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Morlais Project
Environmental Statement

Chapter 12: Marine Mammals

Volume III

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Appendix 12.1: Investigating methods to estimate harbour porpoise (*Phocoena phocoena*) density off West Anglesey (SEACAMS, 2019)

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Chapter 12: Marine Mammals

Appendix 12.1: Investigating methods to estimate harbour porpoise (*Phocoena phocoena*) density off West Anglesey (SEACAMS, 2019)

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INVESTIGATING METHODS TO ESTIMATE HARBOUR PORPOISE (*Phocoena phocoena)* DENSITY OFF WEST ANGLESEY

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PROJECT SC2-RD-B26

Project partners:

Menter Môn & Minesto

Introduction:

The encounter rate of individuals is commonly used as a quantitative parameter to estimate interactions between animals and marine renewable energy developments, such as collision risk models used for predicting potential impacts of tidal turbines on marine mammals. The most established approach is to estimate density of animals in a given area using the distance sampling method (Buckland *et al.* 2001).

Off the west coast of Anglesey, there are two proposed tidal-stream developments; the West Anglesey Demonstration Zone (WADZ) situated in coastal waters and the Deep Green project in the Holyhead Deep (Figure 1). Marine mammals are known to occupy these waters, the most common of these being the harbour porpoise (*Phocoena phocoena*), however local encounter rates are not known. Existing absolute density estimates collected from SCANS-II aerial surveys, a large-scale European Atlantic project (Hammond *et al.* 2013) and are currently the only reference available. However, the relevant survey block encompasses much of the Irish Sea forming an area of over 45000 km^2. These types of survey are crucial for large-scale population studies but may not offer the resolution required for species that are not uniformly distributed and vary their preferences on a fine scale such as the harbour porpoise (Benjamins et al. 2017).

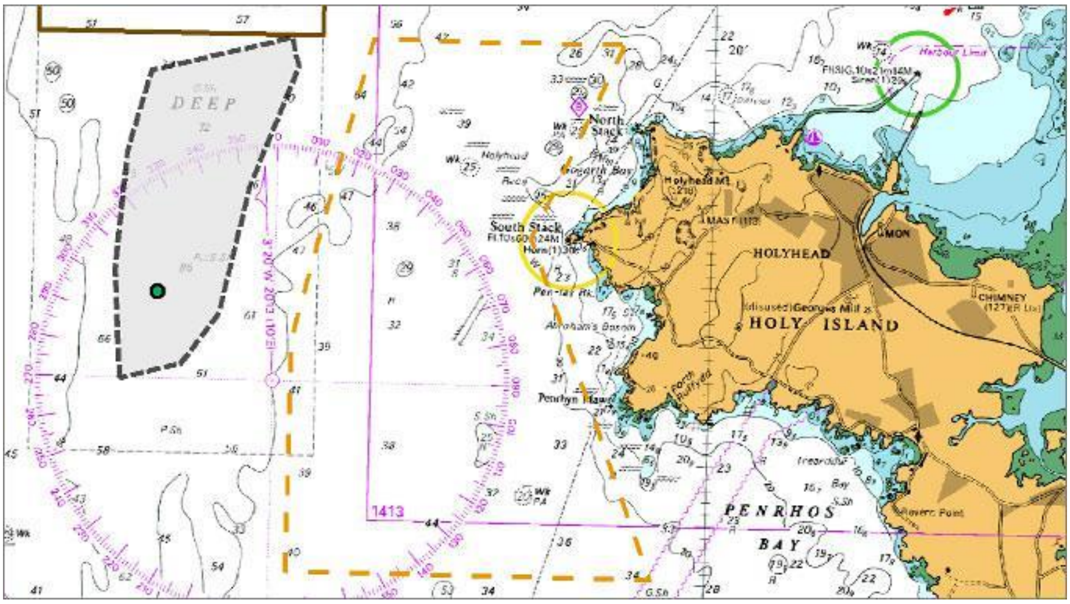


Figure 1: Tidal-stream development areas off Holy Island, West Anglesey. West Anglesey Demonstration Zone- yellow, Deep Green- black. Image taken from www.minesto.com.

This study stemmed from Welsh European Funding Office (WEFO) funds to conduct research within the WADZ, during which a series of pilot vessel-based surveys were conducted to establish preliminary marine mammal encounter rates and to assess methods of data collection at the site (Veneruso 2015).

Following relatively high rates of marine mammals and in particularly harbour porpoise detections, a R&D project was developed in SEACAMS2 in collaboration with WADZ site manager Morlais and Deep Green developer Minesto to expand on the pilot surveys. The aim of the study was to calculate local density estimates for harbour porpoises in the waters off Holy Island using a variety of field methods and model approaches.

Methodology:

Survey area and design

The survey site covers an area that includes the original WADZ boundaries, the Deep Green site as well as a buffer zone. A series of 10 zig zag transect lines were designed to provide even and maximum coverage of the survey area (Figure 2). Spacing between transect lines is approximately one kilometre. The orientation of the lines was designed so that transects cut across the predominant current direction as shown by a SEACAMS hydrodynamic model (Piano 2015) in order to minimise fluctuations in speed over ground caused by strong current speeds.

Surveys were conducted on days where Beaufort sea state was predominantly force two or less. These are known to be favourable conditions to collect visual data on harbour porpoise (*Phocoena phocoena*), the target species. The aimed intensity of surveys was one per month, where one to two transects were completed at an average speed of 10 knots. Surveys were conducted in all seasons.

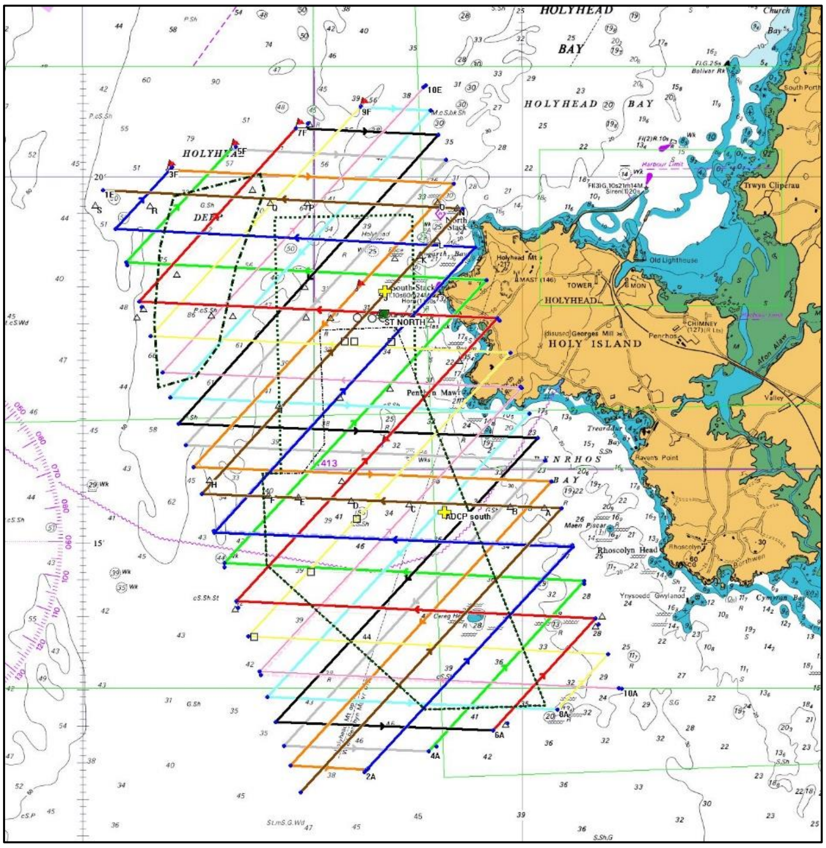


Figure 2: Transect lines designed to survey the area off Holy Island, West Anglesey. Each zig zag transect is represented by one colour.

Shipboard survey methods

Vessel

An 11 metre catamaran 'Seekat C' (Fig. 3) equipped with twin 280hp diesel engines was chartered for surveys. Two purpose-built platforms for up to four observers (two primary and two independent observers) were constructed on the roof of the vessel wheelhouse. The primary observer platform reaches an eye height of approximately 4.5 metres from the sea surface with slight fluctuations depending on observer height. The eye height of the independent observer platform is approximately 5.5 metres from the sea surface. A wind breaker between the two platforms is used during surveys allowing independence between observers.

For further details of the boat specification visit: http://seekatcharters.co.uk/vessel.html.

Figure 3: Survey vessel 'Seekat C'

Data collection

Visual

Methods to estimate density from shipboard surveys were based on standard line transect sampling protocol (Buckland *et al.* 2001; Hammond *et al.* 2002). Observers searched the study area recording all marine mammal species.

Two primary observers were positioned on the platform at all times during transects. Assuming that the transect line is at 0^{o} (the vessel's bow), each observer would scan with the naked eye from 90^{o} on their side of the vessel to 10^{o} on the other. The independent observer platform was positioned directly behind and approximately 1 m higher than the primary station. When independent observers were available, they scanned predominantly with binoculars focussing on detecting further away objects from 45º-10º.

A dedicated data recorder was assigned in the wheelhouse recording environmental and sightings data using software Logger 2010 (IFAW 2010). A system was developed to allow rooftop observers to timestamp detections in Logger remotely by pushing a button. This enabled the detection to be logged as quickly as possible, increasing accuracy of the original position of the animal, which is an important condition of distance sampling theory (Buckland *et al.* 2001). Primary observers would then communicate sightings information to the data recorder by radio. Independent observers would use the button to time-stamp detections in Logger but then record sightings by completing by hand a form so that primary observers were unaware of their sighting reports, allowing one-way independence. Once the animal had passed the beam of the vessel, independent observers would confirm with the primary observer if they had recorded the same animals and log these as duplicates or not. These independent observer records were later input into the Logger database.

The angle and distance of animals were estimated using 7X50 Opticron Marine-2 binoculars that include a compass and reticules. Reticule number (counting from the horizon) would later be converted into radial distance using the binocular's calibration and observer + platform height. Species ID, confidence of ID and group size was also recorded. Where possible behaviour, heading and any additional information was reported.

Logger also continuously logged GPS data which included positions and time, heading and speed over ground from a remote GPS unit. In addition, the data recorder would input environmental information every 15 minutes or when the conditions had changed. Such information included weather and sea conditions and the vessel's progress on the transect line.

Acoustic

A towed hydrophone system was purchased for use in this study consisting of two high frequency hydrophones with preamp and depth sensor. The system was towed from the stern of the vessel at 100 metres when surveying transects. The hydrophone system was connected by deck cable to a series of topside equipment allowing the transfer of audio (.wav) files to the PC hard drive via software PAMGuard (Gillespie *et al.* 2008). As well as the saved recordings, data could be viewed in real time including porpoise detections that were recognised using PAMGuard's automated click detector for the species. The equipment setup was customised to reduce electrical noise and unnecessary electronic equipment on the vessel was turned off to minimise interference.

The acoustic data collected is relatively self-sufficient and requires only that the data recorder check that the software is running normally, that data gathered looks appropriate and to replace laptop batteries.

Data Analysis

Visual

All observations were compiled and perpendicular distances of animals relative to the track line were calculated. Low certainty sightings were removed from further analyses. Harbour porpoise data were formatted into a data frame suitable for distance analysis which includes the survey area, number of kilometres of each completed transect leg, perpendicular distance of the sighting to the track line, group size of observations and associated covariates.

Distance analysis was performed in 'R' (R Development Core Team 2013) using the 'mrds' package (Laake *et al.* 2015; Miller 2015a). Full details of the analysis can be found at Buckland *et al.* 2001, 2004.

Multiple covariate distance sampling (MCDS) was used to generate density estimates from the primary observer data. This involves generating a detection function based on increasing distance from the track line which estimates the proportion of animals likely to be detected at a given range and including covariates that may influence this probability of detection. This value is then entered into Equation 1 to produce density estimates ($\widehat{D}$), where n is number of detections, $\hat{f}(0)$ the probability density function at distance zero, and L is total transect length.

$$\widehat{D} = \frac{n\hat{f}(0)}{2L} \qquad \text{eq. [1]}$$

Exploring the data for evidence of covariate influence on detection distance revealed which covariates should be included in the models. Detection function models were selected based on the lowest Akaike's Information Criteria (AIC) and goodness of fit. Additionally, a detection probability was calculated using the acoustic data for comparison. Density was not calculated from acoustic data since 55% of detections could not be localised to provide estimations of distance.

MCDS includes only primary observer data and assumes that detection on the track line (i.e. at distance zero) is certain. Given that there are a number of conditions in which this assumption will not hold true such as animal availability, observer error and weather conditions, this could result in an under-estimation of density. To combat this the g(0); probability of detection at distance zero, was calculated and applied to the estimates.

To calculate g(0), sightings recorded from the independent observer platform were used as a set of binary trials to test the probability that the animals were also detected by primary observers using mark recapture distance sampling (MRDS, Borchers et al. 1998). A trial point independence model (see Burt *et al.* 2014 for a review of MRDS models) was selected to account for unmodelled heterogeneity that could induce correlation in detection probabilities and therefore bias. Although responsive movement could be anticipated for porpoises, it could not be detected in our visual dataset and therefore was not considered during model selection.

The probability that a group of animals at a given distance and given covariates was detected by the primary observers was modelled using a binary regression generalized linear model (GLM) and a 'logit' link function. The final model and inclusion of covariates was selected based on the lowest AIC and visual assessment.

The trial dataset is small relative to the complete primary platform survey coverage, therefore final densities from visual data were not generated using the MRDS analysis. Rather, the trial analysis was used to calculate the g(0) and applied as a multiplier (shown as $\hat{c}$) to update the density estimate generated by the MCDS analysis by assuming that the g(0) value was representative for the entire dataset (Equation 2). The coefficient of variation (cv) was updated to also include the g(0) (Equation 3).

$$\hat{D} = \frac{n\hat{f}(0)}{2L\hat{c}} \qquad \text{eq. [2]}$$

$$cv(\hat{D}) = \sqrt{\{\text{cv}(\text{n})\}^2 + \{\text{cv}[\hat{\text{f}}(0)]\}^2 + \{\text{cv}(\hat{\text{c}})\}^2} \qquad \text{eq. [3]}$$

Acoustic

Acoustic data were processed in PAMGuard Viewer where all porpoise events detected by the hydrophone were manually logged.

Additionally, where click trains with a clear direction have been recorded, the animal's position can be estimated using target motion analysis in PAMGuard. This is calculated by measuring the time of arrival difference that vocalisations reach each hydrophone. The result is an estimate of perpendicular distance of each animal from the track line which is necessary for distance sampling analysis. Group size was estimated by counting the number of definite zero-crossing points of click trains shown in the bearing-time display in PAMGuard, which represent animals crossing the beam of the hydrophone. This is commonly seen with high quality click trains since the vessel is moving faster than the expected swimming speed of animals. Where there were uncertainties about whether an animal crossed the beam, group size was recorded as one animal.

Localised detections were used for MRDS analysis as trials for primary observer sightings to estimate g(0). In order to match visual and acoustic detections, the expected time for the porpoise to come abeam of the hydrophone was calculated by using each distance between sightings ahead of the vessel to the hydrophone location, divided by speed of the vessel. Errors in the field including time of detection, distance estimation for both visual and acoustic and sighting bearing must be expected. Furthermore, animals are likely to be mobile between first observation and detection on the hydrophone which was situated 106m behind the observer platform. Therefore, we must include some buffer around the predicted time delay to incorporate possible movement and errors and avoid removing true duplicates (see Appendix A7 for details of matching process). Once a time window was selected, visual and acoustic detections were matched and constructed into a series of binary trial data in the same format as for the visual MRDS analysis. Detections that were recorded within 2.5 minutes of each other were removed to reduce the risk of duplication between porpoise events.

A trial point independence model was selected for analysis. During the visual-acoustic matching process, there was evidence suggesting responsive movement. Trial configuration is recommended when movement is present (Burt et al. 2014). The benefits of this approach rely on trial observers searching for animals further away than the primary observers and the tracking of individuals in the field to increase certainty in classifying duplicates. However, the field methods did not allow for either of these criteria, crucially that the hydrophone detects animals after they have passed primary observers. Full independence models can be used to mitigate against responsive movement since they only use duplicate data to model the detection probability. However, full independence models were run during this analysis but resulted in poor fit and are therefore not discussed further.

Since acoustic detections were detected behind the vessel and therefore after the primary observers, an attempt to run a model using acoustic data as observer 1 and primary observers as trials was conducted. This however also resulted in poor fit, most likely because acoustic detections at distance zero were lower than some detections at increasing distance (possibly due to animals avoiding the vessel or not vocalising when the boat is close, Figure 11) and was therefore deemed unsuitable and not presented in these results.

Results:

Eighteen surveys were completed totalling 25 transects, 884 km of effort on transects covering an area of 707km^2 (Table 1). All transects were repeated at least once to increase effort coverage. This resulted in a total of 142 sightings (Table 2, Figure 4) and 99 certain harbour porpoise detections whilst on transect that could be used for distance analysis. Bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*) and Atlantic grey seal (*Halichoerus grypus*) were also detected but not in high enough numbers to estimate densities (Table 2). Harbour porpoise group size ranged between 1 and 5 animals with a mean estimated group size of 1.53 (CV=0.07).

Table 1: Survey dates

Survey #	Survey date
1	22 Jan. 2015
2	10 Feb. 2015
3	10 Mar. 2015
4	19 Mar. 2015
5	09 Apr. 2015
6	08 May 2015
7	23 Jun. 2015
8	16 Jul. 2015
9	12 Aug. 2015
10	08 Sep. 2015
11	14 Oct. 2015
12	22 Mar. 2015
13	27 May 2016
14	02 Aug. 2016
15	17 Aug. 2016
16	10 Oct. 2016
17	21 Oct. 2016
18	02 Dec. 2016

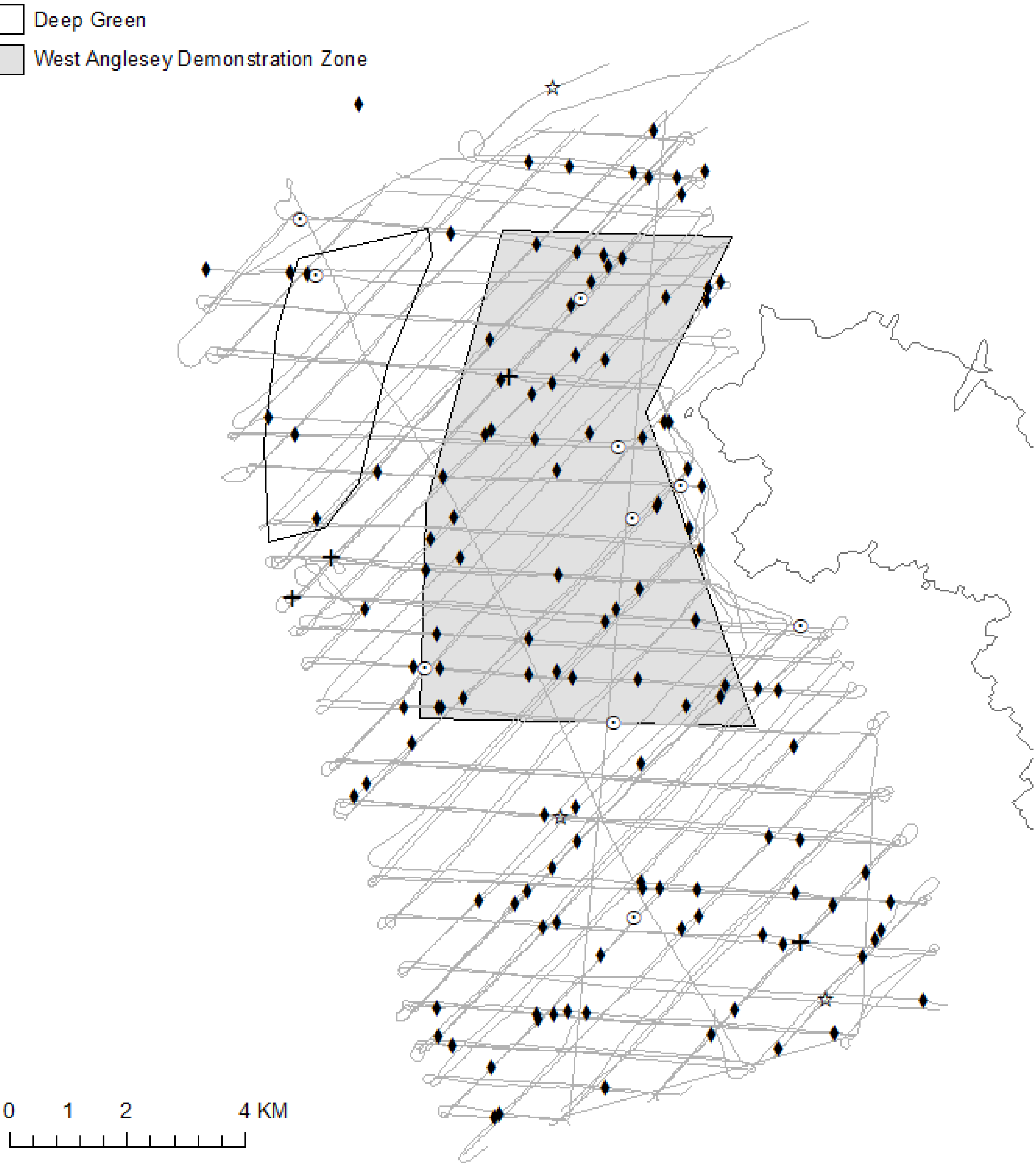
Table 2: All primary and independent observer sightings recorded removing duplicates during vessel-based surveys.

Species	Number of sightings
Harbour porpoise	125
Bottlenose dolphin	3
Risso's *dolphin*	4
Atlantic grey seal	10
Total	142

Visual sightings

Deep Green

West Anglesey Demonstration Zone



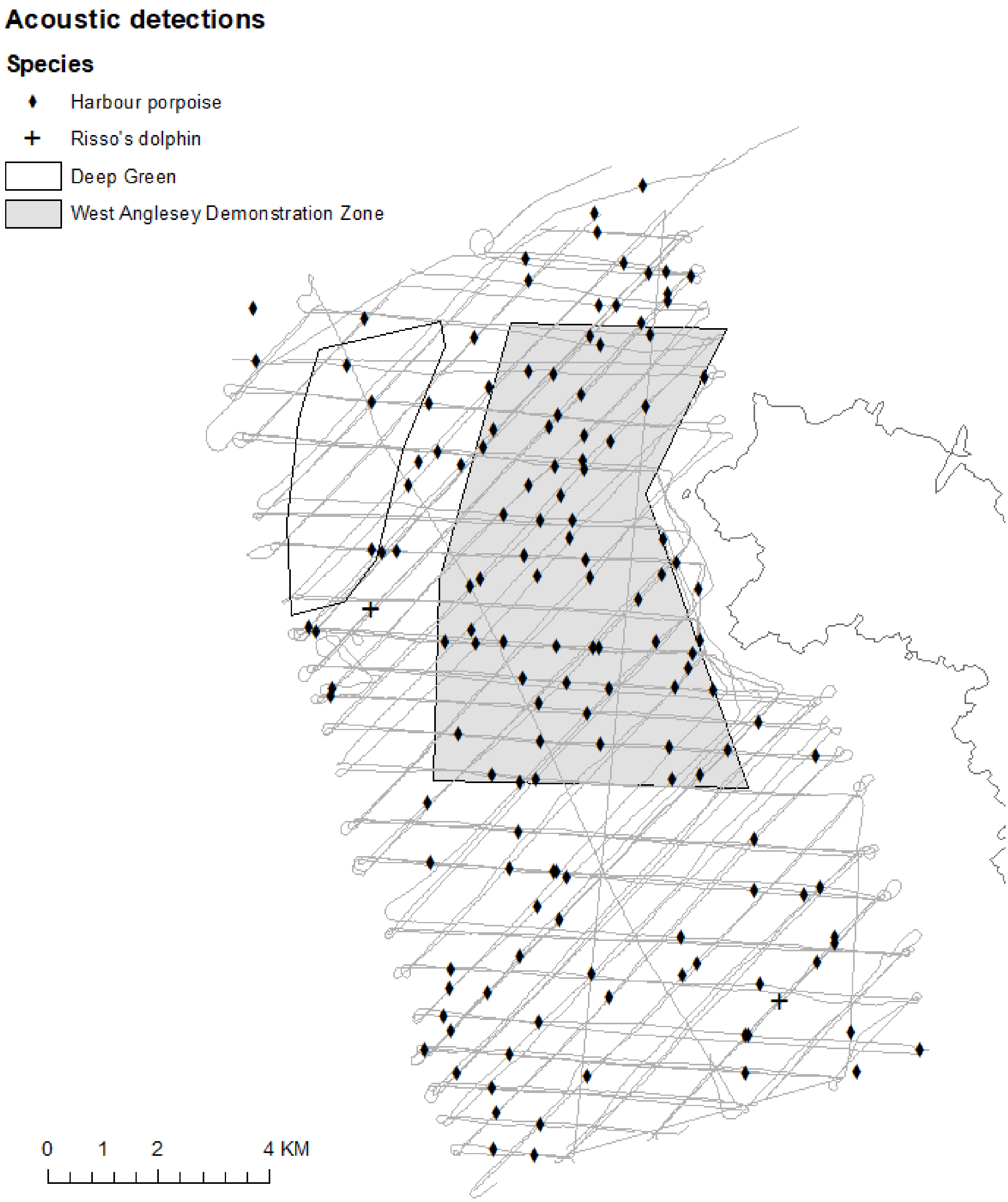


Figure 4: Visual and acoustic detections from the vessel during line transect surveys.

Density estimation:

For the visual sightings analysis, data were truncated at 400 m perpendicular distance. The final model selected for detection probability was a hazard-rate key function that included sea state as a covariate (Figure 5), resulting in a detection probability of 0.49 (Appendix A1, A2). Density estimates for the study site were 0.28 groups of animals per km^2 and 0.43 individuals per km^2 (Table 6, Appendix A3).

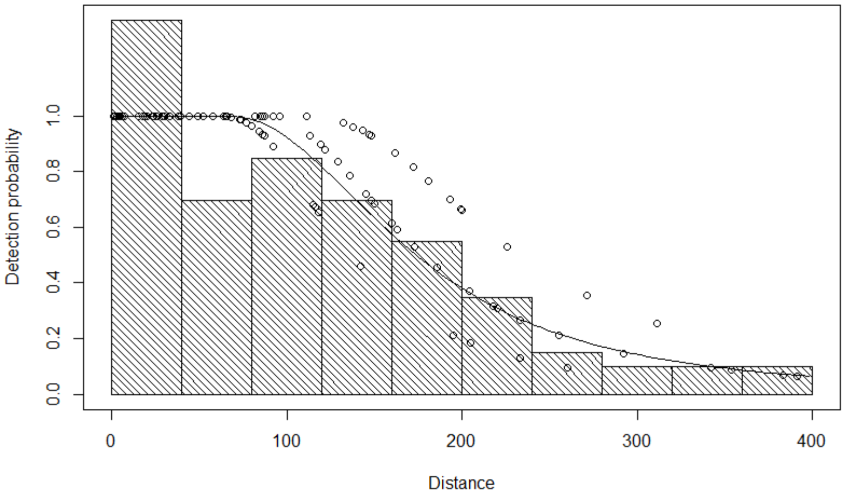


Figure 5: Perpendicular distances to harbour porpoises to the track line, fitted to a multiple covariate distance sampling model with a hazard-rate key function (solid line). Dots are the estimated detection probability for individual detections (low to high sea state from top to bottom).

In comparison, a detection function was calculated using towed hydrophone data as a single ‘observer’. Fifty-five percent of acoustic detections could not be reliably localised to obtain distance from the track line and were therefore removed, leaving 49 detections to be used for analysis. A MCDS half-normal cosine model including sea state was selected producing a detection function of 0.38 (Figure 6, Appendix A4). Due to the removal of acoustic data that could not be localised, density was not extrapolated for the study area.

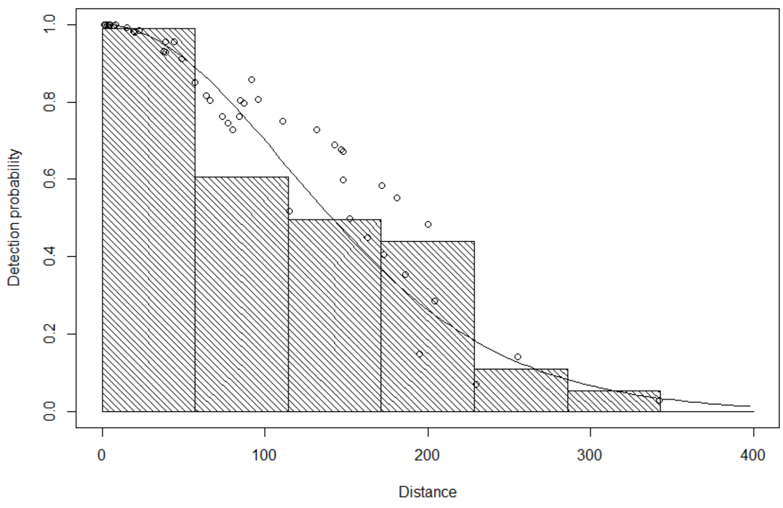


Figure 6: Perpendicular distances of harbour porpoises to the hydrophone beam (track line) using acoustic data, fitted to a multiple covariate distance sampling model with a half-normal cosine function (solid line) including sea state. Dots are the estimated detection probability for individual detections (low to high sea state from top to bottom).

Estimating g(0) using independent observer visual data

Using MRDS and the trial configuration for primary and independent observer data, the final mark-recapture model selected included distance, cloud cover and group size as covariates. A model including distance from the track line and cloud cover provided the lowest AIC (Figures 6 & 7, Appendices A5, A6); however, including group size increased the AIC by just 0.13 and had a relatively large influence on the detection function compared to the other variables (Table 3). Group size has the potential to increase detectability of small cetaceans and so it was decided to keep this variable in the final model. Of the 66 sightings from primary and independent observers that could be used for trial configuration, 54 were detected by the primary and 23 of these were duplicates (Table 4, Figure 8). These figures generated an estimated detection probability on the transect line (g(0)) for primary observers of 0.61 (CV=0.28). By using g(0) as a multiplier the updated density estimates for groups were 0.468 km^2 (CV=0.32) and for individuals 0.812 km^2 (CV=0.33) (Table 6).

Table 3: Conditional detection function parameters

	Coefficient	Standard error
Intercept	-1.701	1.248
Perpendicular distance	-0.003	0.004
Cloud	0.029	0.013
Group size	0.840	0.688

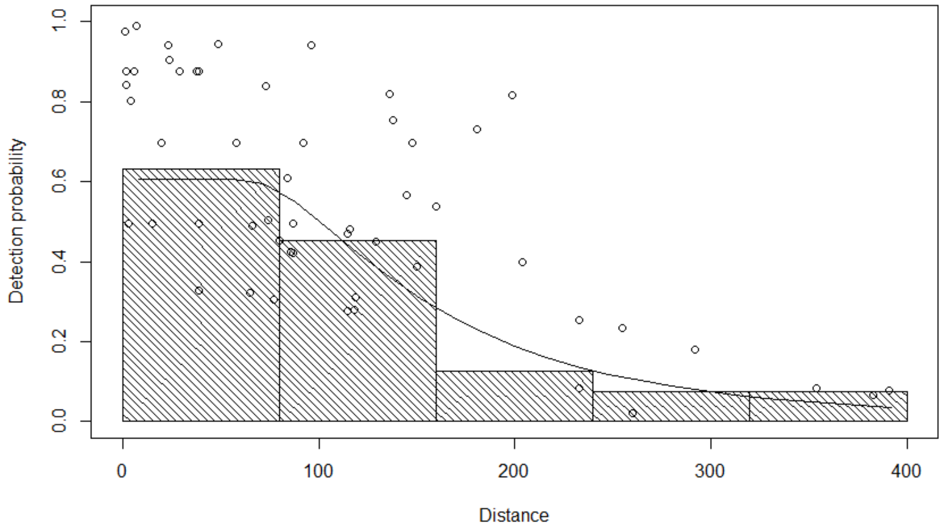


Figure 6: Perpendicular distance distribution of primary observer sightings fitted to a mark recapture distance sampling model. Dots are the estimated detection probability for individual detections.

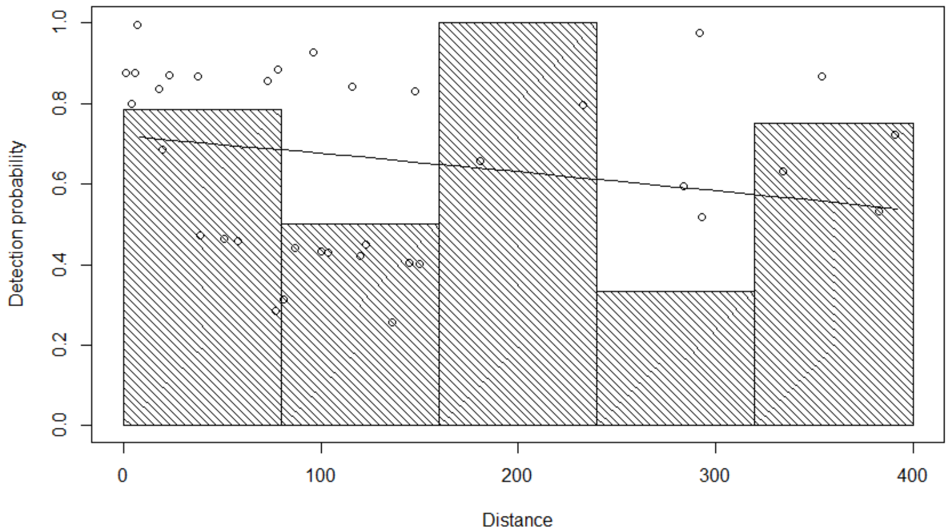


Figure 7: Distribution of the conditional detection probability of primary observers based on trials using a mark recapture distance model. Dots represent the predicted detection probability for individual detections.

