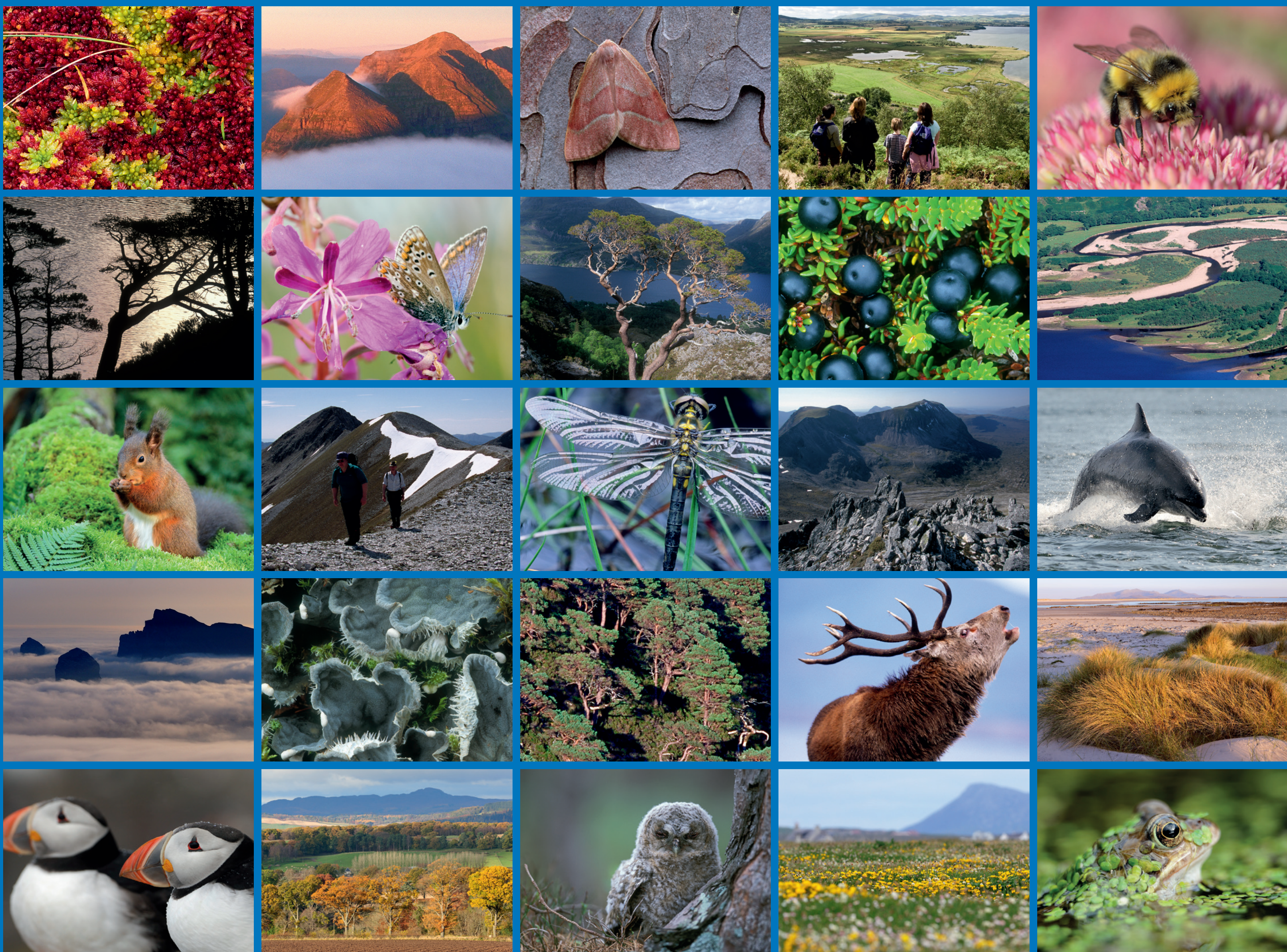
Scottish Natural Heritage
Research Report No. 1081

Cumulative impact assessment of Scottish east coast offshore windfarm construction on key species of marine mammals using iPCoD



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RESEARCH REPORT

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Cumulative impact assessment of Scottish east coast offshore windfarm construction on key species of marine mammals using iPCoD

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RESEARCH REPORT
Summary

Cumulative impact assessment of Scottish east coast offshore windfarm construction on key species of marine mammals using iPCoD

Research Report No. 1081
Contractor: Hazel Smith, SNH PhD Internship Project
Year of publication: 2019

Keywords

Cumulative impact; offshore wind farm construction; iPCoD; bottlenose dolphin; grey seal; harbour porpoise; minke whale; population modelling

Background

One key consenting concern for offshore windfarm development is the population consequences for marine mammals due to the construction activity. Mitigation is available to prevent death and injury; however, the wider consequences of disturbance are unclear.

This three month project assessed the potential cumulative impact of two major clusters of windfarm developments that are consented or anticipated for the east coast of Scotland. Cumulative assessment is not straightforward. Each developer is required to consider the impact of their development in conjunction with other developments. Whilst consistency in methods and input parameters is always advised, this is often difficult to realise due to differing timeframes for submission and reluctance to share data due to commercial sensitivities.

Assessment and quantification of the potential consequences of offshore windfarms for marine mammal populations can be undertaken through implementation of an interim version of the Population Consequences of Disturbance (PCoD) modelling approach.

The aims of this project were first, to consider the sensitivity of the interim PCoD model to key parameters and second, to consider the potential cumulative impact using an independent approach which was as consistent as possible with the available data. Four key species of marine mammal were assessed using the interim PCoD model: bottlenose dolphin (Moray Firth SAC), grey seal (Isle of May SAC), harbour porpoise (North Sea Management Unit) and minke whale (Celtic and Greater North Seas Management Unit).

Main findings

1. <u>Sensitivity analysis</u>

The sensitivity analysis undertaken tested the effects of the key input parameters on the model predictions made. These parameters included: the temporal pattern of piling; the

number of days piling; the number of individuals disturbed on each day of piling; and the proportion of the population vulnerable to disturbance.

It is important to note in this element of the work, some highly unlikely scenarios were used to trigger a model response. The results from this section are not to be taken as predictions of effect.

Key insights:

- If residual disturbance is included, then piling that is more spread out throughout the time frame, has a greater impact on population dynamics than more tightly packed piling schedules (involving consecutive days piling). This effect is more pronounced when the numbers of individuals experiencing disturbance is large, or when the period of residual disturbance is long.
- Spreading the same amount of piling over multiple years has less overall impact on the population if the number of disturbed individuals is relatively small. But a greater overall impact if the number of individuals disturbed is relatively large in comparison to the population.
- Where there are two piling operations and the disturbed population is small there is no difference for the population consequences if the operations occur concurrently or are offset. However, where the number of disturbed individuals is relatively large, scenarios with multiple piling operations on the same day may have less impact than offset scenarios.
- We explored the impact of increasing the number of individuals disturbed and increasing the number of days of disturbance and plotted the results in terms of % of population decline. We used the east coast bottlenose dolphin population as an example, and plotted the results as a contour plot.
- We also found that increasing the proportion of the population vulnerable to disturbance results in a dome-shaped response. This is because when the proportion of population vulnerable to disturbance is small, a small proportion of the population is subject to a relatively large amount of disturbance (with the remainder of the population unaffected). Conversely, when the proportion of population vulnerable to disturbance is large, the disturbance is spread out across a large number of individuals. Each individual therefore only receives a small amount of disturbance.

2. <u>Cumulative assessment</u>

We used the findings from the sensitivity assessment to develop an overall worst case scenario for the following projects: Beatrice, Aberdeen harbour expansion project, Moray East, Neart na Gaoithe, Inch Cape, Seagreen and Moray West.

Information was gathered from each environmental statement. It's worth highlighting that different developers used different density estimates when predicting numbers of individuals impacted. This means that the numbers are not directly comparable across all developments. There was no scope to re-predict the numbers using the same density estimates which would be required for true consistency.

The outputs from this modelling exercise suggest that there is unlikely to be any long-term effect of pile driving/blasting on the harbour porpoise population or the grey seal population from these developments.

