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Appendix 10.3: Marine Mammals iPCod Modelling Report

Array EIA Report
2024

Revision	Comments	Author	Checker	Approver
FINAL	Final	RPS	RPS	RPS

Approval for Issue		
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1. INTRODUCTION

1.1. OVERVIEW

1. This Interim Population Consequences of Disturbance (iPCoD) Technical Report provides a description of the methods used for modelling of marine mammal populations in the presence of construction piling for the Ossian Array which is the subject of this application (hereafter referred to as "the Array"). It also reports and interprets the results of the iPCoD modelling which models the potential impacts on populations from elevated underwater noise from piling at the Array, as well as with other projects that have the potential to contribute a cumulative effect upon marine mammal populations.

2. An Environmental Impact Assessment (EIA) has been carried out to determine the potential effects of the Array, on sensitive marine mammal receptors from a range of impacts. A key impact assessed is the potential for an elevation in underwater noise during piling to lead to injury and behavioural/or disturbance to individual marine mammals.

3. Underwater noise modelling was undertaken (see volume 3, appendix 10.1) to predict the potential spatial scale of the impact of piling associated with the installation of seabed anchors for up to 265 wind turbines and jacket foundations for up to 15 Offshore Substation Platforms (OSPs).

4. Two piling scenarios are modelled across the Array: a single vessel piling sequentially, and concurrent piling where two vessels pile at the same time (i.e. up to two piles installed simultaneously). The impact of single-vessel piling is expected to occur over the greatest temporal scale, and the impact of concurrent piling is expected to occur over the greatest spatial scale. The piling scenarios are hereafter referred to as the 'maximum temporal scenario' and the 'maximum spatial scenario', respectively. For both scenarios a maximum of 1,806 piles are expected to be installed: 1,590 piles for wind turbine anchors, and 216 piles for OSP foundations (section 2.1).

5. Population modelling was carried out to determine the potential for a short to medium term exposure to piling, which could occur intermittently within a 72-month piling period, during the eight-year offshore construction timeframe (expected to occur between 2031 and 2038, inclusive), to result in long term population level effects on any marine mammal species for which population modelling is possible within the iPCoD framework. In this context short term refers to the duration of individual piling operations (i.e. days), medium term refers to the duration of the piling phase (i.e. up to eight years) and long term refers to the period of time over which iPCoD models are able to robustly predict population trajectories (i.e. up to 25 years).

6. The iPCoD model (developed by the Sea Mammal Research Unit (SMRU) with a team of researchers at the University of St Andrews), was adopted to simulate the potential changes in the population over time and is described within this appendix. This approach has been agreed in consultation with Marine Directorate - Licensing Operations Team (MD-LOT) and NatureScot during the initial scoping process (MD-LOT, 2023, Ossian OWFL, 2023).

1.2. BACKGROUND

7. The iPCoD model simulates the potential changes in a population of marine mammals over time, for both a "disturbed" and an "undisturbed population". This provides a comparison of the type of changes in a population that may result from natural environmental variation, demographic stochasticity (i.e. variability in population growth rates) and anthropogenic disturbance (Harwood *et al.*, 2014, King *et al.*, 2015). This approach has been widely used in previous offshore wind applications, and consented projects in the UK (e.g. Berwick Bank Offshore Wind Farm (SSE Renewables, 2022a), Awel y Môr Offshore Wind Farm (RWE Renewables UK, 2021), Hornsea Four Offshore Wind Project (Ørsted, 2021) and Hornsea Project Three Offshore Wind Farm (Ørsted, 2018a)).

8. The iPCoD model is based on expert elicitation, a widely accepted process in conservation science whereby the opinions of many experts are combined when there is an urgent need for decisions to be made but a lack of empirical data with which to inform them (Donovan *et al.*, 2016). The marine mammal experts, detailed in Sinclair *et al.* (2020), were asked for their opinion on how changes in hearing resulting from Permanent Threshold Shift (PTS) and behavioural disturbance (equivalent to a score of 5* or higher on the 'behavioural severity scale' described by Southall *et al.* (2007)) associated with offshore renewable energy developments and how they affect calf and juvenile survival, and the probability of giving birth (Harwood *et al.*, 2014). Experts were asked to estimate values for two parameters which determine the shape of the relationships between the number of days of disturbance experienced by an individual and its vital rates, thus providing parameter values for functions that form part of the iPCoD model (Harwood *et al.*, 2014).

9. The relationship between disturbance and survival/reproduction assumes that individual animals would have a limited ability to alter their activity budget to compensate for a reduction in time spent feeding (King *et al.*, 2015, Houston *et al.*, 2012). The individual's ability to provision/care for young, evade predation or resist disease would likely be affected, and it is expected that effects would be reflected in changes to vital rates. Note, however, that this relationship is highly simplified (Harwood *et al.*, 2014), and an individual's response to disturbance will depend on factors including the context of the disturbance, the individual's existing condition and its exposure history (Ellison *et al.*, 2012). The iPCoD framework applies simulated changes in vital rates to infer the number of animals that may be affected by disturbance to iteratively project the size of the population.

10. Following the initial development of the iPCoD model, a study was undertaken to update the transfer functions on the effects of PTS and disturbance on the probability of survival and giving birth to viable young for harbour porpoise, harbour seal and grey seal (again via expert elicitation) (Booth and Heinis, 2018, Booth *et al.*, 2019). The iPCoD model has been updated in light of additional work undertaken since it was originally launched in February 2014 (version 1) and iPCoD version 5.2 was used in the modelling for this report (Harwood *et al.*, 2014, Sinclair *et al.*, 2019).

11. A potential limitation of the iPCoD model is that no form of density dependence has been incorporated into the model due to the uncertainties as to how to estimate carrying capacity or how to model the mechanism of density dependence. As discussed in Harwood *et al.* (2014), the concept of density dependence is fundamental to understanding how animal populations respond to a reduction in population size. Density-dependent factors, such as resource availability or competition for space, can limit population growth. If the population declines, these factors no longer become limiting and therefore, for the remaining individuals in a population, there is likely to be an increase in survival rate and reproduction. This then allows the population to expand back to previous levels at which density-dependent factors become limiting again (i.e. population remains at carrying capacity).

12. The limitations for assuming a simple linear ratio between the maximum net productivity level and carrying capacity of a population have been highlighted by Taylor and DeMaster (1993), as simple models demonstrate that density dependence is likely to involve several biological parameters which themselves have biological limits (e.g. fecundity and survival). For UK populations of harbour porpoise (and other marine mammal species) however, there is no published evidence for density dependence and, therefore, density dependence assumptions are not currently included within the iPCoD protocol.

13. The iPCoD model v5.2 (Harwood *et al.*, 2014) was set up using the program R v4.3.1 (R Core Team, 2023) with RStudio v 2023.12.0+369 (Posit team, 2023) as the user interface. To enable the iPCoD model to be run, the following data were provided:

- reference population size (section 2.3) and demographic parameters (section 2.4) for the key species;
- user-specified input parameters:
  - vulnerable subpopulations (where appropriate); and
  - residual days of disturbance (section 2.5).
- number of animals predicted to experience PTS and/or disturbance during piling (section 2.6); and
- estimated piling schedule during the proposed construction programme (section 2.7).

2. METHODOLOGY

2.1. MAXIMUM DESIGN SCENARIO

14. The maximum design scenario (MDS) for piling at the Array has been developed on the basis that pile driving operations would be required for the installation of up to 1,806 piles across:

- 265 floating wind turbine anchors with hammer energy up to 3,000 kJ; and
- 15 OSP jacket foundations with hammer energy up to 4,400 kJ.

15. Full details of the MDS are presented in volume 2, chapter 10.

2.1.1. MAXIMUM TEMPORAL SCENARIO

16. The maximum temporal scenario is represented by piling occurring over the greatest number of days, resulting from piling at only one location at a time. Sound introduced into the marine environment over a longer period may increase the risk for disturbance to marine mammals, with potential effects during multiple stages of a species' annual cycle.

17. The maximum temporal scenario was assessed on the number of piles that could be installed within one 24-hour period. Piling is expected to take up to eight hours for each pile, meaning that the maximum temporal scenario (i.e. the longest duration of piling) would be represented by up to three piles being installed around a single turbine location or at a single OSP location, in a single day (24 hours), equating to 602 days for the installation of 1,806 piles.

18. A summary of the maximum temporal scenario for the Array is presented in Table 2.1.

Table 2.1: Summary of the Maximum Temporal Scenario used in iPCoD for Piling of Offshore Foundations at the Array

Piling Operation	Number of Piled Locations	Number of Piles	Maximum Hammer Energy (kJ)	Mean Piles Per Day (24 Hours)	Number of Vessels	Max Piling Days (24 Hours)
Wind turbine anchor	265	1,590	3,000	3	1	530
OSP jacket foundation	15	216	4,400	3	1	72
Total	**268**	**1,806**	**-**	**-**	**-**	**602**

2.1.2. MAXIMUM SPATIAL SCENARIO

19. For the maximum spatial scenario, the largest hammer energy and maximum spacing between concurrent piling events would reduce the time required for piling operations overall but would lead to the largest spatial area of ensonification at any one time. Minimum spacing between concurrent piling locations represents the highest risk of injury to marine mammals as sound from adjacent foundations could combine to produce a greater radius of effect compared to a single piling event.

20. Within the overall piling period, concurrent piling for wind turbine anchors (i.e. at two wind turbines within the same 24 hour period) would occur over 234 days. Concurrent piling of wind turbine anchors and OSP jacket foundations would occur over 63 days of the overall piling period, and single piling for the remaining OSP foundations would occur over nine days of the overall piling period. The maximum duration of piling for the maximum spatial scenario would be 306 days.

21. A summary of the maximum spatial scenario for the Array is presented in Table 2.2.

Table 2.2: Summary of the Maximum Spatial Scenario used in iPCoD for Piling of Offshore Foundations at the Array

Piling Operation	Number of Piled Locations	Number of Piles	Maximum Hammer Energy (kJ)	Mean Piles Per Day (24 Hours)	Number of Vessels	Max Piling Days (24 Hours)
Wind turbine anchor (concurrent)	234	1,401	3,000	3	2	234
Wind turbine anchor + OSP jacket foundation (concurrent)	31 (Wind turbine)/ 13 (OSP)	189 (Wind turbine)/ 189 (OSP)	3,000 (Wind turbine)/ 4,400 (OSP)	3	2	63
OSP jacket foundation (single)	2	27	4,400	3	1	9
Total	**268**	**1,806**	**-**	**-**	**-**	**306**

22. It is estimated that piling activity at the Array will take place within an eight-year timeframe (2031 to 2038). Piling could potentially take place at any point within the foundation installation phase, however, for the purposes of developing the piling schedule for iPCoD (a requirement of the model) an indicative programme has been developed based on a realistic installation approach with piling spread across the eight years, discussed in section 2.7.

2.2. KEY SPECIES

23. Marine mammal species included in the iPCoD model were those that were determined to be important marine mammal features within the regional marine mammal study area, following a review of the Array Digital Aerial Survey (DAS) data, and available published data sets (see volume 3, appendix 10.2), and for which a population model in iPCoD was available.

24. The baseline characterisation for the Array identified the following marine mammal species within the regional marine mammal study area (volume 3, appendix 10.2):

- harbour porpoise *Phocoena phocoena*;
- bottlenose dolphin *Tursiops truncatus*;
- short-beaked common dolphin *Delphinus delphus*;
- minke whale *Balaenoptera acutorostrata;*
- grey seal *Halichoerus grypus*; and
- harbour seal *Phoca vitulina*.

25. Harbour seal occurs in the regional marine mammal study area in numbers considered not high enough to be at risk of a population-level effect and has therefore not been included in iPCoD analysis, with exclusion of harbour seal from further analysis in the EIA agreed with NatureScot (in January 2024) in response to Marine Mammal Consultation Note 1 (volume 3, appendix 5.1, annex D). Similarly, there are currently no parameters available to construct a suitable population model for short-beaked common dolphin in the iPCoD framework and therefore population modelling for short-beaked common dolphin has not been possible for this assessment. In addition, only three individuals were identified from the DAS data therefore it is not considered a key species.

26. Therefore, the species included for iPCoD modelling were:

- harbour porpoise;
- bottlenose dolphin;
- minke whale; and
- grey seal.

27. The piling parameters defined in the MDS (see section 2.1) were subsequently incorporated into an acoustic sound propagation model to predict the potential range of effect (injury and disturbance) for each key species. The assessment considered the efficacy of standard industry mitigation measures (see paragraph 41 for a summary of relevant measures, and volume 1, chapter 3 for full details) to reduce these effects and subsequently the numbers carried forward to this population model were based on any residual effects after accounting for mitigation.

28. The assessment presented a range of densities for each key species (as listed in paragraph 24), however, for the purpose of undertaking the population modelling the most precautionary densities and relevant reference populations were taken forward (paragraph 26). The total number of animals potentially disturbed for each species was quantified by applying the highest density estimate to the dose-response curve derived by Graham *et al.* (2019) . This approach considers a proportional response within consecutive mapped contours denoting incremental 5 dB decreases in received single strike sound exposure level (SEL_{ss}) predicted using the underwater noise model. To this end a 100% disturbance was predicted in all species at received levels >180 dB SEL_{ss}. The predicted rate of disturbance then decreases proportionally in response to received level, reducing at greater distances from the piling source. The dose-response relationship based on published empirical evidence and further detail is provided in volume 2, chapter 10.

2.3. REFERENCE POPULATIONS

29. Key species population estimates based upon Management Units (MUs) were specified in the iPCoD models as the reference populations against which any effects (i.e. number of animals experiencing disturbance or PTS) were assessed. Relevant MUs were determined by their coincidence with the location of the Array. This section details these reference populations.

30. For harbour porpoise and minke whale, only one MU for each species occurs in the vicinity of the Array (IAMMWG, 2022), and the respective population estimates for these MUs have been used for iPCoD modelling: the North Sea MU for harbour porpoise (Figure 2.1) and the Celtic and Greater North Seas MU for minke whale (Figure 2.2).

31. The site boundary coincides with the boundary between two seal MUs (SMU) (Figure 2.3), so for grey seal the reference population comprises the sum of the population estimates for the East Scotland seal MU and the Northeast England seal MU (SCOS, 2023) as agreed with NatureScot in March 2024, in response to Marine Mammal Consultation Note 2 (volume 3, appendix 5.1, annex E).

32. For bottlenose dolphin, the Coastal East Scotland MU (Figure 2.4) was used as the relevant reference population. Given the importance of the Moray Firth Special Area of Conservation (SAC) for bottlenose dolphin within the regional marine mammal study area, the sensitivity of this population and its known ranging behaviour further south towards St Andrews Bay and the Tay Estuary, and inshore in north-east English waters, it is important to capture the potential impact to this important coastal ecotype population which may experience potential barrier effects as a result of increase noise in the marine environment.

33. Whilst there is an abundance estimate for bottlenose dolphin for the Greater North Sea MU (2,022 animals (IAMMWG, 2022)) this large MU extends the entire length of the east coast of the UK and east to Scandinavia, so apportioning numbers of the offshore ecotype to the east coast of Scotland is not possible. It is also unlikely that the Array will create significant barrier effects for this offshore ecotype. Therefore, the assessment has focused on the impacts for the bottlenose dolphin population within the Coastal East Scotland MU, which includes the Moray Firth SAC. This approach has been agreed in consultation with MD-LOT and NatureScot during the initial scoping process (MD-LOT, 2023, Ossian OWFL, 2023).

34. The population estimates used to parameterise iPCoD models were taken from IAMMWG (2022) for cetacean species and from SCOS (2023) for grey seal, and are summarised in Table 2.3.