Table 4: Data summary of primary and independent observations considered for trial configuration

Number of observations	66
Number seen by primary observers	54
Number seen by independent observers	35
Number seen by both observers (duplicates)	23

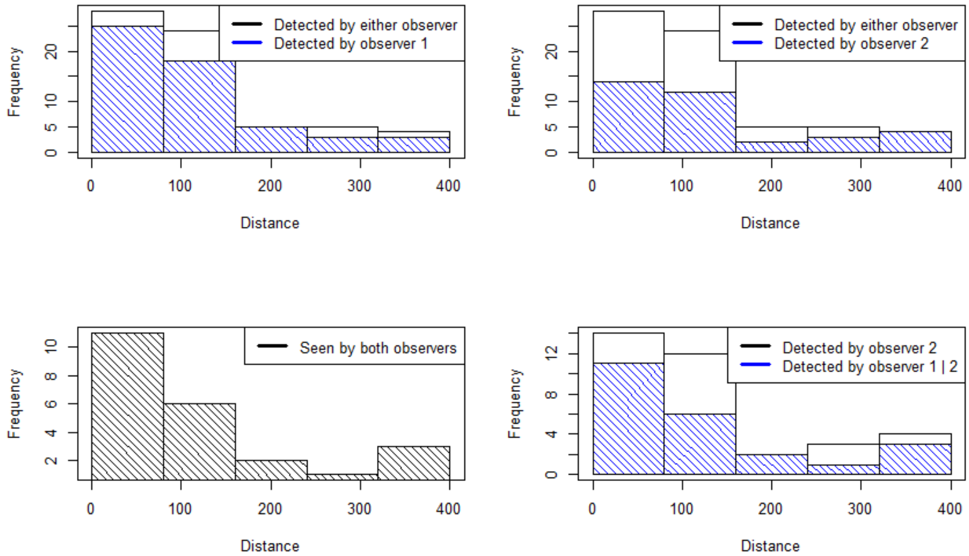


Figure 8: Frequency distributions of the perpendicular distances of primary detections (detections from the primary observers), trials (independent observers) and duplicates, and the conditional primary detections based on trials.

Estimating g(0) using towed hydrophone acoustic data

A total of 92 observations were considered for MRDS trial analysis of primary observers using acoustic data (Table 5). Fifty-five percent of the 126 acoustic detections could not be localised using target-motion analyses to obtain a distance from the track line; these and associated visual records were therefore discarded (Appendix A7). Duplicates were identified as detections that fell between 30s before and 100s after the time expected for animals to arrive at the hydrophone beam. This error allows for a degree of animal movement between observer datasets and potential inaccuracies in distance estimation (Appendix A8).

Table 5: Trial configuration data summary of primary observer and acoustic detections

Number of observations	92
Number seen by primary observers	49
Number of localised acoustic detections	64
Number seen by both observers (duplicates)	21

MRDS data were truncated at 400m. The model with the lowest AIC and best fit was a MCDS hazard rate function including group size and sea state, and a mark-recapture trial configuration with point independence including distance and sea state as covariates. A GLM with logit function was selected based on suitability, AIC and goodness of fit (Figures 8-10, Appendices A9, A10). Estimated detection probability on the track line g(0) was 0.51 (CV=0.26). Updated density estimates were 0.558 (CV=0.30) for groups and 0.852 (CV=0.31) for individuals (Table 6).

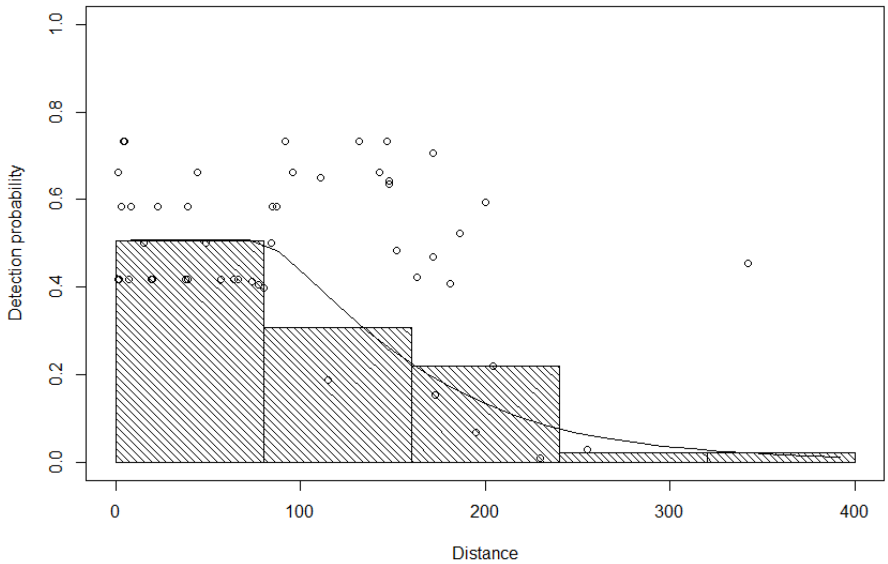


Figure 8: Perpendicular distance distribution of primary observer detections fitted to a mark recapture distance sampling model using acoustic data as Observer 2. Dots are the estimated detection probability for individual detections.

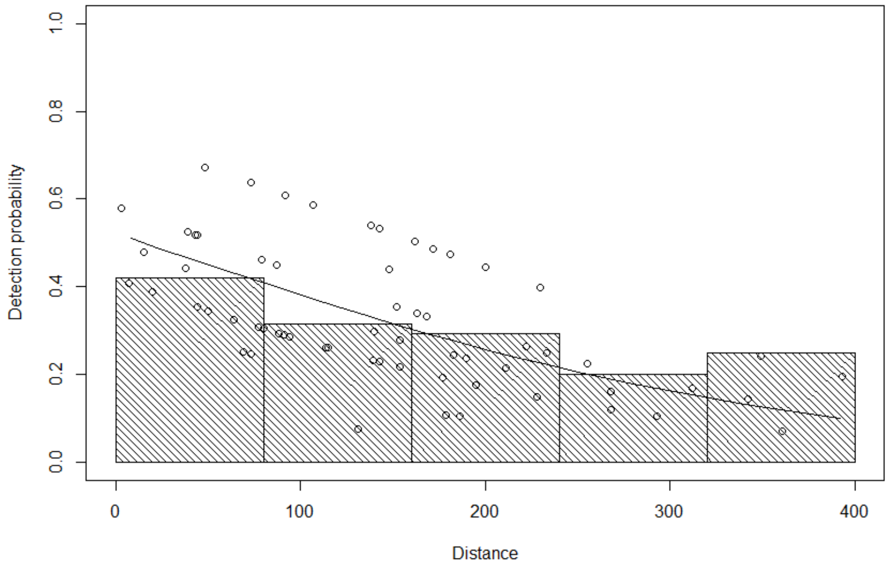


Figure 9: Conditional detection probability of primary observers based on trials of acoustic detections using a mark recapture distance model. Dots represent the predicted detection probability for individual detections

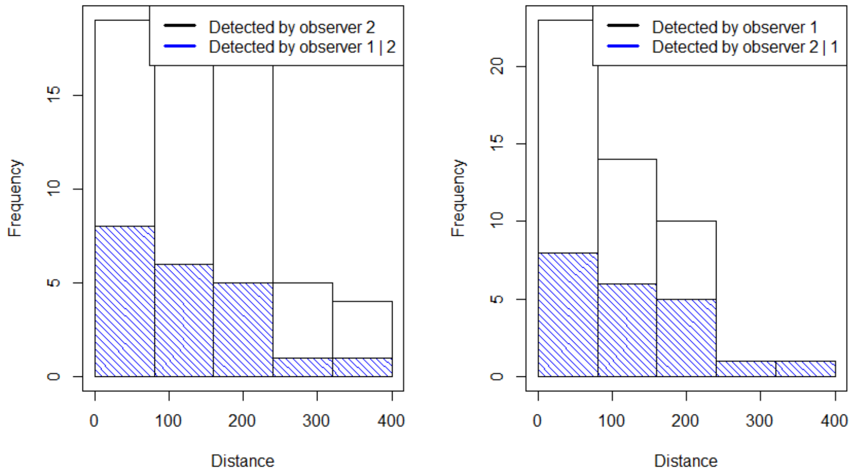


Figure 10: Frequency distributions of the perpendicular distances of primary observations (observer 1) and acoustic detections (observer2) based on trials.

There was evidence that porpoises avoided the vessel, shown by a predominant delay in the time that animals were expected to reach the hydrophone from the original sighting, based on mean vessel speed. (Appendix A8). Distance sampling assumes that animals do not move and there is no ideal model that could successfully deal with responsive movement post-data collection and therefore it is possible that the detection probability and therefore g(0) is biased by responsive movement and should be treated with caution.

An additional analysis was conducted using acoustic data as observer 1 and primary observer as observer 2, so that detections recorded in front of the vessel and potentially prior to responsive movement (or at least to a lesser extent) would serve as the trials. However, all models resulted in poor fit and are therefore not presented further.

Table 6: Number of sightings (n), encounter rate (ER), density of groups (D_G), animal density (D) (unit per km^2) estimates of harbour porpoises off Holy Island using g(0)=1, g(0)= 0.61 as calculated from independent observer trials and g(0)= 0.51 from acoustic data.

	n	ER	CV(ER)	D_G (95% CI)	CV(D_G)	D (95% CI)	CV(D)
g(0)=1	99	0.112	0.12	0.284 (0.208-0.388)	0.15	0.434 (0.306-0.614)	0.18
g(0)=0.61	99	0.112	0.12	0.468	0.32	0.714	0.33
g(0)=0.51	99	0.112	0.12	0.558	0.30	0.852	0.31

Discussion of methods

Primary observer data- MCDS

The primary observer data provided a relative estimate of density with a low error margin. The similarity between the detection function with increasing distance for primary observers and acoustic data suggests that the primary observer method is relatively accurate; however this approach assumes certain detection on the track line which is highly unlikely for cetaceans due to availability bias and observers missing detections.

Primary & independent observer data- MRDS

In order to estimate the proportion of animals detected on the trackline (g(0)), independent observers situated behind and approximately one metre above primary observers recorded all detections that were used as a series of trials to test the proportion of detections matched and missed by the primary observers.

No responsive movement was detected between observers, most likely because independent observers were elevated at just one metre higher than primary observers, resulting in a limited ability to focus on animals further away. This was mediated by predominantly observing through binoculars however data did not suggest that independent observers consistently detected animals at further distance. It could be that animals do not respond to vessels at the distances recorded ahead of the vessel, or it may be possible that the field setup did not allow sufficient opportunity to detect responsive movement at this range.

Observers were both visual and therefore shared the same detection cues. In general, this is favourable compared to observers with different detection capabilities and methods of distance estimation (such as visual vs. acoustic). Unmodelled heterogeneity (dependency of detection cues between observers) can be a problem, however the point independence model was created to deal with this bias and therefore is not considered an issue in this case.

A disadvantage of this approach is that the independent observer dataset was small with 35 detections of which 23 were duplicates.

Primary & acoustic data- MRDS

Acoustic methods are highly suitable for collecting data on harbour porpoise as they are thought to vocalise very regularly and can be challenging to view at the sea surface due to small size and discrete nature. However, for data to be applied to distance sampling, vocalisations need to be localised to obtain an estimated distance from the track line. In this study, a substantial number of detections could not be reliably localised and had to therefore be discarded resulting in a significant loss of data.

Acoustic data were used as trials against primary observers to estimate the g(0). Determining matches between observers is challenging and likely to be more error-prone than the matching protocol used between visual observers. However, in this study, predicted time delays incorporating potential animal movement matched relatively well to the data and therefore should provide confidence in this matching protocol.

In species where responsive movement is expected, towed hydrophone data may not be suitable as the trial observer, since current distance sampling models assumes animals do not move and will calculate a detection function and g(0) that also incorporates avoidance behaviour in this case. Attempts to 'reverse' the observers so that primary observations served as trials for acoustic detections was not successful. This is most likely because acoustic detections did not decrease with increasing distance from the track line (Figure 11). This may be explained by animals avoiding the vessel and since porpoise vocalisations are highly directional, if animals are orientated away from the vessel and thus the hydrophone, the probability of detection will be lower. Lastly, boat noise may mask some detections when animals are close to the vessel. These differences in detection probabilities and cues compared with visual observations can be a limitation when using this approach. However, it is encouraging that the g(0) estimate for the primary observer is comparable to that estimated using independent observers as trials.

A clear advantage of using a towed hydrophone system is in scenarios where it is not possible to house independent observers on a vessel, perhaps due to the absence of a suitable platform or limited funds/space to staff extra observers. This is particularly valid when working with smaller vessels, which are often much more accessible in terms of cost and availability. Another key advantage of using a small vessel as demonstrated in this study, is the logistics and flexibility of daily charters which can survey at short notice making the best of weather windows and reducing the time at sea in unsuitable conditions.

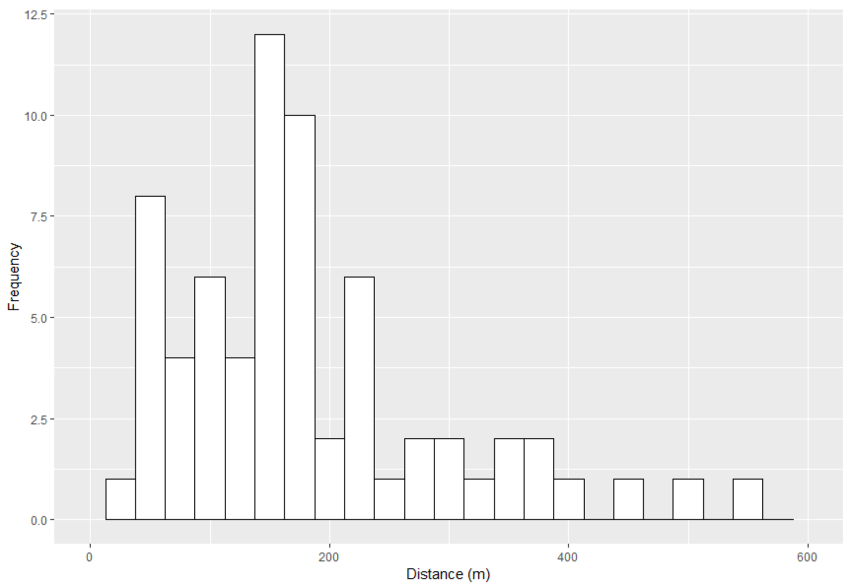


Figure 11: Distribution of distances of harbour porpoises estimated by acoustic data.

Conclusion

In summary, a range of relative and absolute density estimates have been calculated for harbour porpoises off Holy Island, Anglesey. Relative density of individuals is estimated to be 0.43 animals per km^2 (CV=0.18). Correcting for incomplete detection on the track line to compensate for under-estimation, density ranges from 0.714 (CV=0.33) to 0.852 (CV=0.33) individuals per km^2. This is higher than the SCANS-II estimates for the Irish Sea (density=0.335, CV=0.35) (Hammond *et al.* 2013). This survey was conducted close to the coast and in high energy waters, both of which are known to be preferred by harbour porpoise (e.g. Shucksmith *et al.* 2005), so it is not surprising that this area is more densely populated compared to the Irish Sea as a whole and illustrates the importance of obtaining local density estimates. In 2005, Shucksmith *et al.* produced relative density estimates for harbour porpoise off Holy Island. They estimated a significantly higher relative density of 1.267. This larger estimate may be explained by the fact that all surveys were conducted in peak season, during summer months. It may also reflect a decrease in animals in the 10 years since this data were collected or the fact that area surveyed was different, but further study would be required to confirm.

The various field methods and approaches to analyses have provided absolute values of density using a small vessel and relatively small budget. The study demonstrates that without a measure of the proportion of animals missed from the track line, the density of porpoises is significantly under-estimated. This report discusses the pros and cons of the various approaches taken. Implementing acoustic data as trials in particular requires some further study in order to be better suited to distance analysis. Despite these challenges, visual and acoustic trials have produced outputs of density that are within sensible range of each other and other local studies (Shucksmith *et al.* 2005; Hammond *et al.* 2013), suggesting consistency in these numbers.

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INVESTIGATING METHODS TO ESTIMATE HARBOUR PORPOISE (*Phocoena phocoena)* DENSITY OFF WEST ANGLESEY

APPENDICES

Veneruso, G., Bond, J., Piano, M.

January 2019

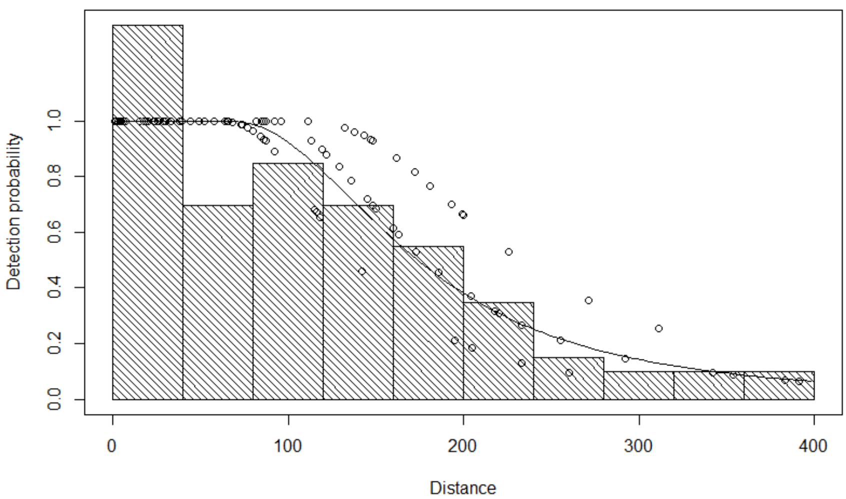
PROJECT SC2-RD-B26

Project partners:

Menter Môn & Minesto

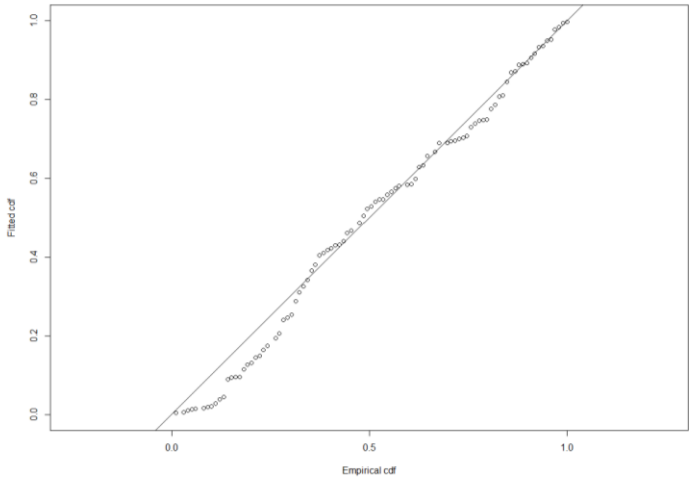
A1: Selected distance detection function model fitted including goodness of fit using multiple covariate distance sampling (MCDS) in the mark recapture distance sampling (MRDS) package in R.

```
Summary for ds object
Number of observations :  99
Distance range         :  0  -  400
AIC                    :  1132.021

Detection function:
 Hazard-rate key function

Detection function parameters
Scale coefficient(s):
                 estimate        se
(Intercept)     5.3243524 0.2034897
seastate.round -0.2666183 0.1469176

Shape coefficient(s):
            estimate        se
(Intercept)   1.0868 0.2362065

                       Estimate          SE        CV
Average p             0.4923468  0.05017802 0.1019160
N in covered region 201.0777928 25.18366148 0.1252434
```




```
Goodness of fit results for ddf object

Chi-square tests
             [0,40]    (40,80]    (80,120]    (120,160]    (160,200]   (200,240] (240,280] (280,
320]   (320,360] (360,400]     Total
Observed  27.000000 14.000000 17.00000000 1.400000e+01 11.00000000 7.00000000 3.0000000 2.000
0000 2.000000000 2.0000000 99.000000
Expected  19.969459 19.919278 17.86140012 1.392478e+01 10.09909132 6.72524828 4.3577613 2.862
1491 1.933624923 1.3472116 99.000000
```

```
Chisquare  2.475205  1.758992  0.04154267 4.063725e-04  0.08036728 0.01122464 0.4230419 0.259
7003 0.002278441 0.3163072  5.369066

P = 0.37252 with 5 degrees of freedom

Distance sampling Kolmogorov-Smirnov test
Test statistic =  0.093294  P =  0.35491

Distance sampling Cramer-von Mises test (unweighted)
Test statistic =  0.14835  P =  0.39463
```



A2: Table showing outputs of various detection function (P_a) models. Uniform and gamma key functions were also explored but were a poor fit, therefore only half-normal key function (hn) and hazard-rate (hr) model outputs are presented here. Adjustments were not deemed necessary due to model fit of key functions.

Data exploration (distance~covariate) was used to select covariates. Group size, sea state, swell and speed showed trends in the data and was therefore used in the detection probability models. The final model selected shown in bold was selected based on low AIC, simplicity and visual inspection of detection curve and goodness of fit.

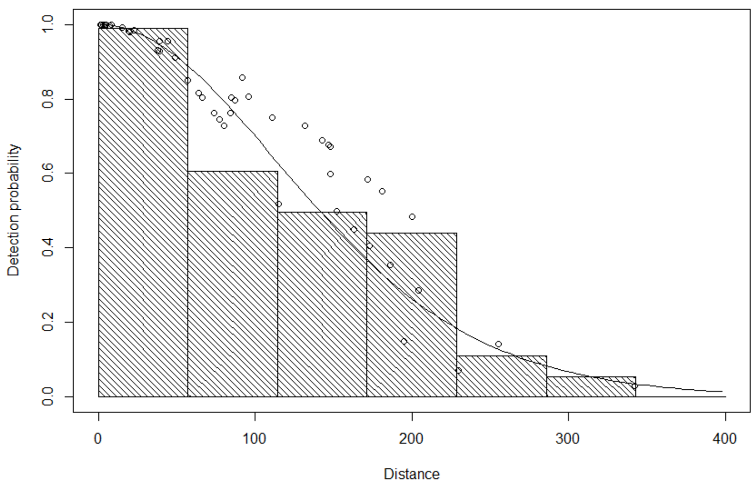
Object	Model	Formula	P_a	$CV(P_a)$	AIC
1	**hr**	**seastate.round**	**0.49**	**0.10**	**1132.02**
2	hr	seastate.round+size	0.50	0.10	1132.02
3	hn	seastate.round	0.47	0.07	1132.61
4	hn	seastate	0.47	0.07	1132.73
5	hn	seastate.round+size	0.46	0.07	1132.76
6	hn	1	0.48	0.07	1133.23
7	hr	seastate.round+swell	0.49	0.10	1133.85
8	hn	swell	0.47	0.07	1133.94
9	hr	size	0.51	0.09	1134.03
10	hn	seastate.round+swell	0.47	0.07	1134.60
11	hr	1	0.51	0.10	1134.87
12	hr	swell	0.51	0.09	1135.33
13	hn	size	0.47	0.07	1132.169

A3: Encounter rates, abundance and density estimates of primary observer data using a hazard-rate detection function model with seastate.

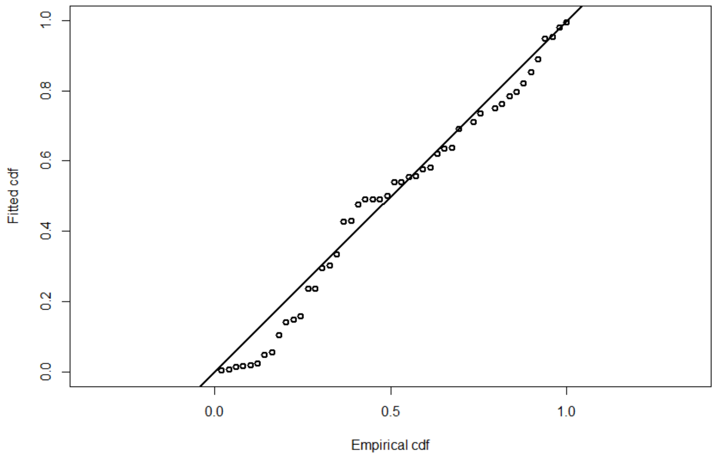
```
Summary for clusters

Summary statistics:
  Region Area CoveredArea   Effort  n  k       ER      se.ER    cv.ER
1      1  136    707.3197 884.1496 99 48 0.111972 0.01392215 0.124336

Abundance:
  Label Estimate       se        cv      lcl      ucl       df
1 Total 38.66226 6.137819 0.1587548 28.27985 52.85638 108.2756

Density:
  Label  Estimate         se        cv       lcl       ucl       df
1 Total 0.2842814 0.04513102 0.1587548 0.2079401 0.3886498 108.2756

Summary for individuals

Summary statistics:
  Region Area CoveredArea   Effort   n        ER      se.ER     cv.ER mean.size    se.mean
1      1  136    707.3197 884.1496 153 0.1730476 0.02568419 0.1484226  1.545455 0.08647179

Abundance:
  Label Estimate      se        cv     lcl      ucl       df
1 Total 59.00141 10.4138 0.1765008 41.6661 83.54915 91.74743

Density:
  Label  Estimate         se        cv       lcl      ucl       df
1 Total 0.4338339 0.07657205 0.1765008 0.3063683 0.614332 91.74743

Expected cluster size
  Region Expected.S se.Expected.S cv.Expected.S
1  Total   1.526072     0.1007174    0.06599776
2  Total   1.526072     0.1007174    0.06599776
```

A4: Selected distance detection function model fitted to acoustic data using multiple covariate distance sampling (MCDS) in the mark recapture distance sampling (MRDS) package in R.

```
Summary for ds object
Number of observations :  49
Distance range         :  0  -  400
AIC                    :  546.6208

Detection function:
 Half-normal key function

Detection function parameters
Scale coefficient(s):
             estimate        se
(Intercept)  5.112159 0.2757442
seastate    -0.252650 0.1921445

                       Estimate          SE         CV
Average p             0.3849374  0.03946137 0.1025137
N in covered region 127.2934311 19.45132587 0.1528070
```



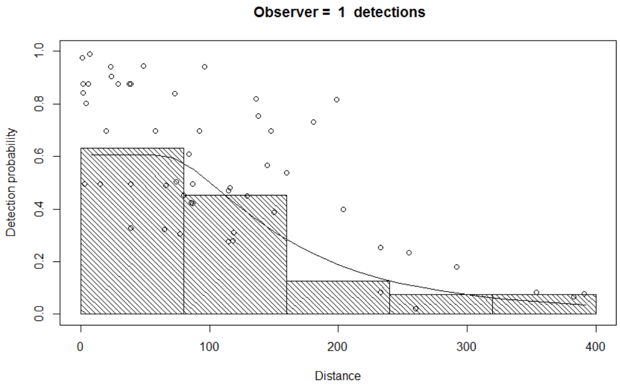

```
Goodness of fit results for ddf object

Chi-square tests
             [0,57.1] (57.1,114]    (114,171] (171,229]   (229,286]    (286,343] (343,400]
Total
Observed   18.00000000 11.0000000 9.000000e+00  8.000000 2.00000000 1.0000000000 0.0000000 49.
000000
Expected   17.49107757 13.9157476 8.975189e+00  4.866149 2.32261257 1.0152308215 0.4139936 49.
000000
Chisquare   0.01480767  0.6109326 6.858672e-05  2.018233 0.04481112 0.0002284977 0.4139936  3.
103076

P = 0.54073 with 4 degrees of freedom

Distance sampling Cramer-von Mises test (unweighted)
Test statistic = 0.0940969 p-value = 0.614595
```

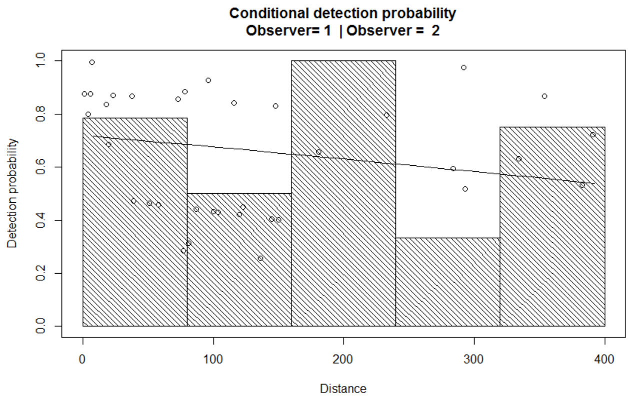


A5: Mark recapture distance sampling (MRDS) analysis using a trial configuration and point independence model to estimate the detection probability of primary observers on the trackline (g(0)) using independent observer data

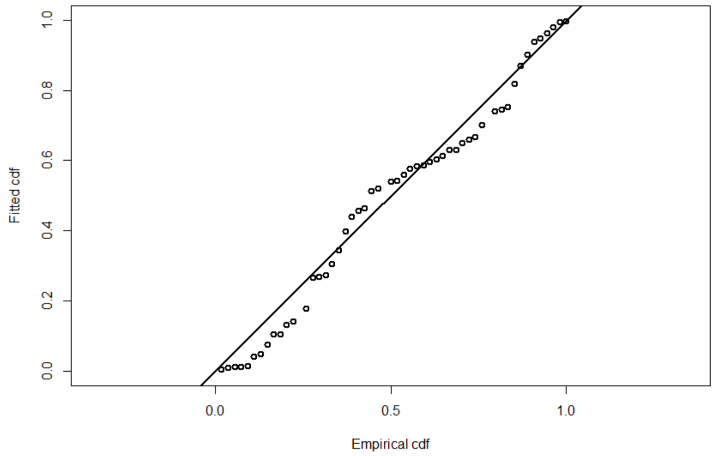
```
Summary for trial.fi object
Number of observations               :  66
Number seen by primary               :  54
Number seen by secondary (trials)    :  35
Number seen by both (detected trials):  23
AIC                                  :  45.01069


Conditional detection function parameters:
                estimate          se
(Intercept) -1.701408937 1.24804094
distance    -0.002569021 0.00367239
cloud        0.028256945 0.01341166
size         0.840241777 0.68756651

                      Estimate        SE        CV
Average primary p(0) 0.6072328 0.1692484 0.2787208



Summary for ds object
Number of observations :  54
Distance range         :  0  -  400
AIC                    :  614.1006

Detection function:
 Hazard-rate key function

Detection function parameters
Scale coefficient(s):
                 estimate        se
(Intercept)     5.6267504 0.4019097
seastate.round -0.4752425 0.2544600

Shape coefficient(s):
            estimate        se
(Intercept) 1.092473 0.2870201

          Estimate         SE        CV
Average p 0.4487522 0.06908879 0.1539575


Summary for trial object

Total AIC value =  659.1113
                       Estimate          SE        CV
Average p             0.2724971  0.08790753 0.3225999
```

```
N in covered region 198.1672641 68.36408052 0.3449817
```

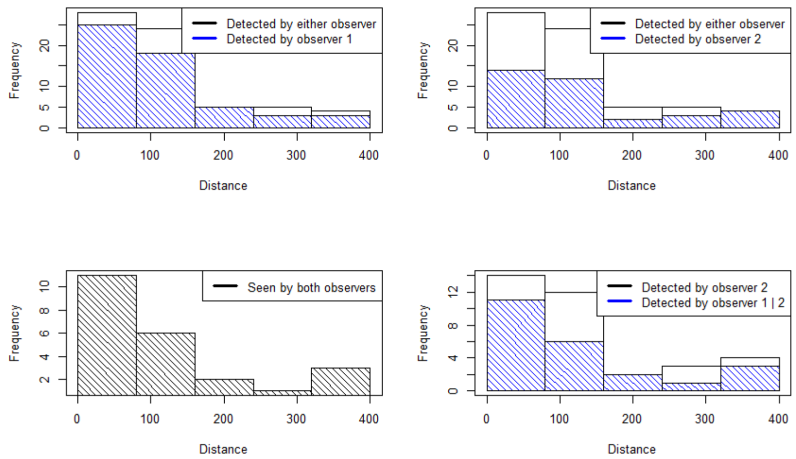





```
Goodness of fit results for ddf object

Chi-square tests

Distance sampling component:
               [0,80]    (80,160] (160,240] (240,320] (320,400]     Total
Observed  25.00000000 18.0000000 5.0000000 3.0000000 3.0000000 54.000000
Expected  23.94372875 16.8730154 7.7046668 3.6072480 1.8713411 54.000000
Chisquare  0.04659713  0.0752737 0.9494534 0.1022248 0.6807263  1.854275

P = 0.17329 with 1 degrees of freedom

Mark-recapture component:
Capture History 01
             [0,80]    (80,160] (160,240] (240,320] (320,400]     Total
Observed  3.0000000 6.00000000 0.0000000 2.0000000 1.0000000 12.000000
Expected  3.4096721 5.64413009 0.5458539 0.9745725 1.4257715 12.000000
Chisquare 0.0492221 0.02243807 0.5458539 1.0789363 0.1271461  1.823597
Capture History 11
               [0,80]    (80,160] (160,240] (240,320]  (320,400]      Total
Observed  11.00000000 6.00000000 2.0000000 1.0000000 3.00000000 23.0000000
Expected  10.59032792 6.35586991 1.4541461 2.0254275 2.57422852 23.0000000
Chisquare  0.01584759 0.01992542 0.2049013 0.5191505 0.07042162  0.8302464

MR total chi-square = 2.6538  P = 0.1033 with 1 degrees of freedom


Total chi-square = 4.5081  P = 0.10497 with 2 degrees of freedom

Distance sampling Cramer-von Mises test (unweighted)
Test statistic = 0.113192 p-value = 0.523993
```




```
Observer 1 detections
           Detected
            Missed Detected
  [0,80]         3       25
  (80,160]       6       18
  (160,240]      0        5
  (240,320]      2        3
  (320,400]      1        3

Observer 2 detections
           Detected
            Missed Detected
  [0,80]        14       14
  (80,160]      12       12
  (160,240]      3        2
  (240,320]      2        3
  (320,400]      0        4

Duplicate detections

   [0,80]  (80,160] (160,240] (240,320] (320,400]
       11         6         2         1         3

Observer 1 detections of those seen by Observer 2
          Missed Detected Prop. detected
[0,80]         3       11      0.7857143
(80,160]       6        6      0.5000000
(160,240]      0        2      1.0000000
(240,320]      2        1      0.3333333
(320,400]      1        3      0.7500000
```



A6: Table showing outputs of MRDS trial point independence models using independent observer data as trials. Final model selection shown in bold was selected based on low AIC, evaluation of coefficients and visual inspection.

