gwerth mewn gwahaniaeth
delivering on distinction

Morlais Project
Environmental Statement

Appendix 11.3: Encounter Rate Modelling, Collision Risk Modelling and Population Viability Analysis Technical Report

Volume III

Applicant: Menter Môn Morlais Limited

Document Reference: PB5034-ES-0113

Appendix 11.3: ERM, CRM and PVA Technical Report

Author: Royal HaskoningDHV

Morlais Document No.:	Status:	Version No:	Date:
MMC363 MOR/RHDHV/APP/0019 (04)	Final	F4.0	22/10/20

TABLE OF CONTENTS

TABLE OF TABLES

GLOSSARY OF ABBREVIATIONS

Acronym	**Term**
CRM	Collision Risk Modelling
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
ERM	Encounter Rate Modelling
MDZ	Morlais Development Zone
MW	Megawatts
PVA	Population Viability Analysis
RSPB	Royal Society for the Protection of Birds
SMP	Seabird Monitoring Programme
SNH	Scottish Natural Heritage
TWG	Technical Working Group

GLOSSARY OF TERMINOLOGY

Density dependent	Where population growth rates are regulated by the density of a population.
Density independent	Where the growth of a population does not depend on the population density.
Deterministic	Where the values for the dependent variables of the system are completely determined by the parameters of the model.
Stochastic	Having a random probability distribution or pattern that may be analysed statistically but may not be predicted precisely.

1. INTRODUCTION

1. This appendix to **Chapter 11, Marine Ornithology** considers in detail the potential for the operational tidal devices to be deployed during the operational phase of the project to kill or injure diving marine ornithology receptors through collision. It presents the results of collision risk modelling studies carried out using two different methods that aim to predict the theoretical impact of collisions on annual mortality rates for each species investigated.

2. For two species, guillemot and razorbill, the outputs of these models are then used as inputs into a deterministic Population Viability Analysis (PVA) assessment to provide further context of theoretical collision risk on the breeding populations of the South Stack and Penlas Seabird Monitoring Programme (SMP) master site, which consists of the South Stack, Abraham's Bosom and Gogarth sub-colonies.

3. Tidal stream devices possess the potential to pose a theoretical risk to diving bird species (Furness et al., 2012; McCluskie et al., 2012; SNH, 2016). The risk is theoretical because any effect has yet to be empirically demonstrated, due largely to the fact that the tidal stream industry is still in its infancy. There are very few studies that have empirically examined collision risk of operational tidal devices.

4. Collision risk has been estimated for seven seabird species, which where appropriate have been assessed on a seasonal basis (Furness, 2015). These are breeding gannet, breeding and non-breeding guillemot, breeding Manx shearwater, breeding puffin, breeding and non-breeding razorbill, non-breeding red-throated diver, and breeding shag. These species have been selected because the baseline ornithological surveys (**Appendix 11.1, Volume III**) and the densities calculated from these (**Appendix 11.2, Volume III**) show that these are the only species regularly using the Morlais Development Zone (MDZ) which may habitually dive to the depth where there is a risk of collision with operational tidal devices.

5. The two methods used to estimate collision risk are Encounter Rate Modelling (ERM) and Collision Risk Modelling (CRM). Both methods have been issued as industry standard guidance by Scottish Natural Heritage (SNH) (SNH, 2016). ERM and CRM have been selected for use on this project following discussions with the Ornithology Technical Working Group (TWG).

6. For both methods of collision risk modelling, the number of collisions is estimated by undertaking predictive modelling of the number of encounters between operational tidal devices and diving birds, and then adjusting this number by an avoidance rate. This is a catch-all term which describes a range of factors, which has a very large effect on the predicted number of collisions. Due to uncertainties surrounding avoidance rates of diving birds, a range of avoidance rates are presented as per SNH (2016) and discussions with the Ornithology TWG.

7. Two different deployment scenarios have been considered. The first presents the estimated number of collisions due to the deployment of a 40 MW array of one of nine different device envelopes. The second considers the estimated number of collisions due to the deployment of a 240 MW array consisting of a selection of these device envelopes. PVAs for the breeding guillemot and razorbill populations have been undertaken for two scenarios; the 40 MW array that produced the highest collision risk for each species, and the 240 MW deployment.

8. Although the modelling outputs are quantitative they should be regarded as indicative. While actual rates of behavioural avoidance, evasion and mortality/injury of diving birds are unknown, model outputs are considered useful in terms of giving a first order and, most likely, precautionary, estimate of the absolute magnitude of the potential collision risk. Model outputs are also a useful tool for comparing different device deployment scenarios.

2. CALCULATING AND INTERPRETING POSSIBLE COLLISION RISK

2.1. INTRODUCTION

9. This section provides an overview of the ERM and CRM methods used to estimate underwater collision risk to diving birds during the operation of the project. It describes the input parameters used for each of the marine ornithology receptors along with the sources of this information, and the device envelopes included in the modelling (the physical parameters of device envelopes and array sizes). Finally, information on how the outputs of the models should be interpreted is provided.

2.2. MODEL INFORMATION

2.2.1. Overview and Comparison of ERM and CRM

10. The details of how both the ERM and CRM processes are carried out are provided in SNH (2016) and are not reproduced here. A brief overview of both methods is provided below.

11. The ERM is based on a predator-prey model initially developed for modelling jellyfish preying on plankton (Gerritsen and Strickler, 1977). More recently, an adapted version of the model was developed to predict the potential for fish and marine mammals to be harmed by open rotor tidal device types (Wilson et al., 2007). The model 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.

12. The CRM is based on the ‘Band model’. This model was developed to estimate the risk of collision of flying birds with wind turbines (Band et al., 2007). It is used widely in Environmental Impact Assessment (EIA) of onshore and offshore wind farms in the UK and Europe. The model has two stages. The first stage estimates the likelihood that a flying bird travelling through the rotor swept area (i.e. the airspace through which turbine blades are moving) will collide with a rotor. The second stage estimates the number of passes by a species through the rotor swept area per unit time. There are a number of differences between the flying birds that this model was originally developed for, and diving birds that are modelled here, that need to be taken into account.

13. ERM produces an “Encounter Rate” and CRM a “Collision Rate”, which can be considered comparable.

2.2.2. Avoidance Rates

14. Neither the Encounter Rate produced by ERM or the Collision Rate produced by CRM take into account the avoidance behaviour of birds, which is incorporated into the outputs of both models

as a correction factor. This approach has and continues to be widely used for estimating collision risk at wind farms both onshore and offshore.

15. It is considered that for diving birds, the avoidance rate should take account of the following factors:

- Avoidance of use of the site;
- Evasive action near a tidal device, or in the vicinity of the rotors;
- Burst speed of diving birds relative to tidal turbine blades, which is substantially higher than equivalent situation for flying birds and wind turbine blades;
- Being swept clear of the blades by hydrodynamic forces; and
- Collisions not resulting in injury/fatality.

16. The current body of evidence relating to diving bird behaviour, and likely avoidance, is limited. For this reason, a wide range of avoidance rates from 0 % to 99.9 % are considered

2.3. BIRD INPUT PARAMETERS

2.3.1. Seasons

17. Both ERM and CRM calculate an approximate number of encounters for each species in a single second. This can be scaled up to a more user-friendly and biologically relevant time period. To enable biologically relevant conclusions to be drawn from the outputs of the modelling, breeding and non-breeding seasons have been used rather than monthly estimates, which are somewhat arbitrary.

18. For all species except red-throated diver, ERM and CRM were carried out separately for the breeding and non-breeding seasons; the latter only being run if birds were present in the MDZ during the surveys at this time of year (**Appendix 11.2, Volume III**). All seasonal information was derived from Furness (2015) and is presented in **Chapter 11, Marine Ornithology** and **Appendix 11.2** (**Volume III**). In the case of red-throated diver, the models have been run without seasonal partitioning. Small numbers of birds were recorded in the MDZ during the breeding season for this species but as this species does not breed in Wales (Stroud et al., 2016), it is assumed that these individuals were non-breeding birds.

2.3.2. Seabird Densities

19. Mean densities of birds on the sea within the MDZ, derived from two years of boat-based surveys (**Appendix 11.2, Volume III**) were used as model inputs, with the exception of gannet, which was the only plunge diving species included in the modelling. For this species, flying densities were used.

20. On-sea densities were calculated using Distance correction (Buckland et al., 2001) where the numbers of observations made this possible; this applied to guillemot and razorbill. Details of this process are provided in **Appendix 11.1** (**Volume III**). For species where this was not possible, generic published corrections to account for missed birds were applied (Stone et al., 1995). Densities of birds in flight are uncorrected as it was assumed that all birds present were recorded.

21. Any observations made to group rather than species level (e.g. “auk species” for guillemot and razorbill) were proportionally allocated to a species by survey (**Appendix 11.2, Volume III**). No filtering of the data on the basis of observations such as feeding behaviour was carried out. In this way, all available data that was considered relevant was used in as a model input.

22. The densities of marine ornithology receptors using the subtidal habitats within the MDZ that have been used as model inputs are presented in **Table 2-1**.

Table 2-1 Marine Ornithology Receptor Densities Used in ERM/CRM

Species	Season (B = breeding, NB = non-breeding)	Density (birds/km on sea unless otherwise stated)	90 % Confidence Interval
Gannet	B	0.234 (flying density)	0.072 (flying density)
Guillemot	B	15.385	7.508
	NB	3.506	1.106
Manx shearwater	B	1.928	2.576
Puffin	B	0.074	0.063
Razorbill	B	2.104	1.114
	NB	1.584	1.037
Red-throated diver	Year round	0.024	0.032
Shag	B	0.032	0.043

2.3.3. Calculation of Diving Bird Densities at Different Depths

23. On-sea or flying densities of marine ornithology receptors need to be converted to densities at collision risk depth to enable ERM and CRM to be carried out. This requires a species-specific ‘dive frequency’ to be calculated. Two possible methods are accepted by both models (SNH, 2016). The parameters used here are presented in **Section 2.3.5**.

24. The proportion of birds visible at surface calculations for ERM and CRM incorporate a watch period calculation, which feeds into a revised density estimate to correct for birds under the water during the observation of a particular area of the sea or airspace, and therefore not recorded by the surveyor. For boat-based surveys, assuming a constant survey vessel speed of 10 knots, the watch period is 58.34 seconds, which is the parameter that has been used in the model.