Table 2.3: Reference Populations Used in the iPCoD Modelling

Species	Management Unit/ Seal Management Unit	Population Estimate (Number of Animals)	Reference
Harbour porpoise	North Sea	346,601	IAMMWG (2022)
Bottlenose dolphin	Coastal East Scotland	224	IAMMWG (2022)
Minke whale	Celtic and Greater North Seas	20,118	IAMMWG (2022)
Grey seal	East Scotland seal MU (10,783) and Northeast England seal MU (25,913)	36,696	SCOS (2023)

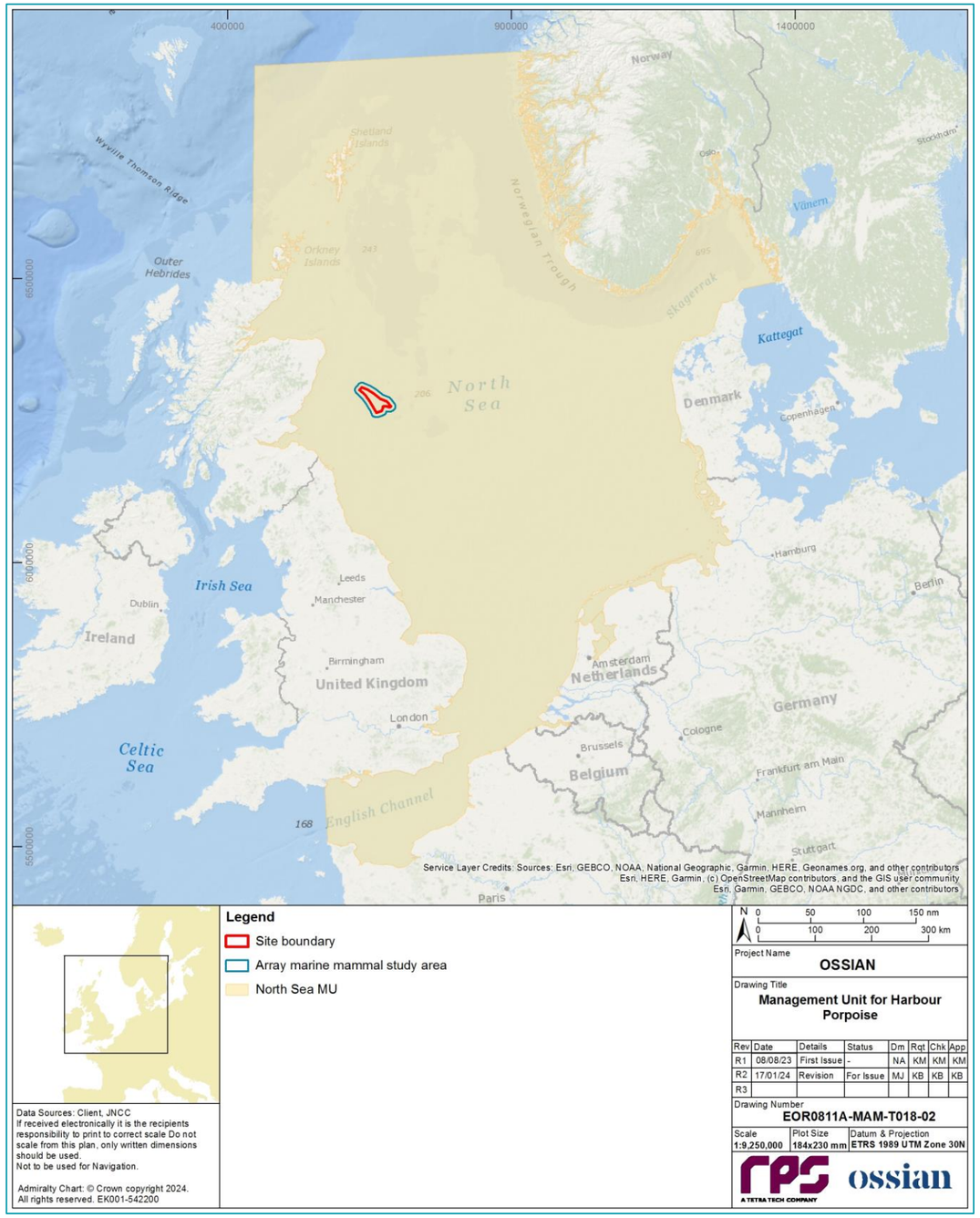

Figure 2.1: North Sea Management Unit for Harbour Porpoise (IAMMWG, 2022)

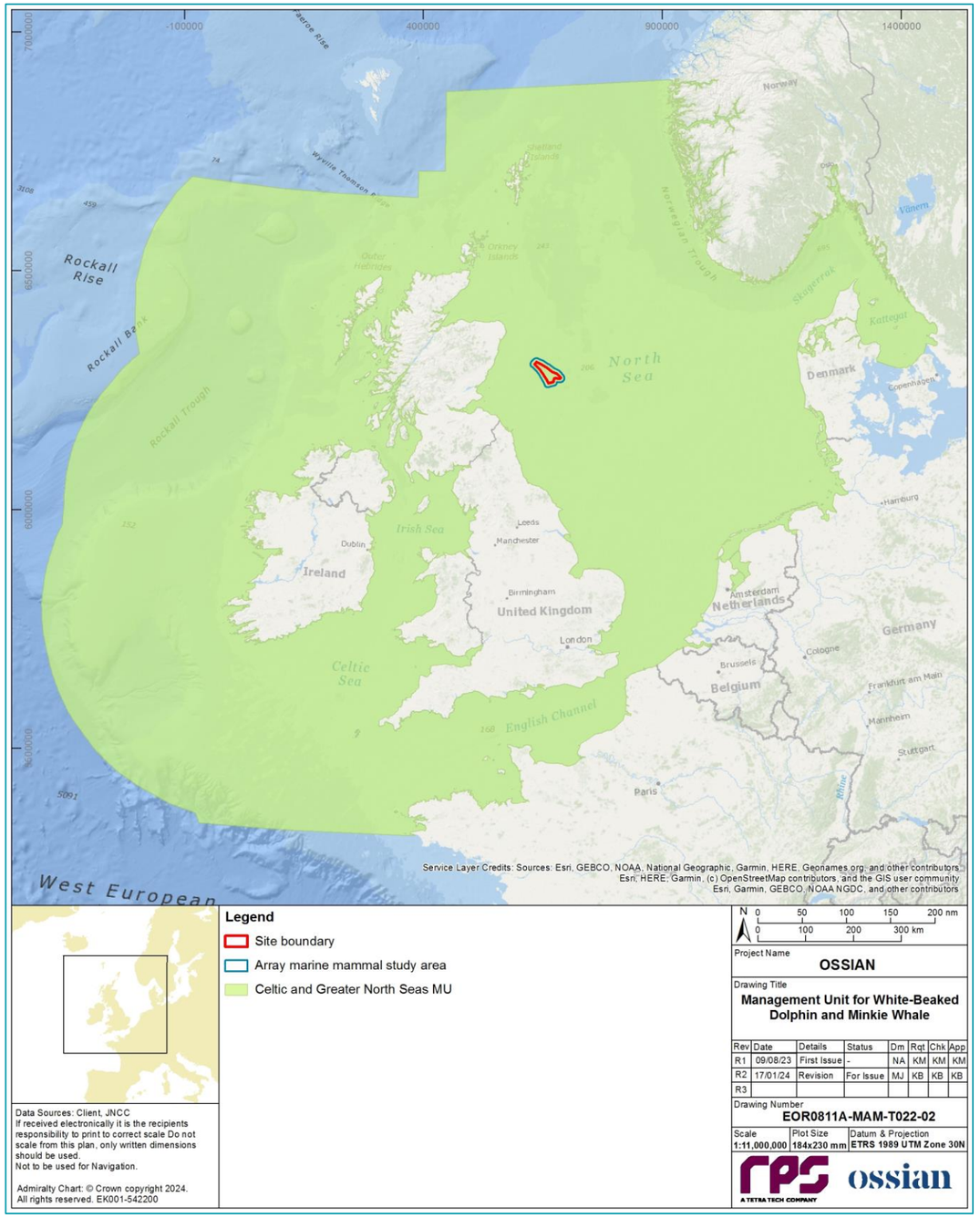

Figure 2.2: Celtic and Greater North Seas Management Unit for Minke Whale (IAMMWG, 2022)

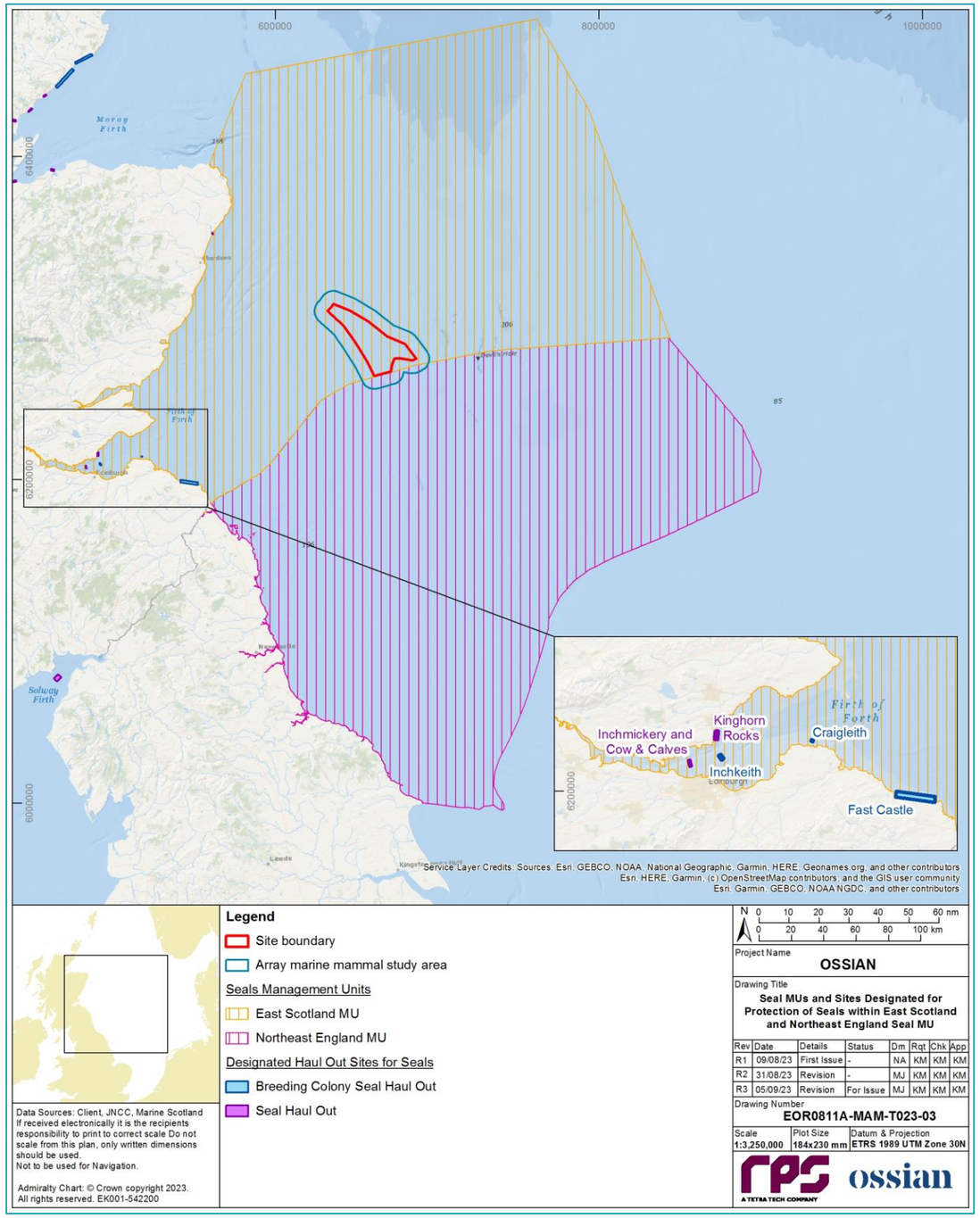

Figure 2.3: East Scotland and Northeast England Seal Management Units (SCOS, 2023)

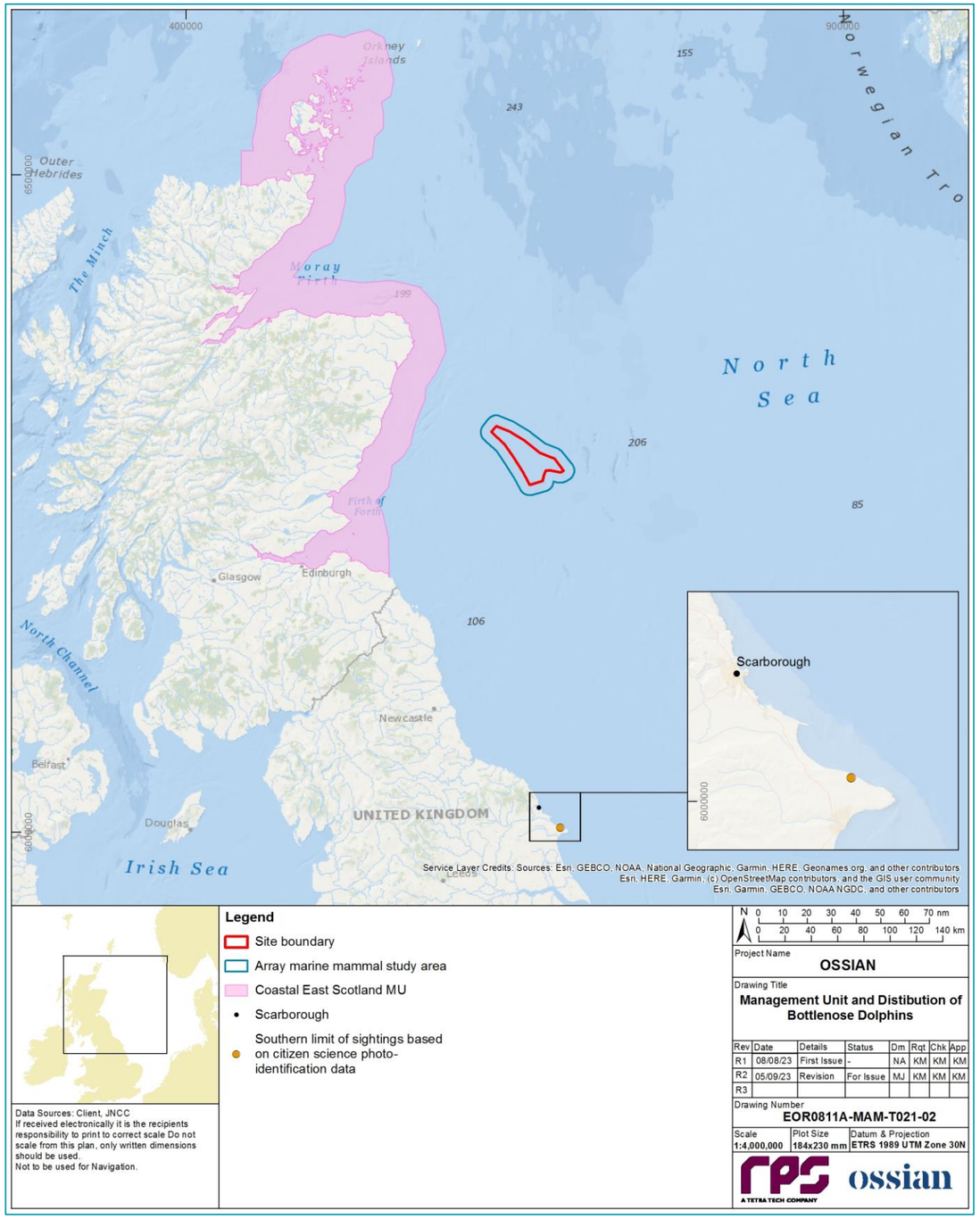

Figure 2.4: Coastal East Scotland Management Unit for Bottlenose Dolphin (IAMMWG, 2022)

2.4. DEMOGRAPHIC PARAMETERS

35. Demographic parameters for the key species that have been used in the population models are presented in Table 2.4. These were selected from Sinclair *et al.* (2020), and agreed with NatureScot via consultation on the Marine Mammal Methodology Note in September 2023 (volume 3, appendix 5.3, annex B) and the Marine Mammal Consultation Note 2 in January 2024 (volume 3, appendix 5.3, annex E).