Object	DS.Model	ds.formula	mrds.formula	g(0)	CV(g(0))	N.covered	Total.AIC
1	hr	seastate.round	distance+cloud	0.63	0.25	191	658.97
2	**hr**	**seastate.round**	**distance+cloud+size**	**0.61**	**0.28**	**198**	**659.11**
3	hr	seastate.round	distance+cloud+glare	0.69	0.22	175	659.66
4	hr	seastate.round	distance+cloud+seastate.round	0.64	0.25	188	660.91
5	hr	seastate.round	distance+cloud+speed	0.64	0.26	188	660.95
6	hr	seastate.round	distance+glare	0.70	0.18	171	662.12
7	hr	seastate.round	distance+size	0.66	0.20	182	662.44
8	hr	seastate.round	distance	0.69	0.17	173	662.94
9	hr	seastate.round	distance+speed	0.70	0.17	171	664.50
10	hr	seastate.round	distance+seastate.round	0.69	0.17	174	664.89

A7: Table of total visual and acoustic detections

Total no. observations	204
No. visual observations	78
No. acoustic detections	126
No. localised acoustic detections	68
No. observations used for distance sampling	92

A8: Matching visual and acoustic detections

Primary observer sightings were matched with acoustic detections based on the expected time delay that each sighting would arrive at the hydrophone beam. A number of errors are expected that would cause deviations from the predicted time delay, including:

Possible error	Mediation
Estimates of observer time of detection, distance & bearing	- During data collection observers used a sighting button that automatically produced a timestamp and position of first detection to increase accuracy. - Observations where the sighting button malfunctioned and therefore timestamp was delayed were removed from analysis. - A compass and reticules were used to estimate bearing and distance but there is no measure of the degree of error and therefore no mediation was possible.
Observer does not detect first surfacing of animals within truncation width	None
Target motion analysis distance error	- Errors were documented and reviewed. Any large outliers were removed from analysis. - Click trains of a minimum of seven clicks were used for target motion analysis.
Animal movement between observers	- predicted time caused by movements towards and away from vessel were calculated.

Animal movement:

An average harbour porpoise swim speed of 2 ms-1 (estimated from SCANS-II) was used to calculate the maximum expected time that animals could arrive at the hydrophone if they were to swim either directly away from the vessel or towards it. The average distance of sightings recorded in front of the vessel (136m), length between observers and hydrophone (106m) and average speed of vessel across all observations (9.3kn.) were used to calculate the expected time delays. If a porpoise were to swim directly away from the vessel the animal would arrive at the hydrophone 86s after the predicted time delay. If an animals were to swim directly towards the vessel the expected time to come abeam of the hydrophone is 21s before the expected time delay. These estimates seem to be represented in the data (Fig. A8.1, A8.2).

The allowable error around the predicted time delay was based on the animal movement estimates, consideration of distance error (mean target motion analysis distance error was the equivalent to 20s travelling at mean speed) and visual inspection of the distribution of data. The final allowable error selected was 30s before the predicted time delay and 100s after.

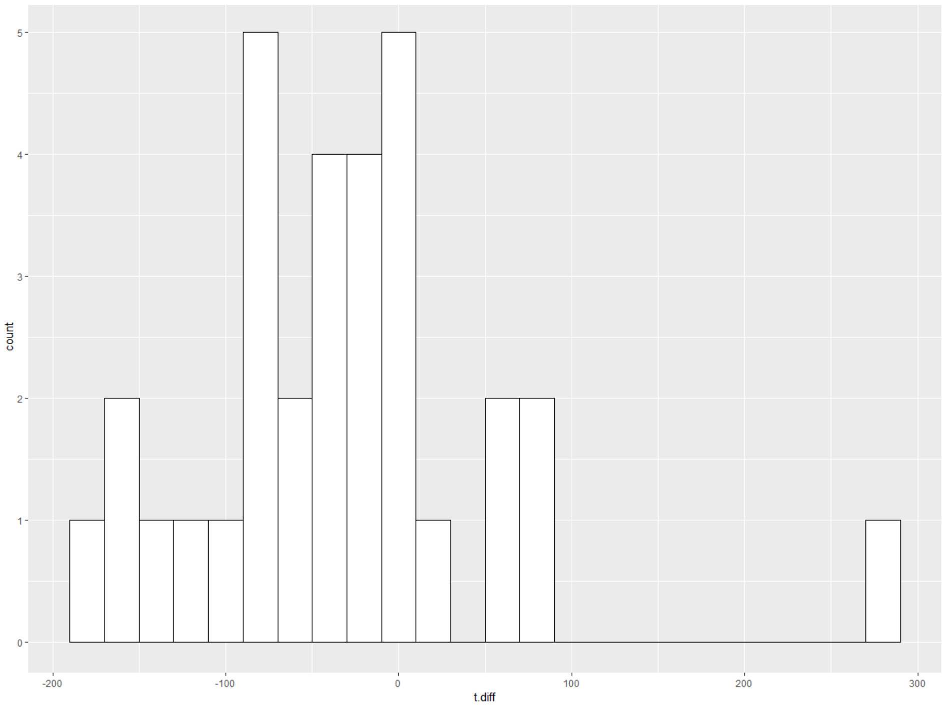


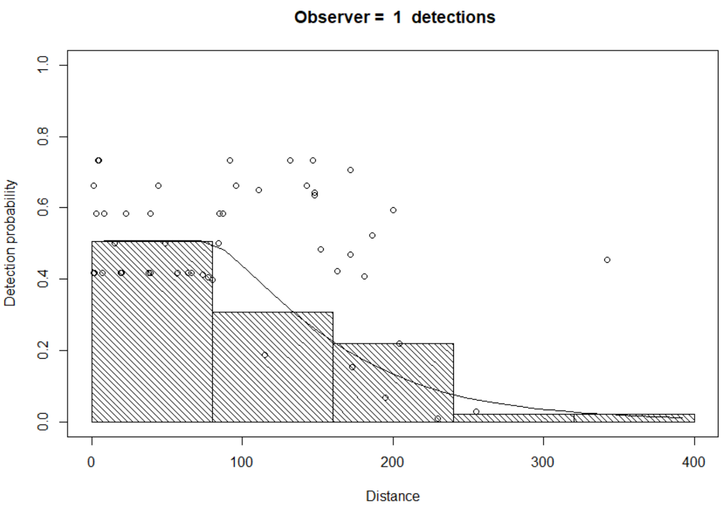
Figure A8.1: Distribution and frequency of the time difference between predicted time to reach abeam of the hydrophone and actual estimated time of arrival. Negative values represent the number of seconds after the predicted time delay, positive values represent detections that occurred before the expected time.

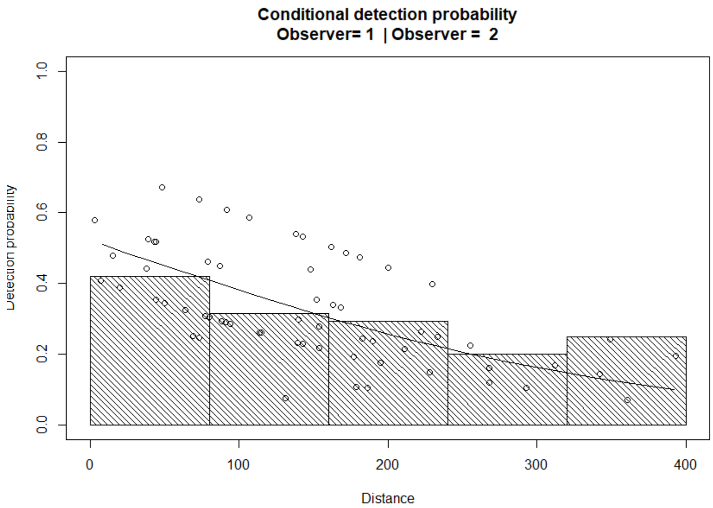
Figure A8.2: Cumulative frequency distribution of the proportion of trials detected with increasing difference from time that animals were predicted to reach Observer 2 (hydrophone). Yellow- no. seconds after predicted time. Grey- no. seconds before predicted time.

A9: Mark recapture distance sampling (MRDS) analysis using a trial and point independence model to estimate the detection probability of primary observers on the trackline (g(0)) using towed hydrophone data.

```
Summary for trial.fi object
Number of observations              :  92
Number seen by primary              :  49
Number seen by secondary (trials)   :  64
Number seen by both (detected trials):  21
AIC                                 :  80.33464


Conditional detection function parameters:
                estimate          se
(Intercept)  1.010307453 0.743286318
distance    -0.006166516 0.003393457
seastate    -0.671001986 0.340482726

                     Estimate        SE        CV
Average primary p(0) 0.509221 0.1303712 0.2560208



Summary for ds object
Number of observations :  49
Distance range         :  0  -  400
AIC                    :  544.9591
```

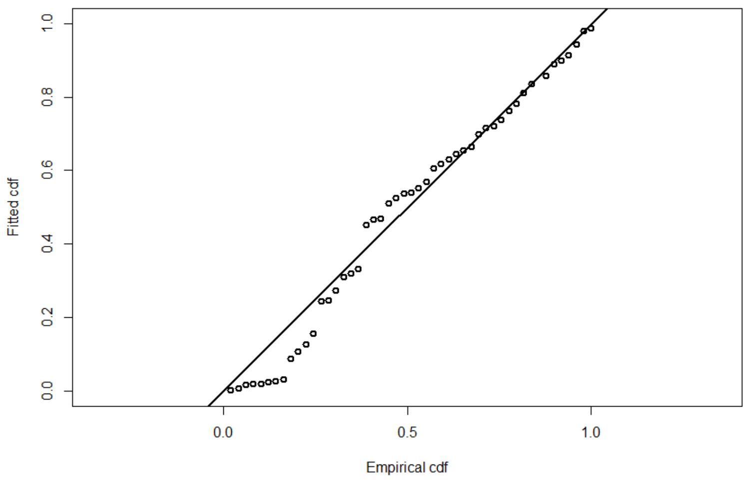
```
Detection function:
 Hazard-rate key function

Detection function parameters
Scale coefficient(s):
              estimate        se
(Intercept)  4.8939384 0.3083799
size         0.2585370 0.1354624
seastate    -0.2608356 0.1595583

Shape coefficient(s):
             estimate        se
(Intercept) 1.499894 0.3251845

           Estimate          SE        CV
Average p 0.4234716 0.04822876 0.113889


Summary for trial object

Total AIC value =  625.2937
                        Estimate          SE        CV
Average p              0.2156406  0.06150952 0.2852408
N in covered region 227.2298890 71.33007031 0.3139115
```





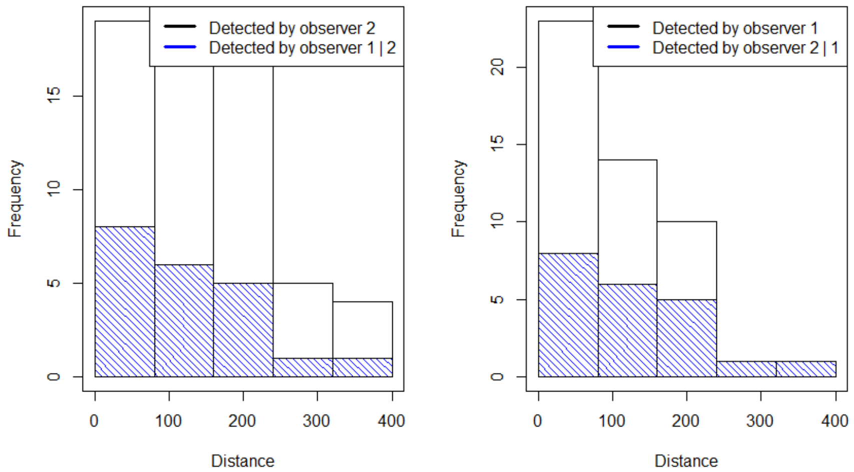

```
Goodness of fit results for ddf object

Chi-square tests


Distance sampling component:
                [0,80]    (80,160]  (160,240]  (240,320]  (320,400]      Total
Observed  2.300000e+01 14.0000000 10.000000  1.000000 1.00000000 49.000000
Expected  2.311801e+01 16.4777563  6.359037  2.196449 0.84875092 49.000000
Chisquare 6.023756e-04  0.3725796  2.084689  0.651729 0.02695288  3.136553

No degrees of freedom for test

Mark-recapture component:
Capture History 01
```

```
                [0,80]    (80,160]    (160,240]  (240,320]  (320,400]       Total
Observed  11.000000000 13.00000000 12.000000000 4.00000000 3.00000000 43.00000000
Expected  10.892258496 12.47029883 12.075969147 4.21669299 3.34478041 42.99999987
Chisquare  0.001065732  0.02250013  0.000477917 0.01113571 0.03554001  0.07071949
Capture History 11
               [0,80]   (80,160]  (160,240]  (240,320] (320,400]      Total
Observed  8.000000000 6.00000000 5.00000000 1.00000000 1.0000000 21.0000000
Expected  8.107741504 6.52970117 4.92403085 0.78330701 0.6552196 21.0000001
Chisquare 0.001431747 0.04297032 0.00117207 0.05994565 0.1814255  0.2869453

MR total chi-square = 0.35766  P = 0.83625 with 2 degrees of freedom


Total chi-square = 3.4942  P = 0.17428 with 2 degrees of freedom

Distance sampling Cramer-von Mises test (unweighted)
Test statistic = 0.111296 p-value = 0.532286
```




```
Observer 1 detections
           Detected
            Missed Detected
  [0,80]        11       23
  (80,160]      13       14
  (160,240]     12       10
  (240,320]      4        1
  (320,400]      3        1

Observer 2 detections
           Detected
            Missed Detected
  [0,80]        15       19
  (80,160]       8       19
  (160,240]      5       17
  (240,320]      0        5
  (320,400]      0        4
```

```
Duplicate detections

   [0,80]  (80,160] (160,240] (240,320] (320,400]
        8         6         5         1         1

Pooled detections

   [0,80]  (80,160] (160,240] (240,320] (320,400]
       34        27        22         5         4

Observer 1 detections of those seen by Observer 2
          Missed Detected Prop. detected
[0,80]        11        8      0.4210526
(80,160]      13        6      0.3157895
(160,240]     12        5      0.2941176
(240,320]      4        1      0.2000000
(320,400]      3        1      0.2500000

Observer 2 detections of those seen by Observer 1
          Missed Detected Prop. detected
[0,80]        15        8      0.3478261
(80,160]       8        6      0.4285714
(160,240]      5        5      0.5000000
(240,320]      0        1      1.0000000
(320,400]      0        1      1.0000000
```



A10: Table showing outputs of various visual-acoustic trial point independence models. Final model selection shown in bold was selected based on low AIC and visual inspection of goodness of fit.

Object	DS Model	DS Formula	MRDS Formula	Coefficient	Primary P0	CV (P0)	Pa	CV (Pa)	N Covered	SE (N)	CV(N)	DS AIC	Total AIC
1	**hr**	**size+seastate**	**trial.pi**	**distance+seastate**	**0.509**	**0.26**	**0.216**	**0.29**	**227.2**	**71.33**	**0.31**	**544.96**	**625.29**
2	hn	size	trial.pi	distance+seastate	0.532	0.24	0.203	0.27	241.4	73.03	0.30	545.39	625.72
3	hn	size+seastate	trial.pi	distance+seastate	0.515	0.25	0.191	0.28	257.0	79.39	0.31	545.44	625.77
4	hr	size+seastate	trial.pi	distance+size+seastate	0.511	0.26	0.216	0.29	226.6	71.95	0.32	544.96	625.86
5	hn	size	trial.pi	distance+size+seastate	0.537	0.24	0.205	0.27	239.4	72.57	0.30	545.39	626.29
6	hn	size+seastate	trial.pi	distance+size+seastate	0.519	0.25	0.192	0.28	254.9	79.07	0.31	545.44	626.34
7	hr	size	trial.pi	distance+seastate	0.532	0.24	0.270	0.26	181.3	51.57	0.28	546.20	626.54
8	hn	seastate	trial.pi	distance+seastate	0.514	0.25	0.198	0.28	247.5	75.45	0.30	546.62	626.96
9	hr	size	trial.pi	distance+size+seastate	0.538	0.24	0.273	0.26	179.6	51.20	0.29	546.20	627.11
10	hr	size+seastate	trial.pi	distance+size	0.497	0.26	0.210	0.28	233.0	73.03	0.31	544.96	627.50
11	hn	seastate	trial.pi	distance+size+seastate	0.527	0.25	0.203	0.27	241.7	73.06	0.30	546.62	627.52
12	hn	-	trial.pi	distance+seastate	0.536	0.24	0.214	0.26	229.4	67.34	0.29	547.20	627.53
13	hr	size+seastate	trial.pi	distance	0.488	0.26	0.207	0.28	237.2	73.84	0.31	544.96	627.55
14	hr	seastate	trial.pi	distance+seastate	0.518	0.26	0.210	0.30	233.9	75.89	0.32	546.86	627.76
15	hr	seastate	trial.pi	distance+size+seastate	0.518	0.26	0.210	0.30	233.9	75.89	0.32	546.86	627.76
16	hn	size	trial.pi	distance+size	0.501	0.26	0.191	0.29	256.5	80.45	0.31	545.39	627.93
17	hn	size+seastate	trial.pi	distance+size	0.500	0.26	0.185	0.28	264.6	83.01	0.31	545.44	627.98
18	hn	size	trial.pi	distance	0.488	0.26	0.186	0.29	263.4	82.91	0.31	545.39	627.98
19	hn	size+seastate	trial.pi	distance	0.488	0.26	0.181	0.29	271.4	85.34	0.31	545.44	628.03
20	hn	-	trial.pi	distance+size+seastate	0.550	0.24	0.219	0.26	223.5	64.72	0.29	547.20	628.10
21	hr	size	trial.pi	distance+size	0.502	0.26	0.255	0.27	192.5	57.04	0.30	546.20	628.74
22	hr	size	trial.pi	distance	0.488	0.26	0.248	0.27	197.9	58.88	0.30	546.20	628.79
23	hn	seastate	trial.pi	distance+size	0.510	0.25	0.196	0.27	249.5	75.30	0.30	546.62	629.16
24	hn	seastate	trial.pi	distance	0.488	0.26	0.188	0.28	261.0	80.12	0.31	546.62	629.21
25	hr	seastate	trial.pi	distance+size	0.509	0.25	0.206	0.29	238.1	75.46	0.32	546.86	629.40
26	hr	seastate	trial.pi	distance	0.488	0.26	0.197	0.29	248.5	79.73	0.32	546.86	629.45
27	hn	-	trial.pi	distance+size	0.513	0.25	0.204	0.27	239.7	72.25	0.30	547.20	629.74
28	hn	-	trial.pi	distance	0.488	0.26	0.195	0.28	251.9	77.52	0.31	547.20	629.79
29	hr	-	trial.pi	distance+seastate	0.536	0.24	0.279	0.26	175.5	49.88	0.28	549.58	629.92
30	hr	-	trial.pi	distance+size+seastate	0.550	0.24	0.286	0.25	171.0	47.89	0.28	549.58	630.49
31	hr	-	trial.pi	distance+size	0.513	0.25	0.267	0.27	183.4	53.64	0.29	549.58	632.12
32	hr	-	trial.pi	distance	0.488	0.26	0.254	0.27	192.7	57.64	0.30	549.58	632.17

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Morlais Project
Environmental Statement

Appendix 12.2: Additional Collision Risk Assessments

Volume III

Applicant: Menter Môn Morlais Limited Document Reference: PB5034-ES-0122 Appendix 12.2: Additional Collision Risk Assessments Author: Royal HaskoningDHV	

Morlais Document No.: MOR/RHDHV/APP/0022	Status: Final	Version No: F3.0	Date: July 2019

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GLOSSARY OF ABBREVIATIONS

CRM	Collision Risk Model
CSIP	Cetaceans Stranding's Investigation Programme
EMMP	Environmental Management and Monitoring Plan
ERM	Encounter Rate Model
ES	Environmental Statement
LAT	Lowest Astronomical Tide
m	Metre
m/s	Meters per second
MDZ	Morlais Development Zone
MU	Management Unit
MW	Mega Watt
NRW	Natural Resource Wales
SCANS	Small Cetaceans in the European Atlantic and North Sea
SNH	Scottish Natural Heritage
TWG	Technical Working Group
UK	United Kingdom

GLOSSARY OF TERMINOLOGY

Adjusted at sea density (per m^2) [D_A]	This is a calculated field. It divides the animal density observed at the surface by the proportion estimated to be visible at the surface, to get the areal density including animals underwater at any one time.
Body width (m) [W]	Marine animals: Body width of animal. Body width is usually around ¼ of the body length.
Grey seal dive profile	Based on a study in the Pentland Firth
Harbour porpoise dive profile	Based on a study in the Sound of Sleat, Skye, using passive acoustic monitoring
Harbour seal dive profile	Based on a study in the Inner Sound, Pentland Firth
Length (m) [L]	Marine animals: Total length of animal (m) from tip to tail.
Mean blade speed relative to water (n) [v]	This is a calculated field, combining the mean tangential blade speed v_r with the mean current speed v_c which is parallel to the rotor axis.
Mean current speed (m/s) [v_c]	This is the tidal current speed (in m/s) at the turbine site, averaged over the time during which the turbine is in operation, i.e. excluding slack tides or excessive tides when the turbine may be closed down.
Mean tangential blade speed (m/s) [v_r]	This is a calculated field. Mean tangential blade speed is a mean across blade length, i.e. the blade speed in m/sec at the mid-point of the blade, relative to the hub.
Mean underwater duration of dive [t_u]	The mean underwater duration of a dive, in seconds.
Morlais Demonstration Zone	An offshore area of 35km^2 within which the Project will deploy arrays of tidal devices and associated infrastructure. Defined by The Crown Estate Lease boundary, the area within which the tidal

	devices/arrays will be deployed along with associated infrastructure such as inter-array cables, export cables, marker buoys, site monitoring equipment and electrical connections to the export cables.
Observed density (per m^2) [D_s]	It is the mean number of animals, per m^2, occupying the site as observed on the sea surface.
Overall dive frequency [F]	Calculated value
Proportion visible at surface	This is a calculated field.
Rotor tip minimum depth (m)	This is the depth (m) of the rotor tips when at their closest to the surface.
Rotation speed (rpm) [Ω]	The mean rotation speed of the rotors when operational, in rpm (revolutions per minute). The spreadsheet converts this to radians per second by multiplying by 2π/60
Tidal Device	A tidal energy convertor, with supporting structures, foundations and / or anchors.
Uniform dive profile	Assumes that animals are uniformly distributed between sea bottom and surface. The proportion at risk is the rotor diameter as a proportion of the sea depth.
Watch period [t_W]	In the wildlife survey from which the observed density DS was obtained, the period during which any one area of water is viewed while scanning the site.

1. INTRODUCTION

1. This Appendix presents additional collision risk assessments using the Encounter Rate Model (ERM) and Collision Risk Model (CRM). This is presented for information only and to provide supporting information to the assessments in **Section 12.6.4.4** of **Chapter, 12 Marine Mammals** (**Volume I**).

2. COLLISION RISK ASSESSMENTS

2. Details of the tidal device parameters used in the ERM and CRM collision risk assessments are provided in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals** (**Volume I**).

3. Details of the marine mammal parameters used in the ERM and CRM collision risk assessments are provided in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals** (**Volume I**).

4. **Table 2-1** of this Appendix illustrates the marine mammal parameters from **Table 12-77-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals** (**Volume I**) used in the assessments presented in **Section 12.6.4.5 of Chapter 12, Marine Mammals** (**Volume I**), based on the inputs to the Scottish Natural Heritage (SNH) spreadsheet following the SNH guidance for assessing collision risk between underwater turbines and marine wildlife (SNH, 2016).

5. The dive profiles were selected from the SNH (2016) spreadsheet as follows:

- Harbour porpoise = harbour porpoise dive profile;
- Bottlenose dolphin = uniform dive profile;
- Risso's dolphin = uniform dive profile;
- Common dolphin = uniform dive profile;
- Minke whale = uniform dive profile;
- Grey seal = grey seal dive profile (with vertical swim speed of 0.61m/s); and
- Harbour seal = harbour seal dive profile (with vertical swim speed of 0.85m/s).

Table 2-1 Marine mammal parameters used in collision risk assessments

Species name					harbour porpoise	harbour seal	grey seal	minke whale	bottlenose dolphin	Risso's dolphin	common dolphin
Observed density (per m^2)	D_S	animals m^{-2}			7.83E-07	5.00E-10	1.55E-07	1.700E-08	2.000E-08	3.100E-08	2.180E-07
correct for proportion underwater?					no	no	no	no	no	no	no
Proportion of animals visible at surface											
mean underwater duration of dive	t_u	s			26.2	180	297	87	25.8	25.8	25.8
mean surface time	t_s	s			3.9	39.5	165	3.5	3.7	3.7	3.7
overall dive frequency	F	dives s^{-1}		$1/(t_u+t_s)$	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
watch period	t_w	s	10		10.0	10.0	10.0	10.0	10.0	10.0	10.0
proportion visible at surface				$1-F*max(0,t_u-t_w)$	1.000	1.0000	1.000	1.000	1.000	1.000	1.000
adjusted at sea density	D_A	animals m^{-2}			7.83E-07	5.00E-10	1.550E-07	1.70E-08	2.00E-08	3.10E-08	2.18E-07

2.1. AVOIDANCE RATES FOR ONE TIDAL DEVICE OF EACH DEVICE TYPE

6. The assessment of the potential impacts and effects have been based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal.

7. Avoidance rates of 0%, 50%, 90%, 95%, 98% and 99% are presented in this Appendix, as agreed with NRW at the 2nd Marine Mammal TWG in February 2019.

8. The marine mammal parameters used in the collision risk assessments are outlined in **Table 2-1** and **Table 12-77-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals** (**Volume I**) and the tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals** (**Volume I**).

9. **Table 2-2** to **Table 2-15** present the 0%, 50%, 90%, 95%, 98% and 99% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal for the ERM and CRM collision risk assessments (number of individuals per year) for one device of each device type.

Table 2-2 Harbour porpoise ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Harbour porpoise**									
Model	**ERM**									
Number of devices =	1	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b	7a
Avoidance rates										
0%	171.63	140.42	116.06	236.82	79.26	20.16	51.70	5.20	18.73	37.60
50%	85.82	70.21	58.03	118.41	39.63	10.08	25.85	2.60	9.37	18.80
90%	17.16	14.04	11.61	23.68	7.93	2.02	5.17	0.52	1.87	3.76
95%	8.58	7.02	5.80	11.84	3.96	1.01	2.58	0.26	0.94	1.88
98%	**3.43**	**2.81**	**2.32**	**4.74**	**1.59**	**0.40**	**1.03**	**0.10**	**0.37**	**0.75**
99%	1.72	1.40	1.16	2.37	0.79	0.20	0.52	0.05	0.19	0.38

Table 2-3 Harbour porpoise CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Harbour porpoise**								
Model	**CRM**								
Number of devices =	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b
Avoidance rates									
0%	188.00	118.56	97.99	104.16	105.79	12.44	61.20	3.63	8.71
50%	94.00	59.28	49.00	52.08	52.89	6.22	30.60	1.81	4.36
90%	18.80	11.86	9.80	10.42	10.58	1.24	6.12	0.36	0.87
95%	9.40	5.93	4.90	5.21	5.29	0.62	3.06	0.18	0.44
98%	**3.76**	**2.37**	**1.96**	**2.08**	**2.12**	**0.25**	**1.22**	**0.07**	**0.17**
99%	1.88	1.19	0.98	1.04	1.06	0.12	0.61	0.04	0.09

CRM not applicable to device group 7a

Table 2-4 Bottlenose dolphin ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Bottlenose dolphin**									
Model	**ERM**									
Number of devices =	1	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b	7a
Avoidance rates										
0%	4.83	5.06	5.06	11.66	3.65	2.82	4.03	1.22	5.48	0.72
50%	2.42	2.53	2.53	5.83	1.83	1.41	2.02	0.61	2.74	0.36
90%	0.48	0.51	0.51	1.17	0.37	0.28	0.40	0.12	0.55	0.07
95%	0.24	0.25	0.25	0.58	0.18	0.14	0.20	0.06	0.27	0.04
98%	**0.10**	**0.10**	**0.10**	**0.23**	**0.07**	**0.06**	**0.08**	**0.02**	**0.11**	**0.01**
99%	0.05	0.05	0.05	0.12	0.04	0.03	0.04	0.01	0.05	0.01

Table 2-5 Bottlenose dolphin CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Bottlenose dolphin**								
Model	**CRM**								
Number of devices =	**1**	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b
Avoidance rates									
0%	6.23	4.40	4.40	4.95	5.28	1.77	5.13	0.88	2.64
50%	3.12	2.20	2.20	2.47	2.64	0.88	2.57	0.44	1.32
90%	0.62	0.44	0.44	0.49	0.53	0.18	0.51	0.09	0.26
95%	0.31	0.22	0.22	0.25	0.26	0.09	0.26	0.04	0.13
98%	**0.12**	**0.09**	**0.09**	**0.10**	**0.11**	**0.04**	**0.10**	**0.02**	**0.05**
99%	0.06	0.04	0.04	0.05	0.05	0.02	0.05	0.01	0.03

CRM not applicable to device group 7a

Table 2-6 Risso's dolphin ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Risso's dolphin**									
Model	**ERM**									
Number of devices =	1	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b	7a
Avoidance rates										
0%	7.04	7.20	7.20	16.27	5.28	4.01	5.81	1.74	7.82	0.98
50%	3.52	3.60	3.60	8.14	2.64	2.00	2.91	0.87	3.91	0.49
90%	0.70	0.72	0.72	1.63	0.53	0.40	0.58	0.17	0.78	0.10
95%	0.35	0.36	0.36	0.81	0.26	0.20	0.29	0.09	0.39	0.05
98%	**0.14**	**0.14**	**0.14**	**0.33**	**0.11**	**0.08**	**0.12**	**0.03**	**0.16**	**0.02**
99%	0.07	0.07	0.07	0.16	0.05	0.04	0.06	0.02	0.08	0.01

Table 2-7 Risso's dolphin CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Risso's dolphin**								
Model	**CRM**								
Number of devices =	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b
Avoidance rates									
0%	8.92	6.27	6.27	6.98	7.56	2.53	7.35	1.25	3.76
50%	4.46	3.13	3.13	3.49	3.78	1.26	3.67	0.63	1.88
90%	0.89	0.63	0.63	0.70	0.76	0.25	0.73	0.13	0.38
95%	0.45	0.31	0.31	0.35	0.38	0.13	0.37	0.06	0.19
98%	**0.18**	**0.13**	**0.13**	**0.14**	**0.15**	**0.05**	**0.15**	**0.03**	**0.08**
99%	0.09	0.06	0.06	0.07	0.08	0.03	0.07	0.01	0.04

CRM not applicable to device group 7a

Table 2-8 Common dolphin ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Common dolphin**									
Model	**ERM**									
Number of devices =	1	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b	7a
Avoidance rates										
0%	41.71	39.15	39.15	83.67	29.87	22.16	32.89	9.44	42.47	5.01
50%	20.86	19.58	19.58	41.83	14.93	11.08	16.45	4.72	21.24	2.51
90%	4.17	3.92	3.92	8.37	2.99	2.22	3.29	0.94	4.25	0.50
95%	2.09	1.96	1.96	4.18	1.49	1.11	1.64	0.47	2.12	0.25
98%	**0.83**	**0.78**	**0.78**	**1.67**	**0.60**	**0.44**	**0.66**	**0.19**	**0.85**	**0.10**
99%	0.42	0.39	0.39	0.84	0.30	0.22	0.33	0.09	0.42	0.05