The overall worst case scenario for bottlenose dolphins suggests a small negative effect on the predicted mean size of the population after 25 years. The worst case scenario considers all individuals are vulnerable to disturbance from all operations; we consider this to be precautionary. In addition, the population size ratio and the growth rate ratio are close to 1, and the centile metric for the impacted population is only slightly lower than the un-impacted population, suggesting that population-level effects are small.

The overall worst case for minke whale showed a decrease in the size of the impacted population after 25 years. However, the expert elicitation process has not been updated for minke whale as it has been for the other species, and therefore includes greater precaution in terms of auditory hearing effects and the results should be interpreted with caution.

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Acknowledgements

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1. OVERVIEW OF THE IPCOD MODEL

Windfarm construction can impact marine mammals primarily as a result of the underwater noise generated by the installation of foundations. Potential consequences for extended or repeated disturbance include behavioural and physiological changes that can affect the health and vital rates of individual animals. This, in turn, can translate into population effects.

The interim Population Consequences of Disturbance (iPCoD) model was developed by SMRU Consulting and the University of St Andrews to predict the population level consequences of disturbance on several key species of marine mammals (bottlenose dolphin, harbour seal, grey seal, harbour porpoise and minke whale) (Harwood *et al*., 2014). The model evaluates the effect of disturbance by comparing simulated populations affected by construction noise with identical undisturbed populations.

The model requires the user to enter key pieces of information including basic demographic parameters, an estimate of population size and an estimate of the proportion of the population vulnerable to disturbance from each operation. Alongside this, the user must also provide a day-by-day schedule of disturbance at each operation as well as an estimate of the number of animals likely to experience disturbance and PTS (permanent threshold shift) on a single day of activity for each operation.

The model uses this information to calculate the number of animals experiencing disturbance and/or PTS each day, and distributes this disturbance randomly amongst members of the vulnerable sub-population. At the end of each reproductive year, the model calculates the total number of days of disturbance experienced by each individual. This information is used to assign individuals to one of three disturbance categories: low, moderate and high. The model then calculates modified survival and fertility rates for each disturbance category using the results of an expert elicitation process, as shown in Figure 1. Individuals in the low disturbance category (<=B days of disturbance) do not experience any reduction in survival or fecundity. Individuals in the high disturbance category (>C days) experience the maximum reduction in survival and fecundity. The survival and fertility rates of individuals in the moderate disturbance category are reduced by the mean number of days of disturbance experienced by all individuals in this category.

The expert elicitation process used to determine the effect of disturbance and PTS on survival and fecundity was initially carried out in 2013-14 for five key priority species (harbour porpoise, grey seal, harbour seal, bottlenose dolphin and minke whale). In 2018, a second expert elicitation process was carried out for harbour porpoise, grey seal, harbour seal and bottlenose dolphin to provide an updated estimate of the effect of PTS on survival and fecundity in these species (Booth and Heinis, 2018). The updated expert elicitation process concluded that PTS has significantly less impact on vital rates than previously thought. The updated expert elicitation values have been incorporated into iPCoD version 4.1, which was released in August 2018, and is used throughout this report. However, the updated expert elicitation process did not consider minke whale. The effects of PTS on the survival and reproductive rates of minke whale have remained unchanged, and are therefore more precautionary in comparison to the other species.

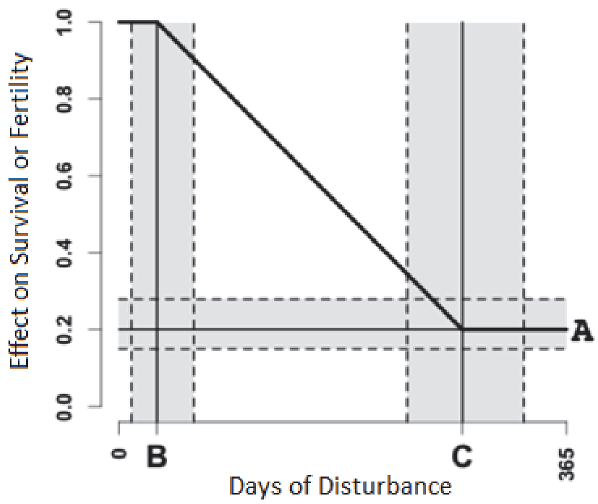

Figure 1. Hypothetical relationship between the number of days of disturbance experienced by an individual during 1 year, and its effect on survival and fecundity rates, where A shows the maximum effect of disturbance, B shows the number of days of disturbance an individual can tolerate before survival or fecundity is affected and C shows the number of days of disturbance required to cause A. Values for A, B and C are provided by an expert elicitation process. Figure taken from (King et al., 2015).

The modified survival and fertility rates, determined via the expert elicitation process, are incorporated into a Leslie matrix which is used to predict the future growth of the impacted population. This process is repeated many times with each simulation drawing parameter values from statistical distributions describing the uncertainty in parameters. In addition to predicting the future growth of the impacted population, the model also predicts the future growth of an un-impacted population using baseline values for survival and fecundity. This generates a number of matched pairs (an impacted population and a baseline un-impacted population) which can be compared in order to determine the effect of disturbance on the population.

2. SENSITIVITY ANALYSIS OF THE IPCOD MODEL

2.1 Introduction

The iPCoD model relies upon a number of user-defined parameters, many of which are difficult to estimate precisely. Here we test the sensitivity of the model to variation in several key user-defined parameters. Specifically, we focus on the sensitivity of model output to:

- The temporal pattern of piling i.e. continuous piling vs. piling interrupted by breaks
- The cumulative effects of two construction sites operating simultaneously
- The number of individuals disturbed by piling and the number of days of piling
- The proportion of the population vulnerable to disturbance.

2.2 Methods

Modelling was carried out using iPCoD ver 4.1, following the guidance set out in the iPCoD help-file (Plunkett *et al*., 2018). In order to test the sensitivity of key parameters we ran the model multiple times. Each time we altered the key parameter whilst holding all other parameters constant. The results were compared using standard iPCoD output metrics. This includes the mean population size, the ratio of the impacted to un-impacted population size, the ratio of the impacted to un-impacted annual growth rate and the centile for the un-impacted population that matches the 50th centile for the impacted population. For the purpose of this report we present only the mean population size as this provides the easiest visual assessment of model results.

iPCoD generates a set of matched pairs, with each impacted population having a corresponding un-impacted population. In this report we have plotted the mean size of multiple impacted populations on the same graph. In order to do so we increased the number of bootstrap iterations to 25,000. This reduced environmental stochasticity and ensured that the mean population size of the baseline un-impacted population was the same across all scenarios.

2.3 Sensitivity Analysis

2.3.1 Temporal pattern of piling in single year

The model requires the user to input a detailed construction schedule indicating the days on which piling activity will take place. However, developers are unlikely to be able to provide this information in advance. The exact days on which construction work will take place is likely to depend on many factors, including weather and the availability of equipment. Here we explore the effect of changes in the temporal pattern of piling, by testing the sensitivity of the model to three different piling schedules:

1) 60 days of consecutive piling
2) (5 days on followed by 5 days off) x 12
3) (1 day on followed by 5 days off) x 60

Each piling schedule has a total of 60 days of piling in a single reproductive year. Note that the reproductive year begins on the 1st of October for grey seals and on the 1st of June for all other species.

Changes in the temporal pattern of piling within a single reproductive year have no effect on population dynamics if the number of residual days of disturbance is set to 0. Population dynamics for all three piling schedules, alongside a baseline non-disturbance scenario, are shown in Figure 2 for a population of bottlenose dolphins. This occurs because the model runs on a yearly timescale. The total number of days of disturbance experienced by each individual is calculated at the end of every reproductive year. This information is used to create a Leslie matrix, which, in turn, is used to predict future population growth. In the absence of residual disturbance, the total amount of disturbance experienced by individuals at the end of the year is the same, regardless of the temporal pattern of piling. Changes in the temporal pattern of piling therefore have no effect on population dynamics within a single reproductive year provided the number of residual days of disturbance in 0.