Table 2.4: Marine Mammal Vital Rates Used to Parameterise iPCoD Models, from Sinclair *et al*. (2020)

Species	Calf/Pup Survival	Juvenile Survival	Adult Survival	Fertility	Age of Independence (Years)	Age of First Birth (Years)
Harbour porpoise	0.8455	0.85	0.925	0.34	1	5
Bottlenose dolphin	0.9250	1.00	1.000	0.24	3	9
Minke whale	0.7000	0.77	0.960	0.91	1	9
Grey seal	0.2220	0.94	0.940	0.84	1	6

2.5. RESIDUAL DAYS DISTURBANCE

36. Empirical evidence from the constructed Beatrice and Horns Rev 2 offshore wind farms (Graham *et al.*, 2019, Brandt *et al.*, 2011) suggests that the detection of animals returns to baseline levels in the hours following disturbance from piling and therefore, for the most part, it can be assumed that the disturbance occurs only on the day (24 hours) that piling takes place.

37. Due to the potential duration of piling occurring at the Array (e.g. up to eight hours maximum piling per pile, therefore three piles installed per day, associated with wind turbine anchors), in a 24 hour period. Therefore, the number of residual days of disturbance has, conservatively, been selected as one, meaning that the model assumes that disturbance occurs on the day of piling and persists for a period of 24 hours after piling has ceased.

2.6. NUMBER OF ANIMALS EXPERIENCING INJURY AND DISTURBANCE

38. The number of animals predicted to experience disturbance or PTS as a result of piling at the Array was based on the density values provided as part of the individual species baseline assessments in volume 3, appendix 10.2.

39. For the assessment of PTS an average density value was applied to the potential area of effect; calculated from the range out to which the injury threshold was modelled to be exceeded for each marine mammal hearing group. For harbour porpoise the maximum density is based upon 24 months of site-specific DAS data, aggregated over the months of April to September (see volume 3, appendix 10.2, annex A for full details of DAS campaign and analysis methods). For bottlenose dolphin and minke whale density estimates were derived from Lacey *et al.* (2022), and for grey seal density estimates were obtained from Carter *et al.* (2022).

Table 2.5: Summary of Species Densities Used in Calculating Numbers of Animals Potentially Disturbed

Species	Density (Animals per km^2)	Source
Harbour porpoise	0.651	Site-specific DAS (see volume 3, appendix 10.2, annex A)
Bottlenose dolphin	0.003	Lacey *et al.* (2022)
Minke whale	0.028	Lacey *et al.* (2022)
Grey seal	0.180	Carter *et al.* (2022)

40. To estimate the number of animals potentially disturbed during piling at the Array, the sound contours were mapped, and a dose response approach applied to calculate the number of animals within each 5 dB isopleth using the density values as described in Table 2.5. For grey seal, however, the quantitative assessment was undertaken by overlaying the unweighted SEL_{ssn} contours on at-sea density maps (Figure 2.5) produced by Carter *et al.* (2022). The number of animals in each 5x5 km grid cell was summed for each isopleth and corrected using the proportional response as per Whyte *et al.* (2020).

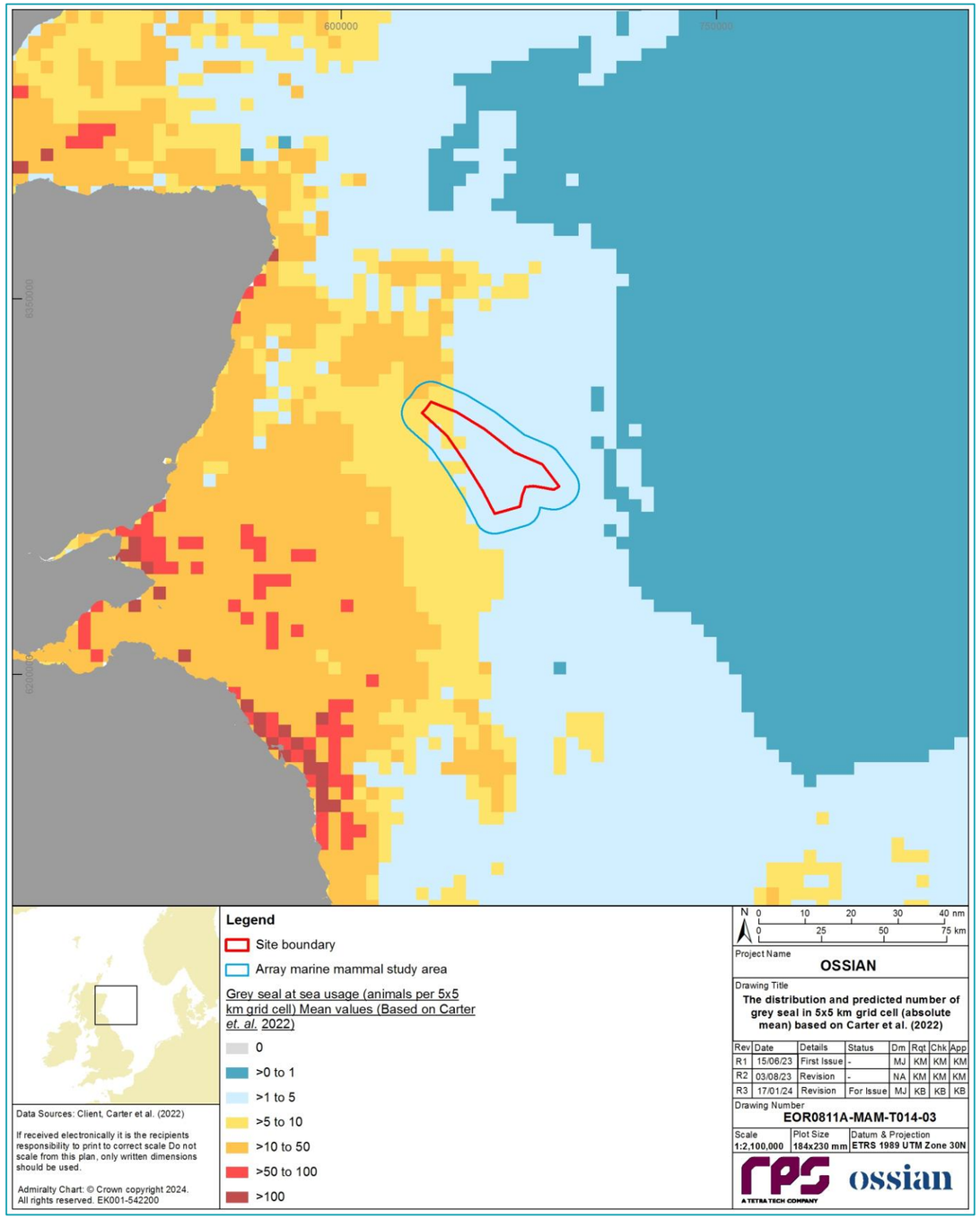

Figure 2.5: Mean Density of Grey Seal per 5 km x 5 km Grid Square (Carter *et al.*, 2022)

41. For all scenarios, designed in measures were applied (see volume 2, chapter 10). Relevant primary mitigation included as designed in measures for the Array are:

    - implementation of soft-start and ramp-up measures or piling and UXO clearance

42. With these designed in mitigation measures in place, the residual number of individuals potentially affected by PTS was taken forward for the iPCoD model. This is a conservative approach since mitigation measures (i.e. application of an outline Marine Mammal Mitigation Plan (MMMP)) will reduce the risk of PTS further. However, the large injury ranges predicted for some species (volume 2, chapter 10) requires that a conservative approach is taken in parameterising iPCoD models.

43. Currently the underwater noise models for the Array, assume one minke whale experiencing PTS for the maximum temporal scenario based on the SEL_{cum} metric, and up to three minke whale (SEL_{cum}) for concurrent piling of wind turbine anchors and OSP foundations under the maximum spatial scenario No other species were predicted to experience PTS based on the SEL_{cum} metric, and models based on the SPL_{pk} metric predicted no individuals experiencing PTS for any species. Maximum potential numbers of animals disturbed and injured (PTS) for the maximum temporal scenario is presented in Table 2.6 and maximum numbers of animals disturbed and injured (PTS) for the maximum spatial scenario is presented in Table 2.7.

44. To provide context between species, iPCoD models for all species incorporate the number of animals predicted to be affected, based on modelling of the SPL_{pk} metric. Since minke whale is the only species with the potential to experience PTS (when the SEL_{cum} metric is considered) additional iPCoD models have also been run for this species to incorporate the potential for PTS. A summary of all models for each species is presented in section 2.9.

45. For the maximum spatial scenario, modelling locations are detailed in volume 3, appendix 10.1. For disturbance, modelling has been undertaken for piling at the northern location concurrently with the central location, and the southern location concurrently with the central location and is representative of the largest separation of the piling vessels, as detailed within volume 1, chapter 3. Modelling of injury ranges has been undertaken for two adjacent piles at the northern and southern locations.

Table 2.6: Maximum Temporal Scenario: Estimated Number of Animals Predicted to be Disturbed or Injured (PTS) at Any One Time During Piling

Species	Activity	Potential Number of Animals Disturbed (No. Individuals)	Potential Number of Animals Injured (PTS) (No. Individuals)
Harbour porpoise	Wind turbine anchor Piling	3,857	0
	OSP jacket foundation Piling	7,310	0
Bottlenose dolphin	Wind turbine anchor Piling	2	0
	OSP jacket foundation Piling	4	0
Minke whale	Wind turbine anchor Piling	169	0
	OSP jacket foundation Piling	319	1 (SEL_{cum})
Grey seal	Wind turbine anchor Piling	131	0
	OSP jacket foundation Piling	344	0

Table 2.7: Maximum Spatial Scenario: Estimated Number of Animals Predicted to be Disturbed or Injured (PTS)[1] at Any One Time During Piling

Species	Operation	Potential Number of Animals Disturbed (No. Individuals)	Potential Number of Animals Injured (PTS) (No. Individuals)
Harbour porpoise	Wind turbine anchor (concurrent) Piling (at Northern and Central locations)	5,951	0
	Wind turbine anchor (at Central location) + OSP jacket foundation (at Northern Location) (concurrent) Piling	8,309	0
	OSP jacket foundation (single) Piling (at the Central Location)	7,310	0
Bottlenose dolphin	Wind turbine anchor (concurrent) Piling (at Northern and Central locations)	3	0
	Wind turbine anchor (at Central Location) + OSP jacket foundation (at Northern Location) (concurrent) Piling	5	0
	OSP jacket foundation (single) Piling (at Northern location)	4	0
Minke whale	Wind turbine anchor (concurrent) Piling (at Northern and Central locations)	260	0
	Wind turbine anchor (at Central location) + OSP jacket foundation (at Northern Location) (concurrent) Piling	362	3 (SEL_{cum})
	OSP jacket foundation (single) Piling (at Central Location)	319	1 (SEL_{cum})
Grey seal	Wind turbine anchor (concurrent) Piling (at Northern and Central locations)	232	0
	Wind turbine anchor (at Central Location) + OSP jacket foundation (at Northern Location) (concurrent) Piling	436	0
	OSP jacket foundation (single) Piling (at Northern Location)	344	0

[1] Since no animals of any species were predicted from modelling of the SPL_{pk} metric to experience PTS, the values presented in Table 2.6 and Table 2.7 are those from modelling of SEL_{cum} only

2.7. INDICATIVE PILING SCHEDULE

46. The piling schedule used in the iPCoD modelling was developed from the Project Description (volume 1, chapter 3). This provides an estimate of the maximum number of days of piling required for installation of the wind turbine anchors and OSP jacket foundations, within a defined piling window.

47. The piling phase for the Array is expected to occur across 63 months within the eight-year offshore construction phase (i.e. between 2031 and 2038), with piling for wind turbine anchors expected to be completed in year seven (i.e. 2037). Offshore construction activities are anticipated to reduce during the winter months due to greater risk of adverse weather restricting operations. The iPCoD models are not able to accommodate fine scale changes in piling intensity over the year, so the estimated piling schedules used for iPCoD modelling assume that no piling will occur in the months of January, February or March.

48. For the purposes of developing the piling schedule for iPCoD (a required input for all models) indicative programmes were specifically developed for the maximum temporal scenario, maximum spatial scenario, and cumulative scenarios, tailored to each species and based on a realistic installation approach, with piling spread across the eight years. It is important to note, however, that while indicative piling schedules are intended to provide a realistic basis on which iPCoD models are run, these schedules are not intended to reflect the actual final piling operations for an individual project. Fine-scale variability such as seabed composition, environmental factors (such as weather conditions) and transit time between piling locations would be too complex to predict at this stage in the project development process, and the iPCoD framework does not facilitate such nuance.

49. For the maximum temporal scenario, piling was assumed to occur over the greatest time frame. The 602 piling days (Table 2.1) have therefore been spread as evenly as practicable across the eight-year construction phase, with an interval of two to three days between piling for wind turbine anchors (530 piling days) and approximately 30 days between piling for OSP jacket foundations (72 piling days).

50. For the maximum spatial scenario, piling was assumed to generate greater levels of underwater noise, but to occur over a shorter time frame than for the maximum temporal scenario. Concurrent piling has been assumed at the wind turbine anchors and the majority of OSP jacket foundations, and all piling at these locations has subsequently been assumed to occur across 306 piling days (Table 2.2).

51. A summary of the piling schedules for the maximum temporal scenario and maximum spatial scenario used in the iPCoD models is presented in Table 2.8, and the time points selected from the iPCoD model outputs are summarised in Table 2.9.

52. Time points have been selected to coincide with key periods in the piling schedule, and with the six-year duration of statutory reporting periods for SACs. Although no SACs are expected to be directly affected by piling for the Array, and the six-year reporting period may not align precisely with key points in the indicative piling schedule, this interval provides a useful periodicity for reporting of population trajectories, and is close to the generation times for the modelled species (i.e. five to nine years: see Table 2.4). Similarly, it is the approach taken for the reporting of offshore piling in Welsh and English waters for the Mona and Morgan Offshore Wind Projects (Mona Offshore Wind Ltd, 2024, Morgan Offshore Wind Ltd, 2023).