25. The final step in this part of the model is to use dive definitions along with vertical swim speed to calculate the proportion of time spent by each species at risk depth, and therefore derive an estimated density at collision risk depth. These values are then used by ERM and CRM. Depth distribution data was not available at the time of assessment, so as suggested by SNH (2016), three diving categories were used to estimate bird densities in ‘at-risk’ depth range from surface densities:

- Deep diving: assumes foraging below collision risk depth; the ‘at risk’ times of each dive occur whilst the bird is passing through the risk depth range during descent and ascent;

- Shallow diving: assumes foraging at collision risk depth; the bird is considered not to be at risk of collision only during the time during which it is descending to and ascending from the level of the upper limit of the collision risk depth; and
- Plunge diving: as per the shallow diving category, but with a plunge speed during descent.

26. It should be noted that the vast majority of dive parameter information available in the literature was collected during the breeding season. Where required (in the cases of guillemot and razorbill) the same parameters have been applied to non-breeding season collision estimates.

2.3.4. Nocturnal Activity

27. The CRM and ERM use known sunrise and sunset times (plus an hour before sunrise and an hour after sunset each day to account for the twilight period) to determine the daytime activity period. Where appropriate, both ERM and CRM apply corrections to account for levels of nocturnal activity that differ from daytime activity; this is presented in **Section 2.3.5**. A justification of how these values have been set is provided for each species in the following paragraphs.

28. Gannet nocturnal flight activity during the breeding season has been empirically estimated from activity data from tagged birds to be 8 % of daytime activity (Furness et al., 2018). Whilst not presented as a percentage, it was noted that nocturnal diving activity was found to be even less frequent than nocturnal flight activity. As data from a large number of studies was drawn upon in the assessment, a high degree of confidence is assigned to this estimate. A precautionary nocturnal diving activity value of 8 % of daytime activity is therefore used in ERM and CRM for gannet.

29. A study on guillemots at a Newfoundland breeding colony (at a similar latitude at UK seabird colonies) reported a peak in guillemot diving activity in the twilight period, with birds continuing to dive through the night at comparable levels to the day. Dive depths during the night were considerably reduced compared to the daytime, which was thought to be in response to vertical movement of the primary prey species (capelin) towards the sea surface (Regular et al., 2010). Further analysis of breeding guillemots in the same study area showed that nocturnal diving occurred much more frequently under moonlit and starlit conditions, and less so when light levels were less than this (implying cloudy conditions) (Regular et al., 2011). Low light conditions also resulted in reductions in diving rates during daylight and twilight periods. Similar observations with respect to differences in dive depth in response to light levels have been recorded elsewhere in thick-billed murres *Uria lomvia* (Elliott and Gaston, 2015) and both thick-billed murres and guillemots (Kokubun et al., 2016). A study from the Isle of May (Thaxter et al., 2009) indicated substantial differences between male and female guillemot foraging behaviour during the breeding season, with males travelling approximately twice as far as females to forage, though no segregation in foraging areas between sexes was noted, and dive frequency between sexes was comparable. Half of foraging trips by males occurred overnight, as opposed to 14 % of female foraging trips; and overnight trips were significantly longer in duration than daytime foraging trips. This resulted in males being approximately twice as likely to be away from the nest during the night than females. Temporal sex-based segregation of diving activity has been reported elsewhere in similar species (Elliott and Gaston, 2015).

30. With regard to razorbill, whilst Shoji et al. (2015) noted a pattern of inactivity during the night during the breeding season, another study noted similar diving activity patterns to guillemot, though unlike guillemot, nocturnal behaviour was comparable between male and female birds (Benvenuti et al., 2001). A trend towards shallower diving depths during nocturnal conditions has been observed, as with guillemot (Benvenuti et al., 2001; Falk et al., 2000; Paredes et al., 2006).

31. On the basis that studies have been identified for both guillemot and razorbill that suggest that nocturnal and daytime activity appear to be quite similar, but may be constrained by overcast conditions, which are prevalent in the UK, a precautionary nocturnal diving activity value of 90 % is used in ERM and CRM for breeding guillemot and razorbill. No attempt has been made to include observed differences in foraging behaviour between male and female guillemots in the model, or potential differences in dive depths during nocturnal conditions.

32. During the non-breeding season, the formation of large single or mixed-species aggregations of guillemots (along with razorbill and kittiwake) just before sunset at common sleeping areas was frequently observed over an extended period in the central North Sea (Camphuysen, 1998). These large, dense aggregations of birds occurred in areas of known low prey species density, with no feeding activity observed when birds were within them. Whilst not confirmed, it is hypothesised that the purpose of these nocturnal concentrations at night may be to provide information on the location of suitable food supplies, safety against predators and/or giving the birds the opportunity to socialise. As this study was based on a long term, reliable dataset, and there is no reason to believe that birds in the western UK wintering population behave differently, a nocturnal diving activity value of 30 % (based on expert judgement, incorporating a precautionary element) is used in ERM and CRM for non-breeding guillemot and razorbill.

33. Manx shearwaters tracked from Skomer Island over three breeding seasons did not exhibit any diving activity at night. Diving activity was heavily constrained to daylight and twilight hours (Dean, 2012; Dean et al., 2012; Shoji et al., 2016). On the basis that the number of study subjects, observations and the multiyear nature of the study provides a high degree of confidence, a nocturnal diving activity of 0 % during the breeding season has been set for Manx shearwater for use in ERM and CRM.

34. A tracking study involving seven puffins in Wales, in a single season revealed very strong evidence of no diving occurring at night (Shoji et al., 2015). Due to the limited sample size and temporal coverage of this study, it is proposed that a precautionary nocturnal correction factor is applied. Therefore, a nocturnal diving activity of 10 % during the breeding season has been set for puffin for use in ERM and CRM.

35. The nocturnal activity of non-breeding red-throated diver is completely unknown, though it is known that it is a visual feeder (Polak and Ciach, 2007), suggesting nocturnal activity is unlikely to be as high as during the day, or that shallower areas of sea may be favoured at night, though both of these possibilities are conjecture. On a precautionary basis it is assumed that this species is as active during the night as it is during the day by the models presented.

36. A study that tracked 21 shags at the Isle of May during the breeding season for a period of 24-53 hours revealed that this species is an exclusively daytime feeding bird, with no diving activity recorded at night (Wanless et al., 1999). Due to the limited sample size and temporal coverage

of this study, it is proposed that a precautionary nocturnal correction factor is applied. Therefore, a nocturnal diving activity of 10 % during the breeding season has been set for shag for use in ERM and CRM.

2.3.5. Diving Seabird Parameters

37. A literature search was carried out to identify parameters considered by expert judgement to be appropriate for ERM and CRM. **Table 2-2, Table 2-3, Table 2-4, Table 2-5, Table 2-6, Table 2-7** and **Table 2-8** summarise the input data used for CRM and ERM for each species considered, along with the sources of this information.

Table 2-2 CRM/ERM Input Parameters for Gannet

Parameter and Unit	Value	Source
Dive type	Plunge	(SNH, 2016)
Length (metres)	0.94	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	1.72	(Robinson, 2019; SNH, 2016)
Mean number of dives per hour	0.90	(Cox et al., 2016)
Mean underwater dive duration (seconds)	7.30	(Robbins, 2017)
Vertical swim speed (metres per second)	1.20	(Garthe et al., 2000)
Plunge speed (metres per second)	5.70	(Robbins, 2017)
Breeding season nocturnal activity (% of daytime activity)	8	(Furness et al., 2018)

Table 2-3 CRM/ERM Input Parameters for Guillemot

Parameter and Unit	Value	Source
Dive type	Deep	Expert judgement based on data in (Robbins, 2017)
Length (metres)	0.40	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	0.67	(Robinson, 2019; SNH, 2016)
Foraging trips per day	3.2	(Robbins, 2017)
Dives per foraging trip	55.3	(Robbins, 2017)
Mean underwater dive duration (seconds)	73.10	(Robbins, 2017)
Vertical swim speed (metres per second)	1.10	(Robbins, 2017)
Breeding season nocturnal activity (% of daytime activity)	90	Expert judgement based on data in (Regular et al., 2010, 2011; Thaxter et al., 2009)
Non-breeding season nocturnal activity (% of daytime activity)	30	Expert judgement based on data in (Camphuysen, 1998)

Table 2-4 CRM/ERM Input Parameters for Manx Shearwater

Parameter and Unit	Value	Source
Dive type	Shallow	Expert judgement based on data in (Dean, 2012; Robbins, 2017; Shoji et al., 2016)
Length (metres)	0.34	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	0.82	(Robinson, 2019; SNH, 2016)
Average number of dives in one hour	4.10	(Dean, 2012)

Parameter and Unit	Value	Source
Mean underwater dive duration (seconds)	13.49	(Shoji et al., 2016)
Vertical swim speed (metres per second)	0.976	(Dean, 2012)
Breeding season nocturnal activity (% of daytime activity)	0	Expert judgement based on data in (Dean, 2012; Dean et al., 2012; Shoji et al., 2016)

Table 2-5 CRM/ERM Input Parameters for Puffin

Parameter and Unit	Value	Source
Dive type	Shallow	Expert judgement based on data in (Robbins, 2017)
Length (metres)	0.28	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	0.55	(Robinson, 2019; SNH, 2016)
Average number of dives in one day	332.9	(Robbins, 2017)
Mean underwater dive duration (seconds)	35.50	(Robbins, 2017)
Vertical swim speed (metres per second)	0.85	No data; razorbill value used as surrogate
Breeding season nocturnal activity (% of daytime activity)	10	Expert judgement based on data in (Shoji et al., 2015)

Table 2-6 CRM/ERM Input Parameters for Razorbill

Parameter and Unit	Value	Source
Dive type	Shallow	(SNH, 2016)
Length (metres)	0.38	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	0.66	(Robinson, 2019; SNH, 2016)
Foraging trips per day	2.40	(Robbins, 2017)
Dives per foraging trip	268.3	(Robbins, 2017)
Mean underwater dive duration (seconds)	36.00	(Robbins, 2017)
Vertical swim speed (metres per second)	0.85	(Robbins, 2017)
Breeding season nocturnal activity (% of daytime activity)	90	Expert judgement based on data in (Regular et al., 2010, 2011; Thaxter et al., 2009)
Non-breeding season nocturnal activity (% of daytime activity)	30	Expert judgement based on data in (Camphuysen, 1998)

Table 2-7 CRM/ERM Input Parameters for Red-Throated Diver

Parameter and Unit	Value	Source
Dive type	Shallow	(SNH, 2016)
Length (metres)	0.61	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	1.11	(Robinson, 2019; SNH, 2016)
Proportion of time foraging when at sea (%)	60.7	(Polak and Ciach, 2007)
Dive frequency when foraging (dives per second)	0.0309	(SNH, 2016)
Mean underwater dive duration (seconds)	27.20	(Robbins, 2017)
Vertical swim speed (metres per second)	1.50	No data; shag value used as surrogate

Table 2-8 CRM/ERM Input Parameters for Shag

Parameter and Unit	Value	Source
Dive type	Deep	SNH (2016)
Length (metres)	0.72	(Robinson, 2019; SNH, 2016)
Wingspan (metres)	0.98	(Robinson, 2019; SNH, 2016)
Foraging trips per day	2.70	(Robbins, 2017)
Dives per foraging trip	27.30	(Robbins, 2017)
Mean underwater dive duration (seconds)	41.10	(Robbins, 2017)
Vertical swim speed (metres per second)	1.50	(Robbins, 2017)

2.4. TURBINE ENVELOPE PARAMETERS

2.4.1. 40 MW Scenario

38. The parameters for the nine device envelopes considered for deployment in a single, 40 MW array, are presented in **Table 2-9**. These parameters have been developed following extensive consultation with a number of tidal device developers. As the parameters shared during the consultation process are commercially sensitive, the device envelopes are identified by alphanumeric codes rather than names.