Table 2-9 Common dolphin CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Common dolphin**								
Model	**CRM**								
Number of devices =	1	1	1	1	1	1	1	1	1
Device Group	1	2a	2b	3	4	5a	5b	6a	6b
Avoidance rates									
0%	48.16	33.37	33.37	36.24	40.98	13.58	39.82	6.67	20.02
50%	24.08	16.69	16.69	18.12	20.49	6.79	19.91	3.34	10.01
90%	4.82	3.34	3.34	3.62	4.10	1.36	3.98	0.67	2.00
95%	2.41	1.67	1.67	1.81	2.05	0.68	1.99	0.33	1.00
98%	**0.96**	**0.67**	**0.67**	**0.72**	**0.82**	**0.27**	**0.80**	**0.13**	**0.40**
99%	0.48	0.33	0.33	0.36	0.41	0.14	0.40	0.07	0.20

CRM not applicable to device group 7a

Table 2-10 Minke whale ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Minke whale**									
Model	**ERM**									
Number of devices =	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Avoidance rates										
0%	11.81	16.91	16.91	49.84	9.89	8.81	11.04	4.05	18.22	3.30
50%	5.91	8.45	8.45	24.92	4.95	4.41	5.52	2.02	9.11	1.65
90%	1.18	1.69	1.69	4.98	0.99	0.88	1.10	0.40	1.82	0.33
95%	0.59	0.85	0.85	2.49	0.49	0.44	0.55	0.20	0.91	0.16
98%	**0.24**	**0.34**	**0.34**	**1.00**	**0.20**	**0.18**	**0.22**	**0.08**	**0.36**	**0.07**
99%	0.12	0.17	0.17	0.50	0.10	0.09	0.11	0.04	0.18	0.03

Table 2-11 Minke whale CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Minke whale**								
Model	**CRM**								
Number of devices =	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**
Avoidance rates									
0%	11.13	8.93	8.93	12.44	9.10	3.30	8.88	1.79	5.36
50%	5.57	4.47	4.47	6.22	4.55	1.65	4.44	0.89	2.68
90%	1.11	0.89	0.89	1.24	0.91	0.33	0.89	0.18	0.54
95%	0.56	0.45	0.45	0.62	0.45	0.17	0.44	0.09	0.27
98%	**0.22**	**0.18**	**0.18**	**0.25**	**0.18**	**0.07**	**0.18**	**0.04**	**0.11**
99%	0.11	0.09	0.09	0.12	0.09	0.03	0.09	0.02	0.05

CRM not applicable to device group 7a

Table 2-12 Grey seal ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Grey seal**									
Model	**ERM**									
Number of devices =	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Avoidance rates										
0%	27.16	23.37	23.37	50.61	16.99	9.99	16.11	3.94	17.72	5.57
50%	13.58	11.68	11.68	25.31	8.49	5.00	8.06	1.97	8.86	2.79
90%	2.72	2.34	2.34	5.06	1.70	1.00	1.61	0.39	1.77	0.56
95%	1.36	1.17	1.17	2.53	0.85	0.50	0.81	0.20	0.89	0.28
98%	**0.54**	**0.47**	**0.47**	**1.01**	**0.34**	**0.20**	**0.32**	**0.08**	**0.35**	**0.11**
99%	0.27	0.23	0.23	0.51	0.17	0.10	0.16	0.04	0.18	0.06

Table 2-13 Grey seal CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Grey seal**								
Model	**CRM**								
Number of devices =	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**
Avoidance rates									
0%	31.57	19.73	19.73	21.35	23.37	6.05	19.51	2.76	8.28
50%	15.79	9.86	9.86	10.67	11.69	3.02	9.75	1.38	4.14
90%	3.16	1.97	1.97	2.13	2.34	0.60	1.95	0.28	0.83
95%	1.58	0.99	0.99	1.07	1.17	0.30	0.98	0.14	0.41
98%	**0.63**	**0.39**	**0.39**	**0.43**	**0.47**	**0.12**	**0.39**	**0.06**	**0.17**
99%	0.32	0.20	0.20	0.21	0.23	0.06	0.20	0.03	0.08

CRM not applicable to device group 7a

Table 2-14 Harbour seal ERM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Harbour seal**									
Model	**ERM**									
Number of devices =	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Avoidance rates										
0%	0.07	0.07	0.07	0.14	0.06	0.04	0.06	0.02	0.05	0.00
50%	0.04	0.04	0.03	0.07	0.03	0.02	0.03	0.01	0.02	0.00
90%	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
95%	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
98%	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
99%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-15 Harbour seal CRM assessment (number of individuals / year) with different avoidance rates for one device of each different tidal device type

Species	**Harbour seal**								
Model	**CRM**								
Number of devices =	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**
Avoidance rates									
0%	0.08	0.06	0.06	0.06	0.08	0.03	0.06	0.01	0.02
50%	0.04	0.03	0.03	0.03	0.04	0.01	0.03	0.01	0.01
90%	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00
95%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98%	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
99%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CRM not applicable to device group 7a

2.2. LESS THAN ONE BOTTLENOSE DOLPHIN SCENARIOS FOR THE INDICATIVE COMBINATION OF DIFFERENT TYPES OF DEVICES

10. As outlined in **Section 12.6.4.5.2** of **Chapter 12, Marine Mammals** (**Volume I**)**,** the assessments are based on the indicative scenarios for the combination of different types of devices where the collision risk is predicted to be less than one bottlenose dolphin (based on the scenarios with the current maximum MW). Each stage of deployment would only progress based on these scenarios and that the regular reviewing of the monitoring and mitigation indicated that there was no increased collision risk.

11. Based on these indicative scenarios and combination of devices the first initial stage of deployment could be 18.15MW to 23.35MW.

12. It is important to note that the output of the devices (MW) used in the assessments are indicative and have been based on the current minimum rating, as a worst-case scenario and prior to deployment it is expected that the rating (MW) for the devices deployed would be higher, although the other parameters are unlikely to change. Further assessments will be conducted prior to deployment as part of the adaptive management and mitigation plan (EMMP).

13. **Table 2-16** to **Table 2-29** present the 0%, 50%, 90%, 95%, 98% and 99% avoidance rates for harbour porpoise, bottlenose dolphin, Risso’s dolphin, common dolphin, minke whale, grey seal and harbour seal for the ERM and CRM collision risk assessments (number of individuals per year) for the less than one bottlenose dolphin scenarios presented in **Section 12.6.4.5.2** of **Chapter 12, Marine Mammals** (**Volume I**).

14. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)** and the tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals** (**Volume I**).

Table 2-16 Harbour porpoise ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Harbour porpoise**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	686.53	140.42	116.06		79.26	40.33	51.70	5.20	18.73		1138.22
50%	343.26	70.21	58.03		39.63	20.16	25.85	2.60	9.37		569.11
90%	68.65	14.04	11.61		7.93	4.03	5.17	0.52	1.87		113.82
95%	34.33	7.02	5.80		3.96	2.02	2.58	0.26	0.94		56.91
98%	**13.73**	**2.81**	**2.32**		**1.59**	**0.81**	**1.03**	**0.10**	**0.37**		**22.76**
99%	6.87	1.40	1.16		0.79	0.40	0.52	0.05	0.19		11.38

Table 2-17 Harbour porpoise CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Harbour porpoise**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	564.00	118.56	97.99		105.79	12.44	61.20	7.26	17.42		984.66
50%	282.00	59.28	49.00		52.89	6.22	30.60	3.63	8.71		492.33
90%	56.40	11.86	9.80		10.58	1.24	6.12	0.73	1.74		98.47
95%	28.20	5.93	4.90		5.29	0.62	3.06	0.36	0.87		49.23
98%	**11.28**	**2.37**	**1.96**		**2.12**	**0.25**	**1.22**	**0.15**	**0.35**		**19.69**
99%	5.64	1.19	0.98		1.06	0.12	0.61	0.07	0.17		9.85

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

Table 2-18 Bottlenose dolphin ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Bottlenose dolphin**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	19.32	5.06	5.06		3.65	5.64	4.03	1.22	5.48		49.47
50%	9.66	2.53	2.53		1.83	2.82	2.02	0.61	2.74		24.74
90%	1.93	0.51	0.51		0.37	0.56	0.40	0.12	0.55		4.95
95%	0.97	0.25	0.25		0.18	0.28	0.20	0.06	0.27		2.47
98%	**0.39**	**0.10**	**0.10**		**0.07**	**0.11**	**0.08**	**0.02**	**0.11**		**0.99**
99%	0.19	0.05	0.05		0.04	0.06	0.04	0.01	0.05		0.49

Table 2-19 Bottlenose dolphin CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Bottlenose dolphin**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	18.70	4.40	4.40		5.28	1.77	5.13	1.76	7.92		49.36
50%	9.35	2.20	2.20		2.64	0.88	2.57	0.88	3.96		24.68
90%	1.87	0.44	0.44		0.53	0.18	0.51	0.18	0.79		4.94
95%	0.94	0.22	0.22		0.26	0.09	0.26	0.09	0.40		2.47
98%	**0.37**	**0.09**	**0.09**		**0.11**	**0.04**	**0.10**	**0.04**	**0.16**		**0.99**
99%	0.19	0.04	0.04		0.05	0.02	0.05	0.02	0.08		0.49

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

Table 2-20 Risso's dolphin ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Risso's dolphin**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	28.18	7.20	7.20		5.28	8.02	5.81	1.74	7.82		71.25
50%	14.09	3.60	3.60		2.64	4.01	2.91	0.87	3.91		35.62
90%	2.82	0.72	0.72		0.53	0.80	0.58	0.17	0.78		7.12
95%	1.41	0.36	0.36		0.26	0.40	0.29	0.09	0.39		3.56
98%	**0.56**	**0.14**	**0.14**		**0.11**	**0.16**	**0.12**	**0.03**	**0.16**		**1.42**
99%	0.28	0.07	0.07		0.05	0.08	0.06	0.02	0.08		0.71

Table 2-21 Risso's dolphin CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Risso's dolphin**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	26.75	6.27	6.27		7.56	2.53	7.35	2.51	11.28		70.50
50%	13.38	3.13	3.13		3.78	1.26	3.67	1.25	5.64		35.25
90%	2.68	0.63	0.63		0.76	0.25	0.73	0.25	1.13		7.05
95%	1.34	0.31	0.31		0.38	0.13	0.37	0.13	0.56		3.53
98%	**0.54**	**0.13**	**0.13**		**0.15**	**0.05**	**0.15**	**0.05**	**0.23**		**1.41**
99%	0.27	0.06	0.06		0.08	0.03	0.07	0.03	0.11		0.71

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

Table 2-22 Common dolphin ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Common dolphin**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	166.85	39.15	39.15		29.87	44.32	32.89	9.44	42.47		404.14
50%	83.43	19.58	19.58		14.93	22.16	16.45	4.72	21.24		202.07
90%	16.69	3.92	3.92		2.99	4.43	3.29	0.94	4.25		40.41
95%	8.34	1.96	1.96		1.49	2.22	1.64	0.47	2.12		20.21
98%	**3.34**	**0.78**	**0.78**		**0.60**	**0.89**	**0.66**	**0.19**	**0.85**		**8.08**
99%	1.67	0.39	0.39		0.30	0.44	0.33	0.09	0.42		4.04

Table 2-23 Common dolphin CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Common dolphin**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	144.47	33.37	33.37		40.98	13.58	39.82	13.35	60.07		379.01
50%	72.23	16.69	16.69		20.49	6.79	19.91	6.67	30.03		189.50
90%	14.45	3.34	3.34		4.10	1.36	3.98	1.33	6.01		37.90
95%	7.22	1.67	1.67		2.05	0.68	1.99	0.67	3.00		18.95
98%	**2.89**	**0.67**	**0.67**		**0.82**	**0.27**	**0.80**	**0.27**	**1.20**		**7.58**
99%	1.44	0.33	0.33		0.41	0.14	0.40	0.13	0.60		3.79

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

Table 2-24 Minke whale ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Minke whale**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	47.25	16.91	16.91		9.89	17.62	11.04	4.05	18.22		141.89
50%	23.63	8.45	8.45		4.95	8.81	5.52	2.02	9.11		70.94
90%	4.73	1.69	1.69		0.99	1.76	1.10	0.40	1.82		14.19
95%	2.36	0.85	0.85		0.49	0.88	0.55	0.20	0.91		7.09
98%	**0.95**	**0.34**	**0.34**		**0.20**	**0.35**	**0.22**	**0.08**	**0.36**		**2.84**
99%	**0.47**	**0.17**	**0.17**		**0.10**	**0.18**	**0.11**	**0.04**	0.18		1.42

Table 2-25 Minke whale CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Minke whale**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	33.40	8.93	8.93		9.10	3.30	8.88	3.57	16.08		92.18
50%	16.70	4.47	4.47		4.55	1.65	4.44	1.79	8.04		46.09
90%	3.34	0.89	0.89		0.91	0.33	0.89	0.36	1.61		9.22
95%	1.67	0.45	0.45		0.45	0.17	0.44	0.18	0.80		4.61
98%	**0.67**	**0.18**	**0.18**		**0.18**	**0.07**	**0.18**	**0.07**	**0.32**		**1.84**
99%	0.33	0.09	0.09		0.09	0.03	0.09	0.04	0.16		0.92

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

Table 2-26 Grey seal ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Grey seal**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	108.63	23.37	23.37		16.99	19.98	16.11	3.94	17.72		230.09
50%	54.31	11.68	11.68		8.49	9.99	8.06	1.97	8.86		115.05
90%	10.86	2.34	2.34		1.70	2.00	1.61	0.39	1.77		23.01
95%	5.43	1.17	1.17		0.85	1.00	0.81	0.20	0.89		11.50
98%	**2.17**	**0.47**	**0.47**		**0.34**	**0.40**	**0.32**	**0.08**	**0.35**		**4.60**
99%	1.09	0.23	0.23		0.17	0.20	0.16	0.04	0.18		2.30

Table 2-27 Grey seal CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Grey seal**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	94.72	19.73	19.73		23.37	6.05	19.51	5.52	24.85		213.48
50%	47.36	9.86	9.86		11.69	3.02	9.75	2.76	12.43		106.74
90%	9.47	1.97	1.97		2.34	0.60	1.95	0.55	2.49		21.35
95%	4.74	0.99	0.99		1.17	0.30	0.98	0.28	1.24		10.67
98%	**1.89**	**0.39**	**0.39**		**0.47**	**0.12**	**0.39**	**0.11**	**0.50**		**4.27**
99%	0.95	0.20	0.20		0.23	0.06	0.20	0.06	0.25		2.13

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

Table 2-28 Harbour seal ERM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Harbour seal**										
Model	**ERM**										
Number of devices =	**4 (8MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**2 (2MW)**	**1 (1.5MW)**	**1 (0.3MW)**	**1 (1.2MW)**	**0**	**Total 12 (16.75MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	
Avoidance rates											
0%	0.29	0.07	0.07		0.06	0.09	0.06	0.02	0.05		0.70
50%	0.14	0.04	0.03		0.03	0.04	0.03	0.01	0.02		0.35
90%	0.03	0.01	0.01		0.01	0.01	0.01	0.00	0.00		0.07
95%	0.01	0.00	0.00		0.00	0.00	0.00	0.00	0.00		0.04
98%	**0.01**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**		**0.01**
99%	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00		0.01

Table 2-29 Harbour seal CRM assessment (number of individuals / year) with different avoidance rates for indicative scenario of each type of device combined for collision risk of less than one bottlenose dolphin

Species	**Harbour seal**										
Model	**CRM**										
Number of devices =	**3 (6MW)**	**1 (1.5MW)**	**1 (1.25MW)**	**0**	**1 (1MW)**	**1 (1MW)**	**1 (1.5MW)**	**2 (0.6MW)**	**3 (3.6MW)**	**0**	**Total 13 (16.45MW)**
Device Group	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a***	
Avoidance rates											
0%	0.23	0.06	0.06		0.08	0.03	0.06	0.03	0.06		0.61
50%	0.12	0.03	0.03		0.04	0.01	0.03	0.01	0.03		0.31
90%	0.02	0.01	0.01		0.01	0.00	0.01	0.00	0.01		0.06
95%	0.01	0.00	0.00		0.00	0.00	0.00	0.00	0.00		0.03
98%	**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**		**0.01**
99%	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00		0.01

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included

2.3. LESS THAN ONE BOTTLENOSE DOLPHIN SCENARIOS FOR THE INDICATIVE MAXIMUM NUMBER OF EACH TYPE OF DEVICE FOR ONE DEVICE TYPE ONLY

15. **Table 2-30** and **Table 2-31** present the ERM and CRM collision risk assessments (number of individuals per year and percentage of reference populations) for the less than one bottlenose dolphin scenarios for the indicative maximum number of each type of device, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal.

16. As previously outlined, it is important to note that the output of the devices (MW) used in the assessments are indicative and have been based on the current minimum rating, as a worst-case scenario and prior to deployment it is expected that the rating (MW) for the devices deployed would be higher, although the other parameters are unlikely to change. Further assessments will be conducted prior to deployment as part of the adaptive management and mitigation plan (EMMP).

17. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals** (**Volume I**) and the tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals** (**Volume I**).

18. The marine mammal reference populations are presented in **Table 12-20** in **Section 12.5.10** of **Chapter 12, Marine Mammals** (**Volume I**).

Table 2-30 Marine mammal ERM assessment (number of individuals / year and % of reference population) with 98% avoidance for less than one bottlenose dolphin scenarios for the indicative maximum number of each type of device type

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Number of Devices	**10 (20MW)**	**9 (13.5MW)**	**9 (11.25MW)**	**4 (4MW)**	**13 (13MW)**	**17 (17MW)**	**12 (18MW)**	**40 (12MW)**	**9(10.8MW)**	**69 (6.9MW)**
Harbour porpoise	34.33	25.28	20.89	4.74	20.61	6.86	12.41	4.16	3.37	51.89
	0.03%	0.02%	0.02%	0.00%	0.02%	0.01%	0.01%	0.004%	0.003%	0.05%
Bottlenose dolphin	0.97	0.91	0.91	0.93	0.95	0.96	0.97	0.97	0.99	0.99
	0.24%	0.23%	0.23%	0.24%	0.24%	0.24%	0.24%	0.25%	0.25%	0.25%
Risso's dolphin	1.41	1.30	1.30	1.30	1.37	1.36	1.40	1.39	1.41	1.35
	0.02%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
Common dolphin	8.34	7.05	7.05	6.69	7.77	7.53	7.89	7.55	7.65	6.92
	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Minke whale	2.36	3.04	3.04	3.99	2.57	3.00	2.65	3.24	3.28	4.55
	0.01%	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%
Grey seal	5.43	4.21	4.21	4.05	4.42	3.40	3.87	3.15	3.19	7.69
	0.09%	0.07%	0.07%	0.07%	0.07%	0.06%	0.06%	0.05%	0.05%	0.13%
Harbour seal	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01
	0.03%	0.03%	0.02%	0.02%	0.03%	0.03%	0.03%	0.03%	0.02%	0.01%

Table 2-31 Marine mammal CRM assessment (number of individuals / year and % of reference population) with 98% avoidance for less than one bottlenose dolphin scenarios for the indicative maximum number of each type of device type

Tidal device category	1	2a	2b	3	4	5a	5b	6a	6b	7a*
Number of Devices	7 (14MW)	11 (16.5MW)	11 (13.75MW)	10 (10MW)	9 (9MW)	27 (27MW)	9 (13.5MW)	55 (16.5MW)	18 (21.6MW)	N/A
Harbour porpoise	26.32	26.08	21.56	20.83	19.04	6.72	11.02	3.99	3.14	N/A
	0.03%	0.02%	0.02%	0.02%	0.02%	0.01%	0.01%	0.004%	0.003%	
Bottlenose dolphin	0.87	0.97	0.97	0.99	0.95	0.96	0.92	0.97	0.95	N/A
	0.22%	0.24%	0.24%	0.25%	0.24%	0.24%	0.23%	0.24%	0.24%	
Risso's dolphin	1.25	1.38	1.38	1.40	1.36	1.36	1.32	1.38	1.35	N/A
	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	
Common dolphin	6.74	7.34	7.34	7.25	7.38	7.33	7.17	7.34	7.21	N/A
	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	
Minke whale	1.56	1.96	1.96	2.49	1.64	1.78	1.60	1.96	1.93	N/A
	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	
Grey seal	4.42	4.34	4.34	4.27	4.21	3.27	3.51	3.04	2.98	N/A
	0.07%	0.07%	0.07%	0.07%	0.07%	0.05%	0.06%	0.05%	0.05%	
Harbour seal	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	N/A
	0.02%	0.03%	0.03%	0.02%	0.03%	0.03%	0.02%	0.03%	0.02%	

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device

2.4. INDICTIVE 30MW OF EACH TYPE OF DEVICE

19. It is currently proposed that the Morlais tidal arrays would be installed in phases, with up to 30MW for each type of device.

20. **Table 2-32** and **Table 2-33** present the ERM and CRM collision risk assessments (number of individuals per year and percentage of the reference populations) for 30MW of each device type, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal. The results are summarised in **Table 2-34**.

21. As outlined in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals** (**Volume I**)**,** these scenarios would only be developed once the monitoring and mitigation indicates that the collision risk would be less than one bottlenose dolphin.

22. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals** (**Volume I**) and the tidal device parameters are as outlined in **Table 12.74** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals** (**Volume I**).

23. The marine mammal reference populations are presented in **Table 12-20** in **Section 12.5.10** of **Chapter 12, Marine Mammals** (**Volume I**).

Table 2-32 Marine mammal ERM assessment (number of individuals / year and % of reference population) with 98% avoidance for 30MW of each tidal device type

Tidal device category	1	2a	2b	3	4	5a	5b	6a	6b	7a	Total
Number of Devices	**15**	**20**	**24**	**30**	**30**	**30**	**20**	**100**	**25**	**300**	**N/A**
Harbour porpoise											
30MW	51.49 (0.05%)	56.17 (0.05%)	55.71 (0.05%)	142.09 (0.14%)	47.55 (0.05%)	12.10 (0.01%)	20.68 (0.02%)	10.41 (0.01%)	9.37 (0.009%)	225.62 (0.22%)	N/A
Bottlenose dolphin											
30MW	1.45 (0.37%)	2.02 (0.51%)	2.43 (0.61%)	7.00 (1.76%)	2.19 (0.55%)	1.69 (0.43%)	1.61 (0.41%)	2.44 (0.61%)	2.74 (0.69%)	4.31 (1.09%)	N/A
Risso's dolphin											
30MW	2.11 (0.02%)	2.88 (0.03%)	3.46 (0.04%)	9.76 (0.11%)	3.17 (0.04%)	2.41 (0.03%)	2.33 (0.03%)	3.47 (0.04%)	3.91 (0.04%)	5.89 (0.07%)	N/A
Common dolphin											
30MW	12.51 (0.02%)	15.66 (0.03%)	18.79 (0.03%)	50.20 (0.09%)	17.92 (0.03%)	13.30 (0.02%)	13.16 (0.02%)	18.88 (0.03%)	21.24 (0.04%)	30.08 (0.05%)	N/A
Minke whale											
30MW	3.54 (0.02%)	6.76 (0.03%)	8.12 (0.03%)	29.90 (0.13%)	5.94 (0.03%)	5.29 (0.02%)	4.43 (0.02%)	8.10 (0.03%)	9.11 (0.04%)	19.79 (0.08%)	N/A
Grey seal											
30MW	8.15 (0.14%)	9.35 (0.16%)	11.22 (0.19%)	30.37 (0.51%)	10.19 (0.17%)	6.00 (0.10%)	6.44 (0.11%)	7.87 (0.13%)	8.86 (0.15%)	33.42 (0.56%)	N/A
Harbour seal											
30MW	0.02 (0.04%)	0.03 (0.06%)	0.03 (0.07%)	0.08 (0.17%)	0.04 (0.08%)	0.03 (0.05%)	0.02 (0.04%)	0.04 (0.08%)	0.02 (0.05%)	0.02 (0.05%)	N/A

Table 2-33 Marine mammal CRM assessment (number of individuals / year and % of reference population) with 98% avoidance for 30MW of each tidal device type

Tidal device category	1	2a	2b	3	4	5a	5b	6a	6b	7a*	Total
Number of Devices	**15**	**20**	**24**	**30**	**30**	**30**	**20**	**100**	**25**	**N/A**	**N/A**
Harbour porpoise											
30MW	56.40 (0.05%)	47.42 (0.05%)	47.04 (0.04%)	62.50 (0.06%)	63.47 (0.06%)	7.46 (0.01%)	24.48 (0.02%)	7.26 (0.01%)	4.36 (0.004%)	N/A	N/A
Bottlenose dolphin											
30MW	1.87 (0.47%)	1.76 (0.44%)	2.11 (0.53%)	2.97 (0.75%)	3.17 (0.8%)	1.06 (0.27%)	2.05 (0.52%)	1.76 (0.44%)	1.32 (0.33%)	N/A	N/A
Risso's dolphin											
30MW	2.68 (0.03%)	2.51 (0.03%)	3.01 (0.03%)	4.19 (0.05%)	4.54 (0.05%)	1.52 (0.02%)	2.94 (0.03%)	2.51 (0.03%)	1.88 (0.02%)	N/A	N/A
Common dolphin											
30MW	14.45 (0.03%)	13.35 (0.02%)	16.02 (0.03%)	21.75 (0.04%)	24.59 (0.04%)	8.15 (0.01%)	15.93 (0.0%)	13.35 (0.02%)	10.01 (0.02%)	N/A	N/A
Minke whale											
30MW	3.34 (0.01%)	3.57 (0.02%)	4.29 (0.02%)	7.47 (0.03%)	5.46 (0.02%)	1.98 (0.01%)	3.55 (0.02%)	3.57 (0.02%)	2.68 (0.01%)	N/A	N/A
Grey seal											
30MW	9.47 (0.16%)	7.89 (0.13%)	9.47 (0.16%)	12.81 (0.21%)	14.02 (0.23%)	3.63 (0.06%)	7.80 (0.13%)	5.52 (0.09%)	4.14 (0.07%)	N/A	N/A
Harbour seal											
30MW	0.02 (0.05%)	0.02 (0.05%)	0.03 (0.05%)	0.04 (0.07%)	0.05 (0.1%)	0.02 (0.03%)	0.03 (0.05%)	0.03 (0.05%)	0.01 (0.02%)	N/A	N/A

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device

Table 2-34 Summary of number of individuals (and % of reference population) that could be at risk of collision with operational tidal devices at Morlais for 30MW scenarios

Species	Magnitude for 30MW scenarios ERM and CRM
Harbour porpoise	**4.4-226 individuals (0.004-0.22% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Bottlenose dolphin	**1.3-7 individuals (0.33-1.76% of MU)** Potential permanent effect with **medium to high** magnitude (0.01% to more than 1% of the reference population anticipated to be exposed to effect).
Risso's dolphin	**2-10 individuals (0.02-0.11% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Common dolphin	**10-50 individuals (0.02-0.09% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Minke whale	**2-30 individuals (0.01-0.13%)** Potential permanent effect with **low to medium** magnitude (0.001-1% of the reference population anticipated to be exposed to effect).
Grey seal	**4-34 individuals (0.07-0.6% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Harbour seal	**0.01-0.08 individuals (0.02-0.2% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).

2.5. INDICTIVE 40MW OF EACH TYPE OF DEVICE

24. It is currently proposed that the Morlais tidal arrays would be installed in phases, with up to 40MW for the first phase. It is currently unknow the different types and number of the different devices that could be deployed for the 40MW scenario, therefore an assessment has been conducted based on 40MW of each device type.

25. **Table 2-35** and **Table 2-36** present the ERM and CRM collision risk assessments (number of individuals per year and percentage of the reference populations) for 40MW of each device type, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal. The results are summarised in **Table 2-37**.

26. As outlined in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I),** these scenarios would only be developed once the monitoring and mitigation indicates that the collision risk would be less than one bottlenose dolphin.

27. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)** and the tidal device parameters are as outlined in **Table 12.74** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**.

28. The marine mammal reference populations are presented in **Table 12.20** in **Section 12.5.10** of **Chapter 12, Marine Mammals (Volume I)**.

Table 2-35 Marine mammal ERM assessment (number of individuals / year and % of reference population) with 98% avoidance for 40MW of each tidal device type

Tidal device category	1	2a	2b	3	4	5a	5b	6a	6b	7a	Total
Number of Devices	**20**	**27**	**32**	**40**	**40**	**40**	**27**	**134**	**34**	**400**	**N/A**
Harbour porpoise											
40MW	68.65 (0.07%)	75.83 (0.07%)	74.28 (0.07%)	189.46 (0.18%)	63.41 (0.06%)	16.13 (0.02%)	27.92 (0.03%)	13.95 (0.01%)	12.74 (0.01%)	300.82 (0.29%)	N/A
Bottlenose dolphin											
40MW	1.93 (0.49%)	2.73 (0.69%)	3.24 (0.82%)	9.33 (2.35%)	2.92 (0.74%)	2.26 (0.57%)	2.18 (0.55%)	3.27 (0.82%)	3.73 (0.94%)	5.74 (1.45%)	N/A
Risso's dolphin											
40MW	2.82 (0.03%)	3.89 (0.04%)	4.61 (0.05%)	13.02 (0.15%)	4.22 (0.05%)	3.21 (0.04%)	3.14 (0.04%)	4.65 (0.05%)	5.31 (0.06%)	7.85 (0.09%)	N/A
Common dolphin											
40MW	16.69 (0.03%)	21.14 (0.04%)	25.06 (0.04%)	66.93 (0.12%)	23.89 (0.04%)	17.73 (0.03%)	17.76 (0.03%)	25.30 (0.04%)	28.88 (0.05%)	40.11 (0.07%)	N/A
Minke whale											
40MW	4.73 (0.02%)	9.13 (0.04%)	10.82 (0.05%)	39.87 (0.17%)	7.91 (0.03%)	7.05 (0.03%)	5.96 (0.03%)	10.85 (0.05%)	12.39 (0.05%)	26.38 (0.11%)	N/A
Grey seal											
40MW	10.86 (0.18%)	12.62 (0.21%)	14.95 (0.25%)	40.49 (0.67%)	13.59 (0.23%)	7.99 (0.13%)	8.70 (0.14%)	10.55 (0.18%)	12.05 (0.20%)	44.56 (0.74%)	N/A
Harbour seal											
40MW	0.03 (0.06%)	0.04 (0.08%)	0.04 (0.09%)	0.11 (0.23%)	0.05 (0.10%)	0.03 (0.07%)	0.03 (0.06%)	0.05 (0.11%)	0.03 (0.06%)	0.03 (0.06%)	N/A

Table 2-36 Marine mammal CRM assessment (number of individuals / year and % of reference population) with 98% avoidance for 40MW of each tidal device type

Tidal device category	1	2a	2b	3	4	5a	5b	6a	6b	7a*	Total
Number of Devices	**20**	**27**	**32**	**40**	**40**	**40**	**27**	**134**	**34**	**400**	**N/A**
Harbour porpoise											
40MW	75.20 (0.07%)	64.02 (0.06%)	62.72 (0.06%)	83.33 (0.08%)	84.63 (0.08%)	9.95 (0.01%)	33.05 (0.03%)	9.73 (0.01%)	5.92 (0.006%)	N/A	N/A
Bottlenose dolphin											
40MW	2.49 (0.63%)	2.38 (0.60%)	2.82 (0.71%)	3.96 (1.00%)	4.22 (1.06%)	1.42 (0.36%)	2.77 (0.70%)	2.36 (0.59%)	1.80 (0.45%)	N/A	N/A
Risso's dolphin											
40MW	3.57 (0.04%)	3.38 (0.04%)	4.01 (0.05%)	5.59 (0.06%)	6.05 (0.07%)	2.02 (0.02%)	3.97 (0.05%)	3.36 (0.04%)	2.56 (0.03%)	N/A	N/A
Common dolphin											
40MW	19.26 (0.03%)	18.02 (0.03%)	21.36 (0.04%)	28.99 (0.05%)	32.79 (0.06%)	10.86 (0.02%)	21.50 (0.04%)	17.89 (0.03%)	13.62 (0.02%)	N/A	N/A
Minke whale											
40MW	4.45 (0.02%)	4.82 (0.02%)	5.72 (0.02%)	9.95 (0.04%)	7.28 (0.03%)	2.64 (0.01%)	4.79 (0.02%)	4.79 (0.02%)	3.64 (0.015%)	N/A	N/A
Grey seal											
40MW	12.63 (0.21%)	10.65 (0.18%)	12.62 (0.21%)	17.08 (0.28%)	18.70 (0.31%)	4.84 (0.08%)	10.54 (0.18%)	7.40 (0.12%)	5.63 (0.09%)	N/A	N/A
Harbour seal											
40MW	0.03 (0.06%)	0.03 (0.07%)	0.04 (0.07%)	0.05 (0.10%)	0.07 (0.13%)	0.02 (0.04%)	0.03 (0.07%)	0.04 (0.07%)	0.014 (0.03%)	N/A	N/A

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device

Table 2-37 Summary of number of individuals (and % of reference population) that could be at risk of collision with operational tidal devices at Morlais for 40MW scenarios

Species	Magnitude for 30MW scenarios ERM and CRM
Harbour porpoise	**6-301 individuals (0.006-0.29% of MU)** Potential permanent effect with t**o medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Bottlenose dolphin	**2-9 individuals (0.5-2.35% of MU)** Potential permanent effect with **medium to high** magnitude (0.01% to more than 1% of the reference population anticipated to be exposed to effect).
Risso's dolphin	**2-13 individuals (0.02-0.15% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Common dolphin	**14-67 individuals (0.02-0.12% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Minke whale	**3-40 individuals (0.01-0.17%)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Grey seal	**5-40.5 individuals (0.08-0.7% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Harbour seal	**0.01-0.1 individuals (0.03-0.2% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).