Table 2.8: Indicative Piling Programme for Each Piling Scenario for the Array Within the Eight-Year Offshore Construction Phase

Year	Quarter	Number of Piling Days				
		Maximum Temporal Scenario		Maximum Spatial Scenario		
		Wind Turbine (Single Piling)	OSP (Single Piling)	Wind Turbine (Concurrent Piling)	Wind Turbine + OSP (Concurrent Piling)	OSP (Single Piling)
Year 1	Q1	No piling		No piling		
	Q2	26	3	12	3	-
	Q3	25	3	12	3	-
	Q4	25	3	12	3	-
Year 2	Q1	No piling		No piling		
	Q2	26	3	12	3	-
	Q3	25	3	12	3	-
	Q4	25	3	12	3	-
Year 3	Q1	No piling		No piling		
	Q2	26	3	12	3	-
	Q3	25	3	12	3	-
	Q4	25	3	12	3	-
Year 4	Q1	No piling		No piling		
	Q2	26	3	12	3	-
	Q3	25	3	12	3	-
	Q4	25	3	12	3	-
Year 5	Q1	No piling		No piling		
	Q2	26	3	12	3	-
	Q3	25	3	12	3	-
	Q4	25	3	12	3	-
Year 6	Q1	No piling		No piling		
	Q2	26	3	9	3	-
	Q3	25	3	9	3	-
	Q4	25	3	9	3	-
Year 7	Q1	No piling		No piling		
	Q2	26	3	9	3	-
	Q3	25	3	9	3	-
	Q4	23	3	9	3	-
Year 8	Q1	No piling		No piling		
	Q2	-	3	-	-	3
	Q3	-	3	-	-	3
	Q4	-	3	-	-	3
Total		**530**	**72**	**234**	**63**	**9**

Table 2.9: Selected Time Points from iPCoD Simulation Output and Corresponding Events

Time Point	Indicative Year	Corresponding Event
1	2031	1st year of piling
2	2032	2nd year of piling
3	2033	3rd year of piling
7	2037	Six years after start of piling (duration of SAC reporting period)
9	2039	End of eighth year of piling: piling complete
13	2043	Twelve years after start of piling (SAC reporting)
15	2045	Six years after end of piling (SAC reporting)
21	2051	Twelve years after end of piling (SAC reporting)
26	2056	25 years after start of piling: maximum extent of model predictions

2.8. CUMULATIVE PROJECTS

53. Cumulative projects for marine mammal species were considered across the regional marine mammal study area, following the cumulative effects assessment methodology described in section 10.12.1 of volume 2, chapter 10. Those projects for which piling is expected to temporally overlap (or to occur in adjacent years) with piling for the Array, and for which quantitative information was available, were included in iPCoD modelling. The Tier 1 (see section 10.12.1 of volume 2, chapter 10) Green Volt Offshore Wind Farm was screened out at this stage since no impact piling will be undertaken for this project. Tier 2 and Tier 3 projects for which quantitative information was not available were not possible to include in models as any estimate would be unlikely to reflect realised piling programmes, and these projects are summarised in Table 10.52 of volume 2, chapter 10. To capture the end of the offshore construction phase at the cumulative projects, the cumulative iPCoD models included an additional year before piling at the Array commenced. A summary of cumulative projects included in iPCoD modelling and indicative offshore piling schedules is provided in Table 2.10.

Table 2.10: Indicative Offshore Piling Programmes and Schedules for Cumulative Projects[2]

Project	Tier	No. Piles	Total Piling Days (24 Hours Period)	Indicative Year												
				2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Array	-	1,806	306				P	P	P	P	P	P	P	P		
Berwick Bank	1	1,496	372				P									
Hornsea Three	1	319	194			P	P									

54. The Array piling scenario carried forward to the cumulative assessment was the maximum temporal scenario as this represented the largest potential effect from piling from the model simulations for the Array alone. Although the number of animals potentially affected was greater for the maximum spatial scenario (Table 2.6 and Table 2.7), the results of the iPCoD model based upon the maximum temporal scenario predicted a greater effect on the respective impacted populations.

55. Both cumulative projects conduct piling in two phases, beginning as early as 2023 (Hornsea Three), and since the duration of robust predictions from iPCoD modelling is limited to 25 years, to maintain focus on predictions from the Array only the second phase of each project's respective piling phase is included in the cumulative iPCoD models. Hence, the number of piling days presented in Table 2.11 is only a proportion of the total piling days presented in Table 2.10. For Berwick Bank, the second piling phase comprises one third of the total piling phase (one year out of a total of three-piling years across both phases), so this has been modelled as one third of the total piling days (SSE Renewables, 2022a).

56. For Hornsea Three, no specific information was available on the split between the two piling phases (Ørsted, 2018a), so an approximately equal split has been assumed (i.e. each piling phase comprises approximately half of the total piling days). Piling at Hornsea Three also comprises two elements: concurrent piling of wind turbines, OSPs and accommodation infrastructure within the array area, and single piling of booster stations within the cable corridor. All single piling for booster station has been assumed to occur in the second piling phase and has been included in the cumulative models.

[2] Shading Indicates Construction Phases for Respective Projects. 'P' Indicates Years in Which Piling is Expected

57. There is no potential for significant cumulative impacts for injury (PTS) from elevated underwater noise during piling for the cumulative projects presented in Table 2.11 as iPCoD simulations for these projects have modelled zero animals experiencing PTS.

58. The iPCoD models were set up as described in sections 2.3 and 2.4 for reference populations and demographic parameters, respectively, and with the same number of days of residual disturbance and number of animals experiencing disturbance and injury specified in section 2.6.

59. Cumulative projects were only included in species' models if they overlap spatially with the species-specific management units described in Table 2.10. For harbour porpoise and minke whale, the cumulative iPCoD models included both Berwick Bank and Hornsea Three, and for bottlenose dolphin and grey seal, models included Berwick Bank only.

60. The number of animals affected for each of the key species and number of days on which piling occurred was taken from the MDS for each of the cumulative projects (SSE Renewables, 2022b, Ørsted, 2018b). A summary of the number of animals for each species affected and number of piling days for each cumulative project is provided in Table 2.11. In cases where less than one animal was expected to experience disturbance or injury, this was rounded up to one animal for the relevant models.

Table 2.11: Summary of Number of Animals Predicted to Experience Disturbance for Cumulative iPCoD Scenario

Project		Modelled Piling Days (24 Hour Period)	Maximum Number of Animals Disturbed			
			Harbour Porpoise (No. Individuals)	Bottlenose Dolphin (No. Individuals)	Minke Whale (No. Individuals)	Grey Seal (No. Individuals)
Array	Wind turbine (single) Piling	530	3,857	2	169	131
	OSP (single)	72	7,310	4	319	344
Berwick Bank	Wind turbine (concurrent) Piling	95	2,822	5	132	1,358
	OSP (single) Piling	17	1,754	4	82	705
Hornsea Three	Array area (concurrent) Piling	157	7,330	N/A	51	N/A
	Cable corridor (single) Piling	5	964	N/A	11	N/A

61. Time points selected from the iPCoD model outputs coincide with key periods in the piling schedule, and with statutory reporting periods for Special Areas of Conservation (SAC), are summarised in Table 2.12.

Table 2.12: Selected Time Points from iPCoD Simulation Output and Corresponding Events for Cumulative Scenario

Time Point	Indicative Year	Corresponding Event
1	2029	Second piling phase starts at Hornsea Three
2	2030	Second piling phase starts at Berwick Bank; Final year of second piling phase at Hornsea Three.
3	2031	1st year of piling at Array; Piling continues at Berwick Bank; 1st year after end of piling at Hornsea Three.
4	2032	2nd year of piling at Array; Final year of piling at Berwick Bank.
5	2033	3rd year of piling at Array; 1st year after end of piling at Berwick Bank.
8	2036	Six years after end of piling at Hornsea Three (SAC reporting)
9	2037	Six years after start of piling at Array (SAC reporting)
10	2038	End of eighth year of piling: piling complete at Array; Six years after end of piling at Berwick Bank (SAC reporting).
14	2042	Twelve years after end of piling at Hornsea Three (SAC reporting).
15	2043	Twelve years after start of piling at Array (SAC reporting);
16	2044	Six years after end of piling at Array (SAC reporting); Twelve years after end of piling at Berwick Bank (SAC reporting).
23	2051	Twelve years after end of piling at Array (SAC reporting)
26	2053	23 years after start of piling at Array: maximum extent of model predictions

2.9. SUMMARY OF IPCOD SCENARIOS

62. A total of 14 iPCoD modelling scenarios were run for the Array alone and the cumulative effect assessment, and these are summarised in Table 2.13 for each of the four key species for which iPCoD modelling has been possible.

Table 2.13: Summary of iPCoD Scenarios Modelled for Key Species Associated with the Array and Relevant Cumulative Projects

Scenario		Population Unit	Population Estimate (Number of Animals)
Harbour porpoise			
HP-01	Maximum temporal scenario	North Sea MU	346,601
HP-02	Maximum spatial scenario		
HP-C1	Cumulative scenario, incorporating: • Berwick Bank; and • Hornsea Three		
Bottlenose dolphin			
BND-01	Maximum temporal scenario	Coastal East Scotland MU	224
BND-02	Maximum spatial scenario		
BND-C1	Cumulative scenario, incorporating: • Berwick Bank		
Minke whale			
MW-01a	Maximum temporal scenario (SPL_{pk})	Celtic and Greater North Seas MU	20,118
MW-01b	Maximum temporal scenario (SEL_{cum})		
MW-02a	Maximum spatial scenario (SPL_{pk})		
MW-02b	Maximum spatial scenario (SEL_{cum})		
MW-C1	Cumulative scenario, incorporating: • Berwick Bank; and • Hornsea Three		
Grey seal			
GS-01	Maximum temporal scenario	East Scotland SMU + Northeast England SMU	36,696
GS-02	Maximum spatial scenario		
GS-C1	Cumulative scenario, incorporating: • Berwick Bank		

2.10. MODEL OUTPUTS

63. The outputs of the iPCoD models are focussed on describing the potential impact to a given marine mammal population under the relevant development scenario, relative to the population in the absence of the development. An estimate is provided for every time step in the scenario (here given as 25 years after commencement of piling), for each simulation (n = 1,000) and is presented in Figure 3.1 to Figure 3.14. The ratio of the simulated impacted population to the unimpacted population sizes can then be expressed

as a ratio, termed the 'counterfactual' of population size. A counterfactual of 1 would therefore correspond to a prediction of no difference in size between the impacted and unimpacted populations. Counterfactuals of <1 would correspond to the impacted population being smaller than the unimpacted population.

64. The mean estimate (plus 95% confidence interval) of impacted and unimpacted population sizes across all simulations, and the corresponding counterfactuals, are reported for each species, and each scenario (Table 3.1 to Table 3.14). The median counterfactual is also presented since this measure can be less sensitive to outliers. However, it is important to note that the median counterfactual may not always be representative of overall projections, and should be interpreted with caution, since this is calculated simply as the central value in the ordered set of counterfactuals from all simulations.

3. RESULTS

3.1. HARBOUR PORPOISE

3.1.1. SCENARIO HP-01: MAXIMUM TEMPORAL SCENARIO

65. Results for the maximum temporal scenario indicate a very small difference in the growth trajectory of harbour porpoise between the unimpacted population and impacted population (Figure 3.1). At all time points, there was little difference in the mean size of the impacted and unimpacted populations, with a maximum difference of 2,048 individuals (approximately 0.59% of the North Sea MU reference population) at time point 9, corresponding to the first year after completion of the piling phase (Table 3.1).

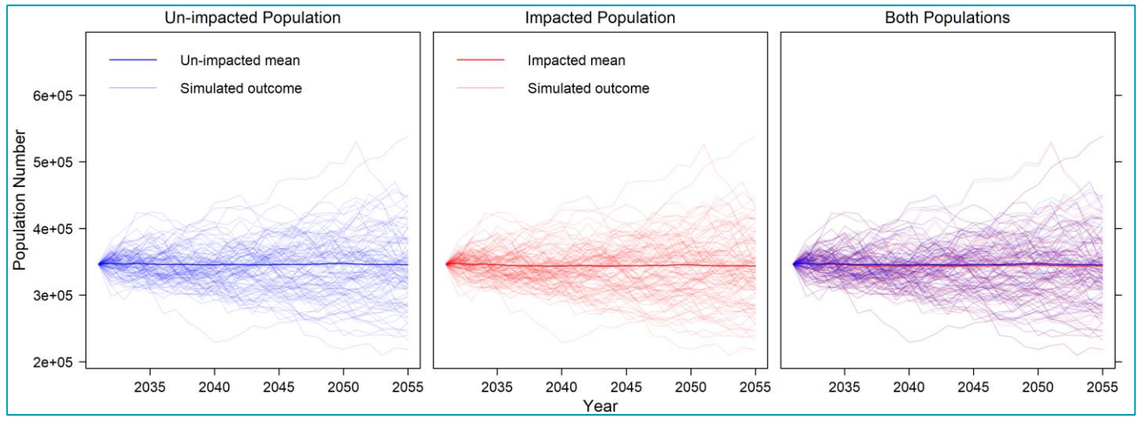

Figure 3.1: Simulated Harbour Porpoise Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Temporal Scenario HP-01

66. At time point 7, which represents the end of the piling phase for wind turbine anchors, and corresponding to the six-year reporting period formerly required under the Habitats Directive, the impacted population was predicted to be 1,608 animals smaller than the unimpacted population (approximately 0.46% of the North Sea MU reference population).

67. At time point 13, which corresponds with six years after the end of the piling phase for wind turbine anchors, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) the difference between the impacted and unimpacted populations was 1,869 animals, approximately 0.54% of the reference population.

Table 3.1: Modelled Estimates for the Unimpacted and Impacted Harbour Porpoise Populations and Counterfactuals of Population Size for the Maximum Temporal Scenario HP-01

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	346,602	**346,602**	346,602	346,602	**346,602**	346,602	1.0000	1.0000
2	319,555	**347,337**	373,037	319,418	**347,279**	372,757	0.9998	1.0000
3	309,727	**346,707**	380,227	309,679	**346,230**	379,106	0.9986	0.9996
7	293,713	**345,896**	405,588	293,327	**344,288**	402,884	0.9954	0.9986
9	285,997	**345,397**	409,874	285,306	**343,349**	405,432	0.9941	0.9984
13	276,323	**345,655**	429,560	274,923	**343,786**	425,177	0.9947	0.9985
15	272,417	**345,805**	432,115	270,720	**343,925**	429,658	0.9946	0.9985
21	256,958	**346,627**	451,743	256,774	**344,742**	449,838	0.9946	0.9986
26	249,430	**345,291**	460,022	247,855	**343,413**	456,445	0.9946	0.9985

68. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is 1,878 animals, corresponding to approximately 0.54% of the reference population (Table 3.1). This suggests that there would not be a long term effect from piling at the Array upon the harbour porpoise population within the North Sea MU.

69. The median counterfactual for this scenario fluctuated between 1.0000 and 0.9984 through the 26-year simulation, whereas the mean counterfactual reduced to 0.9946 by the end of the simulation. Therefore, given that the differences in disturbed to un-disturbed populations approaches a ratio of 1 there is not considered to be a potential for a long term effect from this piling scenario upon harbour porpoise within the North Sea MU.

3.1.2. SCENARIO HP-02: MAXIMUM SPATIAL SCENARIO

70. Results for the maximum spatial scenario indicate a very small difference in the growth trajectory of harbour porpoise between the unimpacted population and impacted population (Figure 3.2). At all time points there was little difference in the mean size of the impacted and unimpacted populations, with a maximum difference of 1,371 individuals (approximately 0.40% of the North Sea MU reference population) at time point 9, corresponding to the first year after the completion of the piling phase (Table 3.2).

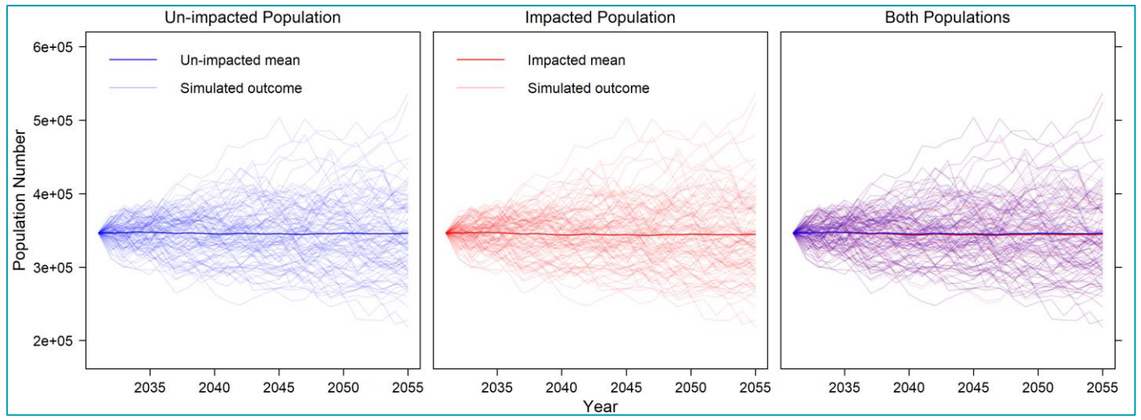

Figure 3.2: Simulated Harbour Porpoise Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Spatial Scenario HP-02

71. At time point 7, which represents the end of the concurrent portion of the piling phase for the Array, and corresponding to the six-year reporting period formerly required under the Habitats Directive, the impacted population was predicted to be 1,142 animals smaller than the unimpacted population (approximately 0.33% of the North Sea MU reference population).