39. With regard to rotor minimum depth, for floating devices this was set at the minimum water depth in which the device can be operated as per information provided by tidal device developers. Actual deployment depths may be deeper, meaning that for floating tidal devices, theoretical collision risk will be overestimated for birds with the “shallow dive” profile selected. For seabed mounted devices, minimum rotor depth was calculated using the average MDZ depth of 40 m (**Chapter 4, Project Description**), minus a single rotor diameter, minus an assumed 5 m clearance between the seabed and the lower reach of the rotor swept area.

Table 2-9 Tidal Device Parameter Envelopes

	1F	2F	3F	4F	5S	6S	7S	8S	9F
Position in water column (F = floating, S = seabed)	F	F	F	F	S	S	S	S	F
Blade length (metres)	10	2.5	5	13.5	7.5	13	5	5	2.5
Rotor minimum depth (metres)	3.2	5	5	6	20	9	25	25	1.3
Number of blades per rotor	2	3	2	2	6	3	2	3	3
Number of rotors per device	2	20	5	1	1	1	1	3	2
Blade “depth” (front to back when device viewed from side)	0.84	0.09	0.25	0.4	0.3	0.4	0.25	0.25	0.064
Blade “width” (edge to edge when device viewed from front)	2	0.2	1.1	0.2	0.2	0.2	0.8	0.8	-
Blade pitch at tip	2.4	0	5	5	5	5	5	0	-
Rotation speed (RPM)	8.71	26.7	18	10.1	7.5	7.5	22	22	13.6

	1F	2F	3F	4F	5S	6S	7S	8S	9F
Indicative power output of one device (MW)	2	1	1.5	1	1	1	0.3	1.2	0.1
Indicative number of devices for 40 MW array	20	40	27	40	40	40	134	34	400

2.4.1. 240 MW Scenario

40. The 240 MW scenario comprises of a combination of the device envelopes detailed in **Table 2-9**, which is described in **Table 2-10**. Whilst device envelopes 2 and 5 are not included in this indicative array, they remain under consideration for deployment, as evidenced by their inclusion in 40 MW scenario modelling. In total, the 240 MW array scenario consists of 259 devices.

Table 2-10 240 MW Array Composition

	1F	1F	4F	9F	3F	8S	3F	7S	6S	3F	Total
Array size (number of devices)	15	15	30	50	20	25	10	50	30	14	259
Array output (MW)	30	30	30	10	30	30	15	15	30	20	240

2.5. INTERPRETING THE OUTPUTS OF ERM AND CRM

2.5.1. Introduction

41. The risk posed to diving seabirds by collision risk with tidal stream devices is theoretical. This is because any effect has yet to be empirically demonstrated (i.e. there are no known records of bird collisions with tidal turbines). This may be due in part to the fact that the tidal stream industry is still in its infancy and there are very few studies in existence that empirically examine collision risk.

42. This section examines the modelling process and identifies a range of considerations that are of high importance when interpreting the outputs of ERM and CRM.

2.5.2. Comparison of ERM and CRM

43. A comparison of ERM and CRM outputs using the same input parameters was undertaken during collision risk assessment for the Fall of Warness tidal energy test site at the European Marine Energy Centre (EMEC). For the range of scenarios tested, the two models gave broadly similar output values but with a relatively consistent difference. The average number of encounter events predicted by CRM exceeded the number of collisions predicted by the Band model by a factor of approximately 1.4 for foot-propelled diving birds (which include red-throated diver and shag in this study) and was between 0.83-1.03 for wing-propelled diving birds (gannet, guillemot, puffin Manx shearwater (which may use both feet and wings for propulsion), and razorbill in this study).

44. The CRM to ERM ratios for this study are presented in **Table 2-11**. There is substantial variation between devices, and substantial differences between the ratios recorded for the Fall of

Warness site and this study. ERM and CRM using device 1F, which of the device envelopes used in this study bears the most similarity to the device used in the comparison described above, produced a CRM to ERM ratio of 0.81 to 4.30 for foot-propelled birds, and 0.45 to 2.67 for wing-propelled birds. These values are comparable to the ratios reported in the study described above.

Table 2-11 CRM/ERM Ratios for All Species

Species	1F	2F	3F	4F	5S	6S	7S	8S
Gannet	0.56	0.45	0.75	0.81	-	-	-	-
Guillemot	0.55	1.05	0.85	0.71	0.77	1.51	0.86	2.67
Manx shearwater	0.60	1.03	0.88	0.76	-	-	-	-
Puffin	0.50	1.01	0.79	0.65	-	1.40	-	-
Razorbill	0.55	1.05	0.85	0.71	-	1.51	-	-
Red-throated diver	0.85	1.73	1.39	1.16	1.20	2.36	1.60	0.78
Shag	0.81	1.80	1.38	1.11	1.18	2.29	1.40	4.30

2.5.3. Model Assumptions Regarding Dive Profiles

45. Diving birds typically possess dive profiles which can be broadly classified as v-shaped or u-shaped, which start and end at the water surface, although they are almost certain to be more complex in reality and dependent on a wide range of factors. Trajectories relative to a tidal device could therefore be orientated at any angle between horizontal and vertical. For diving birds, the CRM assumes that birds approach devices from one direction only (travelling downstream at current speed, in a level swimming pattern front on into the device). In ERM, birds are assumed to be swimming in random directions and orientations with respect to the device. Neither model realistically represents the typical dive profile of many diving seabirds. However, the ERMs assumption of random swim direction and orientation is more akin to the real-life situation than the CRM assumption of perpendicular approach.

2.5.4. Precaution and Uncertainty

46. It is considered that the enforced simplification of assigning dive depth distribution (**Section 2.3.3)** may result in overestimation of the time spent at collision risk depth. Rather than always diving to collision risk depth, shallow diving birds such as razorbill undertake a substantial proportion of their dives in the first few metres of the water column (Benvenuti et al., 2001; MBIEG, 2019), and the same may also be true of deeper diving guillemots (MBIEG, 2019; Thaxter et al., 2010), although this species is adapted to both pelagic and benthic foraging, and therefore spends a relatively large proportion of its diving time at the bottom of u-shaped dives (Chimienti et al., 2017), which could occur at or beyond collision risk depth.

47. Whilst adjustment for diving activity at night has been made where appropriate by reducing by % of activity (**Section 2.3.4**), it is possible that dive profiles at night result in foraging activity occurring at substantially shallower depths in response to lower light levels, and potentially to prey occurring closer to the surface than during the day. This effect has been observed in guillemots (Kokubun et al., 2016; Regular et al., 2011) and razorbills (Benvenuti et al., 2001;

Falk et al., 2000; Paredes et al., 2006). As this factor is not accounted for in the models, as it was considered there was no way of empirically accounting for this in a justifiable manner, substantial overestimation of collision risk at night is likely to have occurred for both guillemot and razorbill.

48. For birds, it should also be noted that ERM is likely to overestimate encounter rate, as it does not take account of the geometry of the blade and underestimates the likelihood that a small animal moving downstream may pass between blades.

2.5.5. Selecting Appropriate Avoidance Rates

49. There is considerable uncertainty regarding avoidance rates for several reasons. Firstly, it is expected that animals of relatively small size such as diving seabirds might be swept past moving tidal device blades while entrained within the tidal stream (Wilson et al., 2007). Secondly, given that the rotation speed of tidal stream turbines is generally much lower than wind turbines (where collisions are assumed to result in 100 % collision mortality) (Fraenkel, 2006), and dive and swim speeds of seabirds are much lower than their flight speeds (Alerstam et al., 2007; Bruderer and Boldt, 2001; Robbins, 2017), it is considered highly unlikely that the strike force of a collision would result in a trauma sufficient to cause injury or death in all collision events (Wilson et al., 2007). This may be particularly applicable to collisions occurring near the centre of rotor, downward strikes occurring on dive descents, and upward strikes occurring on dive ascent. Finally, no information exists on the ability of seabirds to avoid collisions with tidal turbines at any range. It should be noted that the burst speed of some species of diving birds relative to the speed of tidal device turbine blades is thought to be much higher when compared to the equivalent relationships between flying birds and wind turbines (Fraenkel, 2006; Wilson et al., 2007). This suggests that such close-range avoidance behaviour will be more successful in diving seabirds than may be the case for flying birds at wind farms.

50. For balance, it should also be noted that some information suggests that narrow fields of view and/or inability to see great distances underwater may increase the potential vulnerability of diving birds to collision with objects underwater (Martin and Wanless, 2015; White et al., 2007). Furthermore, in general, the eyes of birds occur on the sides of the head, meaning that high resolution occurs in the lateral fields of view, and frontal vision may be therefore be tuned for the detection of movement rather than detail (Martin, 2011), although it is possible that underwater adaptations to diving birds eyesight grants them greater sensitivity than is currently understood. The length, width and position of the bill may result in blind spots. That being said, no extensive reports of underwater collisions between seabirds and underwater objects have been reported. Whilst seabird bycatch due to entanglement of seabirds in fishing nets is a widely reported issue (Žydelis et al., 2013, 2009), this is considered a separate phenomenon to the theoretical risk of underwater collision presented here.

51. It is recognised that the models used here, and the comparability of their outputs to potential real-world impacts, will be shaped enormously by the selection of avoidance rates. As discussed during Ornithology Technical Working Group (TWG) meetings for this project, and in compliance with SNH (2016), a range of avoidance rates from 0 % to 99.9 % have been presented.

3. RESULTS OF CRM AND ERM

3.1. 40 MW SCENARIOS

52. For each species, three tables are presented. These present the predicted number of collisions in a single season for each device envelope for ERM and CRM, and a mean of the two models. The size of the biologically relevant population of birds, based on information in **Chapter 11, Marine Ornithology**, is also provided.

53. As outputs have been presented as whole numbers, any small discrepancies in the mean of ERM and CRM tables are due to rounding up or down of values.

