**	**0.0**	**3.9**	**38.4**
Phase 1, 30 turbines, No Avoidance				1037	0	116	1153
				From Reg. Brd. Pop. =			**1095**
Phase 1&2, 200 turbines, No Avoidance				6914	0	770	7684
				From Reg. Brd. Pop. =			**7299**

Animal data	**CRM**			
Species (c/f)	**Common guillemot**			
Rotor depth scenario	**Intermediate depth scenario**			
Season	**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	**8,692,095**	**1,727,027**	**5,827,465**	
animal density ar risk depth (c/f)	**4.64E-08**	**0.00E+00**	**7.71E-09**	
marine animal or diving bird?	diving bird			
length	0.40			
wingspan / bodywidth	0.67			
CRM ENCOUNTER RATE				
body length used perp to rotor	0.67	0.67	0.67	
body width used in rotor plane	0.40	0.40	0.40	
speed of approach used	1.56	1.56	1.56	
total frontal area	430	430	430	
encounter probability for single transit	19.76%	19.76%	19.76%	
no of rotor transits per second	3.11E-05	0.00E+00	5.17E-06	
encounter rate (per sec) before avoidance	6.15E-06	0.00E+00	1.02E-06	
no of rotor transits in period	**231.6**	**0.0**	**25.8**	
encounters in period before avoidance	**45.8**	**0.0**	**5.1**	**50.9**
Phase 1, 30 turbines, No Avoidance	1373	0	153	1526
	From Reg. Brd. Pop. =			**1449**
Phase 1&2, 200 turbines, No Avoidance	9153	0	1020	10173
	From Reg. Brd. Pop. =			**9663**

Animal data	**CRM**			
Species (c/f)	**Common guillemot**			
Rotor depth scenario	**Deepest depth scenario**			
Season	**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	**8,692,095**	**1,727,027**	**5,827,465**	
animal density ar risk depth (c/f)	**4.26E-08**	**0.00E+00**	**7.08E-09**	
marine animal or diving bird?	diving bird			
length	0.40			
wingspan / bodywidth	0.67			
CRM ENCOUNTER RATE				
body length used perp to rotor	0.67	0.67	0.67	
body width used in rotor plane	0.40	0.40	0.40	
speed of approach used	1.56	1.56	1.56	
total frontal area	430	430	430	
encounter probability for single transit	19.76%	19.76%	19.76%	
no of rotor transits per second	2.86E-05	0.00E+00	4.75E-06	
encounter rate (per sec) before avoidance	5.65E-06	0.00E+00	9.39E-07	
no of rotor transits in period	**212.8**	**0.0**	**23.7**	
encounters in period before avoidance	**42.0**	**0.0**	**4.7**	**46.7**
Phase 1, 30 turbines, No Avoidance	1261	0	141	1402
	From Reg. Brd. Pop. =			**1332**
Phase 1&2, 200 turbines, No Avoidance	8408	0	937	9345
	From Reg. Brd. Pop. =			**8877**

Animal data	**CRM**			
Species (c/f)	**Razorbill**			
Rotor depth scenario	**shallowest depth scenario**			
Season	**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	**7,379,532**	**1,727,027**	**7,140,028**	
animal density ar risk depth (c/f)	**1.03E-10**	**1.91E-11**	**5.90E-12**	
marine animal or diving bird?	diving bird			
length	0.38			
wingspan / bodywidth	0.66			
CRM ENCOUNTER RATE				
body length used perp to rotor	0.66	0.66	0.66	
body width used in rotor plane	0.38	0.38	0.38	
speed of approach used	1.56	1.56	1.56	
total frontal area	429	429	429	
encounter probability for single transit	19.53%	19.53%	19.53%	
no of rotor transits per second	6.87E-08	1.28E-08	3.95E-09	
encounter rate (per sec) before avoidance	1.34E-08	2.49E-09	7.72E-10	
no of rotor transits in period	**0.4**	**0.0**	**0.0**	
encounters in period before avoidance	**0.1**	**0.0**	**0.0**	**0.1**
Phase 1, 30 turbines, No Avoidance	3	0	0	3
	From Reg. Brd. Pop. =			**3**
Phase 1&2, 200 turbines, No Avoidance	17	1	1	19
	From Reg. Brd. Pop. =			**18.1**

ANNEX 3. COPY OF CRM SPREADSHEET FOR SHROUDED OPEN-CENTRED TURBINE (12.8M DIAMETER ROTOR)

CRM					r/R	c/C
					0	0.690
Period data	**symbol**	**units**			0.050	0.730
time in period		**years**			0.100	0.790
time in period (secs)	t	s	0		0.150	0.880
					0.200	0.960
Rotor data					0.250	1.000
number of rotors	B	m	1	for Brims	0.300	0.980
rotor diameter (c/f)	2R	m	**12.8**	for Brims	0.350	0.920
rotor radius	R	m	6.4	for Brims	0.400	0.850
central hole radius	R_1	m	2.05	for Brims	0.450	0.800
number of blades	b		10.0	for Brims	0.500	0.750
maximum blade width	C	m	2.4	for Brims	0.550	0.700
blade pitch at blade tip	γ	degrees	30	for Brims	0.600	0.640
blade profile	c/C			<--	0.650	0.580
rotation speed	Ω	rpm	8.00	for Brims	0.700	0.520
% time not operational	nop		14.4%	for Brims	0.750	0.470
					0.800	0.410
					0.850	0.370
Current data					0.900	0.300
mean current speed (m s^{-1})	v_c	m s^{-1}	1.56	for Brims	0.950	0.240
					1.000	0.000