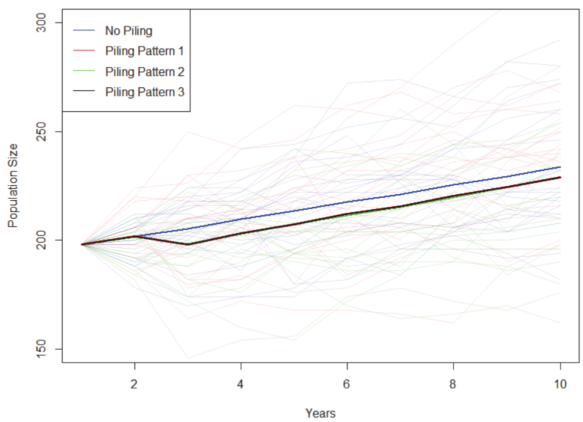

Figure 2. Bottlenose dolphin population dynamics under three piling schedules, which differ in the temporal arrangement of piling within a single reproductive year, alongside a baseline un-impacted population. A full set of parameters used in this simulation are shown in Appendix 1.

However, changes in the temporal pattern of piling become important when the number of residual days of disturbance is greater than or equal to 1. Setting the number of residual days of disturbance >=1 means that individuals are subject to additional days of disturbance after the initial disturbance event. We explored the sensitivity of the model to changes in the temporal pattern of piling in the presence of residual disturbance using the same three piling schedules set out above. We assume that individuals experiencing residual disturbance will not avoid piling operations. This is achieved by setting the parameter “Avoid” to False.

In the presence of residual disturbance, temporal patterns of piling which are more spread out have a greater impact on population dynamics in comparison to tightly packed schedules which involve piling on consecutive days. Individuals experiencing residual disturbance do not avoid piling operations. As a result, some individuals will re-experience disturbance within the period of residual disturbance. This is more likely to occur under tightly packed piling schedules. Individuals which re-experience disturbance within the period of residual disturbance experience less disturbance overall. Tightly packed schedules therefore result in individuals losing out on a greater number of days of residual disturbance and consequently have less impact on the population.

Increasing the number of individuals expected to experience disturbance (numDT) or increasing the number of days of residual disturbance increases the probability of individuals re-experiencing disturbance within the period of residual disturbance. As a result, differences in mean population size due to changes in the temporal pattern of piling are more pronounced when the number of individuals experiencing disturbance is large, as shown in Figure 3, or when the period of residual disturbance is long, as shown in Figure 4.

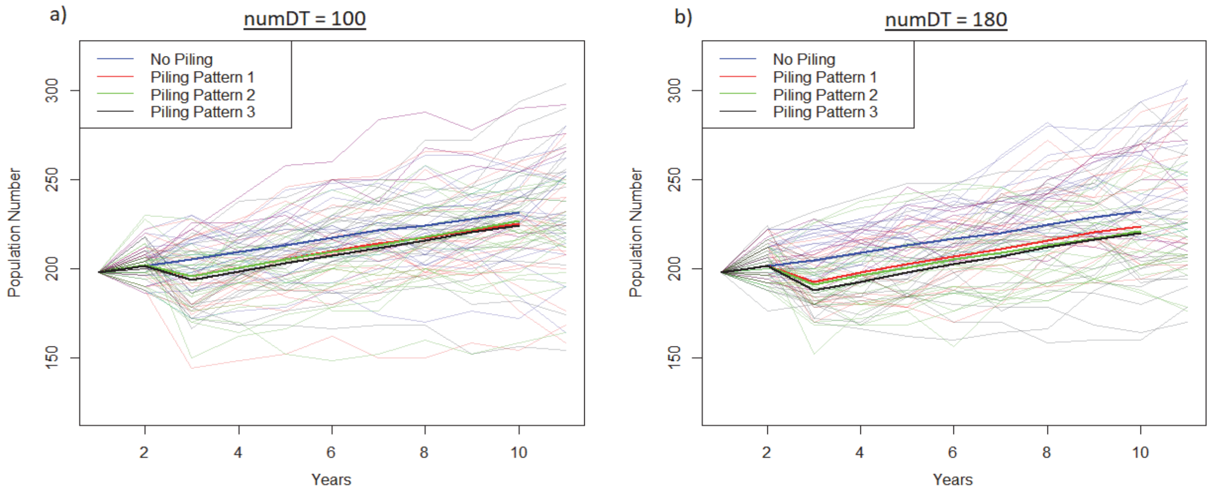

Figure 3. Bottlenose dolphin population dynamics under 3 different piling schedules, which differ in the temporal arrangement of piling within a single reproductive year, alongside a baseline un-impacted population. All parameters are the same in both simulations except the number of individuals experiencing disturbance (numDT) which is 100 in (a) and 180 in (b). A full set of parameters used in this simulation are shown in Appendix 1.

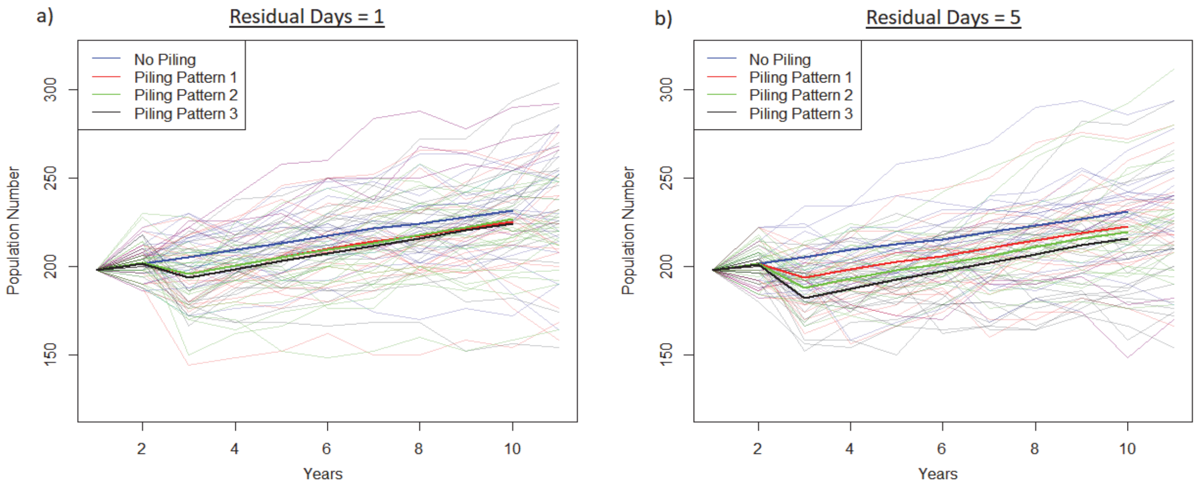

Figure 4. Bottlenose dolphin population dynamics under 3 different piling schedules, which differ in the temporal arrangement of piling within a single reproductive year, alongside a baseline un-impacted population. All parameters are the same in both simulations except the number of days of residual disturbance which is 1 in (a) and 5 in (b). A full set of parameters used in this simulation are shown in Appendix 1.

2.3.2 Temporal pattern of piling over multiple years

Spreading operations out over multiple reproductive years, as opposed to a scenario in which the equivalent amount of piling takes place in a single reproductive year, also affects population dynamics. We tested the sensitivity of the model to three different piling schedules, each containing an equivalent number of piling days:

1) 260 consecutive days of piling in a single year
2) 52 consecutive days of piling each year for 5 years
3) 26 consecutive days of piling each year for 10 years

Spreading operations out over multiple reproductive years, affects population dynamics differently depending on the number of individuals disturbed per day. Spreading the same amount of piling over multiple years has less overall impact if the number of individuals disturbed per day is relatively small in comparison to the size of the population, as shown in Figure 5a for a hypothetical population of harbour seals. However, in direct contrast to this, spreading piling over multiple years can have greater overall impact on the population if the number of individuals disturbed is relatively large in comparison to the size of the population, as shown in Figure 5b.