3.1.1. Breeding Gannet

Table 3-1 ERM Outputs for Breeding Gannet, 40 MW Scenarios

Reference population		138,474 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
0 %	2	20	2	0	0	0	0	0	34
50 %	1	10	1	0	0	0	0	0	17
90 %	0	2	0	0	0	0	0	0	3
95 %	0	1	0	0	0	0	0	0	2
98 %	0	0	0	0	0	0	0	0	1
99 %	0	0	0	0	0	0	0	0	0
99.5 %	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0

Table 3-2 CRM Outputs for Breeding Gannet, 40 MW Scenarios

Reference population		138,474 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
0 %	1	9	2	0	0	0	0	0	-
50 %	0	4	1	0	0	0	0	0	-
90 %	0	1	0	0	0	0	0	0	-
95 %	0	0	0	0	0	0	0	0	-
98 %	0	0	0	0	0	0	0	0	-
99 %	0	0	0	0	0	0	0	0	-
99.5 %	0	0	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

Table 3-3 Mean ERM/CRM Outputs for Breeding Gannet, 40 MW Scenarios

Reference population		138,474 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
0 %	1	14	2	0	0	0	0	0	-
50 %	1	7	1	0	0	0	0	0	-
90 %	0	1	0	0	0	0	0	0	-
95 %	0	1	0	0	0	0	0	0	-
98 %	0	0	0	0	0	0	0	0	-

Reference population		138,474 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
99 %	0	0	0	0	0	0	0	0	-
99.5 %	0	0	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

3.1.2. Breeding Guillemot

Table 3-4 ERM Outputs for Breeding Guillemot, 40 MW Scenarios

Reference population		8,308 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
0 %	3144	9263	3160	4311	3045	4578	3783	4255	5101
50 %	1572	4631	1580	2156	1523	2289	1891	2128	2550
90 %	314	926	316	431	305	458	378	426	510
95 %	157	463	158	216	152	229	189	213	255
98 %	63	185	63	86	61	92	76	85	102
99 %	31	93	32	43	30	46	38	43	51
99.5 %	16	46	16	22	15	23	19	21	26
99.9 %	3	9	3	4	3	5	4	4	5

Table 3-5 CRM Outputs for Breeding Guillemot, 40 MW Scenarios

Reference population		8,308 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
0 %	1737	9711	2686	3070	2351	6908	3237	3792	-
50 %	868	4855	1343	1535	1175	3454	1618	1896	-
90 %	174	971	269	307	235	691	324	379	-
95 %	87	486	134	154	118	345	162	190	-
98 %	35	194	54	61	47	138	65	76	-
99 %	17	97	27	31	24	69	32	38	-
99.5 %	9	49	13	15	12	35	16	19	-
99.9 %	2	10	3	3	2	7	3	4	-

Table 3-6 Mean ERM/CRM Outputs for Breeding Guillemot, 40 MW Scenarios

Reference population		8,308 individuals							
Avoidance Rate	1F	2F	3F	4F	5S	6S	7S	8S	9F
0 %	2440	9487	2923	3691	2698	5743	3510	2605	-
50 %	1220	4743	1462	1845	1349	2871	1755	1303	-
90 %	244	949	292	369	270	574	351	261	-
95 %	122	474	146	185	135	287	175	130	-
98 %	49	190	58	74	54	115	70	52	-
99 %	24	95	29	37	27	57	35	26	-
99.5 %	12	47	15	18	13	29	18	13	-
99.9 %	2	9	3	4	3	6	4	3	-

3.1.3. Non-Breeding Guillemot

Table 3-7 ERM Outputs for Non-Breeding Guillemot, 40 MW Scenarios

Reference population		1,139,220 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	674	1987	678	925	653	982	812	913	1094
50 %	337	994	339	463	327	491	406	457	547
90 %	67	199	68	93	65	98	81	91	109
95 %	34	99	34	46	33	49	41	46	55
98 %	13	40	14	19	13	20	16	18	22
99 %	7	20	7	9	7	10	8	9	11
99.5 %	3	10	3	5	3	5	4	5	5
99.9 %	1	2	1	1	1	1	1	1	1

Table 3-8 CRM Outputs for Non-Breeding Guillemot, 40 MW Scenarios

Reference population		1,139,220 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	373	2083	576	659	504	1482	694	814	-
50 %	186	1042	288	329	252	741	347	407	-
90 %	37	208	58	66	50	148	69	81	-
95 %	19	104	29	33	25	74	35	41	-
98 %	7	42	12	13	10	30	14	16	-
99 %	4	21	6	7	5	15	7	8	-
99.5 %	2	10	3	3	3	7	3	4	-
99.9 %	0	2	1	1	1	1	1	1	-

Table 3-9 Mean ERM/CRM Outputs for Non-Breeding Guillemot, 40 MW Scenarios

Reference population		1,139,220 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	524	2035	627	792	579	1232	753	559	-
50 %	262	1018	314	396	289	616	376	279	-
90 %	52	204	63	79	58	123	75	56	-
95 %	26	102	31	40	29	62	38	28	-
98 %	10	41	13	16	12	25	15	11	-
99 %	5	20	6	8	6	12	8	6	-
99.5 %	3	10	3	4	3	6	4	3	-
99.9 %	1	2	1	1	1	1	1	1	-

3.1.4. Breeding Manx Shearwater

Table 3-10 ERM Outputs for Breeding Manx Shearwater, 40 MW Scenarios

Reference population		673,350 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	33	204	33	6	0	0	0	0	326
50 %	17	102	17	3	0	0	0	0	163

Reference population		673,350 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
90 %	3	20	3	1	0	0	0	0	33
95 %	2	10	2	0	0	0	0	0	16
98 %	1	4	1	0	0	0	0	0	7
99 %	0	2	0	0	0	0	0	0	3
99.5 %	0	1	0	0	0	0	0	0	2
99.9 %	0	0	0	0	0	0	0	0	0

Table 3-11 CRM Outputs for Breeding Manx Shearwater, 40 MW Scenarios

Reference population		673,350 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	20	209	29	5	0	0	0	0	-
50 %	10	105	15	2	0	0	0	0	-
90 %	2	21	3	0	0	0	0	0	-
95 %	1	10	1	0	0	0	0	0	-
98 %	0	4	1	0	0	0	0	0	-
99 %	0	2	0	0	0	0	0	0	-
99.5 %	0	1	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

Table 3-12 Mean ERM/CRM Outputs for Breeding Manx Shearwater, 40 MW Scenarios

Reference population		673,350 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	27	207	31	5	0	0	0	0	-
50 %	13	103	16	3	0	0	0	0	-
90 %	3	21	3	1	0	0	0	0	-
95 %	1	10	2	0	0	0	0	0	-
98 %	1	4	1	0	0	0	0	0	-
99 %	0	2	0	0	0	0	0	0	-
99.5 %	0	1	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

3.1.5. Breeding Puffin

Table 3-13 ERM Outputs for Breeding Puffin

Reference population		120 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	15	137	24	11	0	8	0	0	96
50 %	8	68	12	6	0	4	0	0	48
90 %	2	14	2	1	0	1	0	0	10
95 %	1	7	1	1	0	0	0	0	5
98 %	0	3	0	0	0	0	0	0	2
99 %	0	1	0	0	0	0	0	0	1

Reference population	120 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
99.5 %	0	1	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0

Table 3-14 CRM Outputs for Breeding Puffin, 40 MW Scenarios

Reference population	120 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	8	138	19	7	0	12	0	0	-
50 %	4	69	10	4	0	6	0	0	-
90 %	1	14	2	1	0	1	0	0	-
95 %	0	7	1	0	0	1	0	0	-
98 %	0	3	0	0	0	0	0	0	-
99 %	0	1	0	0	0	0	0	0	-
99.5 %	0	1	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

Table 3-15 Mean ERM/CRM Outputs for Breeding Puffin, 40 MW Scenarios

Reference population	120 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	11	137	22	9	0	10	0	0	-
50 %	6	69	11	5	0	5	0	0	-
90 %	1	14	2	1	0	1	0	0	-
95 %	1	7	1	0	0	1	0	0	-
98 %	0	3	0	0	0	0	0	0	-
99 %	0	1	0	0	0	0	0	0	-
99.5 %	0	1	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

3.1.6. Breeding Razorbill

Table 3-16 ERM Outputs for Breeding Razorbill, 40 MW Scenarios

Reference population	1,458 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	963	9544	1641	753	0	561	0	0	6723
50 %	481	4772	820	376	0	280	0	0	3362
90 %	96	954	164	75	0	56	0	0	672
95 %	48	477	82	38	0	28	0	0	336
98 %	19	191	33	15	0	11	0	0	134
99 %	10	95	16	8	0	6	0	0	67
99.5 %	5	48	8	4	0	3	0	0	34
99.9 %	1	10	2	1	0	1	0	0	7

Table 3-17 CRM Outputs for Breeding Razorbill, 40 MW Scenarios

Reference population		1,458 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	531	10034	1393	534	0	845	0	0	-
50 %	266	5017	696	267	0	423	0	0	-
90 %	53	1003	139	53	0	85	0	0	-
95 %	27	502	70	27	0	42	0	0	-
98 %	11	201	28	11	0	17	0	0	-
99 %	5	100	14	5	0	8	0	0	-
99.5 %	3	50	7	3	0	4	0	0	-
99.9 %	1	10	1	1	0	1	0	0	-

Table 3-18 Mean ERM/CRM Outputs for Breeding Razorbill, 40 MW Scenarios

Reference population		1,458 individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	747	9789	1517	643	0	703	0	0	-
50 %	374	4894	758	322	0	351	0	0	-
90 %	75	979	152	64	0	70	0	0	-
95 %	37	489	76	32	0	35	0	0	-
98 %	15	196	30	13	0	14	0	0	-
99 %	7	98	15	6	0	7	0	0	-
99.5 %	4	49	8	3	0	4	0	0	-
99.9 %	1	10	2	1	0	1	0	0	-

3.1.7. Non-Breeding Razorbill

Table 3-19 ERM Outputs for Non-Breeding Razorbill, 40 MW Scenarios

Reference population		341,422 (minimum) individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	961	9523	1637	751	0	560	0	0	6708
50 %	480	4762	818	376	0	280	0	0	3354
90 %	96	952	164	75	0	56	0	0	671
95 %	48	476	82	38	0	28	0	0	335
98 %	19	190	33	15	0	11	0	0	134
99 %	10	95	16	8	0	6	0	0	67
99.5 %	5	48	8	4	0	3	0	0	34
99.9 %	1	10	2	1	0	1	0	0	7