72. At time point 13, which corresponds with six years after the end of concurrent piling, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) the difference between the impacted and unimpacted populations was 1,284 animals, approximately 0.54% of the reference population.

Table 3.2: Modelled Estimates for the Unimpacted and Impacted Harbour Porpoise Populations and Counterfactuals of Population Size for the Maximum Spatial Scenario HP-02

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	346,602	**346,602**	346,602	346,602	**346,602**	346,602	1.0000	1.0000
2	317,467	**346,654**	370,911	317,466	**346,601**	370,898	0.9998	1.0000
3	310,356	**347,156**	380,785	309,838	**346,817**	380,092	0.9990	0.9999
7	290,428	**346,200**	402,190	290,147	**345,058**	400,544	0.9967	0.9995
9	287,053	**345,951**	416,603	285,769	**344,580**	416,222	0.9961	0.9994
13	274,397	**345,491**	430,589	274,381	**344,207**	430,245	0.9963	0.9994
15	271,371	**345,549**	438,859	270,352	**344,255**	437,418	0.9963	0.9994
21	259,902	**345,869**	453,595	258,764	**344,573**	453,277	0.9963	0.9994
26	248,204	**346,262**	478,332	247,121	**344,960**	476,051	0.9963	0.9994

73. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is 1,302 animals, corresponding to approximately 0.38% of the reference population (Table 3.2). This suggests that there would not be a long term effect from piling at the Array upon the harbour porpoise population within the North Sea MU.

74. The median counterfactual for this scenario reduced from 1.0000 to 0.9994 at the end of the 26-year simulation, while the mean counterfactual reduced to 0.9963 by the end of the simulation. This is greater than the corresponding counterfactual from the maximum temporal scenario, suggesting that the maximum spatial scenario may result in a smaller impact.

75. Given that the differences in disturbed to un-disturbed populations approaches a ratio of 1 there is considered to be no potential for a long term effect from this piling scenario upon the North Sea MU population of harbour porpoise.

3.1.3. SCENARIO HP-C1: CUMULATIVE SCENARIO

76. For scenario HP-C1, in which a total of 306 days of piling were modelled at the Array alongside a total of 273 piling days across Tier 1 cumulative projects (112 days at Berwick Bank, and 161 days at Hornsea Three) these results indicate a small difference in the simulated trajectories of harbour porpoise between the unimpacted population and impacted population (Figure 3.3). This corresponds to a difference of 2,114 fewer animals in the impacted population at time point 26, compared to the un-impacted population (Table 3.3), corresponding to 0.61% of the North Sea MU reference population.

77. At time point 5, which corresponds to the third year of piling at the Array, the first year after the end of piling at Berwick Bank, and three years after the end of piling at Hornsea Three, the difference between impacted and un-impacted populations is 1,210 animals (0.35% of the reference population). When compared to the equivalent time point from scenario HP-01 (i.e. three years into the maximum temporal scenario for the Array alone: section 3.1.1), this is a difference between scenarios of 733 animals.

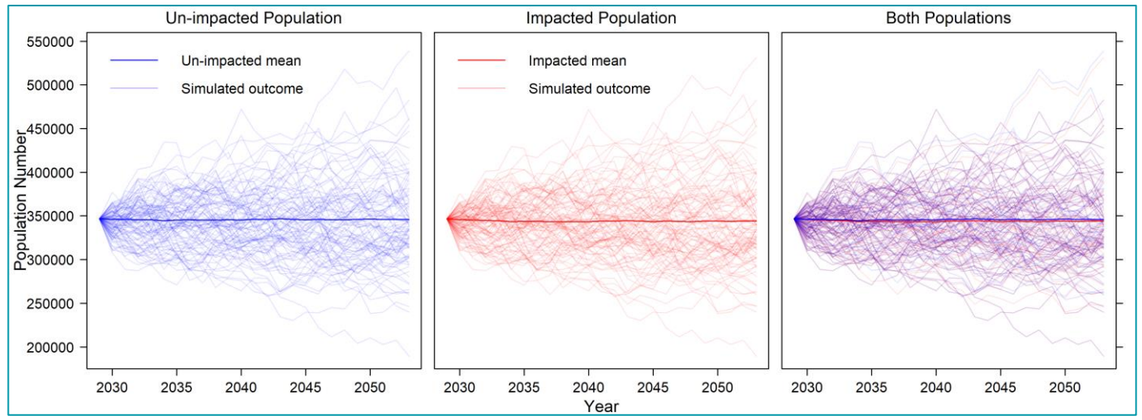

Figure 3.3: Simulated Harbour Porpoise Population Trajectories in an Unimpacted Versus Impacted Population, for Cumulative Scenario HP-C1

Table 3.3: Modelled Estimates for the Unimpacted and Impacted Harbour Porpoise Populations and Counterfactuals of Population Size for Cumulative Scenario HP-C1

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	346,602	**346,602**	346,602	346,602	**346,602**	346,602	1.0000	1.0000
2	317,562	**346,054**	371,245	317,143	**345,841**	371,161	0.9994	1.0000
3	308,820	**345,895**	379,009	308,376	**345,336**	378,551	0.9984	0.9998
4	302,418	**345,756**	387,789	302,325	**345,078**	387,181	0.9980	0.9998
5	297,921	**345,620**	391,149	296,117	**344,410**	389,928	0.9965	0.9992
8	289,666	**345,483**	406,898	288,832	**343,771**	403,775	0.9951	0.9991
9	285,022	**345,117**	412,799	282,965	**343,243**	408,340	0.9946	0.9991
10	280,714	**345,401**	411,334	279,260	**343,299**	409,119	0.9940	0.9990
14	273,859	**346,212**	429,372	272,191	**344,120**	424,655	0.9940	0.9990
15	270,498	**346,696**	437,892	270,278	**344,596**	436,541	0.9940	0.9990
16	270,531	**346,172**	438,454	268,416	**344,064**	436,520	0.9940	0.9990
23	257,169	**345,964**	461,508	254,000	**343,858**	459,265	0.9940	0.9990
26	253,855	**345,823**	470,128	249,528	**343,709**	466,484	0.9940	0.9990

78. At time point 16, six years after the end of piling at the Array and 12 years after the end of piling at Berwick Bank (both corresponding with the duration of Habitats Directive reporting periods), the difference between impacted and unimpacted populations is 2,108. When compared to the equivalent time point from scenario HP-01 (i.e. six years after the end of piling at the Array alone: section 3.1.1), this is a difference between scenarios of 500 animals.

79. The median counterfactual of population size for cumulative scenario HP-C1 was 0.9990 at the end of the 26-year simulation, while the mean counterfactual was 0.9940. Therefore, given that the differences in disturbed to undisturbed populations approaches a ratio of 1 there is not considered to be a potential for a long term population-level effect from this cumulative piling scenario upon harbour porpoise within the North Sea MU.

3.2. BOTTLENOSE DOLPHIN

3.2.1. SCENARIO BND-01: MAXIMUM TEMPORAL SCENARIO

80. Results for the maximum temporal scenario indicate a small difference in the growth trajectory of bottlenose dolphin between the unimpacted population and impacted population (Figure 3.4). At all time points there was little difference in the mean size of the impacted and unimpacted populations, with a maximum difference of seven individuals (approximately 3.13% of the Coastal East Scotland MU reference population) at time point 25 and 26, corresponding to 24 years after the start of piling, and 18 years after the completion of piling for wind turbine anchors (Table 3.4), and both aligning with the duration of Habitats Directive reporting periods.

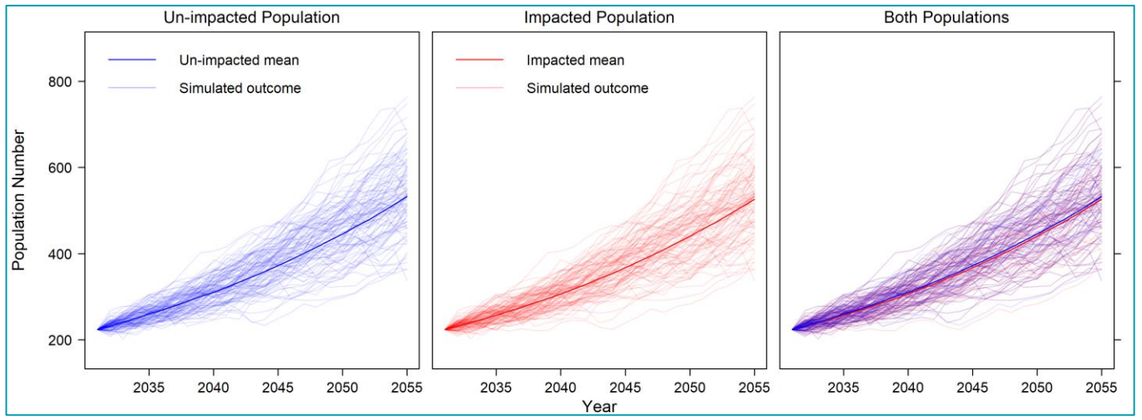

Figure 3.4: Simulated Bottlenose Dolphin Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Temporal Scenario BND-01

81. At time point 7, which represents the end of the piling phase for wind turbine anchors, and corresponds to the six-year reporting period formerly required under the Habitats Directive, the impacted population was predicted to be three animals smaller than the unimpacted population (approximately 1.34% of the Coastal East Scotland MU reference population).

82. At time point 13, which corresponds with six years after the end of the piling phase for wind turbine anchors, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) the difference between the impacted and unimpacted populations was four animals, approximately 1.79% of the reference population.

Table 3.4: Modelled Estimates for the Unimpacted and Impacted Bottlenose Dolphin Populations and Counterfactuals of Population Size for the Maximum Temporal Scenario BND-01

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	224	**224**	224	224	**224**	224	1.0000	1.0000
2	208	**232**	252	208	**232**	252	0.9996	1.0000
3	208	**241**	268	208	**240**	268	0.9968	1.0000
7	224	**279**	332	218	**276**	328	0.9892	1.0000
9	238	**300**	362	224	**296**	360	0.9868	1.0000
13	256	**346**	430	250	**342**	428	0.9887	1.0000
15	274	**372**	472	264	**368**	466	0.9886	1.0000
21	324	**463**	618	318	**457**	610	0.9881	1.0000
26	382	**553**	742	370	**546**	740	0.9882	1.0000

83. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is seven animals, corresponding to approximately 3.13% of the reference population (Table 3.4). This suggests that there would not be a long term effect from piling at the Array upon the bottlenose dolphin population within the Coastal East Scotland MU.

84. The median counterfactual for scenario BND-01 remained at 1.0000 throughout the 26-year simulation, whereas the mean counterfactual fluctuated between a maximum of 1.0000 and a minimum of 0.9868, to finish at 0.9882 by the end of the simulation. Given that the differences in disturbed to un-disturbed populations approaches a ratio of 1 there is considered to be no potential for a long term effect from this piling scenario upon bottlenose dolphin within the Coastal East Scotland MU.

3.2.2. SCENARIO BND-02: MAXIMUM SPATIAL SCENARIO

85. Results for the maximum spatial scenario indicated a small difference in the growth trajectory of bottlenose dolphin between the unimpacted population and impacted population (Figure 3.5). At all time points there was little difference in the mean size of the impacted and unimpacted populations, with a maximum difference of four individuals (approximately 1.79% of the Coastal East Scotland MU reference population) at time points 21 to 26, corresponding to 20 years after the start of piling, and 18 years after the end of the piling phase, respectively (Table 3.5).

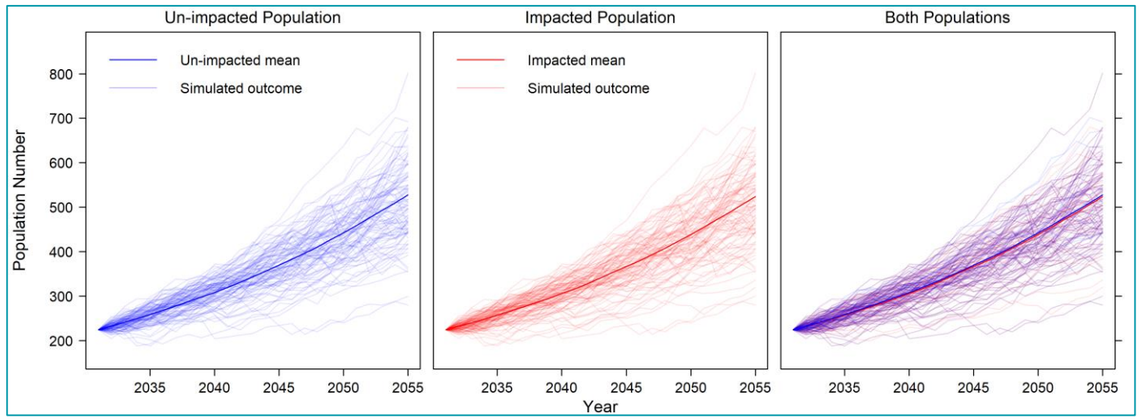

Figure 3.5: Simulated Bottlenose Dolphin Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Spatial Scenario BND-02

86. At time point 7, which represents the end of the concurrent piling portion of the piling phase and corresponds to the six-year reporting period formerly required under the Habitats Directive, the impacted population was predicted to be three animals smaller than the unimpacted population (approximately 1.34% of the Coastal East Scotland MU reference population).

87. At time point 13, which corresponds with six years after the end of the concurrent piling phase, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) the difference between the impacted and unimpacted populations was three animals, approximately 1.34% of the reference population.

Table 3.5: Modelled Estimates for the Unimpacted and Impacted Bottlenose Dolphin Populations and Counterfactuals of Population Size for the Maximum Spatial Scenario BND-02

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	224	**224**	224	224	**224**	224	1.0000	1.0000
2	208	**232**	250	208	**232**	250	0.9997	1.0000
3	208	**241**	270	206	**240**	270	0.9976	1.0000
7	224	**278**	330	222	**275**	328	0.9919	1.0000
9	240	**298**	358	226	**295**	356	0.9907	1.0000
13	258	**344**	430	252	**341**	430	0.9920	1.0000
15	276	**369**	468	266	**366**	468	0.9919	1.0000
21	322	**459**	606	310	**455**	606	0.9916	1.0000
26	362	**547**	742	350	**543**	742	0.9916	1.0000

88. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is four animals, corresponding to approximately 1.79% of the reference population (Table 3.5). This indicates that there would not be a long term effect from piling at the Array upon the bottlenose dolphin population within the Coastal East Scotland MU.

89. The median counterfactual for scenario BND-02 remained at 1.0000 throughout the 26-year simulation, whereas the mean counterfactual fluctuated between a maximum of 1.0000 and a minimum of 0.9907, to finish at 0.9916 by the end of the simulation. This is greater than the corresponding counterfactual from the maximum temporal scenario, suggesting that the maximum spatial scenario may result in a smaller impact.

90. Given that the differences in disturbed to un-disturbed populations approaches a ratio of 1 there is considered to be no potential for a long term effect from this piling scenario upon bottlenose dolphin.

3.2.3. SCENARIO BND-C1: CUMULATIVE SCENARIO

91. For scenario BND-C1, in which a total of 306 days of piling were modelled at the Array alongside a total of 112 piling days at Berwick Bank, these results indicate a small difference in the simulated trajectories of bottlenose dolphin between the unimpacted population and impacted population (Figure 3.6). This corresponds to a difference of 10 fewer animals in the impacted population at time point 26, compared to the un-impacted population (Table 3.6), corresponding to approximately 4.46% of the Coastal East Scotland MU reference population.