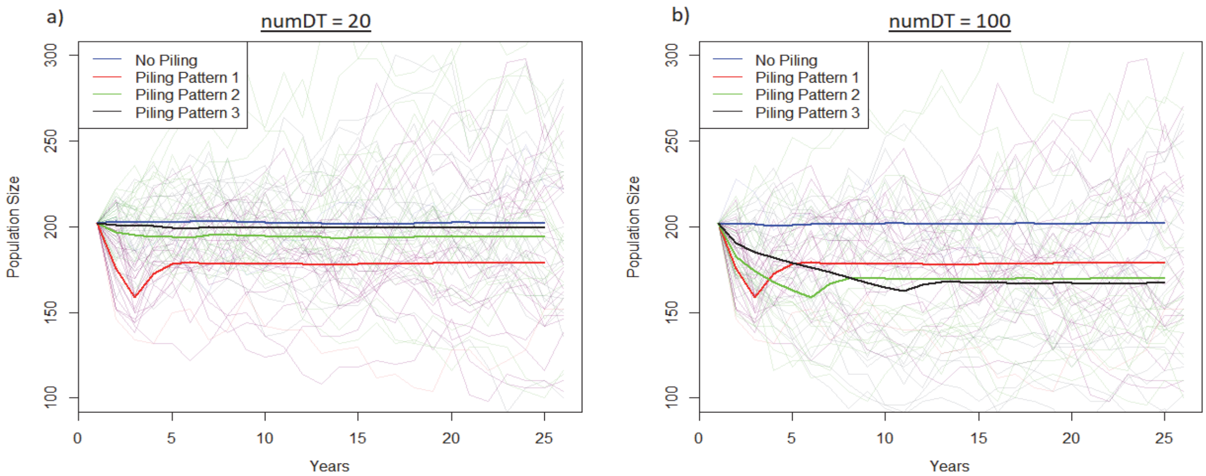

Figure 5. Harbour seal population dynamics under 3 different piling schedules, which differ in the temporal arrangement of piling over multiple reproductive years, alongside a baseline un-impacted population. All parameters are the same in both simulations except the number of individuals experiencing disturbance (numDT) which is 20 in (a) and 100 in (b). A full set of parameters used in this simulation are shown in Appendix 1.

When the number of individuals disturbed per day is relatively small, spreading piling over multiple years increases the number of individuals ending up in the low disturbance category in which there is no associated effect on survival and fecundity rates (see Figure 1). This results in less overall impact on the population as the same amount of piling is spread over multiple years. However, when the number of individuals disturbed per day is relatively large, individuals are able to accumulate enough disturbance to reach the high disturbance category every single year. This results in greater overall impact on the population as the piling is spread out over multiple reproductive years.

2.3.3 Multiple piling operations

The iPCoD model allows users to model concurrent piling across multiple operations. In this section we explore the effect of multiple piling operations occurring on the same day. In order to do this we set up two different scenarios, both of which consist of piling at two different locations:

- Scenario 1: Two piling operations - (1 day piling followed by 5 days off) x 50
    - Piling occurs on the same day in both operations
- Scenario 2: Two piling operations - (1 day piling followed by 5 days off) x 50
    - Offset so that piling does not occur on the same day in both operations

When the number of individuals experiencing disturbance on each piling day (numDT) is relatively small, both scenarios produce the same result, as shown in Figure 6a, for a population of bottlenose dolphins. However, when numDT is relatively large there are not enough individuals to be disturbed by all operations on the same day. This causes individuals to experience less disturbance overall. Scenarios with multiple piling operations on the same day therefore have less overall impact when numDT is relatively large, as shown in Figure 6b.

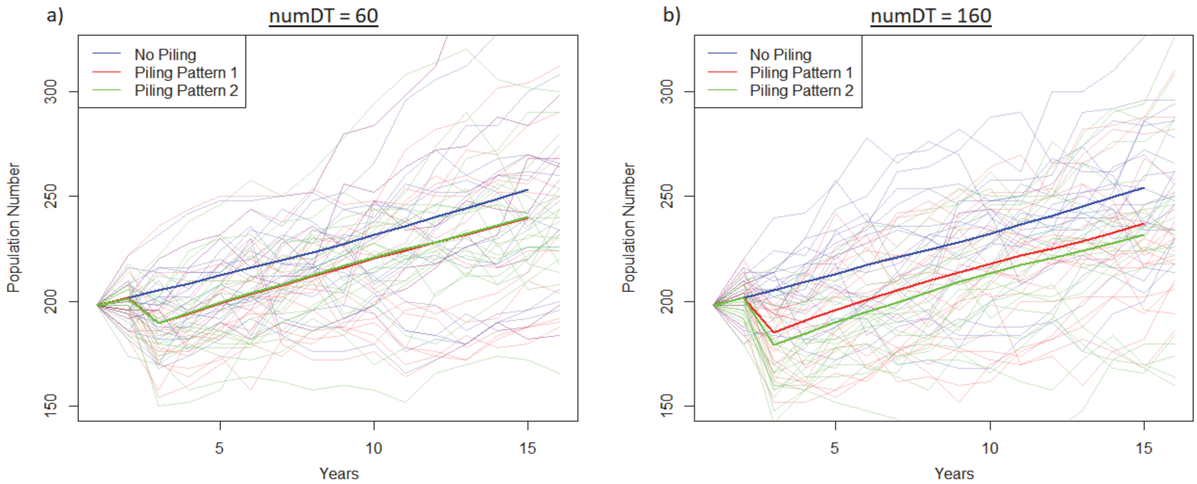

Figure 6. Bottlenose dolphin population dynamics under 2 different scenarios: Scenario 1) piling occurs at multiple locations on the same day and Scenario 2) piling occurs at multiple locations on different days. The number of individuals disturbed by each piling operation is 60 in (a) and 160 in (b). A full set of parameters used in this simulation are shown in Appendix 1.

2.3.4 Number of days of disturbance and number of individuals disturbed

We explored the sensitivity of the model to changes in the number of days of disturbance and to changes in the number of individuals disturbed per day. The iPCoD model was run on a loop in which the number of days of disturbance was increased from 1 to 700 consecutive days. A second loop increased the number of individuals vulnerable to disturbance on each day. All other parameters were held constant. Population decline was calculated at the end of the 25 year simulation period for each day/no. of individual combination using the equation:

$$\text{Population Decline} = \frac{\text{Mean Size of Undisturbed Population} - \text{Mean Size of Disturbed Population}}{\text{Mean Size of Undisturbed Population}} \times 100$$

Contour plots (Figure 7) were created to show the effect of increasing the number of days of disturbance and increasing the number of individuals disturbed per day on a population of 195 bottlenose dolphins. This is equivalent to the size of the bottlenose dolphin population on the east coast of Scotland.