Table 3-20 CRM Outputs for Non-Breeding Razorbill, 40 MW Scenarios

Reference population		341,422 (minimum) individuals							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	530	10012	1390	533	0	843	0	0	530
50 %	265	5006	695	266	0	422	0	0	265
90 %	53	1001	139	53	0	84	0	0	53

Reference population	341,422 (minimum) individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
95 %	27	501	69	27	0	42	0	0	27
98 %	11	200	28	11	0	17	0	0	11
99 %	5	100	14	5	0	8	0	0	5
99.5 %	3	50	7	3	0	4	0	0	3
99.9 %	1	10	1	1	0	1	0	0	1

Table 3-21 Mean ERM/CRM Outputs for Non-Breeding Razorbill, 40 MW Scenarios

Reference population	341,422 (minimum) individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	745	9768	1513	642	0	701	0	0	-
50 %	373	4884	757	321	0	351	0	0	-
90 %	75	977	151	64	0	70	0	0	-
95 %	37	488	76	32	0	35	0	0	-
98 %	15	195	30	13	0	14	0	0	-
99 %	7	98	15	6	0	7	0	0	-
99.5 %	4	49	8	3	0	4	0	0	-
99.9 %	1	10	2	1	0	1	0	0	-

3.1.8. Non-Breeding (Year Round) Red-Throated Diver

Table 3-22 ERM Outputs for Non-Breeding Red-Throated Diver (Year Round), 40 MW Scenarios

Reference population	1,676 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	69	753	126	59	2	52	0	0	506
50 %	35	377	63	29	1	26	0	0	253
90 %	7	75	13	6	0	5	0	0	51
95 %	3	38	6	3	0	3	0	0	25
98 %	1	15	3	1	0	1	0	0	10
99 %	1	8	1	1	0	1	0	0	5
99.5 %	0	4	1	0	0	0	0	0	3
99.9 %	0	1	0	0	0	0	0	0	1

Table 3-23 CRM Outputs for Non-Breeding Red-Throated Diver (Year Round), 40 MW Scenarios

Reference population	1,676 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	59	1300	176	68	3	122	0	0	-
50 %	29	650	88	34	1	61	0	0	-
90 %	6	130	18	7	0	12	0	0	-
95 %	3	65	9	3	0	6	0	0	-
98 %	1	26	4	1	0	2	0	0	-
99 %	1	13	2	1	0	1	0	0	-
99.5 %	0	6	1	0	0	1	0	0	-

Reference population	1,676 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
99.9 %	0	1	0	0	0	0	0	0	-

Table 3-24 Mean ERM/CRM Outputs for Non-Breeding Red-Throated Diver (Year Round), 40 MW Scenarios

Reference population	1,676 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	64	1027	151	64	2	87	0	0	-
50 %	32	513	76	32	1	44	0	0	-
90 %	6	103	15	6	0	9	0	0	-
95 %	3	51	8	3	0	4	0	0	-
98 %	1	21	3	1	0	2	0	0	-
99 %	1	10	2	1	0	1	0	0	-
99.5 %	0	5	1	0	0	0	0	0	-
99.9 %	0	1	0	0	0	0	0	0	-

3.1.9. Breeding Shag

Table 3-25 ERM Outputs for Breeding Shag, 40 MW Scenarios

Reference population	26 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	2	5	2	3	2	3	2	3	3
50 %	1	3	1	1	1	1	1	1	2
90 %	0	1	0	0	0	0	0	0	0
95 %	0	0	0	0	0	0	0	0	0
98 %	0	0	0	0	0	0	0	0	0
99 %	0	0	0	0	0	0	0	0	0
99.5 %	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0

Table 3-26 CRM Outputs for Breeding Shag, 40 MW Scenarios

Reference population	26 individuals								
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	2	10	3	3	2	6	3	4	-
50 %	1	5	1	1	1	3	2	2	-
90 %	0	1	0	0	0	1	0	0	-
95 %	0	0	0	0	0	0	0	0	-
98 %	0	0	0	0	0	0	0	0	-
99 %	0	0	0	0	0	0	0	0	-
99.5 %	0	0	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

Table 3-27 Mean ERM/CRM Outputs for Breeding Shag, 40 MW Scenarios

Reference population		**26 individuals**							
Avoidance Rate	**1F**	**2F**	**3F**	**4F**	**5S**	**6S**	**7S**	**8S**	**9F**
0 %	2	8	2	3	2	5	3	2	-
50 %	1	4	1	1	1	2	1	1	-
90 %	0	1	0	0	0	0	0	0	-
95 %	0	0	0	0	0	0	0	0	-
98 %	0	0	0	0	0	0	0	0	-
99 %	0	0	0	0	0	0	0	0	-
99.5 %	0	0	0	0	0	0	0	0	-
99.9 %	0	0	0	0	0	0	0	0	-

3.2. 240 MW SCENARIO

54. For each species, three tables are presented. These present the predicted number of collisions in a single season for each device envelope for ERM and CRM, and a mean of the two models. The size of the biologically relevant population of birds, based on information in **Chapter 11, Marine Ornithology**, is also provided.

55. As outputs have been presented as whole numbers, any small discrepancies in the totals columns of all tables, and mean of ERM and CRM tables are due to rounding up or down of values.

3.2.1. Breeding Gannet

Table 3-28 ERM Outputs for Breeding Gannet, 240 MW Scenario

Reference population			**138,474 individuals**							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	1	1	0	8	2	0	1	0	0	1	15
50 %	1	1	0	4	1	0	0	0	0	1	8
90 %	0	0	0	1	0	0	0	0	0	1	2
95 %	0	0	0	0	0	0	0	0	0	1	2
98 %	0	0	0	0	0	0	0	0	0	1	1
99 %	0	0	0	0	0	0	0	0	0	1	1
99.5 %	0	0	0	0	0	0	0	0	0	1	1
99.9 %	0	0	0	0	0	0	0	0	0	1	1

Table 3-29 CRM Outputs for Breeding Gannet, 240 MW Scenario

Reference population			**138,474 individuals**								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	1	1	0	8	1	0	1	0	0	1	13
50 %	0	0	0	4	1	0	0	0	0	0	6
90 %	0	0	0	1	0	0	0	0	0	0	1

Reference population		138,474 individuals								
95 %	0	0	0	0	0	0	0	0	0	0	1
98 %	0	0	0	0	0	0	0	0	0	0	0
99 %	0	0	0	0	0	0	0	0	0	0	0
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-30 Mean ERM/CRM Outputs for Breeding Gannet, 240 MW Scenario

Reference population			138,474 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	1	1	0	8	2	0	1	0	0	1	14
50 %	0	0	0	4	1	0	0	0	0	1	7
90 %	0	0	0	1	0	0	0	0	0	0	2
95 %	0	0	0	0	0	0	0	0	0	0	1
98 %	0	0	0	0	0	0	0	0	0	0	1
99 %	0	0	0	0	0	0	0	0	0	0	1
99.5 %	0	0	0	0	0	0	0	0	0	0	1
99.9 %	0	0	0	0	0	0	0	0	0	0	0

3.2.2. Breeding Guillemot

Table 3-31 ERM Outputs for Breeding Guillemot, 240 MW Scenario

Reference population			8,308 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	2358	2358	3234	1275	2370	3192	1185	1418	3433	1185	22008
50 %	1179	1179	1617	638	1185	1596	593	709	1717	593	11004
90 %	236	236	323	128	237	319	119	142	343	119	2201
95 %	118	118	162	64	119	160	59	71	172	59	1100
98 %	47	47	65	26	47	64	24	28	69	24	440
99 %	24	24	32	13	24	32	12	14	34	12	220
99.5 %	12	12	16	6	12	16	6	7	17	6	110
99.9 %	2	2	3	1	2	3	1	1	3	1	22

Table 3-32 CRM Outputs for Breeding Guillemot, 240 MW Scenario

Reference population			8,308 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	1303	1303	2303	1275	2015	2844	1007	607	5181	1007	18844
50 %	651	651	1151	638	1007	1422	504	303	2590	504	9422
90 %	130	130	230	128	201	284	101	61	518	101	1884
95 %	65	65	115	64	101	142	50	30	259	50	942
98 %	26	26	46	26	40	57	20	12	104	20	377
99 %	13	13	23	13	20	28	10	6	52	10	188

Reference population		8,308 individuals								
99.5 %	7	7	12	6	10	14	5	3	26	5	94
99.9 %	1	1	2	1	2	3	1	1	5	1	19

Table 3-33 Mean ERM/CRM Outputs for Breeding Guillemot, 240 MW Scenario

Reference population			8,308 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	1830	1830	2768	1275	2192	1954	1096	1013	4307	1096	19362
50 %	915	915	1384	638	1096	977	548	506	2154	548	9681
90 %	183	183	277	128	219	195	110	101	431	110	1936
95 %	92	92	138	64	110	98	55	51	215	55	968
98 %	37	37	55	26	44	39	22	20	86	22	387
99 %	18	18	28	13	22	20	11	10	43	11	194
99.5 %	9	9	14	6	11	10	5	5	22	5	97
99.9 %	2	2	3	1	2	2	1	1	4	1	19

3.2.3. Non-Breeding Guillemot

Table 3-34 ERM Outputs for Non-Breeding Guillemot, 240 MW Scenario

Reference population			1,139,220 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	506	506	694	274	508	685	763	304	737	763	5739
50 %	253	253	347	137	254	342	381	152	368	381	2869
90 %	51	51	69	27	51	68	76	30	74	76	574
95 %	25	25	35	14	25	34	38	15	37	38	287
98 %	10	10	14	5	10	14	15	6	15	15	115
99 %	5	5	7	3	5	7	8	3	7	8	57
99.5 %	3	3	3	1	3	3	4	2	4	4	29
99.9 %	1	1	1	0	1	1	1	0	1	1	6

Table 3-35 CRM Outputs for Non-Breeding Guillemot, 240 MW Scenario

Reference population			1,139,220 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	279	279	494	274	432	610	216	130	1112	216	4043
50 %	140	140	247	137	216	305	108	65	556	108	2022
90 %	28	28	49	27	43	61	22	13	111	22	404
95 %	14	14	25	14	22	31	11	7	56	11	202
98 %	6	6	10	5	9	12	4	3	22	4	81
99 %	3	3	5	3	4	6	2	1	11	2	40
99.5 %	1	1	2	1	2	3	1	1	6	1	20
99.9 %	0	0	0	0	0	1	0	0	1	0	4

Table 3-36 Mean ERM/CRM Outputs for Non-Breeding Guillemot, 240 MW Scenario

Reference population		1,139,220 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	393	393	594	274	470	419	489	217	924	489	4663
50 %	196	196	297	137	235	210	245	109	462	245	2331
90 %	39	39	59	27	47	42	49	22	92	49	466
95 %	20	20	30	14	24	21	24	11	46	24	233
98 %	8	8	12	5	9	8	10	4	18	10	93
99 %	4	4	6	3	5	4	5	2	9	5	47
99.5 %	2	2	3	1	2	2	2	1	5	2	23
99.9 %	0	0	1	0	0	0	0	0	1	0	5