2.6. INDICTIVE 240MW FULL BUILD SCENARIO

29. It is currently proposed that the Morlais tidal arrays would be installed in phases up to 240MW.

30. **Table 2-38** and **Table 2-39** present the ERM and CRM collision risk assessments (number of individuals per year and percentage of the reference populations) for indicative 240MW full build scenario with different numbers of each device type, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal. The results are summarised in **Table 2-40**.

31. As outlined in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I),** these scenarios would only be developed once the monitoring and mitigation indicates that the collision risk would be less than one bottlenose dolphin.

32. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)** and the tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**.

33. The marine mammal reference populations are presented in **Table 12.20** in **Section 12.5.10** of **Chapter 12, Marine Mammals (Volume I)**.

Table 2-38 Marine mammal ERM assessment (number of individuals / year and % of reference population) with 98% avoidance for indicative 240MW scenario

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**	**Total**
Number of Devices	**30**	**20**	**33**	**0**	**30**	**0**	**20**	**50**	**25**	**50**	
Harbour porpoise											
240MW scenario	154.47 (0.15%)	56.17 (0.05%)	76.60 (0.07%)	0	47.55 (0.05%)	0	20.68 (0.02%)	5.20 (0.005%)	9.37 (0.009%)	37.60 (0.04%)	**407.6440 (0.39%)**
Bottlenose dolphin											
240MW scenario	4.35 (1%)	2.02 (0.51%)	3.34 (0.84%)	0	2.19 (0.55%)	0	1.61 (0.41%)	1.22 (0.31%)	2.74 (0.69%)	0.72 (0.18%)	**18.19 (4.58%)**
Risso's dolphin											
240MW scenario	6.34 (0.07%)	2.88 (0.03%)	4.75 (0.05%)	0	3.17 (0.04%)	0	2.33 (0.03%)	1.74 (0.02%)	3.91 (0.04%)	0.98 (0.01%)	**26.09 (0.30%)**
Common dolphin											
240MW scenario	37.54 (0.07%)	15.66 (0.03%)	25.84 (0.05%)	0	17.92 (0.03%)	0	13.16 (0.02%)	9.44 (0.02%)	21.24 (0.04%)	5.01 (0.01%)	**145.81 (0.26%)**
Minke whale											
240MW scenario	10.63 (0.045%)	6.76 (0.03%)	11.16 (0.05%)	0	5.94 (0.03%)	0	4.42 (0.02%)	4.05 (0.02%)	9.11 (0.04%)	3.30 (0.01%)	**55.36 (0.24%)**
Grey seal											
240MW scenario	24.44 (0.4%)	9.35 (0.16%)	15.42 (0.26%)	0	10.19 (0.17%)	0	6.44 (0.11%)	3.94 (0.07%)	8.86 (0.15%)	5.57 (0.09%)	**84.21 (1.40%)**
Harbour seal											
240MW scenario	0.06 (0.12%)	0.03 (0.06%)	0.05 (0.09%)	0	0.04 (0.08%)	0	0.02 (0.04%)	0.02 (0.04%)	0.2(0.05%)	0.004 (0.01%)	**0.25 (0.49%)**

Table 2-39 Marine mammal CRM assessment (number of individuals / year and % of reference population) with 98% avoidance for indicative 240MW scenario

Tidal device category	1	2a	2b	3	4	5a	5b	6a	6b	7a*	Total
Number of Devices	**30**	**20**	**33**	**0**	**30**	**0**	**20**	**50**	**25**	**50**	
Harbour porpoise											
240MW scenario	169.20 (0.16%)	47.42 (0.05%)	64.68 (0.06%)	0	63.47 (0.06%)	0	24.48 (0.02%)	3.63 (0.003%)	4.36 (0.004%)	37.60 (0.04%)	**414.84 (0.40%)**
Bottlenose dolphin											
240MW scenario	5.61 (1.4%)	1.76 (0.44%	2.90 (0.73%)	0	3.17 (0.8%)	0	2.05 (0.52%)	0.88 (0.22%)	1.32 (0.33%)	0.72 (0.18%)	**18.41 (4.64%)**
Risso's dolphin											
240MW scenario	8.03 (0.09%)	2.51 (0.03%)	4.14 (0.05%)	0	4.54 (0.05%)	0	2.94 (0.03%)	1.25 (0.01%)	1.88 (0.02%)	0.98 (0.01%)	**26.26 (0.30%)**
Common dolphin											
240MW scenario	43.34 (0.08%)	13.35 (0.02%)	22.02 (0.04%)	0	24.59 (0.04%)	0	15.93 (0.03%)	6.67 (0.01%)	10.01 (0.02%)	5.01 (0.01%)	**140.93 (0.25%)**
Minke whale											
240MW scenario	10.02 (0.04%)	3.57 (0.02%)	5.89 (0.03%)	0	5.46 (0.02%)	0	3.55 (0.02%)	1.79 (0.01%)	2.68 (0.01%)	3.30 (0.01%)	**36.26 (0.15%)**
Grey seal											
240MW scenario	28.41 (0.5%)	7.89 (0.13%)	13.02 (0.22%)	0	14.02 (0.23%)	0	7.80 (0.13%)	2.76 (0.05%)	4.14 (0.07%)	5.57 (0.09%)	**83.63 (1.39%)**
Harbour seal											
240MW scenario	0.07 (0.14%)	0.02 (0.05%)	0.04 (0.08%)	0	0.05 (0.1%)	0	0.03 (0.05%)	0.01 (0.03%)	0.01 (0.02%)	0.004 (0.01%)	**0.24 (0.47%)**

*CRM not applicable for vertical blade of cross-flow multi-rotor floating type device, therefore ERM results included for 240MW scenario

Table 2-40 Summary of maximum number of individuals (and % of reference population) that could be at risk of collision with operational tidal devices at Morlais for 240MW scenario

Species	Magnitude for 240MW scenario ERM and CRM
Harbour porpoise	**401-414 individuals (0.4% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Bottlenose dolphin	**18-19 individuals (5% of MU)** Potential permanent effect with **high** magnitude (more than 1% of the reference population anticipated to be exposed to effect).
Risso's dolphin	**26-17 individuals (0.3% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Common dolphin	**141-1465 individuals (0.26% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Minke whale	**36-56 individuals (0.15-0.24% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).
Grey seal	**83-85 individuals (1.4% of MU)** Potential permanent effect with **high** magnitude (more than % of the reference population anticipated to be exposed to effect).
Harbour seal	**0.24-0.25 individuals (0.5% of MU)** Potential permanent effect with **medium** magnitude (0.01-1% of the reference population anticipated to be exposed to effect).

3. ENVIRONMENTAL PARAMETERS

3.1. WATER DEPTH

29. Water depths across the Morlais Development Zone (MDZ) reach over 72m Lowest Astronomical Tide (LAT) in the northwest of the site, with an average depth across the main site of approximately 40m LAT. All depths in this section are based on LAT.

37. Water depths and tidal resource vary across the MDZ. The eight indicative deployment zones are located in parts of the MDZ that support stronger tidal resource, while also offering a range of depth parameters. Across Zones 1, 2 and 3 water depths are mainly between 30m and 40m, with some deeper areas of 40-45m, whilst within the majority of Zones 4, 5, 6 and 7 the water depth is generally 30-35 m.

34. The water depths in the collisions risk assessments are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**. These water depths were based on the most likely water depths at the different deployment zones that the different types of tidal devices would be deployed, as summarised in **Table 3-1**.

Table 3-1 Water depth for tidal devices used in marine mammal collision risk (ERM and CRM) assessments

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Position in water column	Surface	Surface	Mid-water	Surface	Surface	Seabed	Seabed	Seabed	Seabed	Surface
Description	Twin-rotor floating	Multiple-rotor buoyant platform	Multi-rotor buoyant mid water	Multiple-rotor buoyant platform	Spar buoy	Seabed mounted single rotor	Seabed mounted single rotor	Seabed mounted single rotor	Three-rotor seabed mounted platform	Cross-flow multi-rotor floating
Median water depth (m)	42.5	40	40	30	45	43	43	40	40	40
Rotor tip minimum depth (m)	3.2	5	10	5	6	23	14	26	30	1

35. The additional assessments in this section determine the potential effect of water depth on the collision risk assessments, based on a minimum water depth of 25m (with the exception of device type 4 and 5b which was assessed for a minimum depth of 30m to take into account the rotor diameter) and maximum water depth of 50m for all devices.

36. The rotor tip minimum depth was adjusted, if required, to take into account the change in water depth. The minimum water depths and rotor tip minimum depth used in the additional collision risk assessments are presented in **Table 3-2**. The maximum water depths and rotor tip minimum depth used in the additional collision risk assessments are presented in **Table 3-3**.

37. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)** and the other tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**.

Table 3-2 Minimum water depth for tidal devices used in additional collision risk (ERM and CRM) assessments

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Position in water column	Surface	Surface	Mid-water	Surface	Surface	Seabed	Seabed	Seabed	Seabed	Surface
Description	Twin-rotor floating	Multiple-rotor buoyant platform	Multi-rotor buoyant mid water	Multiple-rotor buoyant platform	Spar buoy	Seabed mounted single rotor	Seabed mounted single rotor	Seabed mounted single rotor	Three-rotor seabed mounted platform	Cross-flow multi-rotor floating
Minimum water depth (m)	25	25	25	25	30	25	30	25	25	25
Rotor tip minimum depth (m)	3.2	5	10	5	3	10	4	15	25	1

Table 3-3 Maximum water depth for tidal devices used in additional collision risk (ERM and CRM) assessments

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Position in water column	Surface	Surface	Mid-water	Surface	Surface	Seabed	Seabed	Seabed	Seabed	Surface
Description	Twin-rotor floating	Multiple-rotor buoyant platform	Multi-rotor buoyant mid water	Multiple-rotor buoyant platform	Spar buoy	Seabed mounted single rotor	Seabed mounted single rotor	Seabed mounted single rotor	Three-rotor seabed mounted platform	Cross-flow multi-rotor floating
Maximum water depth (m)	50	50	50	50	50	50	50	50	50	50
Rotor tip minimum depth (m)	3.2	5	10	5	6	30	20	36	35	1

38. **Table 3-4** and **Table 3-5** present the ERM and CRM collision risk assessments (number of individuals per year) for median, minimum and maximum water depth, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal.

39. The results indicate that for some species changing the water depth for some device types can increase the potential collision risk, while for other it can lower the potential collision risk. Therefore, this will be further assessed prior to deployment, based on the types of devices and actual water depth at deployment location, as part of the Environmental Management and Monitoring Plan (EMMP).

Table 3-4 Comparison of median, minimum and maximum water depths for marine mammal ERM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b	7a
Number of Devices		1	1	1	1	1	1	1	1	1	1
Species	Water depth										
Harbour porpoise	Median	3.43	2.81	2.32	4.74	1.59	0.40	1.03	0.10	0.37	0.75
	Minimum	3.94	4.59	3.84	7.84	2.41	1.84	2.55	0.49	2.22	0.34
	Maximum	3.26	2.85	1.74	3.55	1.65	0.26	0.81	0.06	0.30	0.59
Bottlenose dolphin	Median	0.10	0.10	0.10	0.23	0.07	0.06	0.08	0.02	0.11	0.01
	Minimum	0.16	0.16	0.16	0.37	0.11	0.10	0.12	0.04	0.18	0.02
	Maximum	0.08	0.08	0.08	0.19	0.07	0.05	0.07	0.02	0.09	0.01
Risso's dolphin	Median	0.14	0.14	0.14	0.33	0.11	0.08	0.12	0.03	0.16	0.02
	Minimum	0.24	0.23	0.23	0.52	0.16	0.14	0.17	0.06	0.25	0.03
	Maximum	0.12	0.12	0.12	0.26	0.09	0.07	0.10	0.03	0.13	0.02
Common dolphin	Median	0.83	0.78	0.78	1.67	0.60	0.44	0.66	0.19	0.85	0.10
	Minimum	1.42	1.25	1.25	2.68	0.90	0.76	0.94	0.30	1.36	0.16
	Maximum	0.71	0.63	0.63	1.34	0.54	0.38	0.57	0.15	0.68	0.08
Minke whale	Median	0.24	0.34	0.34	1.00	0.20	0.18	0.22	0.08	0.36	0.07
	Minimum	0.40	0.54	0.54	1.59	0.30	0.30	0.32	0.13	0.58	0.11
	Maximum	0.20	0.27	0.27	0.80	0.18	0.15	0.19	0.06	0.29	0.05
Grey seal	Median	0.54	0.47	0.47	1.01	0.34	0.20	0.32	0.08	0.35	0.11
	Minimum	0.55	0.14	0.30	0.66	0.32	0.38	0.32	0.22	0.99	0.11
	Maximum	0.67	0.58	0.65	1.42	0.40	0.10	0.22	0.03	0.15	0.11
Harbour seal	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3-5 Comparison of median, minimum and maximum water depths for marine mammal CRM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b
Number of Devices		1	1	1	1	1	1	1	1	1
Species	Water depth									
Harbour porpoise	Median	3.76	2.37	1.96	2.08	2.12	0.25	1.22	0.07	0.17
	Minimum	4.31	3.88	3.24	3.45	3.22	1.14	3.01	0.34	1.03
	Maximum	3.57	2.40	1.47	1.56	2.20	0.16	0.96	0.04	0.14
Bottlenose dolphin	Median	0.12	0.09	0.09	0.10	0.11	0.04	0.10	0.02	0.05
	Minimum	0.21	0.14	0.14	0.16	0.16	0.06	0.15	0.03	0.08
	Maximum	0.11	0.07	0.07	0.08	0.10	0.03	0.09	0.01	0.04
Risso's dolphin	Median	0.18	0.13	0.13	0.14	0.15	0.05	0.15	0.03	0.08
	Minimum	0.30	0.20	0.20	0.22	0.23	0.09	0.21	0.04	0.12
	Maximum	0.15	0.10	0.10	0.11	0.14	0.04	0.13	0.02	0.06
Common dolphin	Median	0.96	0.67	0.67	0.72	0.82	0.27	0.80	0.13	0.40
	Minimum	1.64	1.07	1.07	1.16	1.23	0.47	1.14	0.21	0.64
	Maximum	0.82	0.53	0.53	0.58	0.74	0.23	0.68	0.11	0.32
Minke whale	Median	0.22	0.18	0.18	0.25	0.18	0.07	0.18	0.04	0.11
	Minimum	0.38	0.29	0.29	0.40	0.27	0.11	0.25	0.06	0.17
	Maximum	0.19	0.14	0.14	0.20	0.16	0.06	0.15	0.03	0.09
Grey seal	Median	0.63	0.39	0.39	0.43	0.47	0.12	0.39	0.06	0.17
	Minimum	0.64	0.12	0.26	0.28	0.45	0.23	0.39	0.15	0.46
	Maximum	0.78	0.49	0.55	0.60	0.55	0.06	0.27	0.02	0.07
Harbour seal	Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.2. CURRENT SPEED

40. The current speed in the collisions risk assessments are as outlined in **Table 12.74** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**. The current speed was based on the mean current speed that the tidal devices would be operating at the MDZ, as summarised in **Table 3-6**.

41. It is important to note that the tidal devices have a minimum and maximum current speed at which they operate, and this has been used to calculate the mean current speed used in the ES assessments.

Table 3-6 Current speed for tidal devices used in marine mammal collision risk (ERM and CRM) assessments

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Position in water column	Surface	Surface	Mid-water	Surface	Surface	Seabed	Seabed	Seabed	Seabed	Surface
Description	Twin-rotor floating	Multiple-rotor buoyant platform	Multi-rotor buoyant mid water	Multiple-rotor buoyant platform	Spar buoy	Seabed mounted single rotor	Seabed mounted single rotor	Seabed mounted single rotor	Three-rotor seabed mounted platform	Cross-flow multi-rotor floating
Mean current speed (m/s)	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
Rotation speed (rpm)	8.71	18	18	26.7	10.1	7.5	7.5	22	22	13.6
Mean tangential blade speed (m/s)	4.56	4.71	4.71	3.5	7.14	2.95	5.11	5.76	5.76	1.78
Mean blade speed relative to water (n)	4.81	4.95	4.95	3.81	7.30	3.31	5.33	5.96	5.96	2.34

42. The additional assessments in this section determine the potential effect of increased current speed on the collision risk assessments, based on a worst-case scenario for a mean current speed of 1.77m/s and adjusting the related parameters, as outlined in **Table 3-7**.

43. It is important to note that the mean current speed is the most appropriate parameter to use as the maximum operating current speed would only be applicable for a relatively short period of the tidal cycle.

44. The marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)** and the other tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**.

45. **Table 3-8** and **Table 3-9** present the ERM and CRM collision risk assessments (number of individuals per year) for current speeds of 1.52m/s and 1.77m/s, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal.

46. The results indicate that for some species changing the current speed and related parameters for some device types can increase the potential collision risk, while for other it can lower the potential collision risk. Therefore, this will be further assessed prior to deployment, based on the parameters of devices to be deployed in relation to current speed, as part of the Environmental Management and Monitoring Plan (EMMP).

Table 3-7 Increased current speed and related parameters used in additional collision risk (ERM and CRM) assessments

Tidal device category	**1**	**2a**	**2b**	**3**	**4**	**5a**	**5b**	**6a**	**6b**	**7a**
Position in water column	Surface	Surface	Mid-water	Surface	Surface	Seabed	Seabed	Seabed	Seabed	Surface
Description	Twin-rotor floating	Multiple-rotor buoyant platform	Multi-rotor buoyant mid water	Multiple-rotor buoyant platform	Spar buoy	Seabed mounted single rotor	Seabed mounted single rotor	Seabed mounted single rotor	Three-rotor seabed mounted platform	Cross-flow multi-rotor floating
Mean current speed (m/s)	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Rotation speed (rpm)	8.71	30	30	18	11.3	9	8	22	22	13.6
Mean tangential blade speed (m/s)	4.56	7.85	7.85	3.5	7.99	3.53	5.45	5.76	5.76	1.78
Mean blade speed relative to water (n)	4.89	8.05	8.05	3.81	8.18	3.95	5.73	6.03	6.03	2.34

Table 3-8 Comparison of mean and increased current speed for marine mammal ERM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b	7a
Number of Devices		1	1	1	1	1	1	1	1	1	1
Species	Current speed										
Harbour porpoise	Mean (1.52m/s)	3.43	2.81	2.32	4.74	1.59	0.40	1.03	0.10	0.37	0.75
	Increased (1.77m/s)	3.43	4.59	3.80	3.39	1.77	0.47	1.10	0.10	0.37	0.75
Bottlenose dolphin	Mean (1.52m/s)	0.10	0.10	0.10	0.23	0.07	0.06	0.08	0.02	0.11	0.01
	Increased (1.77m/s)	0.10	0.16	0.16	0.17	0.08	0.07	0.09	0.02	0.11	0.01
Risso's dolphin	Mean (1.52m/s)	0.14	0.14	0.14	0.33	0.11	0.08	0.12	0.03	0.16	0.02
	Increased (1.77m/s)	0.14	0.23	0.23	0.24	0.12	0.09	0.12	0.03	0.16	0.02
Common dolphin	Mean (1.52m/s)	0.83	0.78	0.78	1.67	0.60	0.44	0.66	0.19	0.85	0.10
	Increased (1.77m/s)	0.83	1.27	1.27	1.23	0.67	0.52	0.70	0.19	0.85	0.10
Minke whale	Mean (1.52m/s)	0.24	0.34	0.34	1.00	0.20	0.18	0.22	0.08	0.36	0.07
	Increased (1.77m/s)	0.24	0.54	0.54	0.76	0.22	0.20	0.23	0.08	0.36	0.07
Grey seal	Mean (1.52m/s)	0.54	0.47	0.47	1.01	0.34	0.20	0.32	0.08	0.35	0.11
	Increased (1.77m/s)	0.54	0.76	0.76	0.75	0.38	0.23	0.34	0.08	0.35	0.11
Harbour seal	Mean (1.52m/s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Increased (1.77m/s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3-9 Comparison of mean and increased current speed for marine mammal CRM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b
Number of Devices		1	1	1	1	1	1	1	1	1
Species	Water depth									
Harbour porpoise	Mean (1.52m/s)	3.76	2.37	1.96	2.08	2.12	0.25	1.22	0.07	0.17
	Increased (1.77m/s)	3.90	2.46	2.04	2.16	2.20	0.26	1.27	0.08	0.18
Bottlenose dolphin	Mean (1.52m/s)	0.12	0.09	0.09	0.10	0.11	0.04	0.10	0.02	0.05
	Increased (1.77m/s)	0.13	0.09	0.09	0.10	0.11	0.04	0.11	0.02	0.05
Risso's dolphin	Mean (1.52m/s)	0.18	0.13	0.13	0.14	0.15	0.05	0.15	0.03	0.08
	Increased (1.77m/s)	0.18	0.13	0.13	0.14	0.16	0.05	0.15	0.03	0.08
Common dolphin	Mean (1.52m/s)	0.96	0.67	0.67	0.72	0.82	0.27	0.80	0.13	0.40
	Increased (1.77m/s)	0.99	0.69	0.69	0.75	0.85	0.28	0.82	0.14	0.41
Minke whale	Mean (1.52m/s)	0.22	0.18	0.18	0.25	0.18	0.07	0.18	0.04	0.11
	Increased (1.77m/s)	0.26	0.21	0.21	0.29	0.21	0.08	0.21	0.04	0.12
Grey seal	Mean (1.52m/s)	0.63	0.39	0.39	0.43	0.47	0.12	0.39	0.06	0.17
	Increased (1.77m/s)	0.65	0.41	0.41	0.44	0.48	0.12	0.40	0.06	0.17
Harbour seal	Mean (1.52m/s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Increased (1.77m/s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

4. MARINE MAMMAL PARAMETERS

4.1. BODY LENGTH AND WIDTH

47. **Table 4-1** outlines the marine mammal dimensions, based on the SNH guidance (SNH, 2016), used for the collision risk assessment, as presented in **Table 12-77** of **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)**. Where possible the values from the SNH guidance (SNH, 2016) were used, as this was a peer-reviewed data source and it also allows, if required, comparison with other collision risk assessments. Where data was not provided bottlenose dolphin, Risso's dolphin and common dolphin these were determined based on Cetacean Stranding's Investigation Programme (CSIP) stranding records from Wales and data collected by Marine Environmental Monitoring (1994-2017).

Table 4-1 Marine mammal dimensions used in the Morlais collision risk assessments

Species	Length (m)	Effective radius/body width (m)	Source
Harbour porpoise	1.48m	0.32m	SNH (2016); Thompson (2015)
Bottlenose dolphin	2.57m	0.64m	Calculated from Welsh stranding data (1994-2017)
Risso's dolphin	2.36m	0.59m	Calculated from Welsh stranding data (1994-2017)
Common dolphin	1.77m	0.44m	Calculated from Welsh stranding data (1994-2017)
Minke whale	8.8m	2.2m	SNH (2016); Horwood (1990)
Grey seal	1.86m	0.42m	SNH (2016); Thompson (2015)
Harbour seal	1.41m	0.34m	SNH (2016)

48. In addition, stranding data from around the Welsh (1994-2017) and UK (2005-2015; including Welsh data) coastline were assessed for all species to determine the mean, maximum, minimum and median values for body length and effective radius/body width (**Table 4-2** and **Table 4-3**).

49. It should be noted that there can be biases and limitations in stranding data, for example, there could be the potential to be an increased representation of very young, sick, and (to a lesser extent) very old animals (i.e., they are representative of the age structure of deaths rather than the age structure of the living population) and towards animals living or moving through coastal waters.

50. Taking into account the body length and effective radius/body width, UK and Welsh stranding data a range of potential values were determined (**Table 4-4**) and assessed for any potential effects on the collision risk assessments.

51. The other marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals**

(Volume I) and the tidal device parameters are as outlined in **Table 12.74** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**.

52. **Table 4-5** and **Table 4-6** present the ERM and CRM collision risk assessments (number of individuals per year) for different body length and effective radius/body width, based on 98% avoidance rates for harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal.

53. The marine mammal parameters will be further reviewed and assessed prior to deployment, based on the latest information and guidance, as part of the Environmental Management and Monitoring Plan (EMMP).

Table 4-2 Marine mammal dimensions from Welsh stranding data (1994-2017)

Species	Parameter	Length (m)	Effective radius/body width (m)
Harbour porpoise (n=1,038)	Maximum	2.51	0.63
	Minimum	0.39	0.10
	Mean	1.22	0.30
	Median	1.23	0.31
Bottlenose dolphin (n=38)	Maximum	3.53	0.88
	Minimum	1.07	0.27
	Mean	2.57	0.64
	Median	2.90	0.73
Risso's dolphin (n=15)	Maximum	3.25	0.81
	Minimum	1	0.25
	Mean	2.37	0.59
	Median	2.43	0.61
Common dolphin (n=124)	Maximum	2.4	0.6
	Minimum	0.61	0.15
	Mean	1.77	0.44
	Median	1.85	0.46
Minke whale (n=4)	Maximum	8.8	2.2
	Minimum	2.43	0.61
	Mean	4.68	1.17
	Median	3.75	0.94
Grey seal (n=92)	Maximum	2.25	0.56
	Minimum	0.6	0.15
	Mean	1.37	0.34
	Median	1.22	0.30

Table 4-3 Marine mammal dimensions from UK stranding data (2005-2015)

Species	Parameter	Length (m)	Effective radius/body width (m)
Harbour porpoise (n=854)	Maximum	1.89	0.47
	Minimum	0.69	0.14

Species	Parameter	Length (m)	Effective radius/body width (m)
	Mean	1.24	0.31
	Median	1.21	0.30
Bottlenose dolphin (n=33)	Maximum	3.41	0.85
	Minimum	1.28	0.32
	Mean	2.45	0.61
	Median	2.60	0.65
Risso's dolphin (n=18)	Maximum	3.08	0.77
	Minimum	1.31	0.33
	Mean	2.36	0.59
	Median	2.31	0.58
Common dolphin (n=216)	Maximum	2.62	0.66
	Minimum	0.73	0.18
	Mean	1.83	0.46
	Median	1.86	0.47
Minke whale (n=26)	Maximum	8.35	2.09
	Minimum	3.13	0.78
	Mean	5.20	1.30
	Median	4.74	1.19

Table 4-4 Marine mammal dimensions used in additional collision risk assessments based on SNH (2016) guidance, Welsh (1994-2017) and UK (2005-2015) stranding data

Species	Parameter	Length (m)	Effective radius/body width (m)	Data source
Harbour porpoise	ES	1.48	0.32	SNH (2016)
	Maximum	2.51	0.63	Welsh data
	Minimum	0.39	0.10	Welsh data
	Mean	1.22	0.30	Welsh data
	Median	1.23	0.31	Welsh data
Bottlenose dolphin	ES (mean)	2.57	0.64	Welsh data
	Maximum	3.53	0.88	Welsh data
	Minimum	1.07	0.27	Welsh data
	Mean	2.45	0.61	UK data
	Median	2.90	0.73	Welsh data
Risso's dolphin	ES (mean)	2.36	0.59	Welsh data
	Maximum	3.25	0.81	Welsh data
	Minimum	1	0.25	Welsh data
	Mean	2.36	0.59	UK data
	Median	2.31	0.61	UK data
Common dolphin	ES (mean)	1.77	0.44	Welsh data
	Maximum	2.62	0.66	UK data

Species	Parameter	Length (m)	Effective radius/body width (m)	Data source
	Minimum	0.61	0.15	Welsh data
	Mean	1.83	0.46	UK data
	Median	1.85	0.46	Welsh data
Minke whale	ES	8.8	2.2	SNH (2016)
	Maximum	8.8	2.2	Welsh data
	Minimum	2.43	0.61	Welsh data
	Mean	5.20	1.30	UK data
	Median	4.74	1.19	UK data
Grey seal	ES	1.86	0.42	SNH (2016)
	Maximum	2.25	0.56	Welsh data
	Minimum	0.6	0.15	Welsh data
	Mean	1.37	0.34	Welsh data
	Median	1.22	0.30	Welsh data
Harbour seal	ES	1.41	0.34	SNH (2016)
	No UK or Welsh stranding data			

Table 4-5 Comparison of body dimensions for marine mammal ERM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b	7a
Number of Devices		1	1	1	1	1	1	1	1	1	1
Species	**Parameter**										
Harbour porpoise	**ES**	**3.43**	**2.81**	**2.32**	**4.74**	**1.59**	**0.40**	**1.03**	**0.10**	**0.37**	**0.75**
	Maximum	4.66	4.47	3.70	8.36	2.34	0.62	1.53	0.17	0.60	1.34
	Minimum	2.19	1.20	0.99	1.47	0.81	0.19	0.53	0.04	0.16	0.22
	Mean	**3.13**	**2.41**	**1.99**	**3.90**	**1.40**	**0.35**	**0.91**	**0.09**	**0.32**	**0.62**
	Median	3.14	2.43	2.00	3.94	1.40	0.35	0.92	0.09	0.32	0.62
Bottlenose dolphin	**ES**	**0.10**	**0.10**	**0.10**	**0.23**	**0.07**	**0.06**	**0.08**	**0.02**	**0.11**	**0.01**
	Maximum	0.12	0.14	0.14	0.34	0.10	0.08	0.11	0.03	0.15	0.02
	Minimum	0.06	0.05	0.05	0.09	0.04	0.03	0.04	0.01	0.05	0.01
	Mean	**0.09**	**0.10**	**0.10**	**0.22**	**0.07**	**0.05**	**0.08**	**0.02**	**0.10**	**0.01**
	Median	0.10	0.11	0.11	0.27	0.08	0.06	0.09	0.03	0.12	0.02
Risso's dolphin	**ES**	**0.14**	**0.14**	**0.14**	**0.33**	**0.11**	**0.08**	**0.12**	**0.03**	**0.16**	**0.02**
	Maximum	0.18	0.20	0.20	0.47	0.14	0.11	0.15	0.05	0.21	0.03
	Minimum	0.09	0.07	0.07	0.13	0.06	0.04	0.06	0.02	0.08	0.01
	Mean	**0.14**	**0.14**	**0.14**	**0.33**	**0.11**	**0.08**	**0.12**	**0.03**	**0.16**	**0.02**
	Median	0.14	0.14	0.14	0.32	0.10	0.08	0.11	0.03	0.15	0.02
Common dolphin	**ES**	**0.83**	**0.78**	**0.78**	**1.67**	**0.60**	**0.44**	**0.66**	**0.19**	**0.85**	**0.10**
	Maximum	1.06	1.12	1.12	2.58	0.81	0.62	0.89	0.27	1.21	0.16
	Minimum	0.54	0.36	0.36	0.61	0.32	0.22	0.35	0.09	0.39	0.04
	Mean	**0.85**	**0.81**	**0.81**	**1.73**	**0.61**	**0.46**	**0.67**	**0.19**	**0.87**	**0.10**
	Median	0.86	0.81	0.81	1.75	0.62	0.46	0.68	0.20	0.88	0.11
Minke whale	**ES**	**0.24**	**0.34**	**0.34**	**1.00**	**0.20**	**0.18**	**0.22**	**0.08**	**0.36**	**0.07**
	Maximum	0.24	0.34	0.34	1.00	0.20	0.18	0.22	0.08	0.36	0.07
	Minimum	0.08	0.08	0.08	0.19	0.06	0.05	0.07	0.02	0.09	0.01
	Mean	**0.14**	**0.18**	**0.18**	**0.48**	**0.12**	**0.10**	**0.13**	**0.04**	**0.20**	**0.03**
	Median	0.13	0.16	0.16	0.43	0.11	0.09	0.12	0.04	0.18	0.03
Grey seal	**ES**	**0.54**	**0.47**	**0.47**	**1.01**	**0.34**	**0.20**	**0.32**	**0.08**	**0.35**	**0.11**
	Maximum	0.61	0.55	0.55	1.25	0.39	0.23	0.37	0.09	0.42	0.14
	Minimum	0.34	0.21	0.21	0.35	0.17	0.09	0.17	0.03	0.16	0.04
	Mean	**0.46**	**0.36**	**0.36**	**0.74**	**0.27**	**0.16**	**0.26**	**0.06**	**0.27**	**0.08**
	Median	0.44	0.33	0.33	0.66	0.26	0.14	0.24	0.06	0.25	0.07

Table 4-6 Comparison of body dimensions for marine mammal CRM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b
Number of Devices		1	1	1	1	1	1	1	1	1
Species	Parameter									
Harbour porpoise	**ES**	**3.76**	**2.37**	**1.96**	**2.08**	**2.12**	**0.25**	**1.22**	**0.07**	**0.17**
	Maximum	6.10	3.96	3.27	3.67	3.41	0.41	1.97	0.12	0.29
	Minimum	1.44	0.89	0.74	0.75	0.82	0.09	0.47	0.03	0.07
	Mean	**3.21**	**2.02**	**1.67**	**1.77**	**1.81**	**0.21**	**1.04**	**0.06**	**0.15**
	Median	3.23	2.04	1.68	1.79	1.82	0.21	1.05	0.06	0.15
Bottlenose dolphin	**ES**	**0.12**	**0.09**	**0.09**	**0.10**	**0.11**	**0.04**	**0.10**	**0.02**	**0.05**
	Maximum	0.17	0.12	0.12	0.14	0.14	0.05	0.14	0.02	0.07
	Minimum	0.06	0.04	0.04	0.04	0.05	0.02	0.05	0.01	0.02
	Mean	**0.12**	**0.08**	**0.08**	**0.09**	**0.10**	**0.03**	**0.10**	**0.02**	**0.05**
	Median	0.14	0.10	0.10	0.11	0.12	0.04	0.12	0.02	0.06
Risso's dolphin	**ES**	**0.18**	**0.13**	**0.13**	**0.14**	**0.15**	**0.05**	**0.15**	**0.03**	**0.08**
	Maximum	0.24	0.17	0.17	0.20	0.20	0.07	0.20	0.03	0.10
	Minimum	0.08	0.06	0.06	0.06	0.07	0.02	0.07	0.01	0.03
	Mean	**0.18**	**0.13**	**0.13**	**0.14**	**0.15**	**0.05**	**0.15**	**0.03**	**0.08**
	Median	0.18	0.12	0.12	0.14	0.15	0.05	0.14	0.02	0.07
Common dolphin	**ES**	**0.96**	**0.67**	**0.67**	**0.72**	**0.82**	**0.27**	**0.80**	**0.13**	**0.40**
	Maximum	1.39	0.98	0.98	1.10	1.17	0.39	1.14	0.20	0.59
	Minimum	0.41	0.28	0.28	0.29	0.36	0.12	0.35	0.06	0.17
	Mean	**0.99**	**0.69**	**0.69**	**0.75**	**0.84**	**0.28**	**0.82**	**0.14**	**0.41**
	Median	1.00	0.70	0.70	0.76	0.85	0.28	0.83	0.14	0.42
Minke whale	**ES**	**0.22**	**0.18**	**0.18**	**0.25**	**0.18**	**0.07**	**0.18**	**0.04**	**0.11**
	Maximum	0.22	0.18	0.18	0.25	0.18	0.07	0.18	0.04	0.11
	Minimum	0.10	0.07	0.07	0.08	0.09	0.03	0.08	0.01	0.04
	Mean	**0.20**	**0.15**	**0.15**	**0.19**	**0.17**	**0.06**	**0.17**	**0.03**	**0.09**
	Median	0.19	0.14	0.14	0.17	0.16	0.06	0.16	0.03	0.09
Grey seal	**ES**	**0.63**	**0.39**	**0.39**	**0.43**	**0.47**	**0.12**	**0.39**	**0.06**	**0.17**
	Maximum	1.54	0.98	0.98	1.08	1.14	0.30	0.95	0.14	0.20
	Minimum	0.26	0.16	0.16	0.16	0.19	0.05	0.16	0.02	0.07
	Mean	**0.49**	**0.30**	**0.30**	**0.32**	**0.36**	**0.09**	**0.30**	**0.04**	**0.13**
	Median	0.44	0.27	0.27	0.29	0.33	0.08	0.27	0.04	0.11

4.2. DENSITY ESTIMATES

54. The density estimates used in the collisions risk assessments for Risso's dolphin, common dolphin and minke whale were based on the SCANS-III survey data (Hammond *et al*., 2017), therefore for consistency the density estimates for harbour porpoise and bottlenose dolphin from the SCANS-III surveys have also been assessed (**Table 4-7**).