92. At time point 5, which corresponds to the third year of piling at the Array and the first year after the end of piling at Berwick Bank, the difference between impacted and un-impacted populations is three animals (1.34% of the reference population). When compared to the equivalent time point from scenario BND-01 (i.e. three years into the maximum temporal scenario for the Array alone: section 3.2.1), this is a difference between scenarios of two animals.

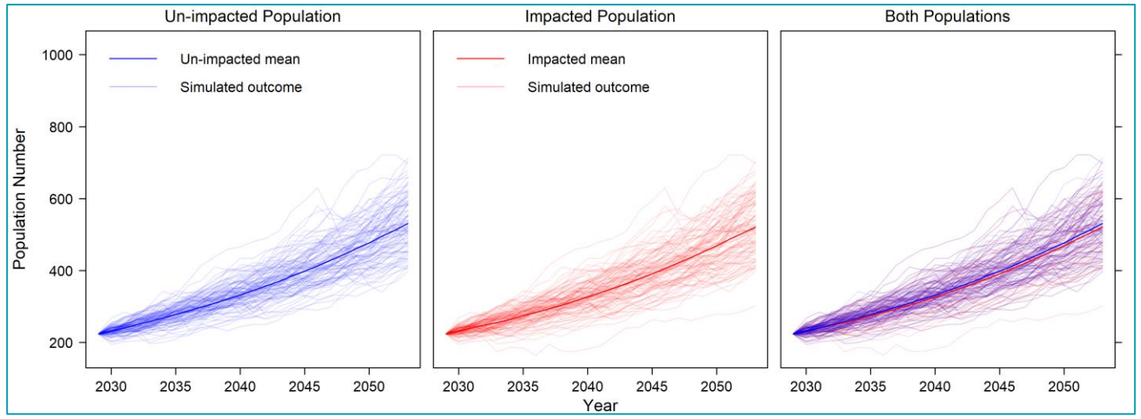

Figure 3.6: Simulated Bottlenose Dolphin Population Trajectories in an Unimpacted Versus Impacted Population, for Cumulative Scenario BND-C1

93. At time point 16, six years after the end of piling at the Array and 12 years after the end of piling at Berwick Bank (both corresponding with the duration of Habitats Directive reporting periods), the difference between impacted and unimpacted populations is seven animals. When compared to the equivalent time point from scenario BND-01 (i.e. six years after the end of piling at the Array alone: section 3.1.1), this is a difference between scenarios of four animals.

94. The median counterfactual of population size for cumulative scenario BND-C1 was 1.0000 throughout the 26-year simulation, while the mean counterfactual was varied between a maximum of 1.000, and a minimum of 0.9820 at time point 11, increasing to 0.9824 at the end of the simulation. Therefore, given that the differences in disturbed to undisturbed populations approaches a ratio of 1 there is not considered to be a potential for a long term population-level effect upon bottlenose dolphin.

Table 3.6: Modelled Estimates for the Unimpacted and Impacted Bottlenose Dolphin Populations and Counterfactuals of Population Size for Cumulative Scenario BND-C1

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	224	**224**	224	224	**224**	224	1.0000	1.0000
2	208	**232**	252	208	**232**	252	1.0000	1.0000
3	210	**240**	270	210	**240**	270	1.0000	1.0000
4	210	**249**	284	208	**248**	282	0.9968	1.0000
5	214	**258**	300	208	**255**	300	0.9872	1.0000
8	230	**288**	344	224	**283**	342	0.9846	1.0000
9	240	**298**	362	224	**293**	356	0.9834	1.0000
10	238	**309**	376	228	**303**	372	0.9824	1.0000
11	246	**317**	390	228	**312**	388	0.9820	1.0000
12	254	**326**	402	228	**321**	400	0.9847	1.0000
13	260	**335**	414	228	**329**	412	0.9821	1.0000
14	268	**357**	446	258	**351**	442	0.9828	1.0000
15	274	**370**	464	266	**363**	462	0.9828	1.0000
16	286	**384**	490	278	**377**	486	0.9827	1.0000
23	350	**495**	652	346	**486**	644	0.9823	1.0000
26	374	**550**	740	364	**540**	740	0.9824	1.0000

3.3. MINKE WHALE

3.3.1. SCENARIO MW-01A: MAXIMUM TEMPORAL SCENARIO (SPL_{PK})

95. Results for the maximum temporal scenario, with numbers of potentially affected animals based upon the SPL_{pk} metric for PTS, indicate a very small difference in the growth trajectory of minke whale between the unimpacted population and impacted population (Figure 3.7). At all time points there was little difference in the mean size of the impacted and unimpacted populations, with a maximum difference of one individual (approximately 0.005% of the Celtic and Greater North Seas MU reference population) at various time points throughout the modelled simulations, including time point 7 and time point 26, corresponding to six years after the start of piling, and 18 years after the completion of piling (Table 3.7), and both aligning with the six-year duration of Habitats Directive reporting periods.

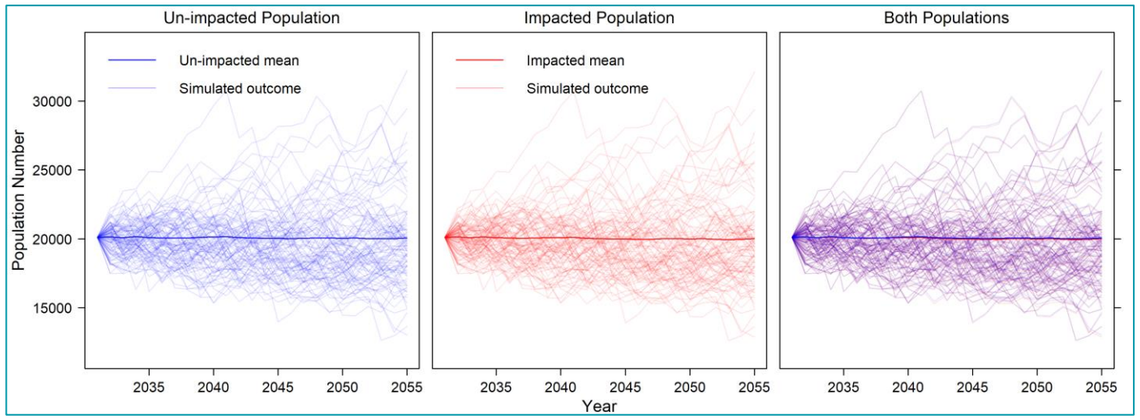

Figure 3.7: Simulated Minke Whale Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Temporal Scenario MW-01a, Based on the SPL_{pk} Metric for PTS

96. At time point 13, which corresponds with six years after the end of the piling phase for wind turbine anchors, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) there was no difference between the size of the impacted and unimpacted populations.

Table 3.7: Modelled Estimates for the Unimpacted and Impacted Minke Whale Populations and Counterfactuals of Population Size for the Maximum Temporal Scenario MW-01a, Based on the SPL_{pk} Metric for PTS

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	20,120	**20,120**	20,120	20,120	**20,120**	20,120	1.0000	1.0000
2	17,954	**20,143**	21,946	17,954	**20,143**	21,946	1.0000	1.0000
3	17,288	**20,125**	22,677	17,288	**20,125**	22,677	1.0000	1.0000
7	16,740	**20,199**	23,884	16,740	**20,198**	23,884	1.0000	1.0000
9	16,483	**20,137**	24,312	16,483	**20,136**	24,312	1.0000	1.0000
13	15,834	**20,082**	25,388	15,834	**20,082**	25,388	1.0000	1.0000
15	15,376	**20,022**	25,844	15,376	**20,022**	25,844	1.0000	1.0000
21	14,869	**20,007**	27,121	14,869	**20,006**	27,121	1.0000	1.0000
26	14,097	**19,932**	27,555	14,097	**19,931**	27,555	1.0000	1.0000

97. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is one animal (Table 3.7), corresponding to approximately 0.005% of the reference population. This suggests that there would not be a long term effect from piling at the Array upon the minke whale population within the Celtic and Greater North Seas MU.

98. Both the median and mean counterfactual for scenario minke whale-01a remained at 1.0000 throughout the 26-year simulation, indicating no discernible difference in the ratio of the disturbed to un-disturbed populations and no potential for a long term population-level effect from this piling scenario upon minke whale.

3.3.2. SCENARIO MW-01B: MAXIMUM TEMPORAL SCENARIO (SEL_{CUM})

99. Results for the maximum temporal scenario, with numbers of potentially affected animals based upon the SEL_{cum} metric for PTS, indicate a small difference in the growth trajectory of minke whale between the unimpacted population and impacted population (Figure 3.8). This difference is larger when compared to results from scenario MW-01a, based upon the SPL_{pk} metric. At all time points there was little difference in the mean size of the impacted and unimpacted populations relative to the reference population, with a maximum difference of 55 individuals (approximately 0.27% of the Celtic and Greater North Seas MU reference population) from time point 21 through to the end of modelled simulations. At time point 7, corresponding to six years after the start of piling and aligning with the six-year duration of Habitats Directive reporting periods, this difference was 16 individuals (Table 3.8).

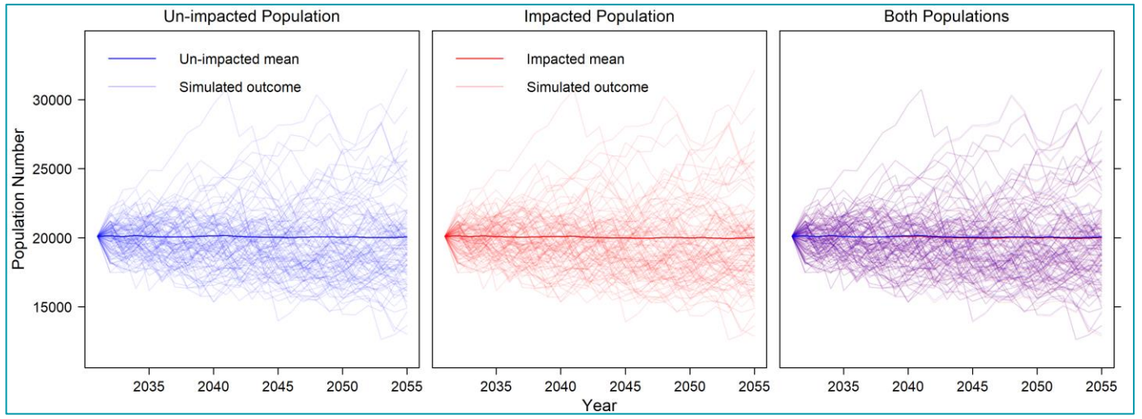

Figure 3.8: Simulated Minke Whale Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Temporal Scenario MW-01b, Based on the SEL_{cum} Metric for PTS

100. At time point 13, which corresponds with six years after the end of the piling phase for wind turbine anchors, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) there was a difference between the size of the impacted and unimpacted populations of 40 individuals.

Table 3.8: Modelled Estimates for the Unimpacted and Impacted Minke Whale Populations and Counterfactuals of Population Size for the Maximum Temporal Scenario MW-01b, Based on the SEL_{cum} Metric for PTS

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	20,120	20,120	20,120	20,120	20,120	20,120	1.0000	1.0000
2	17,976	20,137	21,922	17,976	20,137	21,918	1.0000	1.0000
3	17,536	20,102	22,602	17,534	20,100	22,602	0.9999	1.0000
7	16,730	20,064	23,898	16,719	20,048	23,882	0.9992	0.9996
9	16,396	20,110	24,264	16,362	20,085	24,232	0.9987	0.9992
13	15,994	20,057	25,186	15,946	20,017	25,146	0.9980	0.9986
15	15,783	20,033	25,924	15,753	19,989	25,825	0.9978	0.9983
21	15,178	20,074	26,713	15,124	20,019	26,640	0.9973	0.9979
26	14,504	20,061	27,138	14,385	20,006	27,060	0.9972	0.9977

101. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is 55 animals (Table 3.8), corresponding to approximately 0.27% of the reference population. This suggests that there would not be a long term effect from piling at the Array upon the minke whale population within the Celtic and Greater North Seas MU.

102. Both the median and mean counterfactual for scenario MW-01b started at 1.00 from the start of the 26-year simulation, decreasing to approximately 0.997, indicating minimal discernible difference in the ratio of the disturbed to un-disturbed populations, and no potential for a long term population-level effect from this piling scenario upon minke whale.

3.3.3. SCENARIO MW-02A: MAXIMUM SPATIAL SCENARIO (SPL_{PK})

103. Results for the maximum spatial scenario, with numbers of potentially affected animals based upon the SPL_{pk} metric for PTS, indicated a very small difference in the growth trajectory of minke whale between the unimpacted population and impacted population (Figure 3.5). At all time points there was little difference in the mean size of the impacted and unimpacted populations, with a maximum difference of one individual (approximately 0.005% of the Celtic and Greater North Seas MU reference population) at various time points in the simulation (Table 3.5).

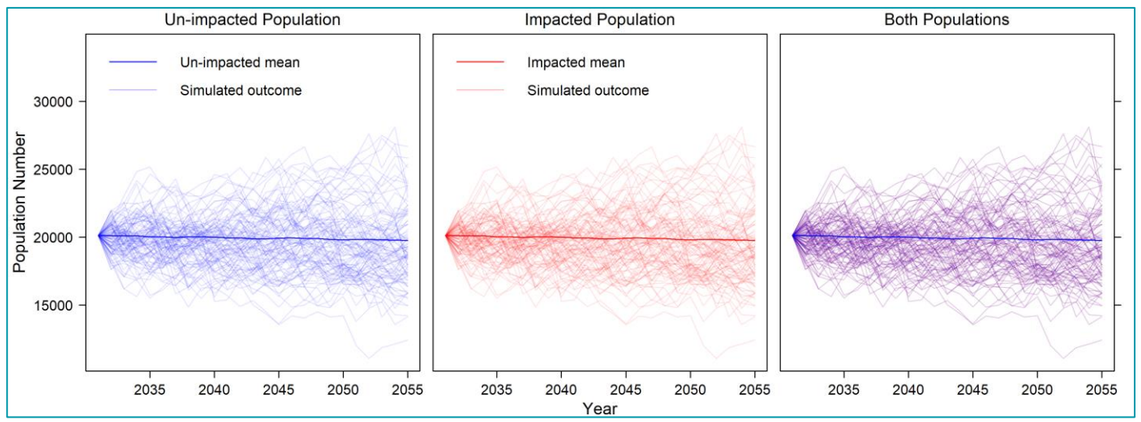

Figure 3.9: Simulated Minke Whale Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Spatial Scenario MW-02, Based on the SPL_{pk} Metric for PTS

104. At time point 7, which represents the end of the concurrent piling phase, and corresponds to the six-year reporting period formerly required under the Habitats Directive, the impacted population was predicted to be the same size as the unimpacted population.

105. At time point 13, which corresponds with six years after the end of the concurrent portion of the piling phase, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) the difference between the impacted and unimpacted populations was one animal, approximately 0.005% of the reference population.

Table 3.9: Modelled Estimates for the Unimpacted and Impacted Minke Whale Populations and Counterfactuals of Population Size for the Maximum Spatial Scenario MW-02b, Based on the SPL_{pk} Metric for PTS

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	20,120	**20,120**	20,120	20,120	**20,120**	20,120	1.0000	1.0000
2	17,872	**20,113**	21,868	17,872	**20,113**	21,868	1.0000	1.0000
3	17,489	**20,115**	22,582	17,489	**20,115**	22,582	1.0000	1.0000
7	16,798	**19,981**	23,804	16,798	**19,981**	23,804	1.0000	1.0000
9	16,661	**20,034**	24,443	16,661	**20,033**	24,443	1.0000	1.0000
13	15,979	**19,888**	24,786	15,979	**19,887**	24,786	1.0000	1.0000
15	15,571	**19,930**	25,449	15,571	**19,930**	25,449	1.0000	1.0000
21	14,872	**19,830**	26,630	14,872	**19,829**	26,630	1.0000	1.0000
26	14,493	**19,803**	26,684	14,493	**19,802**	26,684	1.0000	1.0000

106. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is also one animal, corresponding to approximately 0.005% of the reference population (Table 3.5). This indicates that there would not be a long term effect from piling at the Array upon the minke whale population within the Celtic and Greater North Seas MU.