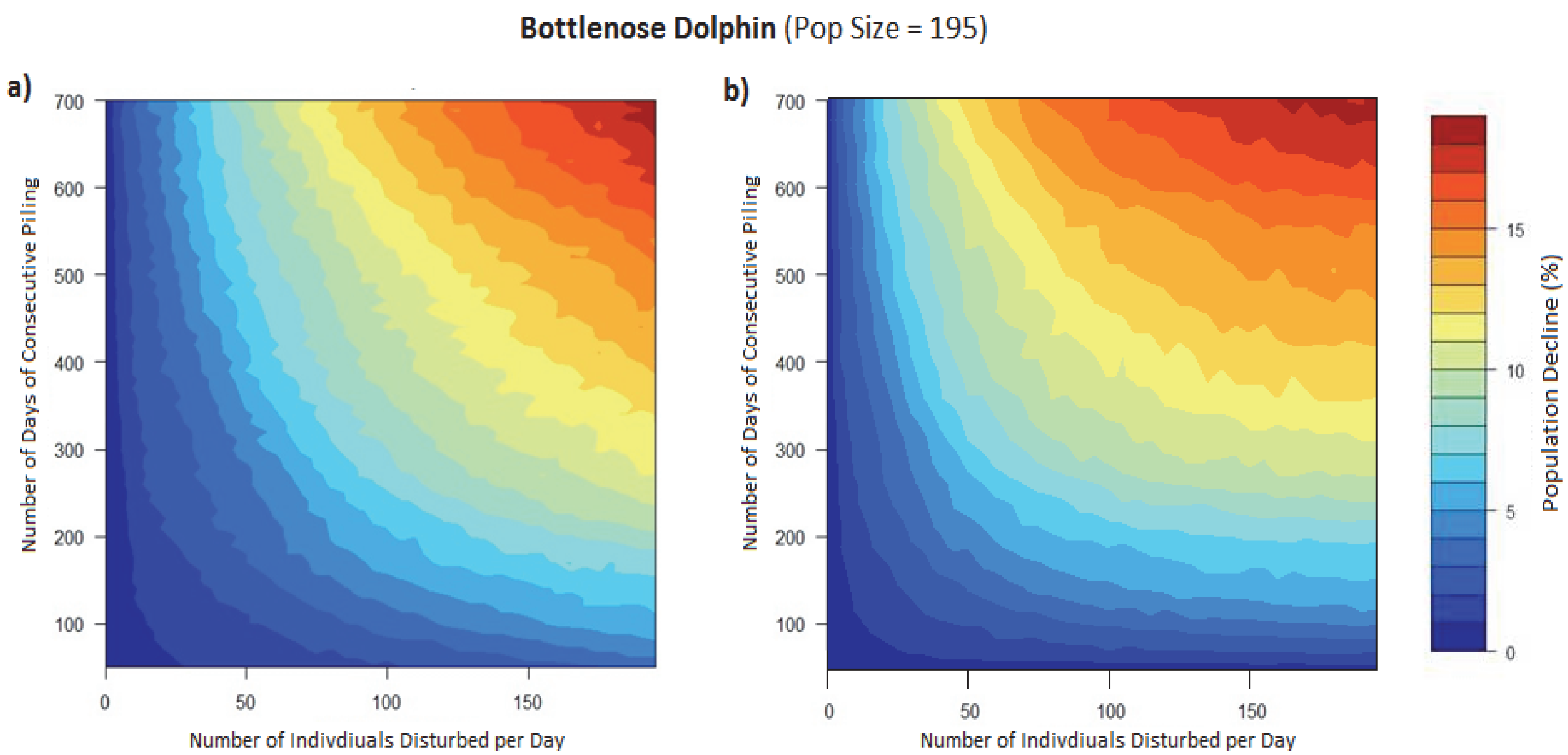

Figure 7. Contour plot showing the effect of increasing the number of days of disturbance and increasing the number of individuals disturbed per day for a population of 195 bottlenose dolphins. The number of days of residual disturbance is set to 0 in (a) and 1 in (b).

2.3.5 Proportion of population vulnerable to disturbance

Within iPCoD it is possible to specify what proportion of the population is vulnerable to the effects of piling from each of the operations being modelled, and consequently, the proportion of the population not affected by piling. This is achieved by setting appropriate values for the parameter “vulnmean”.

We explored the sensitivity of the model to changes in the proportion of the population vulnerable to disturbance by setting up the model to run on a loop in which the proportion of the population vulnerable to disturbance (vulnmean) was gradually increased from 0 to 1. All other parameters were held constant. Population decline was calculated at the end of the 25 year simulation period as described in the previous section.

Increasing the proportion of the population vulnerable to disturbance results in a dome-shaped response curve, as shown in Figure 8. The greatest overall impact is achieved at moderate levels of vulnmean. When the proportion of the population vulnerable to disturbance is small, a small proportion of the population are subject to a relatively large amount of disturbance. However, a large proportion of the population is completely unaffected by disturbance. As a result, there is relatively little overall impact on the population. When the proportion of the population vulnerable to disturbance is large, the disturbance is spread across a large number of individuals. Each individual therefore only receives a small amount of disturbance. This increases the number of individuals in the low disturbance category, in which there is no associated effect on survival or fertility rates (see Figure 1), and therefore reduces the overall impact on the population.

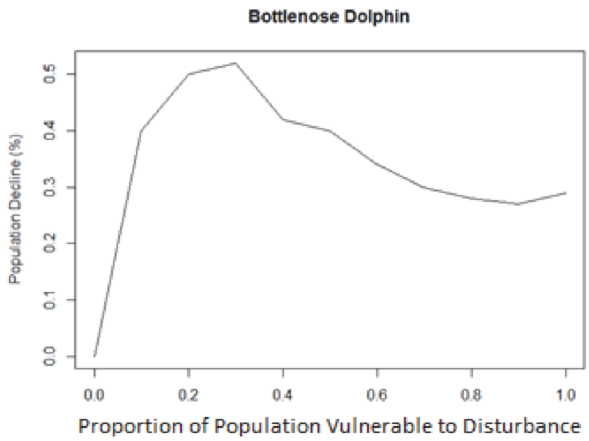

Figure 8. Bottlenose dolphin population dynamics with different proportions of the population vulnerable to disturbance. A full set of parameters used in this simulation are shown in Appendix 1.

2.4 Conclusion

In conclusion, these results show that the iPCoD model is sensitive to variation in several key parameters including the temporal pattern of piling, the number of days of piling, the number of individuals disturbed on each day of piling and the proportion of the population vulnerable to disturbance. This report provides an overview of the effect of changing key model parameters and provides insight into important factors which should be taken into consideration when using the model to predict the effect of offshore windfarm construction on marine mammal populations.

3. CUMULATIVE IMPACT ASSESSMENT OF SCOTTISH EAST COAST OFFSHORE WINDFARM CONSTRUCTION ON KEY SPECIES OF MARINE MAMMALS

3.1 Introduction

Two major clusters of windfarm developments are proposed for the east coast of Scotland (Figure 9). The Moray Firth has already seen the construction of Beatrice Offshore wind farm in 2017-2018 and Moray East is progressing to build out. A number of other applications are anticipated and consented, leaving a question as to how cumulative impact assessment will be undertaken. These major developments, with tens to hundreds of large offshore wind turbines, individually have the potential to input construction noise over tens of kilometres and, taken cumulatively, for a number of years.

Cumulative assessment of these projects is difficult. Each developer is required to consider the impact of their development in conjunction with all other developments (consented and proposed). Whilst we (SNH) have advised consistency in methods, often this is not realised, due to differing timeframes for submission and reluctance to share data due to commercial sensitivities. This means that cumulative assessment is not always done consistently, which results in variable conclusions.

In this section, we assess cumulative impact using an independent approach which is as consistent as possible with the available data. Cumulative impact from disturbance was assessed using the Interim PCoD model (King *et al.,* 2015). We focus on the cumulative potential population impacts to four key species of marine mammals: bottlenose dolphin (Moray Firth SAC), grey seal (Isle of May SAC), harbour porpoise (North Sea Management Unit) and minke whale (Celtic and Greater North Seas Management Unit).

3.2 Methods

3.2.1 Projects included in the cumulative impact assessment

The cumulative impact assessment considered noise generated from the construction (impact piling) of windfarms across the east coast of Scotland as well as noise generated by blasting activities during the expansion project at Aberdeen Harbour. The projects considered within the cumulative impact assessment are:

- Beatrice Offshore Wind Farm (BOWL)
- Aberdeen Harbour Expansion Plan (AHEP)
- Moray East Offshore Wind Farm
- Neart na Gaoithe Offshore Wind Farm (NnG)
- Inch Cape Offshore Wind Farm
- Seagreen Offshore Wind Farm (Projects Alpha + Bravo)
- Moray West Offshore Wind Farm

The locations of all projects included in the cumulative impact assessment are shown in Figure 9.