Animal data					**CRM**			
Species (c/f)					**Common guillemot**			
Rotor depth scenario					**Shallowest depth scenario**			
Season					**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)			sheeet (hours x60 x60)		8,692,095	1,727,027	5,827,465	
animal density ar risk depth (c/f)	D	animals m^{-3}	from ERM spread sheeet		2.68E-08	0.00E+00	4.46E-09	
marine animal or diving bird?					diving bird			
length	L	m			0.40			
wingspan / bodywidth	W	m			0.67			
body length used perp to rotor	L'		swap length & width for diving birds		0.67	0.67	0.67	
body width used in rotor plane	W'		swap length & width for diving birds		0.40	0.40	0.40	
speed of approach used	v_c	m s^{-1}	v_c		1.56	1.56	1.56	
total frontal area		m^2	$B\pi(R+0.5W')^2$		137	137	137	
encounter probability for single transit	pcoll (annular)	$1-(R_1-W)^2/(R+W)^2$	from SNH 2015 guidance text	Note	94.20%	94.20%	94.20%	
no of rotor transits per second		s^{-1}	$D\,B\pi(R+0.5W')^2\,v_c$		5.73E-06	0.00E+00	9.52E-07	
encounter rate (per sec) before avoidance	C_{CRM}		$D(B\pi(R+0.5W')^2\,v_c$ pcoll		5.39E-06	0.00E+00	8.97E-07	
no of rotor transits in period			$D\,B\pi(R+0.5W')^2\,v_c(1\text{-nop})t$		42.6	0.0	4.7	
encounters in period before avoidance		animals	C_{CRM} (1-nop) t		40.1	0.0	4.5	44.6
Phase 1, 30 turbines, No Avoidance					1204	0	134	1338
					From Reg. Brd. Pop. =			**1271**
Phase 1&2, 200 turbines, No Avoidance					8028	0	894	8922
					From Reg. Brd. Pop. =			**8475**

	CRM			
Species (c/f)	**Common guillemot**			
Rotor depth scenario	**Intermediate depth scenario**			
Season	**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	8,692,095	1,727,027	5,827,465	
animal density ar risk depth (c/f)	5.55E-08	0.00E+00	9.23E-09	
marine animal or diving bird?	diving bird			
length	0.40			
wingspan / bodywidth	0.67			
body length used perp to rotor	0.67	0.67	0.67	
body width used in rotor plane	0.40	0.40	0.40	
speed of approach used	1.56	1.56	1.56	
total frontal area	137	137	137	
encounter probability for single transit	94.20%	94.20%	94.20%	
no of rotor transits per second	1.19E-05	0.00E+00	1.97E-06	
encounter rate (per sec) before avoidance	1.12E-05	0.00E+00	1.86E-06	
no of rotor transits in period	88.2	0.0	9.8	
encounters in period before avoidance	83.1	0.0	9.3	92.4
Phase 1, 30 turbines, No Avoidance	2493	0	278	2771
	From Reg. Brd. Pop. =			**2632**
Phase 1&2, 200 turbines, No Avoidance	16623	0	1852	18475
	From Reg. Brd. Pop. =			**17549**

	CRM			
Species (c/f)	**Common guillemot**			
Rotor depth scenario	**Deepest depth scenario**			
Season	**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	8,692,095	1,727,027	5,827,465	
animal density ar risk depth (c/f)	3.52E-08	0.00E+00	5.85E-09	
marine animal or diving bird?	diving bird			
length	0.40			
wingspan / bodywidth	0.67			
body length used perp to rotor	0.67	0.67	0.67	
body width used in rotor plane	0.40	0.40	0.40	
speed of approach used	1.56	1.56	1.56	
total frontal area	137	137	137	
encounter probability for single transit	94.20%	94.20%	94.20%	
no of rotor transits per second	7.51E-06	0.00E+00	1.25E-06	
encounter rate (per sec) before avoidance	7.08E-06	0.00E+00	1.18E-06	
no of rotor transits in period	55.9	0.0	6.2	
encounters in period before avoidance	52.7	0.0	5.9	58.5
Phase 1, 30 turbines, No Avoidance	1580	0	176	1756
	From Reg. Brd. Pop. =			**1668**
Phase 1&2, 200 turbines, No Avoidance	10533	0	1174	11707
	From Reg. Brd. Pop. =			**11120**

	CRM			
Species (c/f)	**Razorbill**			
Rotor depth scenario	**Shallowest depth scenario**			
Season	**breeding**	**Chicks (Aug)**	**aut./winter**	
Exposure time (in secs)	7,379,532	1,727,027	7,140,028	
animal density ar risk depth (c/f)	1.84E-10	3.43E-11	1.06E-11	
marine animal or diving bird?	diving bird			
length	0.38			
wingspan / bodywidth	0.66			
body length used perp to rotor	0.66	0.66	0.66	
body width used in rotor plane	0.38	0.38	0.38	
speed of approach used	1.56	1.56	1.56	
total frontal area	136	136	136	
encounter probability for single transit	94.14%	94.14%	94.14%	
no of rotor transits per second	3.92E-08	7.29E-09	2.26E-09	
encounter rate (per sec) before avoidance	3.69E-08	6.87E-09	2.12E-09	
no of rotor transits in period	0.2	0.0	0.0	
encounters in period before avoidance	0.2	0.0	0.0	0.3
Phase 1, 30 turbines, No Avoidance	7	0	0	8
	From Reg. Brd. Pop. =			**7**
Phase 1&2, 200 turbines, No Avoidance	47	2	3	51
	From Reg. Brd. Pop. =			**50**