107. Both the median and mean counterfactual for scenario MW-01 remained at 1.0000 throughout the 26-year simulation, indicating no discernible difference in the ratio of the disturbed to un-disturbed populations and no potential for a long term population-level effect from this piling scenario upon minke whale.

3.3.4. SCENARIO MW-02B: MAXIMUM SPATIAL SCENARIO (SEL_{CUM})

108. Results for the maximum spatial scenario, with numbers of potentially affected animals based upon the SEL_{cum} metric for PTS, indicated a very small difference in the growth trajectory of minke whale between the unimpacted population and impacted population (Figure 3.10). At all time points there was some difference in the mean size of the impacted and unimpacted populations, with a maximum difference of 173 individuals (approximately 0.86% of the Celtic and Greater North Seas MU reference population) at various time points in the simulation (Table 3.10).

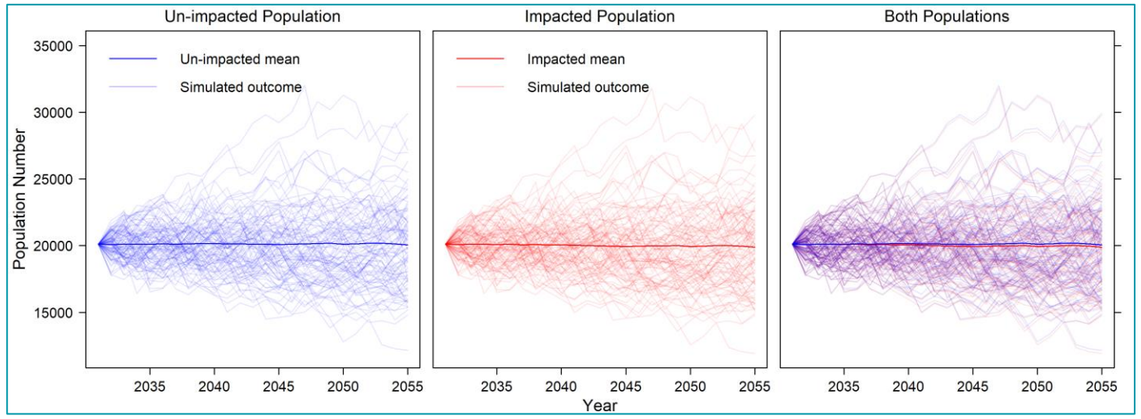

Figure 3.10: Simulated Minke Whale Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Spatial Scenario MW-02b, Based on the SEL_{cum} Metric for PTS

109. At time point 7, which represents the end of the concurrent piling phase, and corresponds to the six-year reporting period formerly required under the Habitats Directive, the impacted population was predicted to be the 53 individuals (0.26%) smaller than the unimpacted population.

110. At time point 13, which corresponds with six years after the end of the concurrent portion of the piling phase, and twelve years after the start of the piling phase (aligning with the duration of one and two Habitats Directive reporting periods, respectively) the difference between the impacted and unimpacted populations was 133 individuals, approximately 0.66% of the reference population.

Table 3.10: Modelled Estimates for the Unimpacted and Impacted Minke Whale Populations and Counterfactuals of Population Size for the Maximum Spatial Scenario MW-02b, Based on the SEL_{cum} Metric for PTS

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	20,120	20,120	20,120	20,120	20,120	20,120	1.0000	1.0000
2	17,909	20,091	21,810	17,909	20,091	21,810	1.0000	1.0000
3	17,509	20,116	22,555	17,499	20,111	22,549	0.9997	0.9999
7	16,790	20,109	23,785	16,776	20,056	23,730	0.9974	0.9980
9	16,628	20,152	24,609	16,536	20,065	24,491	0.9957	0.9966
13	16,250	20,114	25,321	16,224	19,981	25,067	0.9934	0.9945
15	15,888	20,089	25,878	15,836	19,943	25,694	0.9928	0.9939
21	15,111	20,134	26,163	15,016	19,966	26,031	0.9917	0.9928
26	14,881	20,069	27,456	14,732	19,896	27,193	0.9914	0.9924

111. At time point 26, which represents the population at the end point of the iPCoD modelling, 25 years after the start of piling (and 18 years after the completion of the piling phase), this difference is 173 individuals, corresponding to approximately 0.86% of the reference population (Table 3.10). This indicates that there would not be a long term effect from piling at the Array upon the minke whale population within the Celtic and Greater North Seas MU.

112. Both the median and mean counterfactual for scenario MW-02b began at 1.0000 and decreased across the 26-year simulation to 0.9924 (median) and 0.9914 (mean). This small change indicates minimal discernible difference in the ratio of the disturbed to un-disturbed populations and no potential for a long term population-level effect from this piling scenario upon minke whale.

3.3.5. SCENARIO MW-C1: CUMULATIVE SCENARIO

113. For scenario MW-C1, in which a total of 306 days of piling were modelled at the Array alongside a total of 273 piling days across Tier 1 cumulative projects (112 days at Berwick Bank, and 161 days at Hornsea Three) these results indicate no difference in the simulated trajectories of minke whale between the unimpacted population and impacted population (Figure 3.11). This corresponds to no difference in the size of the impacted population at time point 26, compared to the un-impacted population (Table 3.11).

114. At time point 5, which corresponds to the third year of piling at the Array, the first year after the end of piling at Berwick Bank, and three years after the end of piling at Hornsea Three, the difference between impacted and un-impacted populations is one animal (0.005% of the reference population). When compared to the equivalent time point from scenario MW-01 (i.e. three years into the maximum temporal scenario for the Array alone: section 3.3.1), this is a difference between scenarios of one animal.

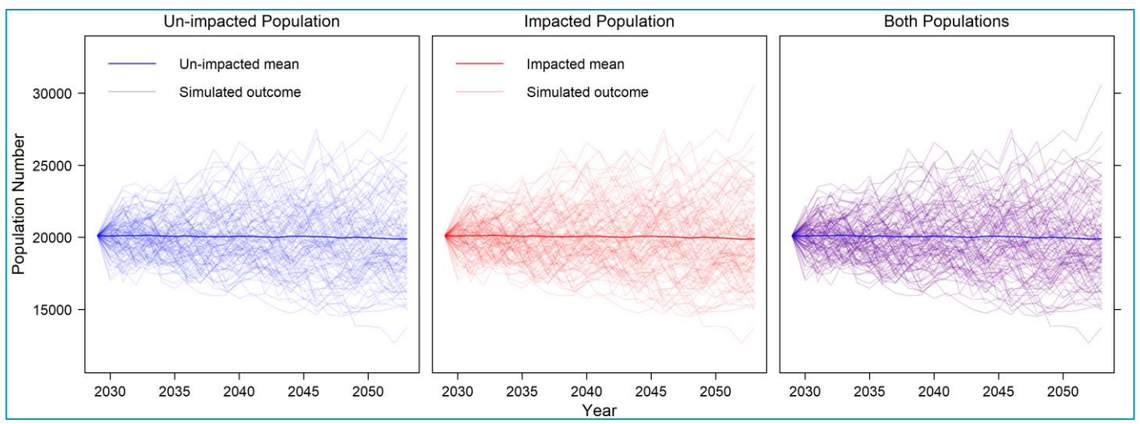

Figure 3.11: Simulated Minke Whale Population Trajectories in an Unimpacted Versus Impacted Population, for Cumulative Scenario MW-C1

Table 3.11: Modelled Estimates for the Unimpacted and Impacted Minke Whale Populations and Counterfactuals of Population Size for Cumulative Scenario MW-C1

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	20,120	**20,120**	20,120	20,120	**20,120**	20,120	1.0000	1.0000
2	17,920	**20,089**	21,812	17,920	**20,089**	21,812	1.0000	1.0000
3	17,439	**20,119**	22,710	17,439	**20,119**	22,710	1.0000	1.0000
4	17,229	**20,118**	22,923	17,229	**20,118**	22,923	1.0000	1.0000
5	16,940	**20,131**	23,446	16,940	**20,130**	23,446	1.0000	1.0000
8	16,642	**20,095**	24,183	16,642	**20,095**	24,183	1.0000	1.0000
9	16,440	**20,055**	24,117	16,440	**20,054**	24,117	1.0000	1.0000
10	16,304	**20,042**	24,682	16,304	**20,041**	24,682	1.0000	1.0000
14	15,757	**20,029**	25,665	15,757	**20,029**	25,665	1.0000	1.0000
15	15,649	**20,008**	25,607	15,649	**20,007**	25,607	1.0000	1.0000
16	15,703	**20,065**	25,577	15,703	**20,065**	25,577	1.0000	1.0000
23	14,612	**19,941**	26,737	14,612	**19,940**	26,737	1.0000	1.0000
26	14,124	**19,898**	27,079	14,124	**19,898**	27,079	1.0000	1.0000

115. Both the median and mean counterfactual of population size for cumulative scenario MW-C1 was 1.0000 throughout the 26-year simulation. Therefore, given that the differences in disturbed to undisturbed populations equates to a ratio of 1 there is not considered to be a potential for a long term population-level effect from this cumulative piling scenario upon minke whale within the Celtic and Greater North Seas MU.

3.4. GREY SEAL

3.4.1. SCENARIO GS-01: MAXIMUM TEMPORAL SCENARIO

116. Results for the maximum temporal scenario indicate no difference in the population trajectory of grey seal between the unimpacted population and impacted populations (Figure 3.12). At all time points there was no difference in the mean size of the impacted and unimpacted populations (Table 3.12), including at all six-year Habitats Directive reporting periods, and at the end of the 25-year model simulation.

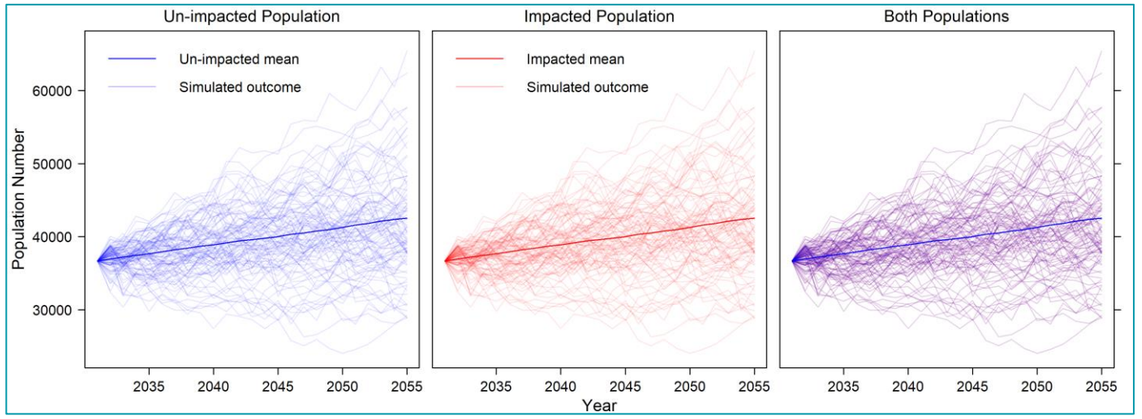

Figure 3.12: Simulated Grey Seal Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Temporal Scenario GS-01

117. Both the median and mean counterfactual for scenario MW-01 remained at 1.0000 throughout the 26-year simulation (Table 3.12), indicating no discernible difference in the ratio of the disturbed to un-disturbed populations and no potential for a long term population-level effect from this piling scenario upon grey seal.

Table 3.12: Modelled Estimates for the Unimpacted and Impacted Grey Seal Populations and Counterfactuals of Population Size for the Maximum Temporal Scenario GS-01

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	36,696	**36,696**	36,696	36,696	**36,696**	36,696	1.0000	1.0000
2	33,702	**36,959**	39,196	33,702	**36,959**	39,196	1.0000	1.0000
3	33,309	**37,196**	40,464	33,309	**37,196**	40,464	1.0000	1.0000
7	32,145	**38,192**	43,825	32,145	**38,192**	43,825	1.0000	1.0000
9	31,686	**38,705**	45,565	31,686	**38,705**	45,565	1.0000	1.0000
13	30,904	**39,615**	48,592	30,904	**39,615**	48,592	1.0000	1.0000
15	30,906	**40,002**	49,126	30,906	**40,002**	49,126	1.0000	1.0000
21	30,477	**41,595**	54,739	30,477	**41,595**	54,739	1.0000	1.0000
26	30,479	**42,833**	57,576	30,479	**42,833**	57,576	1.0000	1.0000

3.4.2. SCENARIO GS-02: MAXIMUM SPATIAL SCENARIO

118. Results for the maximum temporal scenario indicate no difference in the population trajectory of grey seal between the unimpacted population and impacted population (Figure 3.13). At all time points there was no difference in the mean size of the impacted and unimpacted populations (Table 3.13) including at all six-year Habitats Directive reporting periods, and at the end of the 25-year model simulation.

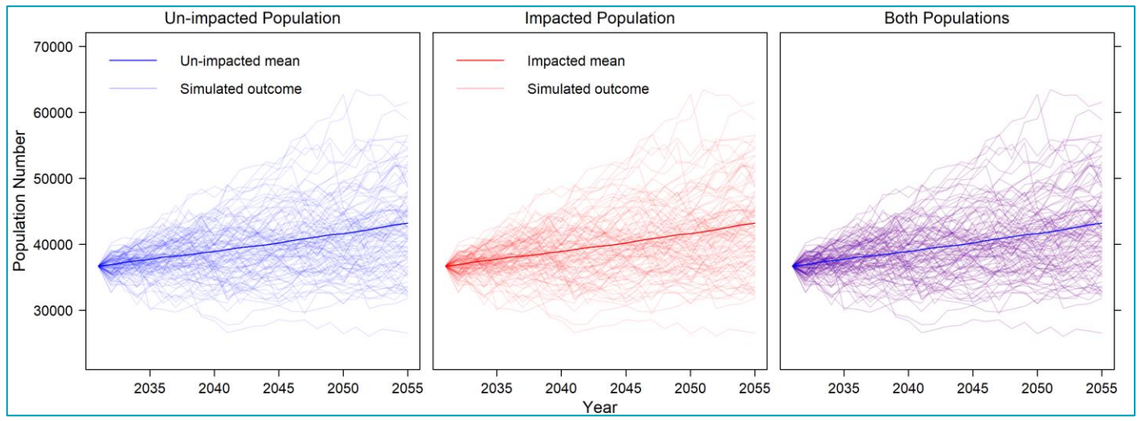

Figure 3.13: Simulated Grey Seal Population Trajectories in an Unimpacted Versus Impacted Population, for the Maximum Spatial Scenario GS-02

Table 3.13: Modelled Estimates for the Unimpacted and Impacted Grey Seal Populations and Counterfactuals of Population Size for the Maximum Spatial Scenario GS-02

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	36,696	**36,696**	36,696	36,696	**36,696**	36,696	1.0000	1.0000
2	33,645	**36,916**	39,344	33,645	**36,916**	39,344	1.0000	1.0000
3	32,962	**37,244**	40,577	32,962	**37,244**	40,577	1.0000	1.0000
7	31,347	**38,212**	43,778	31,347	**38,212**	43,778	1.0000	1.0000
9	31,412	**38,708**	45,509	31,412	**38,708**	45,509	1.0000	1.0000
13	30,754	**39,699**	48,839	30,754	**39,699**	48,839	1.0000	1.0000
15	30,547	**40,204**	50,524	30,547	**40,204**	50,524	1.0000	1.0000
21	30,547	**41,891**	55,210	30,547	**41,891**	55,210	1.0000	1.0000
26	30,427	**43,379**	59,336	30,427	**43,379**	59,336	1.0000	1.0000

119. Both the median and mean counterfactual for scenario MW-01 remained at 1.0000 throughout the 26-year simulation (Table 3.13), indicating no discernible difference in the ratio of the disturbed to un-disturbed populations and no potential for a long term population-level effect from this piling scenario upon grey seal.