Table 4-7 Harbour porpoise and bottlenose dolphin density estimates

Species	ES assessment	SCANS-III survey
Harbour porpoise	0.783/km^2 West Anglesey (SEACAMS; Appendix 12.1)	0.239/km^2 SCANS-III Block E (Hammond *et al*., 2017)
Bottlenose dolphin	0.02/km^2 Area from Anglesey to Cardigan Bay (Feingold and Evans, 2013)	0.008/km^2 SCANS-III Block E (Hammond *et al*., 2017)

55. The other marine mammal parameters used in the collision risk assessments are as outlined in **Table 2-1** and **Table 12-77 to 12-78** in **Section 12.6.4.5.1.3** of **Chapter 12, Marine Mammals (Volume I)** and the tidal device parameters are as outlined in **Table 12-76** in **Section 12.6.4.5.1.2** of **Chapter 12, Marine Mammals (Volume I)**.

56. **Table 4-8** and **Table 4-9** present the ERM and CRM collision risk assessments (number of individuals per year) for the harbour porpoise and bottlenose dolphin density estimates, based on 98% avoidance rates.

57. The values used in the collision risk assessments in **Section 12.6.4.5.2** of **Chapter 12, Marine Mammals (Volume I)** are robust and the most suitable values to use. However, the marine mammal density estimates will be further reviewed and assessed prior to deployment, based on the latest information and guidance, as part of the Environmental Management and Monitoring Plan (EMMP).

Table 4-8 Comparison of harbour porpoise and bottlenose dolphin density estimates for marine mammal ERM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b	7a
Number of Devices		1	1	1	1	1	1	1	1	1	1
Species	Density Estimate										
Harbour porpoise	ES	3.43	2.81	2.32	4.74	1.59	0.40	1.03	0.10	0.37	0.75
	SCANS-III	1.05	0.86	0.71	1.45	0.48	0.12	0.32	0.03	0.11	0.23
Bottlenose dolphin	ES	0.10	0.10	0.10	0.23	0.07	0.06	0.08	0.02	0.11	0.01
	SCANS-III	0.04	0.04	0.04	0.09	0.03	0.02	0.03	0.01	0.04	0.01

Table 4-9 Comparison of harbour porpoise and bottlenose dolphin density estimates for marine mammal CRM assessment (number of individuals / year) with 98% avoidance for one device of each device type

Tidal device category		1	2a	2b	3	4	5a	5b	6a	6b
Number of Devices		1	1	1	1	1	1	1	1	1
Species	Density Estimate									
Harbour porpoise	ES	3.76	2.37	1.96	2.08	2.12	0.25	1.22	0.07	0.17
	SCANS-III	1.15	0.72	0.60	0.64	0.65	0.08	0.37	0.02	0.05
Bottlenose dolphin	ES	0.12	0.09	0.09	0.10	0.11	0.04	0.10	0.02	0.05
	SCANS-III	0.05	0.04	0.04	0.04	0.04	0.01	0.04	0.01	0.02

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Morlais Project
Environmental Statement

Appendix 12.3: Assessment of Potential for Population Level Effects for Marine Mammals

Volume III

Applicant: Menter Môn Morlais Limited Document Reference: PB5034-ES-0123 Appendix 12.3: Assessment of Potential for Population Level Effects for Marine Mammals Author: Royal HaskoningDHV			
Morlais Document No.: MOR/RHDHV/APP/0023	Status: Final	Version No: F3.0	Date: July 2019

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GLOSSARY OF ACRONYMS

EV	Environmentally caused Variation
IAMMWG	Inter Marine Mammal Working Group
iPCOD	Interim Population Consequences of Disturbance Model
MDZ	Morlais Development Zone
MU	Management Unit
PDV	Phocine Distemper Virus
PVA	Population Viability Analysis

GLOSSARY OF TERMINOLOGY

Deterministic models	The output of the model is fully determined by the parameter values and the initial conditions
Stochastic models	The models possess some inherent randomness. Consequently, the same set of parameter values and initial conditions will lead to a variety of different outputs each time the model is run. This is thought to be a better representation of natural processes – which are naturally stochastic.

1. INTRODUCTION

1. The following brief report outlines the results of a Population Viability Analysis (PVA) conducted for seven species of marine mammal, to model the potential impact of any collision mortality on populations of these species in the vicinity of the Morlais Development Zone (MDZ).

2. As all marine mammal species have legal protection within UK waters, there is a need to consider conservation of these populations and research the effects of renewable energy devices whilst also working towards securing renewable energy sources for the future. To fulfil these obligations, analyses were conducted using the software package Vortex v10 (Lacy and Pollak, 2017). The Interim Population Consequences of Disturbance Model (iPCOD) was considered, but as of June 2019 was unavailable for use due to a coding issue (Annex 1). Using R (rramas) was also considered to undertake the PVA, however, as outlined in Annex 2, there are limitations in the data available. Vortex PVAs are individual-based simulation models that use population parameters specified by the user. Demographic factors such as mortality rates, reproductive rates and sex ratio are modelled as binomial distributions; environmental variability and carrying capacity are modelled as normal distributions (Lacy *et al.,* 2017).

3. PVA was first introduced by Gilpin and Soulé (1986) as a method for assessing probability of extinction and exploring the factors threatening the future viability of a population. As well as assessment of extinction risk, this methodology can be used to guide conservation and management actions, for example by being able to explore the consequences of fatalities on a population (Morris and Doak, 2002).

4. PVA has been widely used for many marine mammal species, e.g. dugongs *Dugong dugon* (Heinsohn *et al.,* 2004), manatees *Trichechidae Sp.* (Marmontel *et al.,* 1997), Steller sea lions *Eumetopias jubatus* (Winship and Trites, 2006), killer whales *Orcinus orca* (Kuningas, 2014), Hector’s dolphins *Cephalorhynchus hectori* (Burkhart and Slooten, 2003) and bottlenose dolphins *Tursiops truncatus* (Thompson *et al.,* 2000; Gaspar, 2003; Fortuna, 2006; Currey *et al.,* 2009). Population growth in marine mammals has been found to be more sensitive to changes in adult survival, than reproductive rates (Marmontel *et al.,* 1997).

5. PVA as a methodology has not been without criticisms, which generally focus on the quality of available data to put into the modelling framework, as for many rare and endangered species, detailed knowledge of these parameters may be unavailable (e.g. Harwood, 2000; Coulson *et al.,* 2001). This is also true of the marine mammal species modelled here, and this should be considered when using the model outputs.

6. Good quality input data are of intrinsic importance when conducting a population viability analysis and using it to make predictions about the future, and they should be made over a realistic timescale (Ralls *et al.,* 2002). Care must be taken when drawing conclusions from any derived predictions and with making management plans based on these values (Beissinger, 2002; Ralls *et al.,* 2002).

2. METHODS

7. Population viability analyses was conducted for bottlenose dolphin, harbour porpoise *Phocoena phocoena*, Risso’s dolphin *Grampus griseus*, common dolphin *Delphinus delphis*, minke whale

Balaenoptera acutorostrata and grey seal *Halichoerus grypus* at the MDZ. Models were conducted using software package Vortex v10 (Lacy and Pollak, 2017).

2.1. MODEL ASSUMPTIONS

8. Any model is a simplification of reality, and consequently contains simplifying assumptions concerning the life history of the study population, as well as factors such as environmental variation.

9. The PVA scenarios developed below for this report are density independent, and survival and birth rates are assumed to vary independently.

10. It is assumed that the species modelled belong to a single closed population. In reality, the study area is used by a small part of a much larger population, which may include large parts of the north Atlantic (e.g. minke whale and common dolphin). It is important to note that these results do not take account of any immigration or emigration that may be occurring, whether permanent or temporary.

2.2. MODEL PARAMETERS

11. Population viability analysis utilises a set of population parameters characterising each species.

12. The model scenarios had the following features:

- Extinction was defined as only one sex surviving;
- Reproductive rates were not thought likely to change with changing population size, so density dependent reproduction was not selected; and
- Supplementation was not considered.

2.2.1. Inbreeding Depression

13. There are no available data on the inbreeding level of these wild populations of marine mammals.

14. For bottlenose dolphin, with a reference population of 397 individuals (Inter Marine Mammal Working Group (IAMMWG), 2015), the population is so small, it seems likely that there will be some level of reduced fitness as is common in most studied diploid species (Lacy *et al.,* 2017), and so a precautionary estimate of inbreeding is included in the model. For the remaining species, which are considered to be part of a much larger population, this is not included in the model.

2.2.2. Catastrophic Events

15. Catastrophic events are categorised by Vortex as extreme environmental variation and include events such as disease epidemics. Catastrophic events are not included in the models for any of the modelled species.

2.2.3. Carrying Capacity

16. The carrying capacity of these populations is unknown. As these models are designed to investigate the effects of potential collision risk on the population, an artificially high carrying capacity was set in the models. This meant the model was not limited by this parameter. Sensitivity tests (**Section 2.2.5**) were conducted prior to running the models to help establish a value to be used.

2.2.4. Environmental Variation

17. As the parameters used in these models are derived from the literature and not from direct analysis of population specific data, the required information was not available to calculate bespoke environmentally caused variation (EV) values for each species. Where available, values from Harwood and King (2014), derived for the iPCOD models were used. For common dolphin and Risso's dolphin, for which these values were not available, bottlenose dolphin was used as a proxy species.

2.2.5. Sensitivity Testing

18. Values for carrying capacity and percentage of males in the breeding pool were not available in the literature for the majority of species. Consequently, a sensitivity analysis for these two parameters was conducted prior to running the full collision simulations (see **Section 3**).

19. Neither was found to have a significant influence on the population growth rate. This agrees with previous studies which have found population growth in marine mammals to be more sensitive to changes in adult survival, than reproductive rates (e.g. Marmontel *et al.,* 1997; Lacey, 2015).

2.2.6. Scenarios

20. A baseline model was constructed for each species. For parameters where a range of input values were available from the literature, the value for the base model was chosen as a result of the sensitivity analysis. In all cases the baseline model did not include any fatalities as a result of collision.

21. The effect of any potential collisions was then modelled using the same parameters as the baseline in all cases except for the "harvest" inputs, which are the collision estimates.

22. Parameters for the baseline models for each species are shown in **Table 2.1** for bottlenose dolphin, **Table 2.2** for Risso's dolphin, **Table 2.3** for common dolphin, **Table 2.4** for harbour porpoise, **Table 2.5** for minke whale, and **Table 2.6** for grey seal.

Table 2.1 Input parameters used in baseline VORTEX simulation for bottlenose dolphin

Bottlenose dolphin		
Parameter	**Value**	**Notes**
Number of model iterations	1000	
Number of years	250	Approximately 10 generations (after Thomson *et al.,* 2000).
Inbreeding depression	Yes	See **section 2.2.1**.
Lethal equivalents	6.29	See **section 2.2.1**.
Mating system	Polygynous	A polygamous reproductive system was selected; female bottlenose dolphins have been noted mating with several males (Wells *et al.,* 1987).
Age of first offspring females	9	Harwood and King (2014).
Maximum age of female reproduction	67	There is no indication of reproductive senescence in this species (Marsh and Kasuya, 1986).
Age of first offspring males	9	Harwood and King (2014).
Max age of male reproduction	67	There is no indication of reproductive senescence in this species (Marsh and Kasuya, 1986).
Max lifespan	67	Marsh and Kasuya (1986).
Max number of progeny per brood	1	Female bottlenose dolphins give birth to a single calf (Connor *et al.,* 2000).
Sex ratio at birth (in % males)	50	The sex ratio at birth for this population is unknown. Assumed to be 1:1.
% adult females breeding	29	Calculated based on inter birth interval of 3.4 years (Lohrengel *et al.,* 2018).
SD in % breeding due to EV	5.5	Harwood and King (2014).
Mortality of females 0-3 (Calf)	20	Harwood and King (2014).
SD due to EV	5	Harwood *et al.* (2014).
3-9 (juvenile)	6	Harwood and King (2014).
SD due to EV	4.47	Harwood *et al.* (2014).
9+ (adult)	6	Harwood and King (2014).
SD due to EV	4.47	Harwood *et al.* (2014).
Mortality of males	As females	
% males breeding	75 %	See **section 2.2.5**.
Initial population size (scenario A)	397	Irish Sea Management Unit (IAMMWG, 2015).
Initial population size (scenario B)	330	SAC population size (Feingold and Evans, 2014)
Carrying capacity	414	See **section 2.2.5**.
Collision risk	1	Up to one adult dolphin based on collision risk assessments for less than one bottlenose dolphin scenarios
	1,2,3 or 7	Based on worst-case collision risk for 30MW scenarios

Bottlenose dolphin		
Parameter	**Value**	**Notes**
	17 or 19	Based on worst-case collision risk for 240MW scenarios

Table 2.2 Input parameters used in baseline VORTEX simulation for Risso's dolphin

Risso's dolphin		
Parameter	**Value**	**Notes**
Number of model iterations	500	Due to considerable processing time, only 500 iterations of this model were performed
Number of years	50	This model was run for 50 years to exceed the lifetime of the devices
Inbreeding depression	No	See **section 2.2.1**.
Lethal equivalents	N/A	See **section 2.2.1**.
Mating system	Polygynous	Hartman (2018).
Age of first offspring females	9	Range 8-10 years of age (Amano and Miyazaki, 2004).
Maximum age of female reproduction	50	It is not known whether reproductive senescence occurs in this species. Using bottlenose dolphins as a proxy, and assuming reproductive capacity for full lifetime.
Age of first offspring males	11	Hartman *et al*. (2016)
Max age of male reproduction	50	It is not known whether reproductive senescence occurs in this species. Using bottlenose dolphins as a proxy, and assuming reproductive capacity for full lifetime.
Max lifespan	50	Hartman *et al*. (2016).
Max number of progeny per brood	1	
Sex ratio at birth (in % males)	50	The sex ratio at birth for this population is unknown. For the purposes of this model it was assumed to be 1:1.
% adult females breeding	31.25	Range 2.4-4 years. Using mean value of 3.2 years (Bloch *et al*., 2012).
SD in % breeding due to EV	5.5	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
Mortality of females 0-3 (Calf)	20	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
SD due to EV	5	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins by Harwood *et al*. (2014) as proxy values.
3-9 (juvenile)	6	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins

Risso's dolphin		
Parameter	**Value**	**Notes**
		by Harwood and King (2014) as proxy values.
SD due to EV	4.47	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins by Harwood *et al.* (2014) as proxy values.
9+ (adult)	6	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
SD due to EV	4.47	Value unknown for Risso's dolphins. Using the values provided for bottlenose dolphins by Harwood *et al.* (2014) as proxy values.
Mortality of males	As females	Same as females across age classes.
% males breeding	75 %	See **section 2.2.5**.
Initial population size	8,794	Celtic and Greater North Sea MU population; Paxton *et al.* (2016).
Carrying capacity	20,000	See **section 2.2.5**.
Collision risk	1 or 2	Based on collision risk assessments for less than one bottlenose dolphin scenarios
	1, 2, 5 or 10	Based on worst-case collision risk for 30MW scenarios
	25 or 27	Based on worst-case collision risk for 240MW scenarios

Table 2.3 Input parameters used in baseline VORTEX simulation for common dolphin

Common dolphin		
Parameter	**Value**	**Notes**
Number of model iterations	500	Due to considerable processing time, only 500 iterations of this model were performed
Number of years	50	This model was run for 50 years to exceed the lifetime of the devices
Inbreeding depression	No	See **section 2.2.1**.
Lethal equivalents	N/A	See **section 2.2.1**.
Mating system	Polygynous	Westgate and Read (2007).
Age of first offspring females	8	Danil and Chivers (2007).
Maximum age of female reproduction	30	No evidence of reproductive senescence in this species (Danil and Chivers, 2007).
Age of first offspring males	12	Murphy (2009)
Max age of male reproduction	30	No evidence of reproductive senescence in this species (Danil and Chivers, 2007).
Max lifespan	50	Murphy (2009)
Max number of progeny per brood	1	
Sex ratio at birth (in % males)	50	The sex ratio at birth for this population is unknown. For the purposes of this model it was assumed to be 1:1.

Common dolphin		
Parameter	**Value**	**Notes**
% adult females breeding	26	Murphy (2009).
SD in % breeding due to EV	5.5	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
Mortality of females 0-3 (Calf)	20	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
SD due to EV	5	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood *et al.* (2014) as proxy values.
3-9 (juvenile)	6	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
SD due to EV	4.47	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood *et al.* (2014) as proxy values.
9+ (adult)	6	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood and King (2014) as proxy values.
SD due to EV	4.47	Value unknown for common dolphins. Using the values provided for bottlenose dolphins by Harwood *et al*. (2014) as proxy values.
Mortality of males	As females	Same as females across age classes
% males breeding	75 %	See **section 2.2.5**.
Initial population size	56,556	IAMMWG (2015).
Carrying capacity	96,920	See **section 2.2.5**.
Collision risk	142	Based on worst-case collision risk for 240MW scenarios

Table 2.4 Input parameters used in baseline VORTEX simulation for harbour porpoise

Harbour porpoise		
Parameter	**Value**	**Notes**
Number of model iterations	500	Due to considerable processing time, only 500 iterations of this model were performed
Number of years	50	This model was run for 50 years to exceed the lifetime of the devices
Inbreeding depression	No	See **section 2.2.1**.
Lethal equivalents	N/A	See **section 2.2.1**.
Mating system	Polygynous	Fontaine and Barrette (1997).
Age of first offspring females	4	Learmonth *et al.* (2014).
Maximum age of female reproduction	30	No evidence of reproductive senescence in this species (Marsh and Kasuya, 1986).

Harbour porpoise		
Parameter	**Value**	**Notes**
Age of first offspring males	5	Learmonth *et al.* (2014).
Max age of male reproduction	30	No evidence of reproductive senescence in this species (Marsh and Kasuya, 1986).
Max lifespan	20	Learmonth *et al.* (2014).
Max number of progeny per brood	1	
Sex ratio at birth (in % males)	60	Lockyer (2003).
% adult females breeding	50	Murphy *et al.* (2015).
SD in % breeding due to EV	5	Harwood and King (2014).
Mortality of females 0-3 (Calf)	40	Harwood and King (2014).
SD due to EV	5	Harwood *et al.* (2014).
3-9 (juvenile)	15	Harwood and King (2014).
SD due to EV	5.47	Harwood *et al.* (2014).
9+ (adult)	15	Harwood and King (2014).
SD due to EV	5.47	Harwood *et al.* (2014).
Mortality of males	As females	Same as females across age classes.
% males breeding	75 %	See **section 2.2.5**.
Initial population size	104,695	IAMMWG (2015).
Carrying capacity	193,065	See **section 2.2.5**.
Collision risk	424	Based on worst-case collision risk for 240MW scenarios

Table 2.5 Input parameters used in baseline VORTEX simulation for minke whale

Minke whale		
Parameter	**Value**	**Notes**
Number of model iterations	500	Due to considerable processing time, only 500 iterations of this model were performed
Number of years	50	This model was run for 50 years to exceed the lifetime of the devices
Inbreeding depression	No	See **section 2.2.1**.
Lethal equivalents	N/A	See **section 2.2.1**.
Mating system	Polygynous	
Age of first offspring females	9	Harwood and King (2014).
Maximum age of female reproduction	51	No evidence of reproductive senescence in this species (Marsh and Kasuya, 1986).
Age of first offspring males	9	Harwood and King (2014).
Max age of male reproduction	51	No evidence of reproductive senescence in this species (Marsh and Kasuya, 1986).
Max lifespan	51	Harwood and King (2014).
Max number of progeny per brood	1	
Sex ratio at birth (in % males)	39	Hauksson *et al.* (2011).
% adult females breeding	90	Perrin *et al.* (2018).
SD in % breeding due to EV	4.47	Harwood and King (2014).

Minke whale		
Parameter	**Value**	**Notes**
Mortality of females 0-3 (Calf)	30	Harwood and King (2014).
SD due to EV	5	Harwood *et al.* (2014).
3-9 (juvenile)	23	Harwood and King (2014).
SD due to EV	4.47	Harwood *et al.* (2014).
9+ (adult)	4	Harwood and King (2014).
SD due to EV	4.47	Harwood *et al.* (2014).
Mortality of males	As females	Same as females across age classes.
% males breeding	75 %	See **section 2.2.5**.
Initial population size	23,528	IAMMWG (2015).
Carrying capacity	39,572	See **section 2.2.5**.
Collision risk	52	Based on worst-case collision risk for 240MW scenarios

Table 2.6 Input parameters used in baseline VORTEX simulation for grey seal

Grey seal		
Parameter	**Value**	**Notes**
Number of model iterations	500	Due to considerable processing time, only 500 iterations of this model were performed
Number of years	50	This model was run for 50 years to exceed the lifetime of the devices
Inbreeding depression	No	See **section 2.2.1**.
Lethal equivalents	N/A	See **section 2.2.1**.
Mating system	Polygynous	Hall and Russell (2018).
Age of first offspring females	3	Hall and Russell (2018).
Maximum age of female reproduction	20	No evidence of reproductive senescence in this species (SCOS, 2018).
Age of first offspring males	10	Harwood and King (2014).
Max age of male reproduction	20	No evidence of reproductive senescence in this species (SCOS, 2018).
Max lifespan	20	Harwood and King (2014).
Max number of progeny per brood	1	
Sex ratio at birth (in % males)	50	The sex ratio at birth for this population is unknown. For the purposes of this model it was assumed to be 1:1.
% adult females breeding	82	Boyd (1985).
SD in % breeding due to EV	4.47	Harwood and King (2014).
Mortality of females 0-3 (Calf)	76.5	Harwood and King (2014).
SD due to EV	5.47	Harwood *et al.* (2014).
3-9 (juvenile)	6	Harwood and King (2014).
SD due to EV	5.47	Harwood *et al.* (2014).
9+ (adult)	6	Harwood and King (2014).
SD due to EV	4.47	Harwood *et al.* (2014).

Grey seal		
Parameter	**Value**	**Notes**
Mortality of males	As females	Same as females across age classes.
% males breeding	10%	Hall and Russell (2018).
Initial population size	6,000	IAMMWG (2013).
Carrying capacity	7,500	See **section 2.2.5**.
Collision risk	2, 3 or 5	Based on collision risk assessments for less than one bottlenose dolphin scenarios
	2. 3. 5, 14 or 34	Based on worst-case collision risk for 30MW scenarios
	81 or 85	Based on worst-case collision risk for 240MW scenarios

3. RESULTS

3.1. BOTTLENOSE DOLPHIN

23. Two bottlenose dolphin scenarios were modelled, one for the Irish Sea Management Unit (scenario A), and one for the Cardigan Bay and Pen Llŷn a’r Sarnau SAC population (scenario B).

3.1.1. Sensitivity Analyses

24. In order to determine the appropriate parameters for the collision scenario models, sensitivity analysis was run on the parameters on which there was no available information in the literature.

3.1.1.1. Carrying Capacity

25. Using the Sensitivity Test function in programme VORTEX, single-factor simulations were run to test a selection of values for carrying capacities ranging from 414 individuals (the upper confidence limit of the bottlenose dolphin management unit, IAMMWG, 2015) to 2,000 individuals (an unrealistically high carrying capacity for a coastal population of bottlenose dolphins) (**Table 3.1**).

Table 3.1 Summary of results of the sensitivity analysis on the influence of carrying capacity (K) on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model

	Scenario	Det-r	Stoc-R (SD)	% change in Stoc-R from baseline
1	Baseline (K=414)	0.0355	0.0344 (0.0546)	N/A
2	K = 500	0.3555	0.0344 (0.0545)	0
3	K= 750	0.3555	0.0345 (0.0538)	0.3
4	K= 1,000	0.3555	0.0343 (0.0532)	0.3
5	K= 1,500	0.3555	0.0346 (0.0530)	0.6
6	K= 2,000	0.3555	0.0344 (0.0526)	0

26. Based on the results of this analysis, the carrying capacity will be set at 414 animals for the models to investigate collision impacts.

3.1.1.2. Percentage of Males in the Breeding Population

There are no published values for the percentage of males in the breeding population for this species. Consequently, the Sensitivity Test function in programme VORTEX was used to run single-factor simulations to test a selection of values of percentage of breeding males in the population (**Table 3.2**).

Table 3.2 Summary of results of the sensitivity analysis on the influence of percentage of breeding males in the population on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model

	Scenario	Det-r	Stoc-R (SD)	% change in Stoc-R from baseline
1	Baseline (% males = 75)	0.0355	0.0344 (0.0543)	N/A
2	% males = 50	0.3555	0.0344 (0.0545)	0
3	% males = 80	0.3555	0.0342 (0.0543)	0.6
4	% males = 90	0.3555	0.0343 (0.0544)	0.6
5	% males = 100	0.3555	0.0343 (0.0544)	0.6

27. Based on the results of this analysis, the percentage males in the breeding population makes little difference to the overall growth rate. this will be set at 75% (after Thompson *et al.,* 2000) for the models to investigate collision impacts.

28. As the two reference populations are similar in size, the same parameters for carrying capacity and percentage males in the breeding population are used for both scenario A and scenario B.

3.1.2. Scenario A - Effects of Collisions

29. The population trajectories of the baseline and collision scenarios 1-3 animals are all very similar, showing a largely stable population (**Plate 3.1**), which starts to decline when the number of collisions exceeds three adults per year.

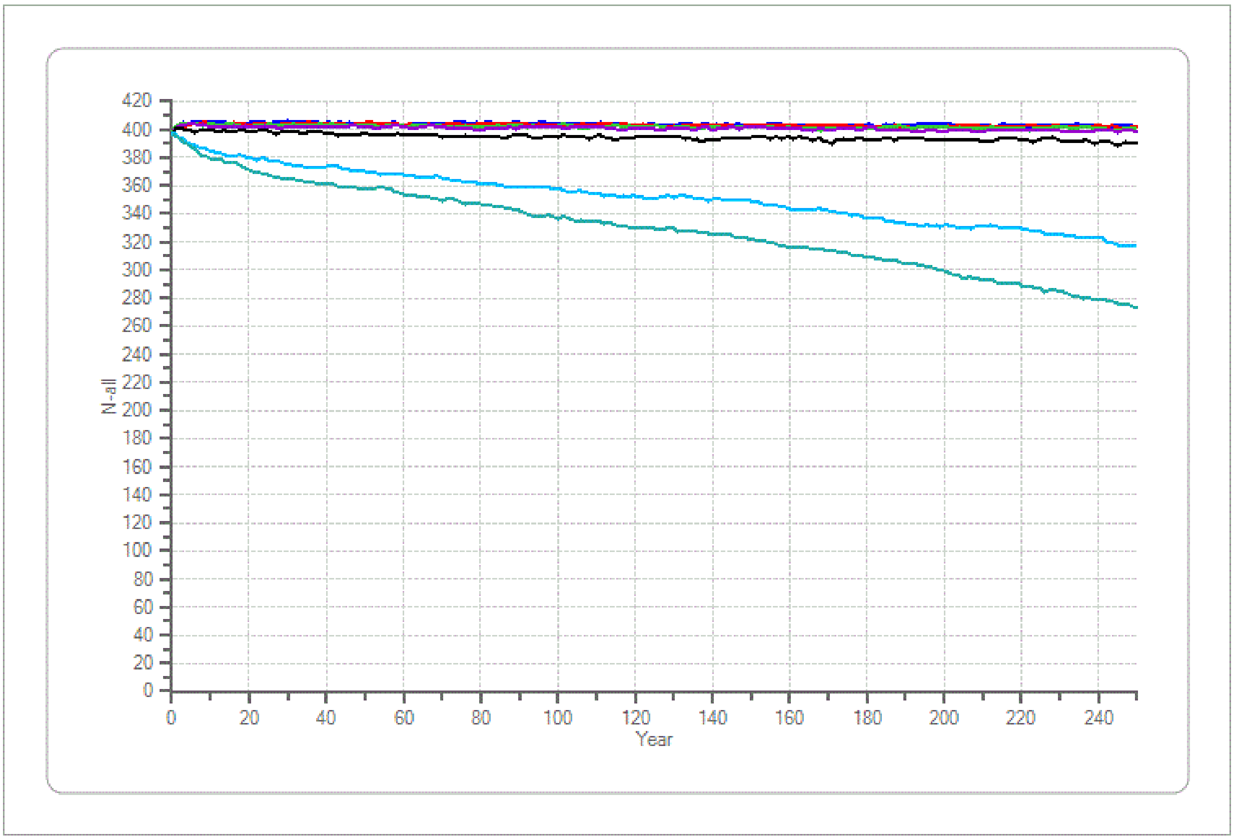

Plate 3.1 VORTEX simulations for the different collision scenarios: Baseline (blue), Collision = 1 (red), Collision = 2 (green), Collision = 3 (purple) all show very similar population trajectories. Collision = 7 (black), collision = 17 (turquoise) and collision = 19 (teal) show a decline in the predicted number of animals within the modelled population

3.1.3. Scenario B - Effects of Collisions

30. The population trajectories of the baseline and collision scenarios 1-3 animals are all very similar, showing a largely stable population (**Plate 3.2**), which starts to decline when the number of collisions exceeds three adults per year.