3.2.4. Breeding Manx Shearwater

Table 3-37 ERM Outputs for Breeding Manx Shearwater, 240 MW Scenario

Reference population		673,350 individuals									
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	25	25	5	82	25	0	13	0	0	13	186
50 %	12	12	2	41	13	0	6	0	0	6	93
90 %	2	2	0	8	3	0	1	0	0	1	19
95 %	1	1	0	4	1	0	1	0	0	1	9
98 %	0	0	0	2	1	0	0	0	0	0	4
99 %	0	0	0	1	0	0	0	0	0	0	2
99.5 %	0	0	0	0	0	0	0	0	0	0	1
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-38 CRM Outputs for Breeding Manx Shearwater, 240 MW Scenario

Reference population		673,350 individuals									
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	15	15	3	82	22	0	11	0	0	11	159
50 %	7	7	2	41	11	0	5	0	0	5	79
90 %	1	1	0	8	2	0	1	0	0	1	16
95 %	1	1	0	4	1	0	1	0	0	1	8
98 %	0	0	0	2	0	0	0	0	0	0	3
99 %	0	0	0	1	0	0	0	0	0	0	2
99.5 %	0	0	0	0	0	0	0	0	0	0	1
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-39 Mean ERM/CRM Outputs for Breeding Manx Shearwater, 240 MW Scenario

Reference population		673,350 individuals									
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**

Reference population			673,350 individuals							
0 %	20	20	4	82	24	0	12	0	0	12	173
50 %	10	10	2	41	12	0	6	0	0	6	86
90 %	2	2	0	8	2	0	1	0	0	1	17
95 %	1	1	0	4	1	0	1	0	0	1	9
98 %	0	0	0	2	0	0	0	0	0	0	3
99 %	0	0	0	1	0	0	0	0	0	0	2
99.5 %	0	0	0	0	0	0	0	0	0	0	1
99.9 %	0	0	0	0	0	0	0	0	0	0	0

3.2.5. Breeding Puffin

Table 3-40 ERM Outputs for Breeding Puffin, 240 MW Scenario

Reference population			120 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	11	11	9	24	18	0	9	0	6	9	99
50 %	6	6	4	12	9	0	5	0	3	5	49
90 %	1	1	1	2	2	0	1	0	1	1	10
95 %	1	1	0	1	1	0	0	0	0	0	5
98 %	0	0	0	0	0	0	0	0	0	0	2
99 %	0	0	0	0	0	0	0	0	0	0	1
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-41 CRM Outputs for Breeding Puffin, 240 MW Scenario

Reference population			120 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	6	6	6	24	15	0	7	0	9	7	79
50 %	3	3	3	12	7	0	4	0	4	4	40
90 %	1	1	1	2	1	0	1	0	1	1	8
95 %	0	0	0	1	1	0	0	0	0	0	4
98 %	0	0	0	0	0	0	0	0	0	0	2
99 %	0	0	0	0	0	0	0	0	0	0	1
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-42 Mean ERM/CRM Outputs for Breeding Puffin, 240 MW Scenario

Reference population			120 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	9	9	7	24	16	0	8	0	8	8	89
50 %	4	4	4	12	8	0	4	0	4	4	44
90 %	1	1	1	2	2	0	1	0	1	1	9

Reference population			120 individuals							
95 %	0	0	0	1	1	0	0	0	0	0	4
98 %	0	0	0	0	0	0	0	0	0	0	2
99 %	0	0	0	0	0	0	0	0	0	0	1
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

3.2.6. Breeding Razorbill

Table 3-43 ERM Outputs for Breeding Razorbill, 240 MW Scenario

Reference population			1,458 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	722	722	565	1681	1230	0	615	0	421	615	6571
50 %	361	361	282	840	615	0	308	0	210	308	3285
90 %	72	72	56	168	123	0	62	0	42	62	657
95 %	36	36	28	84	62	0	31	0	21	31	329
98 %	14	14	11	34	25	0	12	0	8	12	131
99 %	7	7	6	17	12	0	6	0	4	6	66
99.5 %	4	4	3	8	6	0	3	0	2	3	33
99.9 %	1	1	1	2	1	0	1	0	0	1	7

Table 3-44 CRM Outputs for Breeding Razorbill, 240 MW Scenario

Reference population			1,458 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	398	398	400	1681	1045	0	522	0	634	522	5601
50 %	199	199	200	840	522	0	261	0	317	261	2800
90 %	40	40	40	168	104	0	52	0	63	52	560
95 %	20	20	20	84	52	0	26	0	32	26	280
98 %	8	8	8	34	21	0	10	0	13	10	112
99 %	4	4	4	17	10	0	5	0	6	5	56
99.5 %	2	2	2	8	5	0	3	0	3	3	28
99.9 %	0	0	0	2	1	0	1	0	1	1	6

Table 3-45 Mean ERM/CRM Outputs for Breeding Razorbill, 240 MW Scenario

Reference population			1,458 individuals							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	560	560	482	1681	1137	0	569	0	527	569	6086
50 %	280	280	241	840	569	0	284	0	264	284	3043
90 %	56	56	48	168	114	0	57	0	53	57	609
95 %	28	28	24	84	57	0	28	0	26	28	304
98 %	11	11	10	34	23	0	11	0	11	11	122
99 %	6	6	5	17	11	0	6	0	5	6	61

Reference population		1,458 individuals								
99.5 %	3	3	2	8	6	0	3	0	3	3	30
99.9 %	1	1	0	2	1	0	1	0	1	1	6

3.2.7. Non-Breeding Razorbill

Table 3-46 ERM Outputs for Non-Breeding Razorbill, 240 MW Scenario

Reference population			**341,422 (minimum) individuals**							
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	721	721	563	1677	1228	0	614	0	420	614	6557
50 %	360	360	282	839	614	0	307	0	210	307	3278
90 %	72	72	56	168	123	0	61	0	42	61	656
95 %	36	36	28	84	61	0	31	0	21	31	328
98 %	14	14	11	34	25	0	12	0	8	12	131
99 %	7	7	6	17	12	0	6	0	4	6	66
99.5 %	4	4	3	8	6	0	3	0	2	3	33
99.9 %	1	1	1	2	1	0	1	0	0	1	7

Table 3-47 CRM Outputs for Non-Breeding Razorbill, 240 MW Scenario

Reference population			**341,422 (minimum) individuals**								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	398	398	399	1677	1042	0	521	0	632	521	5589
50 %	199	199	200	839	521	0	261	0	316	261	2794
90 %	40	40	40	168	104	0	52	0	63	52	559
95 %	20	20	20	84	52	0	26	0	32	26	279
98 %	8	8	8	34	21	0	10	0	13	10	112
99 %	4	4	4	17	10	0	5	0	6	5	56
99.5 %	2	2	2	8	5	0	3	0	3	3	28
99.9 %	0	0	0	2	1	0	1	0	1	1	6

Table 3-48 Mean ERM/CRM Outputs for Non-Breeding Razorbill, 240 MW Scenario

Reference population			**341,422 (minimum) individuals**								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	559	559	481	1677	1135	0	567	0	526	567	6073
50 %	280	280	241	839	567	0	284	0	263	284	3036
90 %	56	56	48	168	113	0	57	0	53	57	607
95 %	28	28	24	84	57	0	28	0	26	28	304
98 %	11	11	10	34	23	0	11	0	11	11	121
99 %	6	6	5	17	11	0	6	0	5	6	61
99.5 %	3	3	2	8	6	0	3	0	3	3	30
99.9 %	1	1	0	2	1	0	1	0	1	1	6

3.2.8. Non-Breeding (Year Round) Red-Throated Diver

Table 3-49 ERM Outputs for Non-Breeding Red-Throated Diver (Year Round), 240 MW Scenario

Reference population			1,676 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	52	52	44	126	95	0	47	0	39	47	503
50 %	26	26	22	63	47	0	24	0	19	24	252
90 %	5	5	4	13	9	0	5	0	4	5	50
95 %	3	3	2	6	5	0	2	0	2	2	25
98 %	1	1	1	3	2	0	1	0	1	1	10
99 %	1	1	0	1	1	0	0	0	0	0	5
99.5 %	0	0	0	1	0	0	0	0	0	0	3
99.9 %	0	0	0	0	0	0	0	0	0	0	1

Table 3-50 CRM Outputs for Non-Breeding Red-Throated Diver (Year Round), 240 MW Scenario

Reference population			1,676 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	44	44	51	126	132	0	66	0	92	66	621
50 %	22	22	26	63	66	0	33	0	46	33	311
90 %	4	4	5	13	13	0	7	0	9	7	62
95 %	2	2	3	6	7	0	3	0	5	3	31
98 %	1	1	1	3	3	0	1	0	2	1	12
99 %	0	0	1	1	1	0	1	0	1	1	6
99.5 %	0	0	0	1	1	0	0	0	0	0	3
99.9 %	0	0	0	0	0	0	0	0	0	0	1

Table 3-51 Mean ERM/CRM Outputs Non-Breeding Red-Throated Diver (Year Round), 240 MW Scenario

Reference population			1,676 individuals								
Avoidance Rate	**1F**	**1F**	**4F**	**9F**	**3F**	**8S**	**3F**	**7S**	**6S**	**3F**	**Total**
0 %	48	48	48	126	113	0	57	0	65	57	562
50 %	24	24	24	63	57	0	28	0	33	28	281
90 %	5	5	5	13	11	0	6	0	7	6	56
95 %	2	2	2	6	6	0	3	0	3	3	28
98 %	1	1	1	3	2	0	1	0	1	1	11
99 %	0	0	0	1	1	0	1	0	1	1	6
99.5 %	0	0	0	1	1	0	0	0	0	0	3
99.9 %	0	0	0	0	0	0	0	0	0	0	1

3.2.9. Breeding Shag

Table 3-52 ERM Outputs for Breeding Shag, 240 MW Scenario

Reference population			26 individuals								
Avoidance Rate	1F	1F	4F	9F	3F	8S	3F	7S	6S	3F	Total
0 %	1	1	2	1	1	2	1	1	2	1	13
50 %	1	1	1	0	1	1	0	0	1	0	7
90 %	0	0	0	0	0	0	0	0	0	0	1
95 %	0	0	0	0	0	0	0	0	0	0	1
98 %	0	0	0	0	0	0	0	0	0	0	0
99 %	0	0	0	0	0	0	0	0	0	0	0
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-53 CRM Outputs for Breeding Shag, 240 MW Scenario