3.4.3. SCENARIO GS-C1: CUMULATIVE SCENARIO

120. For scenario GS-C1, in which a total of 306 days of piling were modelled at the Array alongside a total of 112 piling days at Berwick Bank, these results indicate no difference in the simulated trajectories of grey seal between the unimpacted population and impacted population (Figure 3.14). This corresponds to no difference in the size of the impacted population at time point 26, compared to the un-impacted population (Table 3.14[3]).

121. At all time points in the 26-year model simulation there is no difference in the size of the impacted population, compared to the unimpacted population. When compared to the equivalent time point from scenario GS-01 (i.e. three years into the maximum temporal scenario for the Array alone: section 3.2.1), this is also no difference between populations.

122. Both the median and mean counterfactual of population size for cumulative scenario GS-C1 was 1.0000 throughout the 26-year simulation. Therefore, given that the differences in disturbed to undisturbed populations equates to a ratio of 1 there is not considered to be a potential for a long term population-level effect from this cumulative piling scenario upon grey seal.

[3] Figure 3.12 illustrates a potential increase in grey seal population trajectory for the cumulative iPCoD modelling scenario. This is likely to be due to different conditions (e.g. piling parameters and number of animals affected) at the cumulative projects at the outset of this model, so the simulated trajectory for this model also reflects this difference.

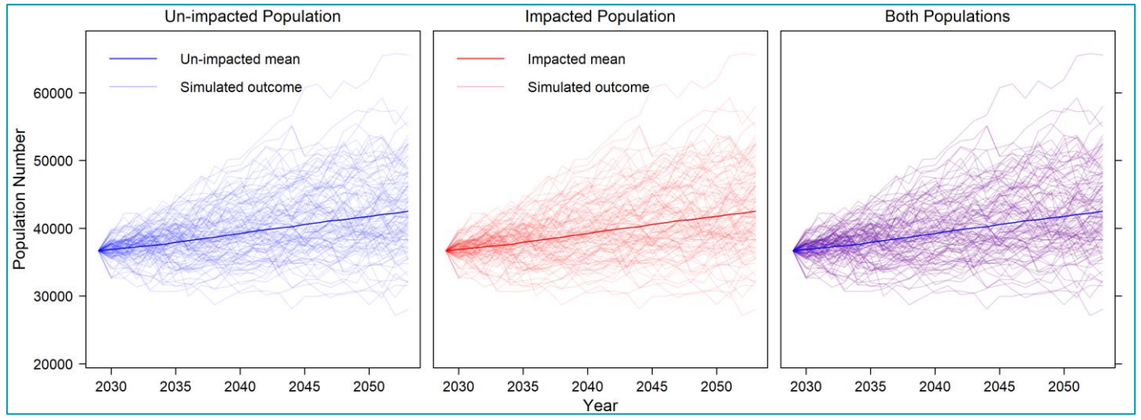

Figure 3.14: Simulated Grey Seal Population Trajectories in an Unimpacted Versus Impacted Population, for Cumulative Scenario GS-C1

Table 3.14: Modelled Estimates for the Unimpacted and Impacted Grey Seal Populations and Counterfactuals of Population Size for Cumulative Scenario GS-C1

Time Point	Unimpacted Population (Number of Animals)			Impacted Population (Number of Animals)			Counterfactual	
	Lower 2.5%	Mean	Upper 2.5%	Lower 2.5%	Mean	Upper 97.5%	Mean	Median
1	36,696	**36,696**	36,696	36,696	**36,696**	36,696	1.0000	1.0000
2	33,088	**36,871**	39,346	33,088	**36,871**	39,346	1.0000	1.0000
3	32,727	**37,086**	40,224	32,727	**37,086**	40,224	1.0000	1.0000
4	32,432	**37,279**	41,097	32,432	**37,279**	41,097	1.0000	1.0000
5	31,478	**37,459**	41,820	31,478	**37,459**	41,820	1.0000	1.0000
8	31,424	**38,180**	44,807	31,424	**38,180**	44,807	1.0000	1.0000
9	31,126	**38,427**	45,889	31,126	**38,427**	45,889	1.0000	1.0000
10	31,062	**38,694**	46,199	31,062	**38,694**	46,199	1.0000	1.0000
14	30,670	**39,780**	49,339	30,670	**39,780**	49,339	1.0000	1.0000
15	30,905	**40,029**	50,850	30,905	**40,029**	50,850	1.0000	1.0000
16	30,690	**40,238**	50,537	30,690	**40,238**	50,537	1.0000	1.0000
23	30,120	**42,029**	55,997	30,120	**42,029**	55,997	1.0000	1.0000
26	30,348	**42,709**	58,275	30,348	**42,709**	58,275	1.0000	1.0000

4. SUMMARY

123. This Technical Report presents the results of iPCoD modelling for harbour porpoise, bottlenose dolphin, minke whale and grey seal populations as a result of the Array alone and cumulatively with other projects. The numbers of animals potentially experiencing disturbance were based on two maximum design scenarios. The maximum temporal scenario of a combination of 3,000 kJ and 4,400 kJ maximum hammer energies (depending on the foundation type) across 602 days, and the maximum spatial scenario of the same maximum hammer energies, incorporating concurrent piling at 3,000 kJ and 4,400 kJ, and single piling at 4,400 kJ, across a total of up to 306 days. However, these would not be the maximum hammer energies for all locations (with maximum hammer energies only anticipated to be required at locations where there are challenging ground conditions), and the realistic hammer energy would likely be lower, affecting fewer animals. Therefore the iPCoD modelling presented represents a conservative precautionary assessment, which uses maximum hammer energies at all piling locations as the MDS.

124. The results suggest that, even with the conservative assumptions made, there would be no population-level effects either in the short-term or long term for any of the species investigated, as a result of piling at the Array alone, or when considered alongside cumulative projects.

125. Results of the cumulative models should be interpreted with caution as limited information on the actual piling schedules was available to inform the iPCoD models presented here. However, the parameters used to develop the models for the cumulative projects have been informed by the respective Environmental Statements, and are considered to represent a conservative and accurate depiction of these projects.

126. The assessment adopted a precautionary approach throughout, considering the maximum design scenario for the Array, precautionary demographic parameters for each species, conservative assumptions in the noise modelling and conservative estimates for the densities of key species to apply to the quantitative assessment. For all species there was negligible difference predicted in the trajectory of the impacted population compared to the un-impacted populations. The predicted differences in the numbers of animals would be expected to fall within the natural inter-annual variation of the population. Such variation is exemplified in the differences in abundance estimates from successive survey campaigns in the Small Cetacean Abundance in the European Atlantic and North Sea (SCANS) monitoring programme. This is particularly evident in the results of SCANS-III (Hammond *et al.*, 2021) and SCANS-IV (Gilles *et al.*, 2023), which employed survey blocks that largely coincide spatially between surveys.

127. Variation in demographic rates between years may exist as a result of changes in environmental conditions, as a result of random processes or chance events which impact vital rates (e.g. survival, fertility, etc.), or other sources of heterogeneity. In two, otherwise identical populations that experience exactly the same sequence of environmental conditions, demographic stochasticity will mean populations could follow slightly different trajectories over time.

128. These models assume that the effects of environmental variation on survival and fertility are adequately reflected by the range of values obtained from the expert elicitation (and shown in the spread of simulated trajectories around the means). In addition, the models assume that survival and fertility rates are not density-dependent and are therefore not affected by population size.

129. Whilst it is understood that iPCoD is a relatively simple population model (simulating the link between days of disturbance and changes in individual vital rates), the most obvious sources of uncertainty are considered to have been adequately captured in the development of these models. In addition, the precautionary approach applied throughout the marine mammal assessment has been adopted to buffer the uncertainties with respect to how animals respond to repeated piling over time.

5. REFERENCES

Booth, C. and Heinis, F. (2018). *Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of permanent threshold shifts on vital rates in marine mammal species.* pp.34.

Booth, C., Heinis, F. and Harwood, J. (2019). *Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of disturbance on vital rates in marine mammal species.* SMRU Consulting pp.28.

Brandt, M. J., Diederichs, A., Betke, K. and Nehls, G. (2011). *Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea*. Marine Ecology Progress Series*,* 421**,** pp.205-216. DOI:10.3354/meps08888.

Carter, M. I. D., Boehme, L., Cronin, M. A., Duck, C. D., Grecian, W. J., Hastie, G. D., Jessopp, M., Matthiopoulos, J., McConnell, B. J., Miller, D. L., Morris, C. D., Moss, S. E. W., Thompson, D., Thompson, P. M. and Russell, D. J. F. (2022). *Sympatric Seals, Satellite Tracking and Protected Areas: Habitat-Based Distribution Estimates for Conservation and Management*. Frontiers in Marine Science*,* 9**,** pp.18. DOI:10.3389/fmars.2022.875869.

Donovan, C., Harwood, J., King, S., Booth, C., Caneco, B. and Walker, C. (2016). *Expert Elicitation Methods in Quantifying the Consequences of Acoustic Disturbance from Offshore Renewable Energy Developments*. *In:* Popper, A. and Hawkins, A. (eds.) *The Effects of Noise on Aquatic Life II. Advances in Experimental Medicine and Biology.* New York: Springer.

Ellison, W. T., Southall, B. L., Clark, C. W. and Frankel, A. S. (2012). *A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds*. Conserv Biol*,* 26 (1)**,** pp.21-8. DOI:10.1111/j.1523-1739.2011.01803.x.

Gilles, A., Authier, M., Ramirez-Martinez, N. C., Araújo, H., Blanchard, A., Carlström, J., Eira, C., Dorémus, G., Fernández-Maldonado, C., Geelhoed, S. C. V., Kyhn, L., Laran, S., Nachtsheim, D., Panigada, S., Pigeault, R., Sequeira, M., Sveegaard, S., Taylor, N. L., Owen, K., Saavedra, C., Vázquez-Bonales, J. A., Unger, B. and Hammond, P. S. (2023). *Estimates of cetacean abundance in European Atlantic waters in summer 2022 from the SCANS-IV aerial and shipboard surveys.* Final report published 29 September 2023 pp.64.

Graham, I. M., Merchant, N. D., Farcas, A., Barton, T. R., Cheney, B., Bono, S. and Thompson, P. M. (2019). *Harbour porpoise responses to pile-driving diminish over time*. Royal Society Open Science*,* 6 (6)**,** pp.190335. DOI:doi:10.1098/rsos.190335.

Hammond, P. S., C. Lacey, A. Gilles, S. Viquerat, P. Börjesson, H. Herr, K. Macleod, V. Ridoux, M. Santos, M. Scheidat, J. Teilmann, J. Vingada and N. Øien. (2021). *Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. Revised June 2021.* pp.42.

Harwood, J., King, S., Schick, R., Donovan, C. and Booth, C. (2014). *A Protocol for Implementing the Interim Population Consequences of Disturbance (PCoD) Approach: Quantifying and Assessing the Effects of UK Offshore Renewable Energy Developments on Marine Mammal Populations.* Scottish Marine and Freshwater Science Volume 5 Number 2. Marine Scotland Science pp.90.

Houston, A. I., Prosser, E. and Sans, E. (2012). *The cost of disturbance: a waste of time and energy?* Oikos*,* 121 (4)**,** pp.597-604.

IAMMWG. (2022). *Updated abundance estimates for cetacean Management Units in UK waters.* JNCC Report No. 680 (Revised March 2022). JNCC. Peterborough. Document Number 0963-8091. pp.22.

King, S. L., Schick, R. S., Donovan, C., Booth, C. G., Burgman, M., Thomas, L., Harwood, J. and Kurle, C. (2015). *An interim framework for assessing the population consequences of disturbance*. Methods in Ecology and Evolution*,* 6 (10)**,** pp.1150-1158. DOI:10.1111/2041-210x.12411.

Lacey, C., Gilles, A., Börjesson, P., Herr, H., Macleod, K., Ridoux, V., Santos, M. B., Scheidat, M., Teilmann, J., Sveegaard, S., Vingada, J., Viquerat, S., Øien, N. and Hammond, P. S. (2022). *Modelled density surfaces of cetaceans in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys.* SCANS-III project report 2. University of St Andrews. UK pp.31.

MD-LOT. (2023). *Scoping Opinion for Ossian Array.* Marine Directorate – Licensing Operations Team. Edinburgh

Mona Offshore Wind Ltd. (2024). *Mona Offshore Wind Project Environmental Statement Volume 2, Chapter 4: Marine Mammals.*

Morgan Offshore Wind Ltd. (2023). *Volume 2, chapter 9: Marine mammals.* Preliminary Environmental Information Report. Morgan Offshore Wind Project: Generation Assets

Ørsted. (2018a). *Hornsea Project Three Offshore Wind Farm Environmental Statement: Volume 5, Annex 4.1 – Marine Mammal Technical Report.*

Ørsted. (2018b). *Environmental Statement: Volume 2, Chapter 4 – Marine Mammals.* Hornsea Project Three Offshore Wind Farm

Ørsted. (2021). *Hornsea Project Four: Environmental Statement Volume A5, Annex 4.1: Marine Mammal Technical Report.*

Ossian OWFL (2023). *Ossian Array EIA Scoping Report.* Ossian pp.353.

Posit team. (2023). *RStudio: Integrated Development Environment for R.* Boston, MA: Posit Software, PBC.

R Core Team. (2023). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

RWE Renewables UK. (2021). *Volume 2, Chapter 7: Marine Mammals.* Awel y Môr Offshore Wind Farm Preliminary Environmental Information Report. Awel y Môr Offshore Wind Farm pp.185pp.

SCOS. (2023). *Scientific Advice on Matters Related to the Management of Seal Populations: 2022.* Natural Environment Research Council, Special Committee on Seals pp.206.

Sinclair, R. R., Booth, C. G., Harwood, J. and Sparling, C. E. (2019). *Helpfile for the interim PCoD v5 model.* SMRU Consulting pp.63.

Sinclair, R. R., Sparling, C. E. and Harwood, J. (2020). *Review Of Demographic Parameters And Sensitivity Analysis To Inform Inputs And Outputs Of Population Consequences Of Disturbance Assessments For Marine Mammals.* Scottish Marine and Freshwater Science Vol 11 No 14. Marine Scotland Science

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr, C. R., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E. and Richardson, W. J. (2007). *Marine mammal noise-exposure criteria: initial scientific recommendations*. Aquatic Mammals*,* 33 (4).

SSE Renewables. (2022a). *Appendix 10.4: Marine mammal iPCoD modelling report.* Berwick Bank Wind Farm Offshore Environmental Impact Assessment pp.33.

SSE Renewables. (2022b). *Chapter 10: Marine Mammals.* Berwick Bank Wind Farm Environmental Impact Assessment Report Volume 2. Berwick Bank Wind Farm pp.149.

Taylor, B. L. and DeMaster, D. P. (1993). *Implications of Non-linear Density Dependence*. Marine Mammal Science*,* 9 (4)**,** pp.360-371.

Whyte, K. F., Russell, D. J. F., Sparling, C. E., Binnerts, B. and Hastie, G. D. (2020). *Estimating the effects of pile driving sounds on seals: Pitfalls and possibilities*. The Journal of the Acoustical Society of America*,* 147 (6)**,** pp.3948. DOI:10.1121/10.0001408.

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