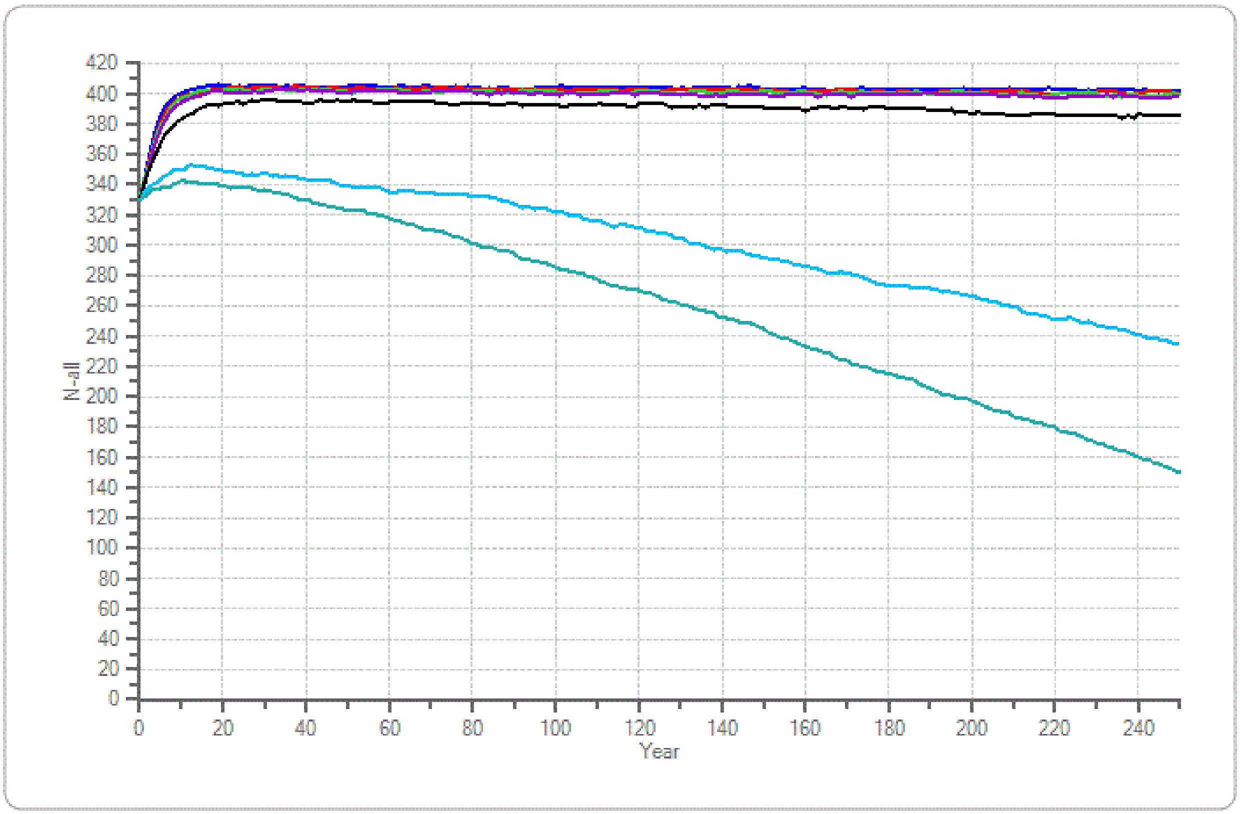

Plate 3.2 VORTEX simulations for the different collision scenarios: Baseline (blue), Collision = 1 (red), Collision = 2 (green), Collision = 3 (purple) all show very similar population trajectories. Collision = 7 (black), collision = 17 (turquoise) and collision = 19 (teal) show a decline in the predicted number of animals within the modelled population

3.2. RISSO'S DOLPHIN

3.2.1. Sensitivity Analyses

31. In order to determine the appropriate parameters for the collision scenario models, sensitivity analysis was run on the parameters on which there was no available information in the literature.

3.2.1.1. Carrying Capacity

32. Using the Sensitivity Test function in programme VORTEX, single-factor simulations were run to test a selection of values for carrying capacities ranging from 9,000 individuals to 50,000 individuals (an unrealistically high carrying capacity for a coastal population of Risso's dolphins) (**Table 3.3**).

Table 3.3 Summary of results of the sensitivity analysis on the influence of carrying capacity (K) on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model

	Scenario	det-r	Stoc-R (SD)
1	Baseline (K=9,000)	0.0389	0.0380 (0.0524)

	Scenario	det-r	Stoc-R (SD)
2	K = 10,000	0.0389	0.0382 (0.0523)
3	K= 20,000	0.0389	0.0379 (0.0524)
4	K= 50,000	0.0389	0.0377 (0.0523)

33. The results of this analysis show that carrying capacity is not currently influencing the growth rate of this population. As no upper confidence limit is available, carrying capacity will be set at 20,000 animals for the models to investigate collision impacts. This is an unrealistically high level, which will ensure no influence on the models of collision.

3.2.1.2. Percentage of Males in the Breeding Population:

34. There are no published values for the percentage of males in the breeding population for this species. Consequently, the Sensitivity Test function in programme VORTEX was used to run single-factor simulations to test a selection of values of percentage of breeding males in the population (**Table 3.4**).

Table 3.4 Summary of results of the sensitivity analysis on the influence of percentage of breeding males in the population on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model

	Scenario	det-r	Stoc-R (SD)
1	Baseline (% males = 75)	0.0389	0.0379 (0.0523)
2	% males = 50	0.0389	0.0380 (0.0523)
3	% males = 80	0.0389	0.0380 (0.0524)
4	% males = 90	0.0389	0.0378 (0.0523)
5	% males = 100	0.0389	0.0378 (0.0523)

35. Based on the results of this analysis, the percentage males in the breeding population makes little difference to the overall growth rate. this will be set at 75% (after Thompson et al., 2000) for the models to investigate collision impacts.

3.2.2. Effects of Collisions

36. The population trajectories of the baseline and all modelled collision scenarios very similar, showing an increasing population with a stochastic growth rate of 0.04 for all (**Plate 3.3**). It should be noted that this species is modelled as a closed population due to limitations in the methodology, but in reality, the area of interest represents a small part of a much larger range for this species. It is likely not a closed population, and these results do not consider any immigration or emigration, permanent or temporary.

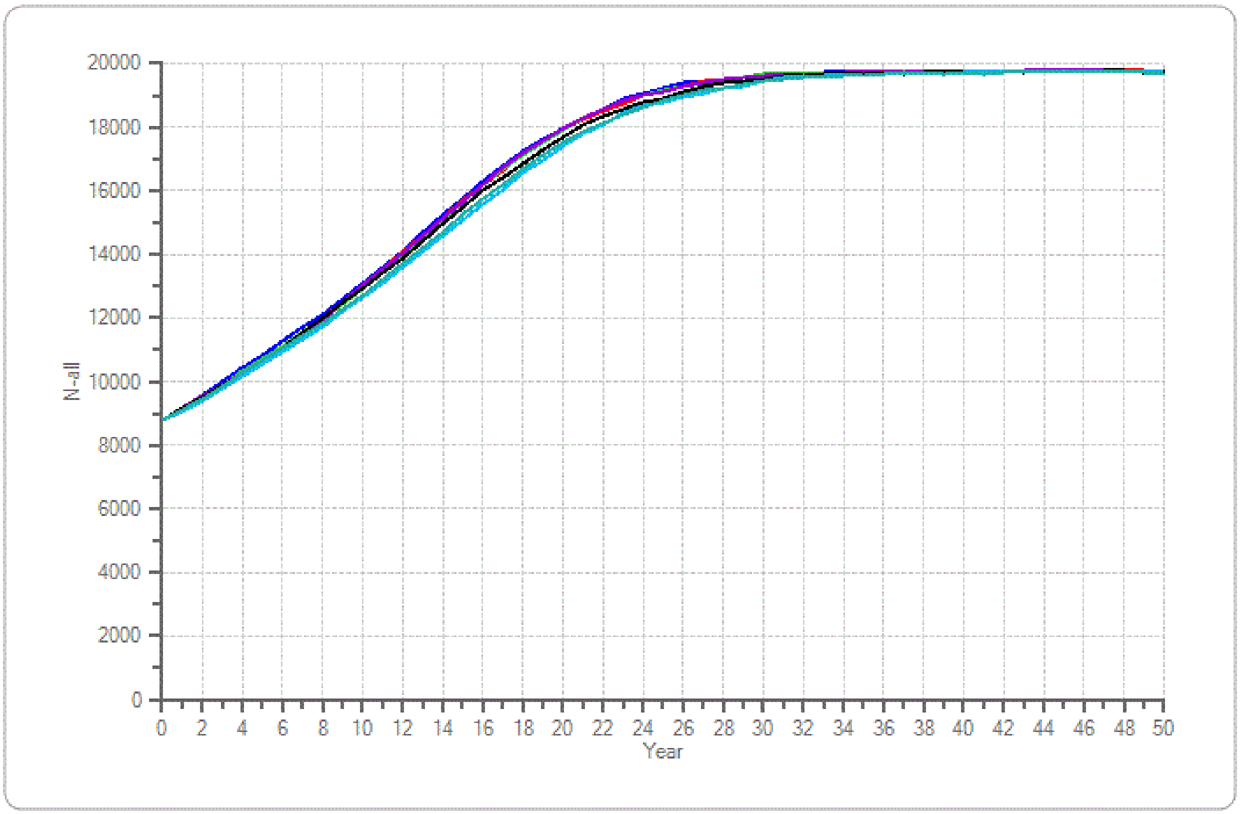

Plate 3.3 VORTEX simulations for the different Risso's dolphin collision scenarios: Baseline (blue), Collision = 1 (red), Collision = 2 (green), Collision = 5 (purple), Collision = 10 (black), Collision = 25 (turquoise) and Collision = 27 (teal) all show very similar population trajectories with a stochastic growth rate of 0.04

3.3. COMMON DOLPHIN

3.3.1. Sensitivity Analyses

37. In order to determine the appropriate parameters for the collision scenario models, sensitivity analysis was run on the parameters on which there was no available information in the literature.

3.3.1.1. Carrying Capacity

38. Using the Sensitivity Test function in programme VORTEX, single-factor simulations were run to test a selection of values for carrying capacities ranging from 96920 individuals (the upper confidence limit of the common dolphin management unit, IAMMWG, 2015) to 150,000 individuals (an estimated high carrying capacity) (**Table 3.5**).

Table 3.5 Summary of results of the sensitivity analysis on the influence of carrying capacity (K) on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model for common dolphins

	Scenario	Det-r	Stoc-R (SD)
1	Baseline (K=96920)	0.0167	0.0141 (0.0698)
2	K = 100,000	0.0167	0.0149 (0.0704)

	Scenario	Det-r	Stoc-R (SD)
3	K= 150,000	0.0167	0.0140 (0.0702)

39. Based on the results of this analysis, the carrying capacity will be set at 96,920 animals for the models to investigate collision impacts.

3.3.1.2. Percentage of Males in the Breeding Population

There are no published values for the percentage of males in the breeding population for this species. Consequently, the Sensitivity Test function in programme VORTEX was used to run single-factor simulations to test a selection of values of percentage of breeding males in the population (**Table 3.6**).

Table 3.6 Summary of results of the sensitivity analysis on the influence of percentage of breeding males in the population on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model for common dolphins

	Scenario	Det-r	Stoc-R (SD)
1	Baseline (% males = 75)	0.0167	0.0149 (0.0965)
2	% males = 50	0.0167	0.0148 (0.0701)
3	% males = 80	0.0167	0.0141 (0.0700)
4	% males = 90	0.0167	0.0141 (0.0700)
5	% males = 100	0.0167	0.0148 (0.0697)

40. Based on the results of this analysis, the percentage males in the breeding population makes little difference to the overall growth rate. this will be set at 75% (after Thompson *et al.,* 2000) for the models to investigate collision impacts.

3.3.2. Effects of Collisions

41. The population trajectories of the baseline and modelling 142 collisions per year are very similar, showing an increasing population with a stochastic growth rate of 0.02 for all (**Plate 3.4**). It should be noted that this species is modelled as a closed population due to limitations in the methodology, but in reality, the area of interest represents a small part of a much larger range for this species. It is likely not a closed population, and these results do not consider any immigration or emigration, permanent or temporary.

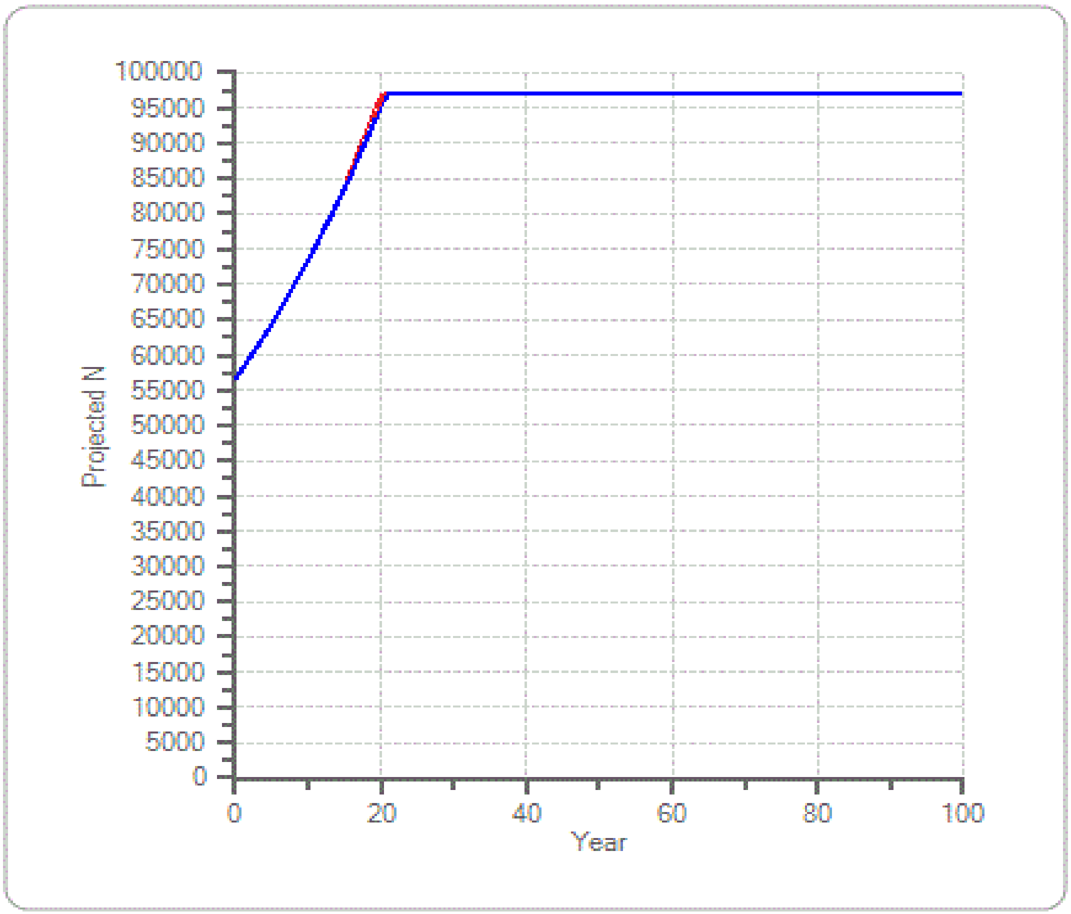

Plate 3.4 VORTEX simulations for 142 animals per year common dolphin collision scenario: Baseline (blue), Collision = 142 (red)

3.4. HARBOUR PORPOISE

3.4.1. Sensitivity Analyses

42. In order to determine the appropriate parameters for the collision scenario models, sensitivity analysis was run on the parameters on which there was no available information in the literature.

3.4.1.1. Carrying Capacity

43. Using the Sensitivity Test function in programme VORTEX, single-factor simulations were run to test a selection of values for carrying capacities ranging from 193,065 individuals (the upper confidence limit of the harbour porpoise management unit, IAMMWG, 2015) to 2,000 individuals (an unrealistically high carrying capacity for a coastal population of bottlenose dolphins) (**Table 3.7**).

Table 3.7 Summary of results of the sensitivity analysis on the influence of carrying capacity (K) on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model for harbour porpoise

	Scenario	Det-r	Stoc-R (SD)
1	Baseline (K=193,065)	0.0167	0.0148 (0.0697)
2	K = 200,000	0.0167	0.0146 (0.0703)
3	K= 500,000	0.0167	0.0143 (0.0698)

44. Based on the results of this analysis, the carrying capacity will be set at 193,065 animals for the models to investigate collision impacts.

3.4.1.2. Percentage of Males in the Breeding Population

There are no published values for the percentage of males in the breeding population for this species. Consequently, the Sensitivity Test function in programme VORTEX was used to run single-factor simulations to test a selection of values of percentage of breeding males in the population (**Table 3.8**).

Table 3.8 Summary of results of the sensitivity analysis on the influence of percentage of breeding males in the population on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model

	Scenario	Det-r	Stoc-R (SD)
1	Baseline (% males = 75)	0.0167	0.0143 (0.0699)
2	% males = 50	0.0167	0.0137 (0.0704)
3	% males = 80	0.0167	0.0148 (0.0699)
4	% males = 90	0.0167	0.0141 (0.0699)
5	% males = 100	0.0167	0.0144 (0.0696)

45. Based on the results of this analysis, the percentage males in the breeding population makes little difference to the overall growth rate. this will be set at 75% (after Thompson *et al.,* 2000) for the models to investigate collision impacts.

3.4.2. Effects of Collisions

46. The population trajectories of the baseline and modelling 424 collisions per year are very similar, showing an increasing population with a stochastic growth rate of 0.013 for the maximum collision scenario, and 0.014 for the baseline scenario (**Plate 3.5**). It should be noted that this species is modelled as a closed population due to limitations in the methodology, but in reality the area of interest represents a small part of a much larger range for this species. It is likely not a closed population, and these results do not consider any immigration or emigration, permanent or temporary.

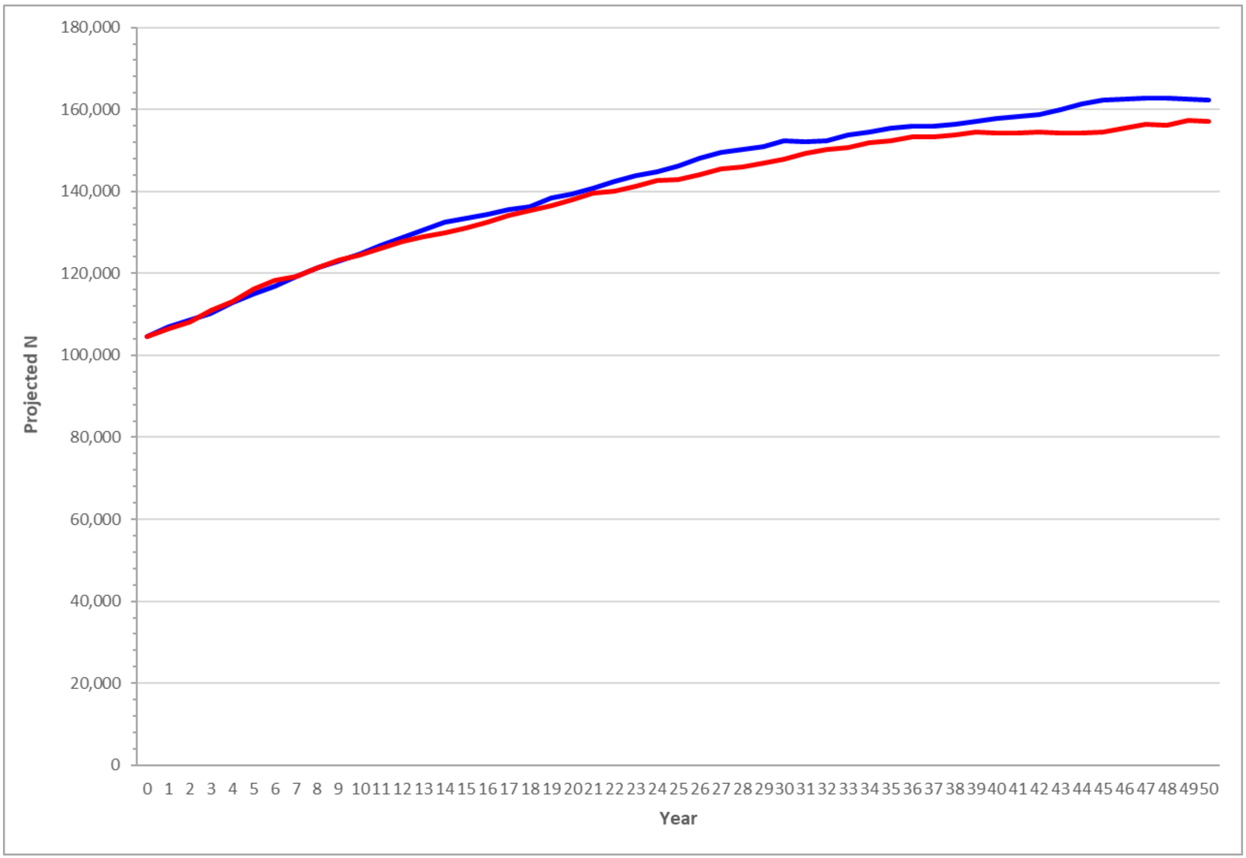

Plate 3.5 VORTEX simulations for 424 animals per year harbour porpoise collision scenario: Baseline (blue), Collision = 424 (red)

3.5. MINKE WHALE

3.5.1. Sensitivity Analyses

47. In order to determine the appropriate parameters for the collision scenario models, sensitivity analysis was run on the parameters on which there was no available information in the literature.

3.5.1.1. Carrying Capacity

48. Using the Sensitivity Test function in programme VORTEX, single-factor simulations were run to test a selection of values for carrying capacities ranging from 39572 individuals (the upper confidence limit of the minke whale management unit, IAMMWG, 2015) to 75,000 individuals (an estimated unrealistically high carrying capacity) (**Table 3.10**).

Table 3.9 Summary of results of the sensitivity analysis on the influence of carrying capacity (K) on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model for minke whale

	Scenario	Det-r	Stoc-R (SD)
1	Baseline (K=59572)	0.0417	0.0407 (0.0601)
2	K = 5000	0.0417	0.0408 (0.0595)
3	K= 6000	0.0417	0.0403 (0.0598)
4	K= 7500	0.0417	0.0403 (0.0593)

49. Based on the results of this analysis, the carrying capacity will be set at 39,572 animals for the models to investigate collision impacts.

3.5.1.2. Percentage of Males in the Breeding Population

There are no published values for the percentage of males in the breeding population for this species. Consequently, the Sensitivity Test function in programme VORTEX was used to run single-factor simulations to test a selection of values of percentage of breeding males in the population (**Table 3.11**).

Table 3.10 Summary of results of the sensitivity analysis on the influence of percentage of breeding males in the population on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model

	Scenario	Det-r	Stoc-R (SD)
1	Baseline (% males = 75)	0.0417	0.0403 (0.0597)
2	% males = 50	0.0417	0.0398 (0.0596)
3	% males = 80	0.0417	0.0401 (0.0593)
4	% males = 90	0.0417	0.0404 (0.0598)
5	% males = 100	0.0417	0.0401 (0.0598)

50. Based on the results of this analysis, the percentage males in the breeding population makes little difference to the overall growth rate. this will be set at 75% (after Thompson *et al.,* 2000) for the models to investigate collision impacts.

3.5.2. Effects of Collisions

51. The population trajectories of the baseline and all modelled collision scenarios very similar, showing an increasing population with a stochastic growth rate of 0.04 for all (**Plate 3.6**). It should be noted that this species is modelled as a closed population due to limitations in the methodology, but in reality, the area of interest represents a small part of a much larger range for this species. It is likely not a closed population, and these results do not consider any immigration or emigration, permanent or temporary.

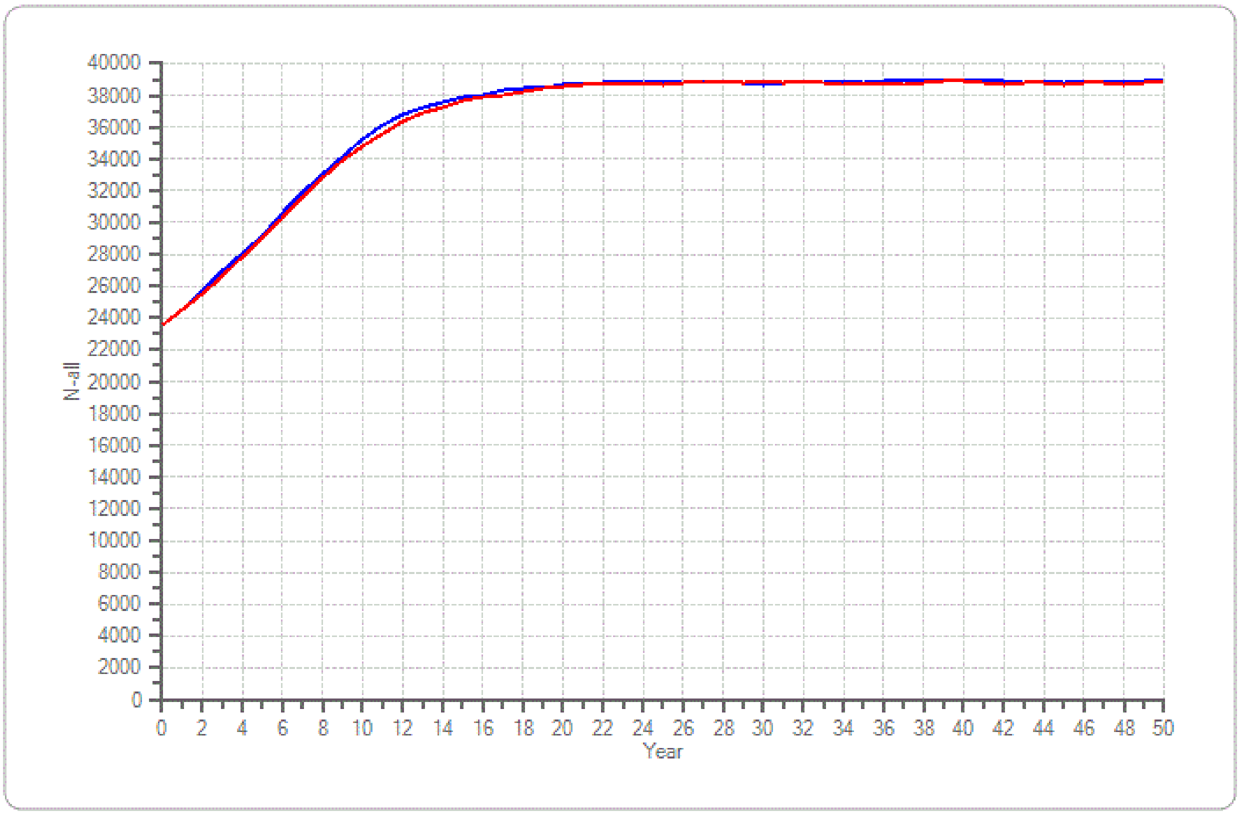

Plate 3.6 VORTEX simulations for the different minke whale collision scenarios: Baseline (blue) and Collision = 52 (red). Models were conducted over a 50-year time period. Both scenarios show very similar population trajectories with a stochastic growth rate of 0.04

3.6. GREY SEAL

3.6.1. Sensitivity Analyses

52. In order to determine the appropriate parameters for the collision scenario models, sensitivity analysis was run on the parameters on which there was no available information in the literature.

3.6.1.1. Carrying Capacity

53. Using the Sensitivity Test function in programme VORTEX, single-factor simulations were run to test a selection of values for carrying capacities ranging from 6,500 to 10,000 individuals (**Table 3.16**).

Table 3.11 Summary of results of the sensitivity analysis on the influence of carrying capacity (K) on the deterministic growth rate (det-r) and the stochastic growth rate (stoc-r) in comparison with the baseline model for grey seals

	Scenario	**Det-r**	**Stoc-R (SD)**
1	Baseline (K=6500)	0.0539	0.0505 (0.0839)
2	K = 7,000	0.0539	0.0515 (0.0832)
3	K= 7,500	0.0539	0.0510 (0.0834)

	Scenario	Det-r	Stoc-R (SD)
4	K= 9,000	0.0539	0.0507 (0.0839)
5	K= 10,000	0.0539	0.0515 (0.0832)

54. Based on the results of this analysis, the carrying capacity will be set at 7,500 animals for the models to investigate collision impacts.

3.6.1.2. Percentage of Males in the Breeding Population

There is a published value of 10% (Hall and Russell, 2018), sensitivity analyses for this parameter were not carried out

3.6.2. Effects of Collisions

55. The population trajectories of the baseline and all modelled collision scenarios very similar, showing an increasing population with a stochastic growth rate of 0.05 for all (**Plate 3.7**). It should be noted that this species is modelled as a closed population due to limitations in the methodology, but in reality, the area of interest represents a small part of a much larger range for this species. It is likely not a closed population, and these results do not consider any immigration or emigration, permanent or temporary.

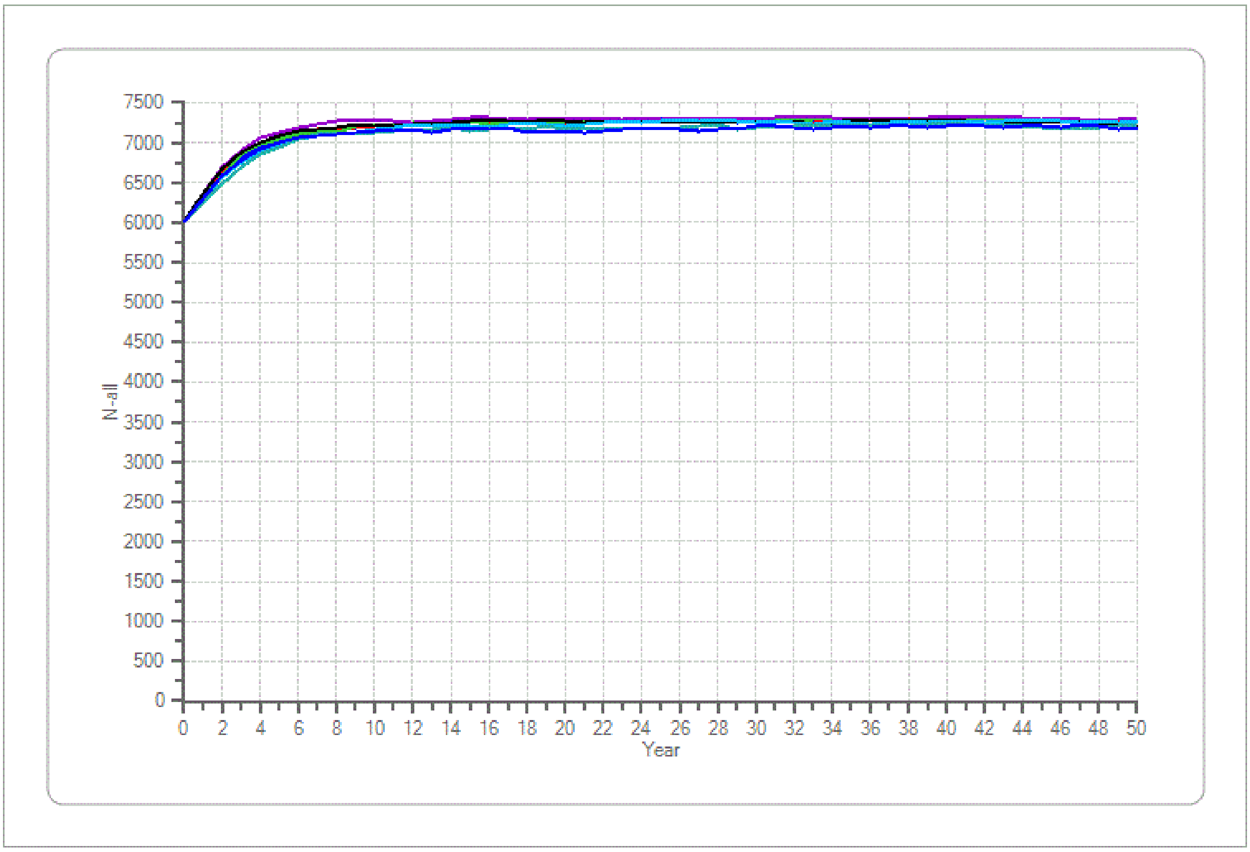

Plate 3.7 VORTEX simulations for the different grey seal collision scenarios: Baseline (blue), Collision = 5 (red). Models were conducted over a 50-year time period. Baseline (blue), Collision = 5 (red), Collision = 2 (green), Collision = 3 (purple), Collision = 14 (black), Collision = 34 (turquoise), Collision = 81 (teal) and Collision = 85 (dark blue) all show very similar population trajectories with a stochastic growth rate of 0.05

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ANNEX 1

Plate 1 Screenshot of the iPCOD download page – taken on 28/06/2019.

ANNEX 2

Note on using R (rramas) for Population Viability Analysis to Assess Effects on Marine Mammal Populations

R can be used to undertake Population Viability Analysis (PVA), using the package ‘rramas’, developed by de la Cruz (2019)[1], using abundance, transition, and management (or harvest) matrices to determine what the population may be in the future, over a set number of ‘time steps’ (or years), taking into account possible losses from the population.

With regard to using this model for marine mammals, research into available transition matrices (or Leslie matrices) has shown that there is not the required detailed information in order to generate a robust result using the rramas tool for PVA available within the scientific literature for each species. Although it would be possible to generate a basic transition matrix for most of the needed marine mammal species using known fecundity and survival rates, it has been determined that there would not be enough confidence in this in order for any assessment using this as the input to be robust, and any resultant impact assessment would be too low in confidence to be suitable for use. For this reason, the rramas tool will not be used to undertake PVA in order to assess the effects of collision risk associated with this project, on marine mammal populations.

[1] de la Cruz., Rot M (2019). Rramas: Matrix Population Models. R package version 0.1-6, https://CRAN.R-project.org/package=Rramas

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Morlais Project
Environmental Statement

Appendix 12.4: Underwater noise technical note (Subacoustech, 2019)

Volume III

Applicant: Menter Môn Morlais Limited

Document Reference: PB5034-ES-0124

Chapter 12: Marine Mammals

Appendix 12.4: Underwater noise technical note (Subacoustech, 2019)

Morlais Document No.: MOR/RHDHV/APP/0024	Status: Final	Version No: F3.0	Date: July 2019

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Project:	Morlais tidal project, Holy Island – Underwater noise technical note		
Reference:	P256P0102	**Date:**	03/07/2019
Prepared by:	Tim Mason	**Email:**	tim.mason@subacoustech.com
Prepared for:	Frank Fortune, *HaskoningDHV UK Ltd* Tel: +44 (0) 131 5612295, Email: frank.fortune@rhdhv.com		

Introduction

The region of the Irish Sea to the west of Anglesey has been identified by the Crown Estate as suitable for operation of marine energy devices. Known previously as the West Anglesey Tidal Demonstration Zone (WADZ), the area is now described as the Morlais Demonstration Zone (MDZ) and covers an area of 35 km^2, situated in water depths of approximately 20 to 80 metres. An overview map of the zone is shown in Figure 1.