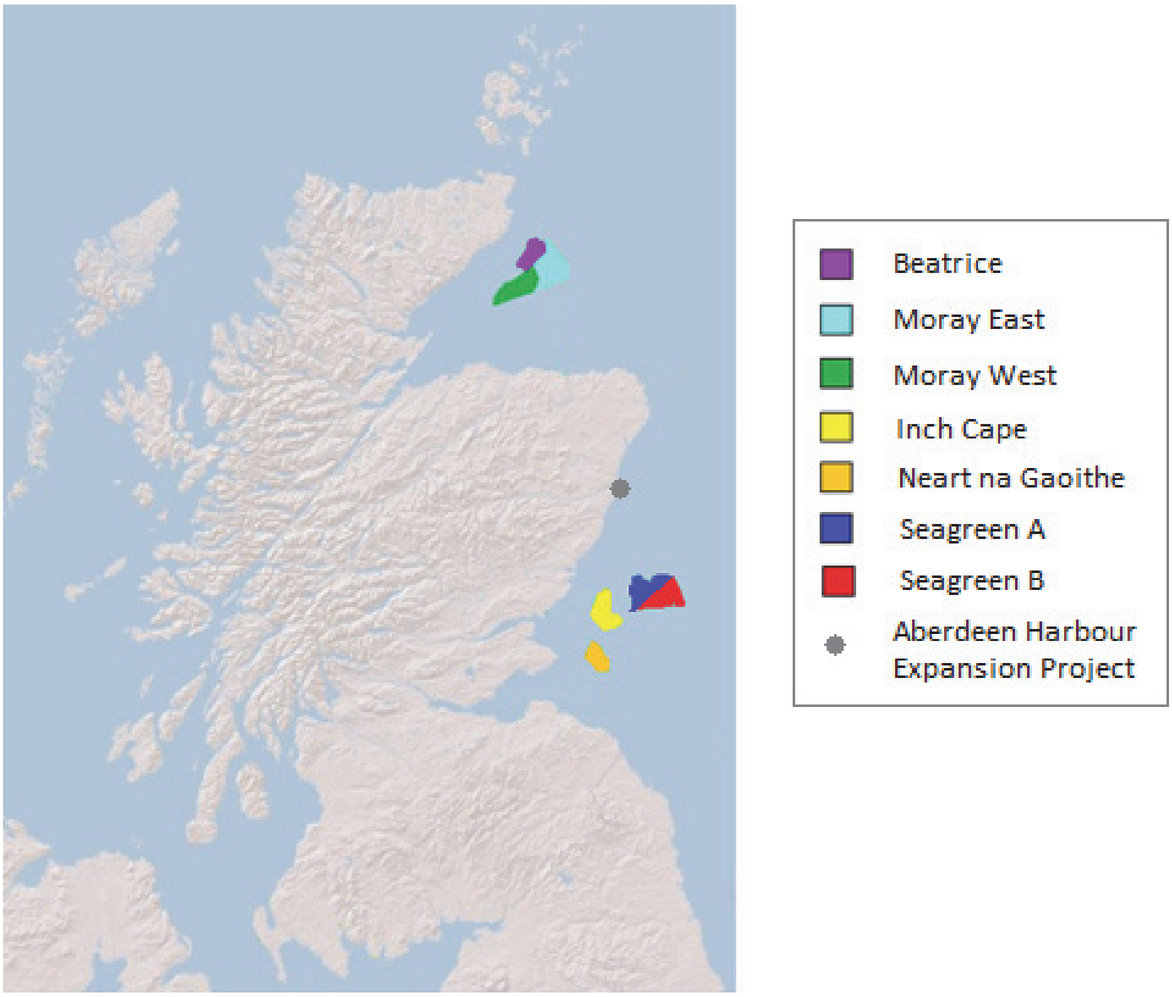

Figure 9. Map showing the location of projects considered in the cumulative impact assessment

3.2.2 Management units and population sizes

Potential impacts to marine mammal species were assessed in relation to management unit areas and population sizes. Management unit areas are shown in Figure 10 with corresponding estimates of population size shown in Table 1.

Table 1. Population estimates of marine mammals for the management units considered in the cumulative impact assessment.

Species	Management Unit	Population Estimate	Reference
Bottlenose Dolphin	East Coast	195	(IAMMWG, 2015)
Grey Seal	East Coast	14,714	(SCOS, 2017)
Minke Whale	Celtic and Greater North Sea	23,528	(IAMMWG, 2015)
Harbour Porpoise	North Sea	227,298	(IAMMWG, 2015)

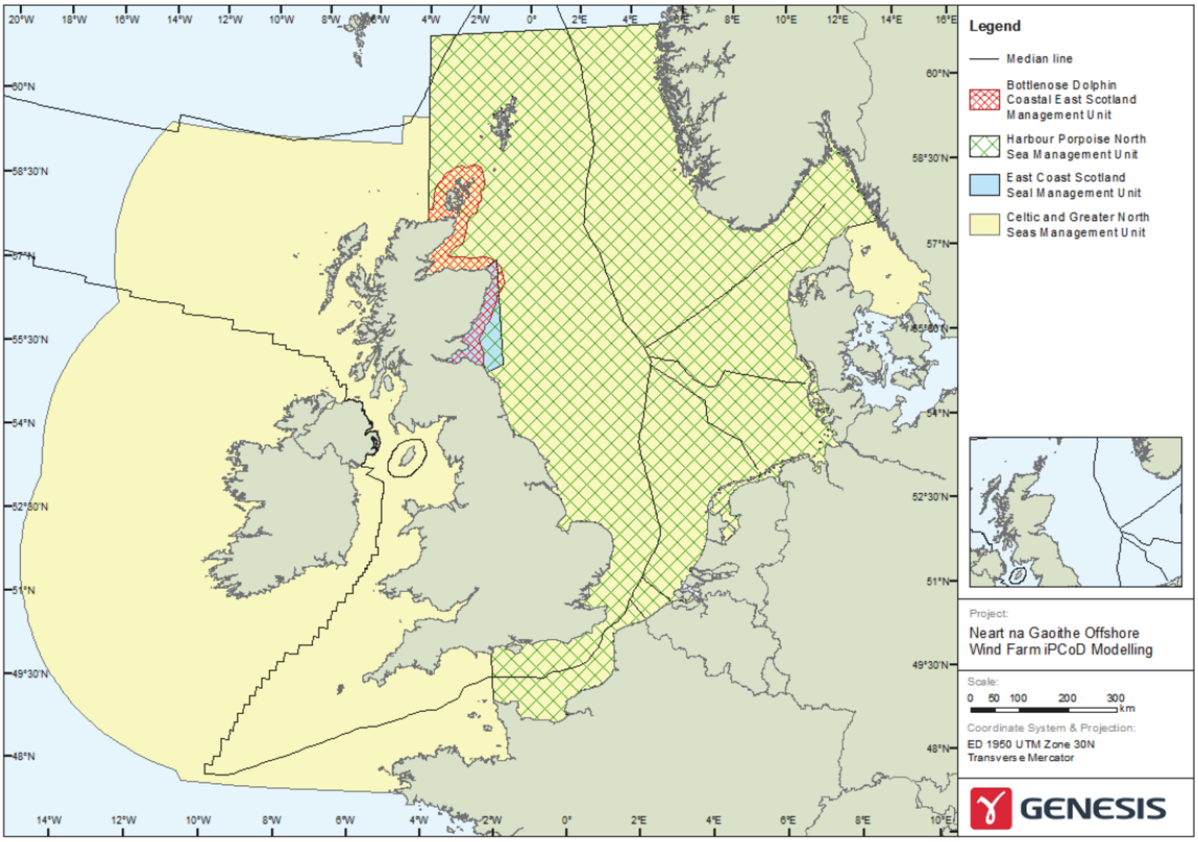

Figure 10. Management unit areas used for the assessment of marine mammals. Figure taken from Neart na Gaoithe Environmental Impact Statement.

All projects shown in Figure 9 were included in the cumulative impact assessment for bottlenose dolphin, harbour porpoise and minke whale. The cumulative impact assessment for grey seals focussed on the grey seal population within the East Coast Management Area. This covers the Forth and Tay but not the Moray Firth, as shown in Figure 10. The cumulative impact assessment for grey seals therefore only considered projects located in the Forth and Tay (Neart na Gaoithe, Inch Cape and Seagreen). Aberdeen Harbour Expansion Project was not included in the cumulative impact assessment for grey seals, despite being located in the East Coast Management Unit, due to the lack of data available for this project, relevant to grey seals.

3.2.3 Demographic parameters

Demographic parameters for all four marine mammal populations were taken from Harwood and King (2017). Demographic parameters used in the model are shown in Table 2.

Table 2. Demographic parameters for each species as recommended by Harwood and King (2017).

Species	Age 1 (Age at Independence)	Age 2 (Age at First Breeding)	Calf Survival	Juvenile Survival	Adult Survival	Fecundity
Bottlenose Dolphin	2	9	0.9	0.94	0.945	0.3
Grey Seal	1	5	0.222	0.94	0.94	0.84
Harbour Porpoise	1	5	0.6	0.85	0.85	0.958
Minke Whale	1	9	0.72	0.77	0.96	0.9

3.2.4 Construction schedule and number of animals experiencing disturbance

Environmental impact statements typically present a number of construction options for each project. Most developers consider scenarios involving the use of one vessel alone as well as the use of two vessels concurrently. Additionally, some developers also consider construction using monopiles and/or pinpiles.