Reference population			26 individuals								
Avoidance Rate	1F	1F	4F	9F	3F	8S	3F	7S	6S	3F	Total
0 %	1	1	2	1	2	3	1	1	5	1	17
50 %	1	1	1	0	1	1	0	0	2	0	9
90 %	0	0	0	0	0	0	0	0	0	0	2
95 %	0	0	0	0	0	0	0	0	0	0	1
98 %	0	0	0	0	0	0	0	0	0	0	0
99 %	0	0	0	0	0	0	0	0	0	0	0
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

Table 3-54 Mean ERM/CRM Outputs for Breeding Shag, 240 MW Scenario

Reference population			26 individuals								
Avoidance Rate	1F	1F	4F	9F	3F	8S	3F	7S	6S	3F	Total
0 %	1	1	2	1	2	2	1	1	3	1	14
50 %	1	1	1	0	1	1	0	0	2	0	7
90 %	0	0	0	0	0	0	0	0	0	0	1
95 %	0	0	0	0	0	0	0	0	0	0	1
98 %	0	0	0	0	0	0	0	0	0	0	0
99 %	0	0	0	0	0	0	0	0	0	0	0
99.5 %	0	0	0	0	0	0	0	0	0	0	0
99.9 %	0	0	0	0	0	0	0	0	0	0	0

4. PVA

4.1. INTRODUCTION

56. PVAs were undertaken to assess the potential population-level impacts of the predicted collision and displacement mortalities as a result of the project on the South Stack and Penlas SMP master site breeding guillemot and breeding razorbill populations. The outputs of the estimation of collision mortalities is provided in **Section 3**, and for PVA, the means of ERM and CRM outputs are used as inputs. Also included in the PVA are any mortalities due to airborne noise and visual disturbance, details of which are provided in **Chapter 11, Marine Ornithology**.

4.2. METHODS

57. PVAs were based on density independent, deterministic, Leslie-matrix population models (Green et al., 2016) run over a 25-year projection period. The growth of each population over the projection period was simulated using a matrix-based age-structured model, generally termed a transition matrix, as commonly used in population modelling (Caswell, 2000). Age-structured models attempt to account for the fact that organisms of different ages have different characteristics, with these reflected in their vital rates (e.g. annual survival rates).

58. Population growth for each species under baseline conditions (i.e. with no additional mortality as a result of the project) was modelled using the starting population sizes for the breeding adult age class, which consisted of the total number of breeding adults at the South Stack, Gogarth and Abraham's Bosom sub-colonies at the last available count. This was calculated by multiplying the total number of individuals on land counted by an appropriate k-value correction factor to give an estimate of the breeding adult population (in this case 1.34 (Harris et al., 2015)), together with the estimates of age-specific annual survival rates and breeding productivity (i.e. the demographic rates) presented in **Table 4-1** for guillemot and **Table 4-3** for razorbill.

59. The number of individuals in the non-adult age classes at the start of the projection was calculated from the population stable age distribution, as estimated on the basis of the breeding adult population size and the demographic rates. The population models were based on a post-breeding census (i.e. immediately after annual reproduction) and assumed an even sex ratio.

60. The starting populations used for both species was that according to the latest SMP count multiplied by an appropriate k-value (1.34) (Harris et al., 2015). Had more recent RSPB count been available when the model had been run, the starting population would have been 12,984 for guillemot, and 1,790 for razorbill. These population estimates are approximately 75 % and 34 % larger than the starting populations used by the PVA. Larger starting populations would result in a population which may possess greater resilience with respect to additional mortality. As a result, the model outputs present a further layer of precaution.

61. Annual collision and displacement mortality (estimated using a matrix-based approach detailed in **Chapter 11, Marine Ornithology**) was assumed to be additive and was applied to the breeding adult age class only, resulting in a highly precautionary set of outputs. This additional mortality was applied in such a way that it was proportional to the population size throughout the projection period.

62. Population models were undertaken using the Rramas package, available in the R statistical software, and were run in R (R Core Team, 2016). The population stable age distribution was first estimated in Rramas, to provide the population sizes of each age class, prior to modelling the population projection and impact of the additional mortality.

63. Outputs from the PVAs were expressed in terms of the counterfactuals of the end-point population size (i.e. the ratio of the size of the impacted to predicted baseline population size after 25 years) and of the annual growth rate (i.e. the ratio of the growth rate of the impacted to predicted baseline population). These metrics have been demonstrated to have low sensitivity to the mis-specification of input parameters (e.g. demographic rates) and to the underlying assumptions of the population models from which the PVAs are derived (Cook and Robinson, 2016; Jitlal et al., 2017).

64. Although PVAs produced from deterministic population models may give less precautionary outputs than those based on stochastic population models (Cook and Robinson, 2016), recent work indicates that their overall performance is similar (Searle, 2018). Input Parameters

65. The input parameters used for the PVAs for guillemot and razorbill are presented in **Table 4-1, Table 4-2, Table 4-3** and **Table 4-4.**

Table 4-1 PVA Input Parameters for Guillemot

Parameter	Value	Source
Starting population size (in terms of no. of breeding adults)	7,457	(JNCC, 2018)
Age of first breeding	6	(Horswill and Robinson, 2015)
Annual survival rate of breeding adults (and immatures beyond 3 years)	0.939	(Horswill and Robinson, 2015)
Juvenile annual survival rate	0.56	(Horswill and Robinson, 2015)
Immature (1-2) annual survival rate	0.792	(Horswill and Robinson, 2015)
Immature (2-3) annual survival rate	0.917	(Horswill and Robinson, 2015)
Annual breeding success per active site	0.72	(Stubbings et al., 2017)

Table 4-2 PVA Annual Harvest Figures for Guillemot

Avoidance Rate	Annual Harvest (Collision, 40 MW Worst Case)	Annual Harvest (Collision, 240 MW)	Annual Harvest (Displacement)	Total Annual Harvest (40 MW Worst Case)	Total Annual Harvest (240 MW)
95 %	287	1052	12	299	1064
98 %	115	421	12	127	433
99 %	57	210	12	69	222
99.5 %	29	105	12	41	117
99.9 %	6	21	12	18	33

Table 4-3 PVA Input Parameters for Razorbill

Parameter	Value	Source
Starting population size (in terms of no. of breeding adults)	1,467	(JNCC, 2018)
Age of first breeding	5	(Horswill and Robinson, 2015)

Parameter	Value	Source
Annual survival rate of breeding adults (and immatures beyond 3 years)	0.895	(Horswill and Robinson, 2015)
Average survival rate, juvenile to recruitment	0.63	(Horswill and Robinson, 2015)
Annual breeding success per active site	0.53	(Stubbings et al., 2017)

Table 4-4 PVA Annual Harvest Figures for Razorbill

Avoidance Rate	Annual Harvest (Collision, 40 MW Worst Case)	Annual Harvest (Collision, 240 MW)	Annual Harvest (Displacement)	Total Annual Harvest (40 MW Worst Case)	Total Annual Harvest (240 MW)
95 %	76	324	0	76	324
98 %	30	130	0	30	130
99 %	15	65	0	15	65
99.5 %	8	32	0	8	32
99.9 %	2	6	0	2	6

4.3. RESULTS

4.3.1. Guillemot

Table 4-5 PVA Outputs for Guillemot at 40 MW Worst Case Device Deployment

Avoidance Rate	Growth Rate	Population After 25 Years (total individual breeding adults)	Counterfactual of Growth Rate	Counterfactual of 25 Year Population	25 Year Population Relative to Current Population
Baseline	1.037	18,353	N/A	N/A	2.461
95 %	1.014	10,522	0.978	0.573	1.411
98 %	1.028	15,034	0.992	0.819	2.016
99 %	1.032	16,583	0.996	0.904	2.224
99.5 %	1.034	17,370	0.998	0.946	2.329
99.9 %	1.036	17,977	0.999	0.980	2.411

Table 4-6 PVA Outputs for Guillemot at 240 MW Deployment

Avoidance Rate	Growth Rate	Population After 25 Years (total individual breeding adults)	Counterfactual of Growth Rate	Counterfactual of 25 Year Population	25 Year Population Relative to Current Population
Baseline	1.037	18,353	N/A	N/A	2.461
95 %	0.911	438	0.893	0.024	0.059
98 %	1.004	7,437	1.000	0.405	0.996
99 %	1.023	12,691	1.021	0.692	1.700
99.5 %	1.031	15,461	1.030	0.842	2.071
99.9 %	1.035	17,539	1.035	0.956	2.350

4.3.1. Razorbill

Table 4-7 PVA Outputs for Razorbill at 40 MW Worst Case Device Deployment

Avoidance Rate	Growth Rate	Population After 25 Years (total individual breeding adults)	Counterfactual of Growth Rate	Counterfactual of 25 Year Population	25 Year Population Relative to Current Population
Baseline	1.035	3,430	N/A	N/A	2.338
95 %	0.977	827	0.945	0.241	0.564
98 %	1.021	2,446	0.987	0.713	1.667
99 %	1.028	2,953	0.994	0.861	2.013
99.5 %	1.031	3,140	0.996	0.915	2.140
99.9 %	1.033	3,266	0.998	0.952	2.226

Table 4-8 PVA Outputs for Razorbill at 240 MW Deployment

Avoidance Rate	Growth Rate	Population After 25 Years (total individual breeding adults)	Counterfactual of Growth Rate	Counterfactual of 25 Year Population	25 Year Population Relative to Current Population
Baseline	1.035	3,430	N/A	N/A	2.338
95 %	0.233	0	0.226	0.000	0.000
98 %	0.889	77	0.859	0.022	0.052
99 %	0.990	1,152	0.957	0.336	0.785
99.5 %	1.019	2,371	0.985	0.691	1.616
99.9 %	1.032	3,186	0.997	0.929	2.172

5. REFERENCES

Alerstam, T., Rosén, M., Bäckman, J., Ericson, P.G.P., Hellgren, O., 2007. Flight Speeds among Bird Species: Allometric and Phylogenetic Effects. PLOS Biology 5, e197. https://doi.org/10.1371/journal.pbio.0050197

Band, W., Madders, M., Whitfield, P., 2007. Developing field and analytical methods to assess avian collision risk at windfarms, in: De Lucas, M., Janss, G., Ferrer, M. (Eds.), Birds and Wind Power.

Benvenuti, S., Dall'Antonia, L., Lyngs, P., 2001. Foraging behaviour and time allocation of chick-rearing Razorbills Alca torda at Græsholmen, central Baltic Sea. Ibis 143, 402–412. https://doi.org/10.1111/j.1474-919X.2001.tb04941.x

Bruderer, B., Boldt, A., 2001. Flight characteristics of birds: I. radar measurements of speeds. Ibis 143, 178–204. https://doi.org/10.1111/j.1474-919X.2001.tb04475.x

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, Oxford.