It is proposed to investigate the environmental effects of the installation of Tidal Energy Converter devices (TECs). It is recognised that the proposed devices have the potential to generate underwater noise. Subacoustech Environmental Ltd has investigated the underwater noise levels likely to arise and to consider the magnitude of any impact on key species of fish and marine mammals in relation to the latest thresholds and criteria. This Technical Note presents an overview of the pre-existing background noise levels, the potential underwater noise that could be generated by these devices and Acoustic Deterrent Devices (ADDs) to discourage marine mammals from the TECs, and the impacts these could have on marine life present in the area.

Background noise west of Anglesey

A series of underwater noise monitoring stations were installed by SEACAMS (University of Bangor) to sample the background noise levels in the MDZ over periods of between 15 and 30 days in 2016, 2017 and 2018. Four of these datasets from different time periods and locations have been analysed to provide a range of noise levels to define a baseline over a daily (high-low) and fortnightly (springs-neaps) tidal cycle. The locations and periods of sampling are shown in Figure 2 and Table 1 below.

Period	Location	Approx. distance from coast	Days
April 2017	53° 18.038 N, 4° 42.621 W	1,200 m	15 days
June 2017	53° 17.513 N, 4° 43.503 W	2,000 m	22 days
July 2017	53° 17.482 N, 4° 43.510 W	2,500 m	30 days
July 2018	53° 17.148 N, 4° 43.014 W	1,900 m	30 days

Table 1 – Summary of background noise monitoring locations and periods

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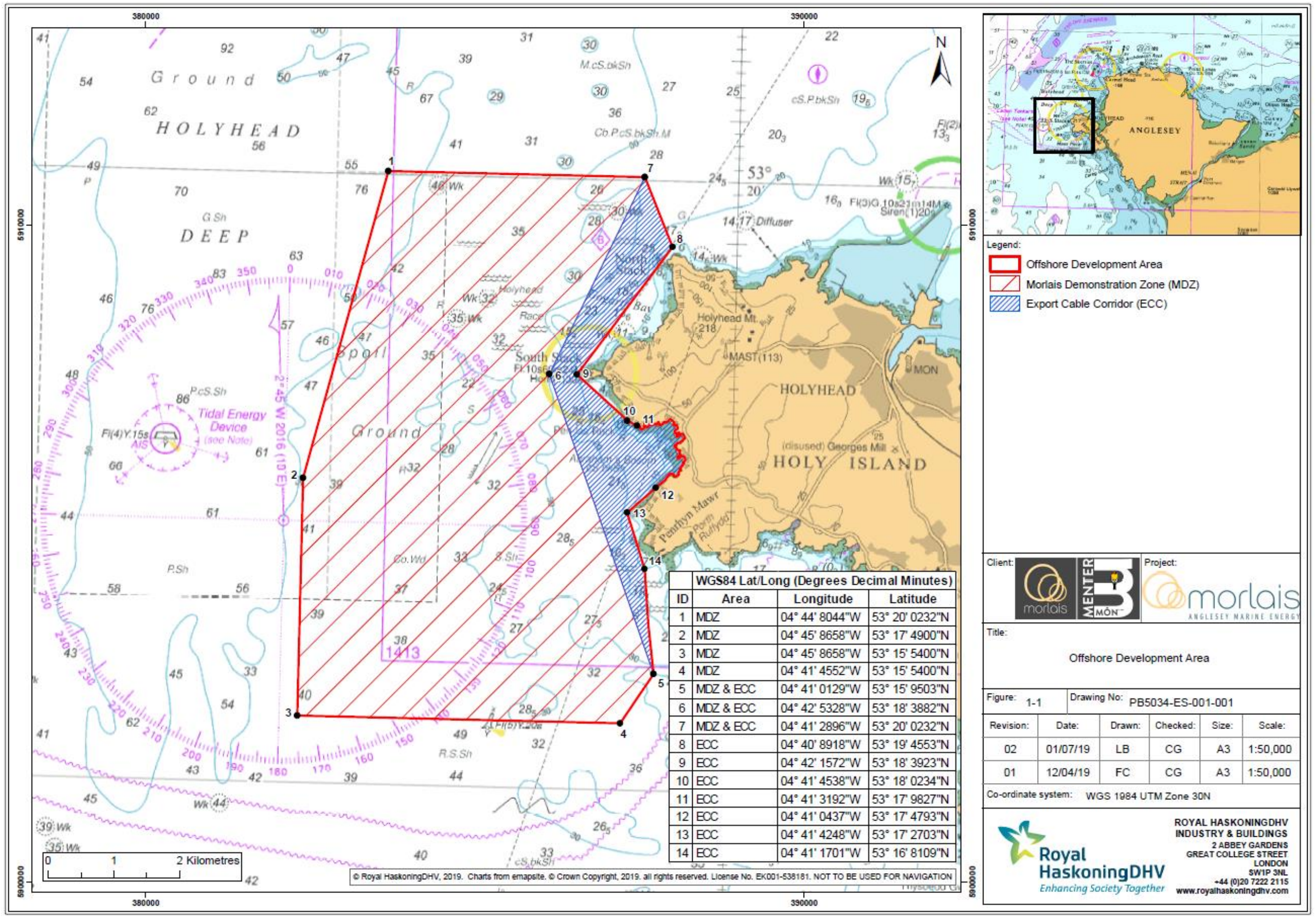

Figure 1 – Morlais Demonstration Zone and Offshore Lease Area (Royal HaskoningDHV 2019)

Figure 2 – Sampling locations with sample times (©Google Earth, SIO, NOAA, U.S. Navy, NGA, GEBCO

All measurements analysed were taken with a 48 kHz sample rate and with contiguous 10-minute samples, except the June 2017 sample period which used a finer 1-minute sample period throughout.

The results of the background noise monitoring in these locations show a remarkable degree of consistency in all locations and time periods, and noise levels vary with position of the tide, except for occasional, rare outliers expected to be associated with passing vessel traffic. All locations show a range of noise levels of 89 dB to 107 dB SPL RMS re 1 µPa (as either 1-minute or 10-minute samples).

An overview of the noise levels sampled at each location is given in Table 2 (excluding outliers).

Period	Overall average noise level	Tide cycle: Springs		Tide cycle: Neaps	
		Max SPL_{RMS}	Min SPL_{RMS}	Max SPL_{RMS}	Min SPL_{RMS}
April 2017	98.3 dB SPL_{RMS}	103.0 dB	91.9 dB	99.7 dB	90.7 dB
June 2017	96.9 dB SPL_{RMS}	104.1 dB	89.1 dB	97.5 dB	89.7 dB
July 2017	98.9 dB SPL_{RMS}	106.4 dB	92.7 dB	100.2 dB	95.2 dB
July 2018	98.0 dB SPL_{RMS}	106.6 dB	89.9 dB	99.8 dB	92.6 dB

Table 2 – Summary of background noise monitoring locations and periods

The distance from the coast does not appear to have any significance in reference to the overall average measured noise levels. The highest noise levels (July 2017) were sampled at the furthest measured location, although as the location with the lowest noise levels (June 2017) was the closest to this position the variation is more likely to be caused by local effects.

Detailed charts showing the noise level range for each period and location are provided at the end of this report.

With the lack of features in the remainder of the site as shown in Figure 1, these background noise levels are likely to be reasonably consistent at other locations in the MDZ.

It is worth investigating the effect of frequency on background noise; Figure 3 shows the well-known Wenz curves (Wenz, 1962) for ambient noise levels at various wind and sea conditions. The frequencies of greatest hearing sensitivity for the marine mammals of interest – primarily grey seal, bottlenose dolphin and harbour porpoise – are in excess of 1,000 Hz and the ambient noise at these frequencies will be below that of the lower frequencies which will control the 'overall' background noise levels identified in Table 2, even at the noisiest of environmental conditions (i.e. shifting sediment or wave noise).

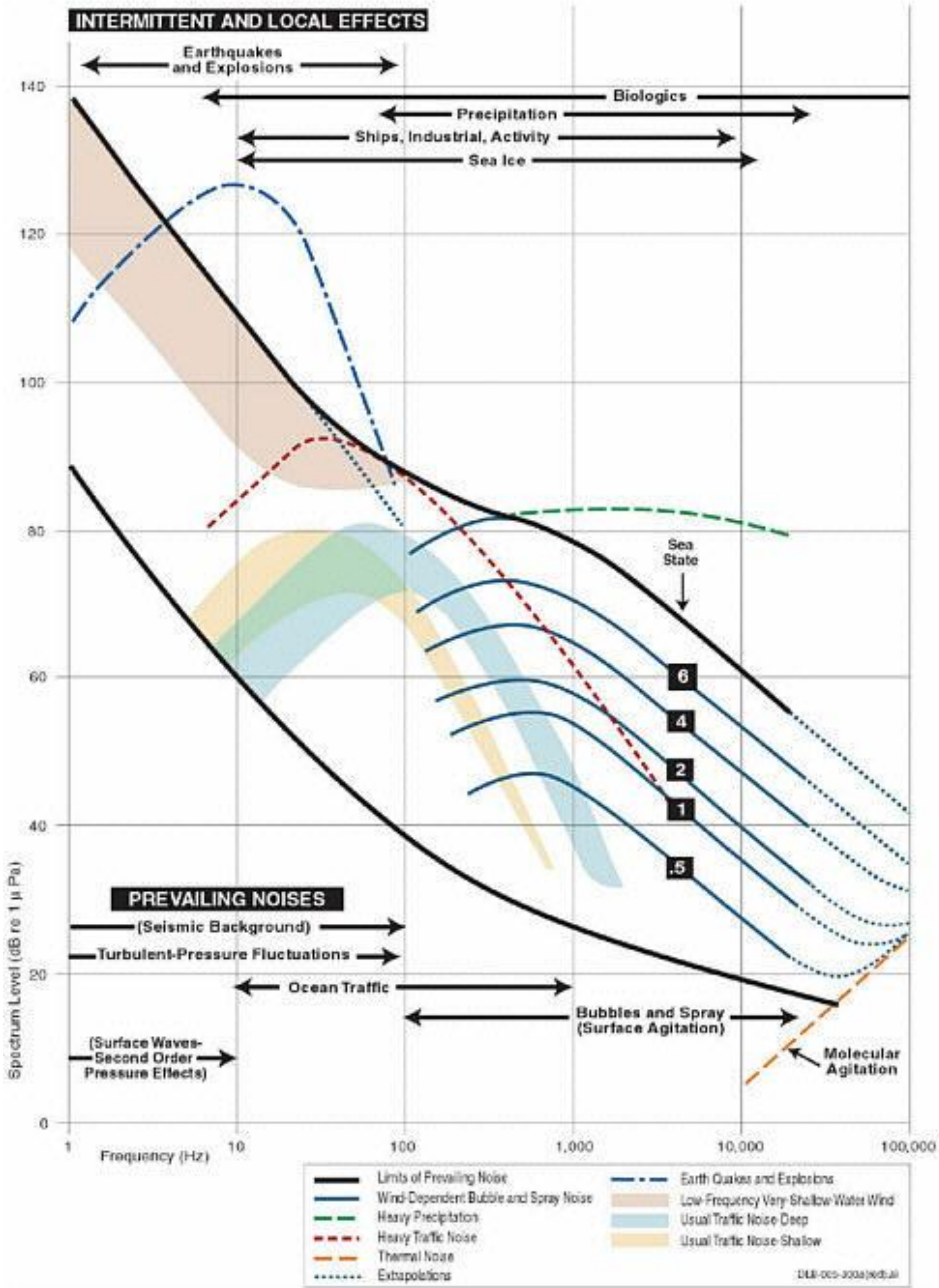

Figure 3 – Ambient open-water noise levels by frequency and environmental conditions, adapted from Wenz, 1962

Noise emissions from tidal energy converters

The tidal energy generation devices for installation at the MDZ have not been finalised, and a broad project design envelope is sought that will allow installation of several technologies. This technical note has been based on published and publicly available underwater noise data from tidal energy converter (TEC) designs, using the site-specific background noise data presented above as a baseline.

A selection of underwater noise source levels from TECs was presented in the Brims Underwater Noise Assessment for SSE (Xodus, 2015), which identified the limited data available on studies of seven different devices and locations along with the operational source levels. Predicted source noise levels (i.e. noise levels at 1 m) from the devices identified range from approximately 145 to 175 dB, although the frequency data is not presented in this report. The best available noise data the paper references is the study by Lossent *et al.* (2018) for a 16 m diameter, 0.5 MW, OpenHydro turbine. This predicted a source noise level of 152 dB SPL_{RMS} and an acoustic spectrum with most energy in the 125 Hz ⅓ octave frequency band. Outside of this band, noise levels are a minimum of 10 dB lower.

The low frequency for the OpenHydro turbine is well below the peak hearing sensitivity of both pinniped and, especially, harbour porpoise species, where at the greatest sensitivity range for these species the predicted octave-band source noise level from the device is at least 25 and 35 dB, respectively, below the low frequency peak. These noise levels are considerably below any which could potentially lead to PTS or TTS in the species. Moving away from the source location, this will fall quickly to the order of background noise levels and Lossent *et al.* (2018) estimated that this 'footprint' would be of the order of 1.0 to 1.5 km^2 around a turbine.

Kongsberg (2012) produced a technical report for the MeyGen project in the Pentland Firth, with predicted noise levels of up to 177 dB SPL_{RMS} for a 2.4 MW turbine (extrapolated from a measured 0.3 MW Marine Current Turbines (MCT) turbine in Strangford Lough, Northern Ireland). Most noise energy for this turbine was below 100 Hz, although there were also significant peaks in the 1,500 Hz and 5,000 Hz bands. Although this predicted level is somewhat higher than the OpenHydro model with higher frequency components, a grey seal, bottlenose dolphin or harbour porpoise could not remain close enough to a turbine for any length of time to receive a dangerous level of noise exposure as per criteria defined by Southall *et al.* 2019.

Although the noise levels are below injury levels, they may still be high enough to lead to avoidance behaviour. Hastie *et al*. (2018) studied the reaction of harbour seals (which have similar hearing capabilities to grey seals) to simulated turbine noise in Kyle Rhea on the west coast of Scotland. The study found a reduction in seal abundance of between 11% and 41% at the source location. At up to 500 m the reduction was just under 10%. The source used by Hastie *et al.* was based on a 1.2 MW MCT design measured at SeaGen at Strangford Lough and was 20 dB louder than the OpenHydro turbine identified above and thus of a similar order to the MeyGen device. For the device measured in Lossent *et al.* (2018) the noise level at peak sensitivity for harbour seal (in the region of 2-10 kHz) would be 10-20 dB above the ambient noise levels at the MDZ based on the measurements taken, and thus would be audible. The MeyGen device had a similar predicted noise spectrum to that used by Hastie *et al*, and would be more likely to be audible due to its higher frequency components.

Noise emissions from acoustic deterrent devices (ADD)

A variety of devices exist for the purposes of excluding marine mammals from an area, typically to protect fish stocks in aquaculture or to displace any individuals before a much larger noise source, such as explosives or piling, commences. The most commonly used and available devices' performances are examined in McGarry *et al.* (2018), which shows source noise levels of between 132 and 197 dB re 1 µPa over various frequency ranges, depending on the 'target' species. Although the noise levels for some of the devices are high and have the theoretical potential to exceed relevant injury (i.e. permanent threshold shift, or PTS) criteria for marine mammals (Southall *et al.* 2019), McGarry *et al.* 2018 conclude that the risk of any injury occurring is low as individuals would have to remain very close to the operational devices for an extended period of time, which is unlikely.

As previously, detailed modelling has not been undertaken. All of the devices are significantly above the background noise in the area and so this should not interfere with the audibility for the target species when in the vicinity of the devices. Although the source noise level, presented as an overall, broadband level, may be lower than the figure presented for a TEC, it must be borne in mind that the acoustic frequency produced by each device is critical; an ADD, to be effective in being audible to a marine mammal, will operate at a much higher frequency, typically >5,000 Hz, than the dominant frequencies that will be produced by a TEC, and will thus remain clearly audible. It would otherwise be lost in the 'noise' if it was operating at frequencies similar to those produced by a TEC.

Commonly used ADDs supplied by Lofitech (Seal Scarer) and Ace Aquatech (e.g. the Marine Mammal Mitigation Device (MF) for pinnipeds and cetaceans) have a stated source level of 204 dB and 195 dB respectively, operating at frequency ranges of 10-20 kHz and 8-24 kHz. These are likely to be over 80 dB louder than the TECs at around 10 m from the turbine.

Most ADDs claim an effective displacement ranges (for their respective target species) of between 50 m and 1,000 m (McGarry *et al.* 2018), although Brandt *et al*. (2012) presents data showing that an Airmar ADD could theoretically be audible to a harbour seal, and thus also a grey seal, to around 10 km. However, audibility should not be considered the same as disturbance or displacement. The differences in the frequencies of typical ambient coastal noise, TEC machinery and an ADD means that there will be negligible interference with ADD audibility within the near vicinity of a TEC, where physical harm from a collision could occur. An ADD would thus still be effective in the WADZ region and near a TEC.

Conclusions

An overview technical note on the background noise conditions at the MDZ, in comparison to the noise levels produced by example TECs and ADDs, has been undertaken. Ambient noise levels were, as expected, controlled by the state of the tide and varied little across the site. The overall noise levels varied between approximately 89 and 107 dB SPL_{RMS}.

At present, the TECs to be installed have not been finalised and broad project design envelope is sought. Therefore consideration of published noise levels from a number of devices for which data are available have been investigated. None of the devices for which data are available are likely to cause any potential for hearing damage, permanent or temporary, to any species of marine mammal in the vicinity in any plausible scenario. However, the devices identified are significantly louder in equivalent frequency bands than the ambient noise and thus are expected to remain audible to a grey seal, although the sensitivity of bottlenose dolphin and harbour porpoise to low frequency noise will mean that much of the noise output from an operation TEC may be inaudible.

Commonly used ADDs manufactured by Ace Aquatech and Lofitech operate at frequencies to which their target species are sensitive, which are considerably higher than much of the existing ambient noise at the WADZ and example TEC devices. Thus, the audibility of the ADDs to these species is expected to be good and their effectiveness will not be diminished by the natural environment nor the installation of TECs at distances required to protect receptors from physical injury.

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Appendix A: Detailed results: April 2017

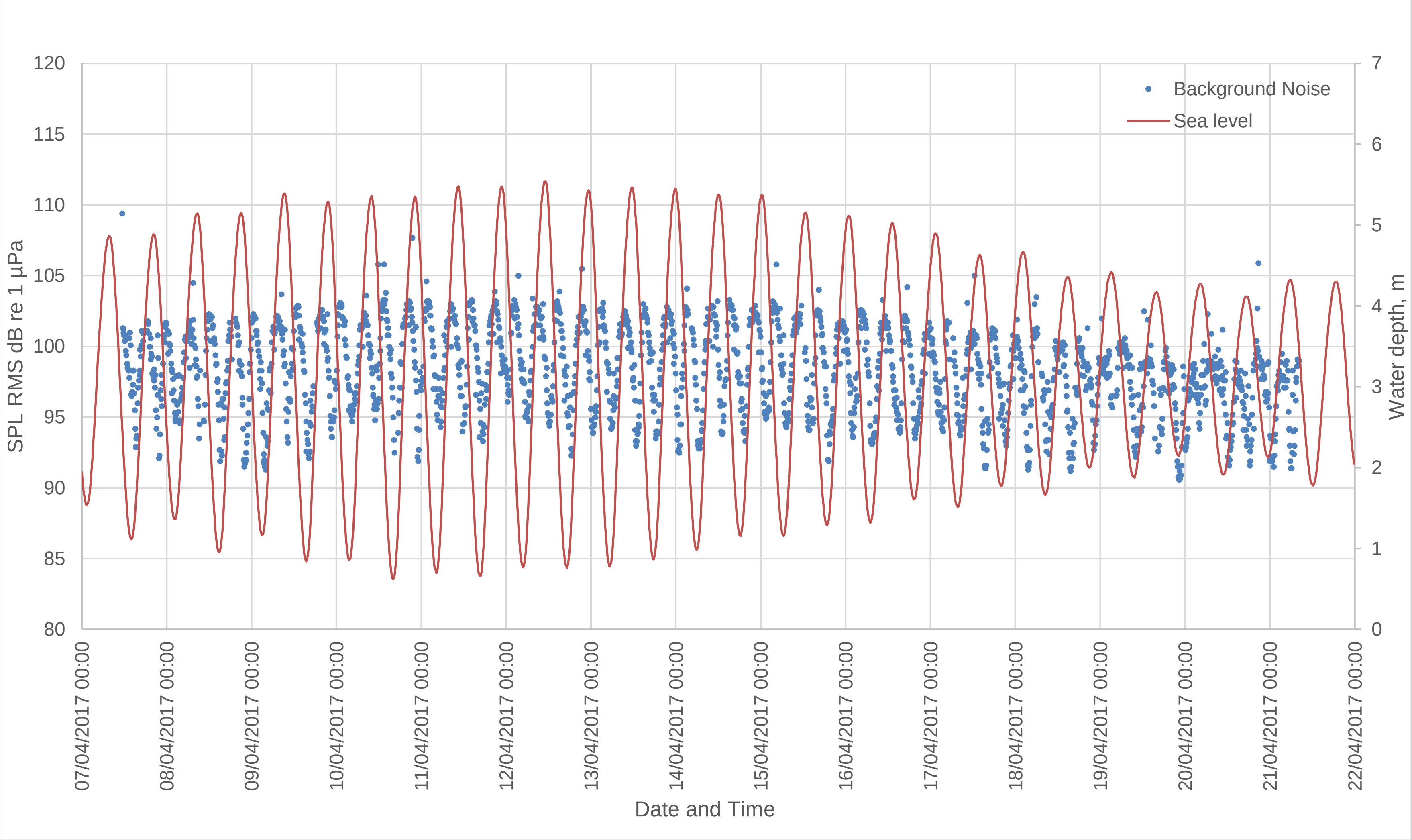

Figure 4 – Underwater noise levels and tide height, April 2017, 10 minute averages

Detailed results: June 2017

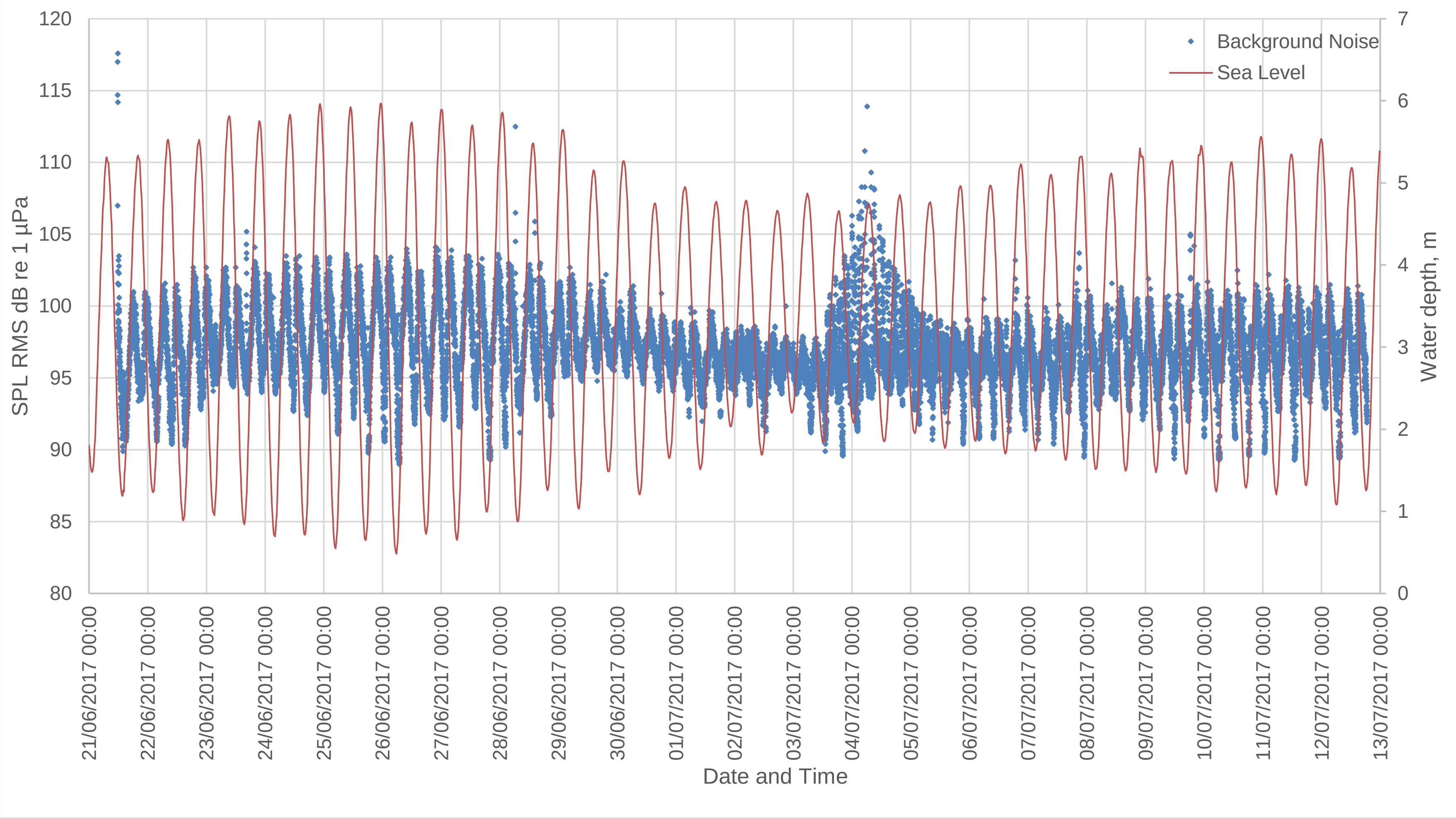

Figure 5 – Underwater noise levels and tide height, June 2017, 1 minute averages

Detailed results: July 2017

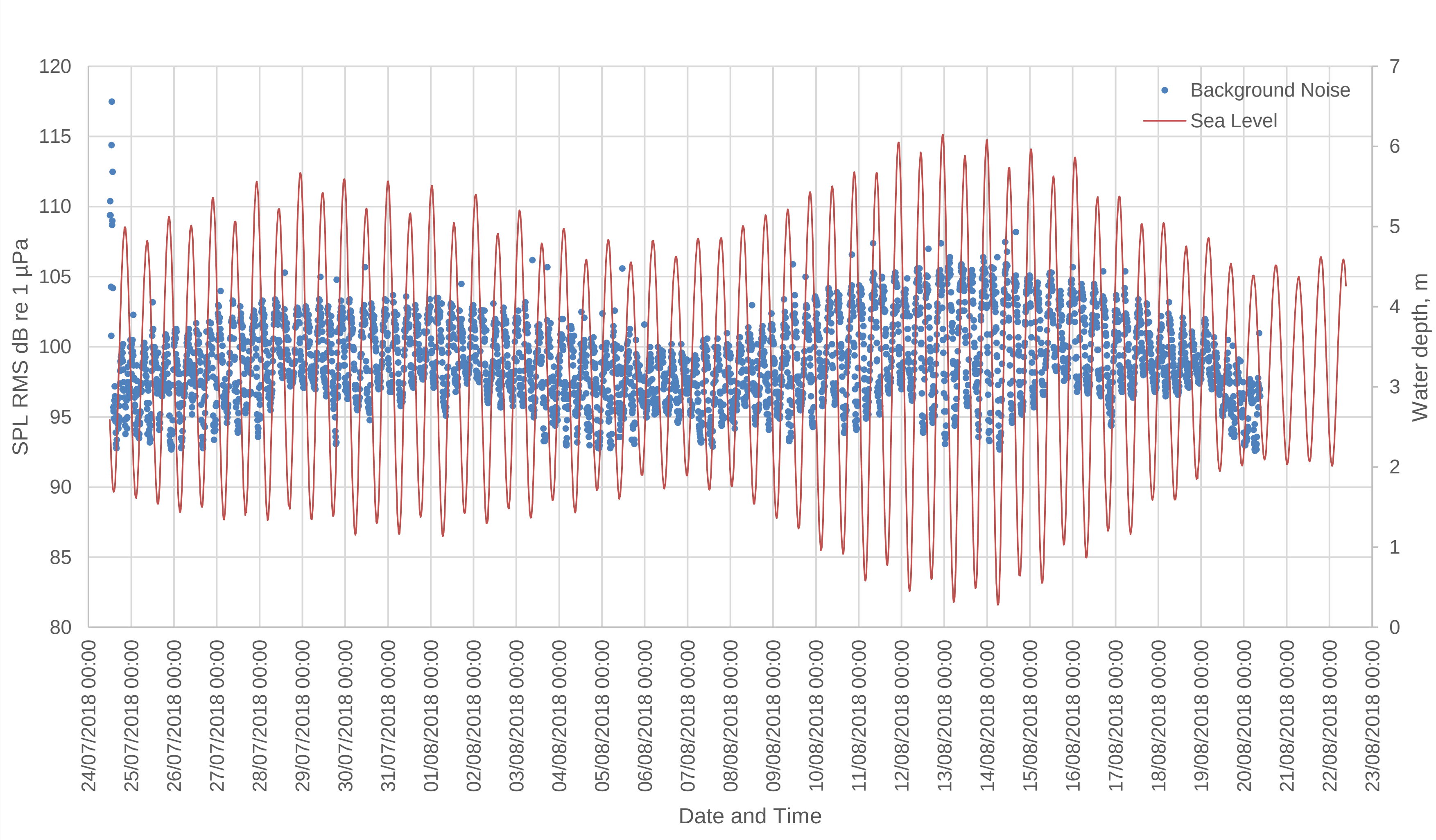

Figure 6 – Underwater noise levels and tide height, July 2017, 10 minute averages

Detailed results: July 2018

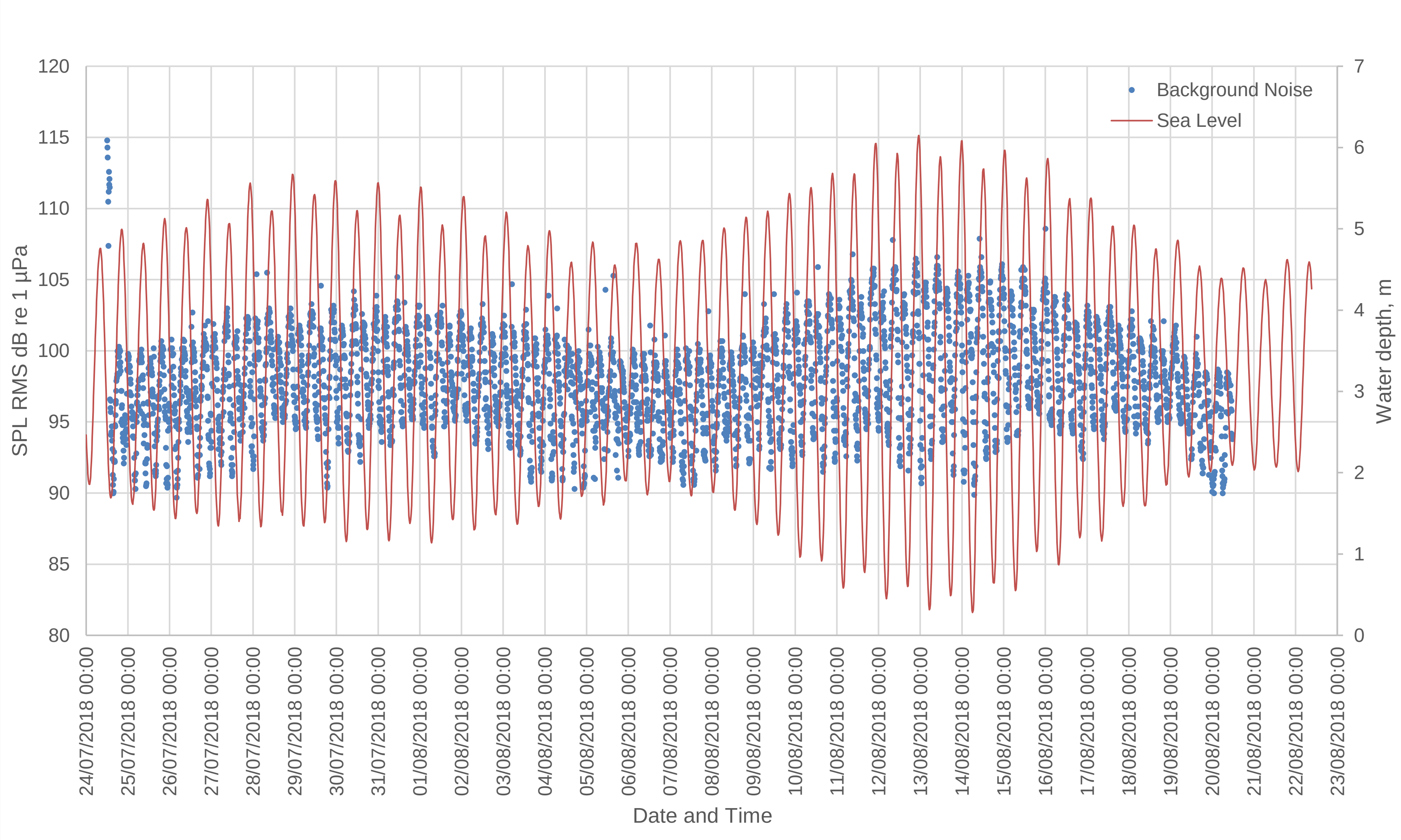

Figure 7 – Underwater noise levels and tide height, July 2018, 10 minute averages