The worst-case scenario for each development was used in the cumulative impact assessment. This was determined by carrying out an initial assessment for each individual project using the iPCoD model. The number of animals predicted to experience disturbance and PTS on one day of piling for each proposed scenario was taken from the relevant impact assessment. Pile-driving schedules were also created for each scenario using information presented in the relevant impact assessment. The pile driving schedule for BOWL was created according to the actual construction timeline. Pile driving schedules for all other projects were based on the proposed development dates and the estimated number of days of piling.

The worst-case scenario for each project is shown in Table 3, alongside estimates of the number of animals predicted to experience disturbance and PTS under this scenario. The worst-case scenario was found to be the same across all species for all projects excluding Moray West. The worst case scenario for Moray West was found to be single vessel installation of monopiles for harbour porpoise and single vessel installation of pinpiles for bottlenose dolphin, grey seals and minke whales. A construction timeline of the worst-case scenarios for each project is shown in Table 4.

It is important to note that different developers have assumed different density estimates of animals. The number of animals predicted to experience disturbance is therefore not directly comparable between all operations. However, it is difficult to convert all estimates on to the same scale. Values were therefore taken directly from the reports and no conversion factors were applied.

Table 3. Construction timeline and number of individuals predicted to experience PTS and disturbance for each project. The table shows the worst-case scenario for each project, determined by carrying out an initial assessment for each individual project using the iPCoD model. Note the worst-case scenario for Moray West is not the same across all species.

				Predicted number of animals that will experience PTS on each days of piling				Predicted number of animals that will experience disturbance on each day of piling			
Project	**Start Date**	**End Date**	**Number of Days of Piling**	**BND**	**GS (Forth and Tay Only)**	**HP**	**MW**	**BND**	**GS (Forth and Tay Only)**	**HP**	**MW**
BOWL	02/04/2017	02/12/2017	102	0	NA	0	0	19	NA	1205	106
AHEP (blasting)	15/09/2018	18/06/2019	36	0	0	0	0	4	0	61	4
Moray East - Single Vessel	01/04/2019	10/06/2020	134	0	NA	7	13	17	NA	2933	168
Neart na Gaoithe - Single Vessel	01/07/2021	30/09/2022	54	0	1	77	14	2	821	1177	77
Inch Cape - Monopiles - Single Vessel	12/03/2021	17/10/2021	74	0	0	0	0.3	7	1058	261	138
Seagreen Alpha - Pinpiles - Single Vessel	03/01/2022	29/12/2022	140	0	0	0	0	3	27	971	63
Seagreen Bravo - Pinpiles - Single Vessel	06/01/2023	29/12/2023	100	0	0	0	0	2	14	1103	71
Moray West - Monopiles - Single Vessel	01/04/2022	05/02/2023	133	NA	NA	NA	NA	NA	NA	1377	NA
Moray West - Pin Piles - Single Vessel	01/04/2022	09/09/2022	87	0	NA	NA	0	10	NA	NA	23

Table 4. Chart illustrating the construction period for each project

Date		BOWL	AHEP	**Moray East -** Single Vessel	**NnG -** Single Vessel	**Inch Cape -** Monopiles - Single Vessel	**Seagreen A -** Pinpile - Single Vessel	**Seagreen B -** Pinpile - Single Vessel	**Moray West**	
									Pinpiles - Single Vessel	Monopiles - Single Vessel
2017	**Q1**									
	Q2									
	Q3									
	Q4									
2018	**Q1**									
	Q2									
	Q3									
	Q4									
2019	**Q1**									
	Q2									
	Q3									
	Q4									
2020	**Q1**									
	Q2									
	Q3									
	Q4									
2021	**Q1**									
	Q2									
	Q3									
	Q4									
2022	**Q1**									
	Q2									
	Q3									
	Q4									
2023	**Q1**									
	Q2									
	Q3									
	Q4									

3.2.5 Cumulative model parameters

We carried out a number of different cumulative impact assessments in order to allow us to examine the impact of unknown parameters.

Key unknowns:

- Whether animals experience 0 or 1 day of residual disturbance.
- Whether animals avoid operations whilst experiencing residual disturbance or if animals can be re-disturbed within a period of residual disturbance.
- The proportion of the population vulnerable to disturbance from each project:
  - For bottlenose dolphins we compared scenarios in which 100% of the population is vulnerable to disturbance from all developments with scenarios in which 50% of the population is vulnerable to disturbance in the Moray Firth and 50% of individuals vulnerable to disturbance in the Forth and Tay.
  - For harbour porpoise we compared scenarios in which 100% of the population is vulnerable to disturbance from all developments with scenarios in which individuals in SCANS-III block S (6147 individuals, 3% of population) are vulnerable to disturbance from projects in the Moray Firth and individuals in SCANS-III block R (38,646 individuals, 17% of population) are vulnerable to disturbance from AHEP and projects in the Forth and Tay.
  - For minke whale we compared scenarios in which 100% of the population is vulnerable to disturbance from all developments with scenarios in which individuals in SCANS-III block S (383 individuals, 2% of population) are vulnerable to disturbance from projects in the Moray Firth and individuals in SCANS-III block R (2498 individuals, 11% of population) are vulnerable to disturbance from AHEP and projects in the Forth and Tay.

In order to allow us to determine the effect of these unknown parameters on the model results, a total of 6 scenarios were run for bottlenose dolphins, harbour porpoise and minke whale and 3 scenarios for grey seals. A summary of the main differences between each scenario is provided in Tables 5, 6, 7 and 8 for bottlenose dolphin, grey seal, harbour porpoise and minke whale respectively. Full sets of parameters used in each scenario are shown in Appendix 2.

Table 5. Summary of the scenarios included in the sensitivity analysis for bottlenose dolphins.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Number of Days of Residual Disturbance	1	1	0	1	1	0
Do animals avoid operations during a period of residual disturbance?	No	Yes	No	No	Yes	No
Population Structure	All individuals vulnerable to disturbance from all operations	All individuals vulnerable to disturbance from all operations	All individuals vulnerable to disturbance from all operations	50% of individuals vulnerable to operations in the Moray Firth and 50% vulnerable to operations in the Forth and Tay	50% of individuals vulnerable to operations in the Moray Firth and 50% vulnerable to operations in the Forth and Tay	50% of individuals vulnerable to operations in the Moray Firth and 50% vulnerable to operations in the Forth and Tay

Table 6. Summary of the scenarios included in the sensitivity analysis for grey seals.

	Scenario 1	Scenario 2	Scenario 3
Number of Days of Residual Disturbance	1	1	0
Do animals avoid operations during a period of residual disturbance?	No	Yes	No
Population Structure	All individuals vulnerable to disturbance from operations in the Forth and Tay	All individuals vulnerable to disturbance from operations in the Forth and Tay	All individuals vulnerable to disturbance from operations in the Forth and Tay

Table 7. Summary of the scenarios included in the sensitivity analysis for harbour porpoise.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Number of Days of Residual Disturbance	1	1	0	1	1	0
Do animals avoid operations during a period of residual disturbance?	No	Yes	No	No	Yes	No
Population Structure	All individuals vulnerable to disturbance from all operations	All individuals vulnerable to disturbance from all operations	All individuals vulnerable to disturbance from all operations	3% of individuals vulnerable to operations in the Moray Firth and 17% vulnerable to operations in the Forth and Tay	3% of individuals vulnerable to operations in the Moray Firth and 17% vulnerable to operations in the Forth and Tay	3% of individuals vulnerable to operations in the Moray Firth and 17% vulnerable to operations in the Forth and Tay

Table 8. Summary of the scenarios included in the sensitivity analysis for minke whale.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Number of Days of Residual Disturbance	1	1	0	1	1	0
Do animals avoid operations during a period of residual disturbance?	No	Yes	No	No	Yes	No
Population Structure	All individuals vulnerable to disturbance from all operations	All individuals vulnerable to disturbance from all operations	All individuals vulnerable to disturbance from all operations	2% of individuals vulnerable to operations in the Moray Firth and 11% vulnerable to operations in the Forth and Tay	2% of individuals vulnerable to operations in the Moray Firth and 11% vulnerable to operations in the Forth and Tay	2% of individuals vulnerable to operations in the Moray Firth and 11% vulnerable to operations in the Forth and Tay

3.3 Results

Results of the iPCoD modelling for all scenarios are presented in Tables 9-12. For each scenario a number of different metrics are used to assess the impact on the population. This includes:

1) The predicted mean population size at the end of 24 years
2) The mean of the ratio of the impacted to un-impacted population size, using the population sizes at the end of years 1, 6, 12, 18 and 24
3) The mean of the ratio of the impacted to un-impacted annual growth rate at the end of years 1, 6, 12, 18 and 24
4) The centile for the un-impacted population that matches the 50th centile for the impacted population at the end of years 1, 6, 12, 18 and 24.