Camphuysen, C., 1998. Diurnal Activity Patterns and Nocturnal Group Formation of Wintering Common Murres in the Central North Sea. Colonial Waterbirds 21, 406. https://doi.org/10.2307/1521652

Caswell, H., 2000. Matrix Population Models: Construction, Analysis and Interpretation, 2nd Edition. ed. Sinauer Associates Inc, United States.

Chimienti, M., Cornulier, T., Owen, E., Bolton, M., Davies, I.M., Travis, J.M.J., Scott, B.E., 2017. Taking movement data to new depths: Inferring prey availability and patch profitability from seabird foraging behavior. Ecology and Evolution 7, 10252–10265. https://doi.org/10.1002/ece3.3551

Cook, A.S.C.P., Robinson, R.A., 2016. Testing sensitivity of metrics of seabird population response to offshore wind farm effects (JNCC Report No. 553). JNCC.

Cox, S.L., Miller, P.I., Embling, C.B., Scales, K.L., Bicknell, A.W.J., Hosegood, P.J., Morgan, G., Ingram, S.N., Votier, S.C., 2016. Seabird diving behaviour reveals the functional significance of shelf-sea fronts as foraging hotspots. Royal Society Open Science 3. https://doi.org/10.1098/rsos.160317

Dean, B., 2012. The at-sea behaviour of the Manx shearwater (Thesis submitted for the degree of Doctor of Philosophy). University of Oxford, Oxford.

Dean, B., Freeman, R., Kirk, H., Leonard, K., Phillips, R., M Perrins, C., Guilford, T., 2012. Behavioural mapping of a pelagic seabird: Combining multiple sensors and a hidden Markov model reveals the distribution of at-sea behaviour. Journal of the Royal Society Interface 10. https://doi.org/10.1098/rsif.2012.0570

Elliott, K.H., Gaston, A.J., 2015. Diel vertical migration of prey and light availability constrain foraging in an Arctic seabird. Marine Biology 162, 1739–1748. https://doi.org/10.1007/s00227-015-2701-1

Falk, K., Benvenuti, S., Dall'Antonia, L., Kampp, K., Ribolini, A., 2000. Time allocation and foraging behaviour of chick-rearing Brünnich's Guillemots Uria lomvia in high-arctic Greenland. Ibis 142, 82–92. https://doi.org/10.1111/j.1474-919X.2000.tb07687.x

Fraenkel, P.L., 2006. Tidal Current Energy Technologies. Ibis 148, 145–151. https://doi.org/10.1111/j.1474-919X.2006.00518.x

Furness, R., 2015. Non-breeding season populations of seabirds in UK waters: Population sizes for Biologically Defined Minimum Population Scales (BDMPS). Natural England Commissioned Report 164.

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

Furness, R.W., Wade, H.M., Robbins, A.M.C., Masden, E.A., 2012. Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. ICES Journal of Marine Science 69, 1466–1479. https://doi.org/10.1093/icesjms/fss131

Garthe, S., Benvenuti, S., Montevecchi, W.A., 2000. Pursuit plunging by northern gannets (Sula bassana) feeding on capelin (Mallotus villosus). Proc Biol Sci 267, 1717. https://doi.org/10.1098/rspb.2000.1200

Gerritsen, J., Strickler, J.R., 1977. Encounter Probabilities and Community Structure in Zooplankton: a Mathematical Model. J. Fish. Res. Bd. Can. 34, 73–82. https://doi.org/10.1139/f77-008

Green, R.E., Langston, R.H.W., McCluskie, A., Sutherland, R., Wilson, J.D., 2016. Lack of sound science in assessing wind farm impacts on seabirds. Journal of Applied Ecology 53, 1635–1641. https://doi.org/10.1111/1365-2664.12731

Harris, M.P., Heubeck, M., Newell, M.A., Wanless, S., 2015. The need for year-specific correction factors (k values) when converting counts of individual Common Guillemots Uria aalge to breeding pairs. Bird Study 62, 276–279. https://doi.org/10.1080/00063657.2015.1017444

Horswill, C., Robinson, R.A., 2015. Review of seabird demographic rates and density dependence (JNCC Report No. 552). JNCC, Peterborough.

Jitlal, M., Burthe, S., Freeman, S., Daunt, F., 2017. Testing and Validating Metrics of Change Produced by Population Viability Analysis (PVA) (Vol. 8 No. 23), Scottish Marine and Freshwater Science.

JNCC, 2018. Seabird Monitoring Programme Online Database (Online Database). JNCC.

Kokubun, N., Yamamoto, T., Sato, N., Watanuki, Y., Will, A., Kitaysky, A.S., Takahashi, A., 2016. Foraging segregation of two congeneric diving seabird species breeding on St. George Island, Bering Sea. Biogeosciences 13, 2579–2591. https://doi.org/10.5194/bg-13-2579-2016

Martin, G.R., 2011. Understanding bird collisions with man-made objects: a sensory ecology approach. Ibis 153, 239–254. https://doi.org/10.1111/j.1474-919X.2011.01117.x

Martin, G.R., Wanless, S., 2015. The visual fields of Common Guillemots Uria aalge and Atlantic Puffins Fratercula arctica: foraging, vigilance and collision vulnerability. Ibis 157, 798–807. https://doi.org/10.1111/ibi.12297

MBIEG, 2019. Improved understanding of underwater collision risks of marine renewable energy devices for birds while diving. A report produced by British Trust for Ornithology for the Marine Management Organisation on behalf of the Marine Biodiversity Impacts Evidence Group (No. MMO Project No: 1139).

McCluskie, A.E., Langston, R.H.W., Wilkinson, N.I., 2012. Birds and wave & tidal stream energy: an ecological review (RSPB Research Report No. 42). RSPB.

Paredes, R., L. Jones, I., Boness, D., 2006. Parental roles of male and female thick-billed murres and razorbills at the Gannet Islands, Labrador. Behaviour 143, 451–481. https://doi.org/10.1163/156853906776240641

Polak, M., Ciach, M., 2007. Behaviour of black-throated diver Gavia arctica and red-throated diver Gavia stellata during autumn migration stopover. Ornis Svecica 17, 90–94.

R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Regular, P., Davoren, G., Hedd, A., Montevecchi, W., 2010. Crepuscular foraging by a pursuit-diving seabird: Tactics of common murres in response to the diel vertical migration of capelin. Marine Ecology Progress Series 415, 295–304. https://doi.org/10.3354/meps08752

Regular, P.M., Hedd, A., Montevecchi, W.A., 2011. Fishing in the dark: a pursuit-diving seabird modifies foraging behaviour in response to nocturnal light levels. PloS one 6, e26763–e26763. https://doi.org/10.1371/journal.pone.0026763

Robbins, A.M.C., 2017. Seabird ecology in high-energy environments: approaches to assessing impacts of marine renewables. University of Glasgow, Glasgow.

Robinson, R.A., 2019. BirdFacts: profiles of birds occurring in Britain & Ireland (BTO Research Report No. 407). British Trust for Ornithology, Thetford.

Searle, K., 2018. Regional Population Viability Analysis for Key Bird Species: a review of different modelling approaches.

Shoji, A., Dean, B., Kirk, H., Freeman, R., Perrins, C.M., Guilford, T., 2016. The diving behaviour of the Manx Shearwater Puffinus puffinus. Ibis 158, 598–606. https://doi.org/10.1111/ibi.12381

Shoji, A., Elliot, K., Fayet, A., Boyle, D., Perrins, C., Guilford, T., 2015. Foraging behaviour of sympatric razorbills and puffins. Mar Ecol Prog Ser 520, 257–267.

SNH, 2016. Assessing collision risk between underwater turbines and marine wildlife (Guidance note). Scottish Natural Heritage.

Stone, C.J., Webb, A., Barton, C., Ratcliffe, N., Reed, T.C., Tasker, M.L., Camphuysen, C.J., Pienkowski, M.W., 1995. An atlas of seabird distribution in north-west European waters. JNCC, Peterborough.

Stroud, D.A., Bainbridge, I.P., Maddock, A., Anthony, S., Baker, H., Buxton, N., Chambers, D., Enlander, I., Hearn, R.D., Jennings, K.R., Mavor, R., Whitehead, S., Wilson, J.D., 2016. The status of UK SPAs in the 2000s: the Third Network Review. JNCC, Peterborough.

Stubbings, E., Büche, B., Riordan, J., Moss, J., Wood, M., 2017. Seabird monitoring on Skomer Island in 2017 (JNCC Report).

Thaxter, C.B., Daunt, F., Hamer, K.C., Watanuki, Y., Harris, M.P., Grémillet, D., Peters, G., Wanless, S., 2009. Sex-specific food provisioning in a monomorphic seabird, the common guillemot Uria aalge: nest defence, foraging efficiency or parental effort? Journal of Avian Biology 40, 75–84. https://doi.org/10.1111/j.1600-048X.2008.04507.x

Thaxter, C.B., Wanless, S., Daunt, F., Harris, M.P., Benvenuti, S., Watanuki, Y., Grémillet, D., Hamer, K.C., 2010. Influence of wing loading on the trade-off between pursuit-diving and flight in common guillemots and razorbills. J. Exp. Biol. 213, 1018. https://doi.org/10.1242/jeb.037390

Wanless, S., Finney, S.K., Harris, M., McCafferty, D., 1999. Effect of the diel light cycle on the diving behaviour of two bottom feeding marine birds: the Blue-eyed Shag Phalacrocorax atriceps and the European Shag P. aristotelis. Marine Ecology Progress Series 188, 219–224. https://doi.org/10.3354/meps188219

White, C.R., Day, N., Butler, P.J., Martin, G.R., 2007. Vision and Foraging in Cormorants: More like Herons than Hawks? PLOS ONE 2, e639. https://doi.org/10.1371/journal.pone.0000639

Wilson, B., Batty, R.S., Daunt, F., Carter, C., 2007. Collision risks between marine renewable energy devices and mammals, fish and diving birds (Report to the Scottish Executive). Scottish Association for Marine Science.

Žydelis, R., Bellebaum, J., Osterblom, H., Vetemaa, M., Schirmeister, B., Stipniece, A., Dagys, M., van Eerden, M., Garthe, S., 2009. Bycatch in gillnet fisheries - An overlooked threat to waterbird populations. Biological Conservation 142, 1269–1281.

Žydelis, R., Small, C., French, G., 2013. The incidental catch of seabirds in gillnet fisheries: A global review. Biological Conservation 162, 76–88. https://doi.org/10.1016/j.biocon.2013.04.002