Table 9. Bottlenose dolphin metrics for all 6 scenarios tested in the sensitivity analysis.

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Median Population Size Year 24	**Baseline Mean**	304	304	303	303	303	304
	Impacted Mean	287	287	293	289	289	295
	Difference in Population Size	17	17	10	14	14	9
	Impacted as a % of Un-impacted	94.41	94.41	96.70	95.38	95.38	97.04
Ratio of the impacted to un-impacted population size	**Year 1 Mean**	0.992	0.992	0.996	0.991	0.992	0.995
	Year 6 Mean	0.947	0.947	0.966	0.953	0.956	0.967
	Year 12 Mean	0.948	0.948	0.966	0.953	0.955	0.968
	Year 18 Mean	0.945	0.945	0.964	0.950	0.953	0.967
	Year 24 Mean	0.946	0.946	0.964	0.951	0.954	0.967
Ratio of the impacted to un-impacted annual growth rate	**Year 1 Mean**	0.992	0.992	0.996	0.991	0.992	0.995
	Year 6 Mean	0.990	0.990	0.994	0.991	0.992	0.994
	Year 12 Mean	0.995	0.995	0.997	0.996	0.996	0.997
	Year 18 Mean	0.996	0.996	0.998	0.997	0.997	0.998
	Year 24 Mean	0.997	0.997	0.998	0.998	0.998	0.998
Centile for un-impacted population which matches the 50th centile for the impacted population	**Year 1**	43%	45%	45%	45%	45%	45%
	Year 6	50%	48%	48%	48%	48%	47%
	Year 12	49%	49%	49%	49%	49%	50%
	Year 18	49%	50%	49%	50%	50%	49%
	Year 24	50%	50%	50%	50%	50%	50%

Table 10. Grey seal metrics for all 3 scenarios tested in the sensitivity analysis.

		Scenario 1	Scenario 2	Scenario 3
Median Population Size Year 24	**Baseline Mean**	18683	18704	18707
	Impacted Mean	18665	18688	18699
	Difference in Population Size	18	16	8
	Impacted as a % of Un-impacted	99.90	99.91	99.96
Ratio of the impacted to un-impacted population size	**Year 1 Mean**	1.000	1.000	1.000
	Year 6 Mean	0.999	0.999	1.000
	Year 12 Mean	0.999	0.999	1.000
	Year 18 Mean	0.999	0.999	1.001
	Year 24 Mean	0.999	0.999	1.001
Ratio of the impacted to un-impacted annual growth rate	**Year 1 Mean**	1.000	1.000	1.000
	Year 6 Mean	1.000	1.000	1.000
	Year 12 Mean	1.000	1.000	1.000
	Year 18 Mean	1.000	1.000	1.000
	Year 24 Mean	1.000	1.000	1.000
Centile for un-impacted population which matches the 50th centile for the impacted population	**Year 1**	50%	50%	50%
	Year 6	50%	50%	50%
	Year 12	50%	50%	50%
	Year 18	50%	50%	50%
	Year 24	50%	50%	50%

Table 11. Harbour porpoise metrics for all 6 scenarios tested in the sensitivity analysis.

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Median Population Size Year 24	**Baseline Mean**	226435	225956	226221	226355	223077	226230
	Impacted Mean	226071	225590	226112	224032	220822	225451
	Difference in Population Size	364	366	109	2323	2255	779
	Impacted as a % of Un-impacted	99.84	99.84	99.95	98.97	98.99	99.66
Ratio of the impacted to un-impacted population size	**Year 1 Mean**	1.000	1.000	1.000	0.999	0.999	1.000
	Year 6 Mean	0.999	0.999	1.000	0.993	0.993	0.997
	Year 12 Mean	0.998	0.998	1.000	0.990	0.990	0.997
	Year 18 Mean	0.998	0.998	1.000	0.990	0.990	0.997
	Year 24 Mean	0.998	0.998	1.000	0.990	0.990	0.997
Ratio of the impacted to un-impacted annual growth rate	**Year 1 Mean**	1.000	1.000	1.000	0.999	0.999	1.000
	Year 6 Mean	1.000	1.000	1.000	0.999	0.999	1.000
	Year 12 Mean	1.000	1.000	1.000	0.999	0.999	1.000
	Year 18 Mean	1.000	1.000	1.000	0.999	0.999	1.000
	Year 24 Mean	1.000	1.000	1.000	1.000	1.000	1.000
Centile for un-impacted population which matches the 50th centile for the impacted population	**Year 1**	50%	50%	50%	50%	50%	50%
	Year 6	50%	50%	50%	50%	50%	50%
	Year 12	50%	50%	50%	50%	50%	50%
	Year 18	50%	50%	50%	50%	50%	50%
	Year 24	50%	50%	50%	50%	50%	50%

Table 12. Minke whale metrics for all 6 scenarios tested in the sensitivity analysis.

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Median Population Size Year 24	**Baseline Mean**	23584	23279	23583	23501	23660	23730
	Impacted Mean	21676	21402	21681	22263	22403	22470
	Difference in Population Size	1908	1877	1902	1238	1257	1260
	Impacted as a % of Un-impacted	91.91	91.94	91.93	94.73	94.69	94.69
Ratio of the impacted to un-impacted population size	**Year 1 Mean**	0.999	0.999	0.999	0.999	0.999	0.999
	Year 6 Mean	0.980	0.980	0.980	0.983	0.983	0.983
	Year 12 Mean	0.938	0.938	0.938	0.959	0.959	0.958
	Year 18 Mean	0.924	0.924	0.924	0.950	0.950	0.950
	Year 24 Mean	0.919	0.9191	0.919	0.947	0.947	0.947
Ratio of the impacted to un-impacted annual growth rate	**Year 1 Mean**	0.999	0.999	0.999	0.999	0.999	0.999
	Year 6 Mean	0.997	0.997	0.997	0.997	0.997	0.997
	Year 12 Mean	0.995	0.995	0.995	0.997	0.996	0.996
	Year 18 Mean	0.996	0.996	0.996	0.997	0.997	0.997
	Year 24 Mean	0.996	0.996	0.996	0.998	0.998	0.998
Centile for un-impacted population which matches the 50th centile for the impacted population	**Year 1**	50%	50%	50%	50%	50%	50%
	Year 6	50%	50%	50%	50%	50%	50%
	Year 12	50%	50%	50%	50%	50%	50%
	Year 18	50%	50%	50%	50%	50%	50%
	Year 24	50%	50%	50%	50%	50%	50%

The results show that across all species there is no difference between scenarios in which individuals avoid operations during residual disturbance and scenarios in which they do not. The results show a small difference between scenarios in which the number of residual days of disturbance is set to 1 and scenarios in which the number of residual days of disturbance is set to 0. Scenarios in which the number of residual days of disturbance is 1 have more impact on the population.

The results also show that the model is sensitive to the proportion of the population vulnerable to disturbance from each project. For bottlenose dolphins, scenarios in which the whole population is vulnerable to disturbance from all operations had more impact on the population in comparison to scenarios in 50% of the population is vulnerable to disturbance in the Moray Firth and the other 50% vulnerable to disturbance in the Forth and Tay.

Similarly, minke whale scenarios in which the whole population is vulnerable to disturbance from all operations had more impact on the population in comparison to scenarios in which individuals in SCANS-III block S are vulnerable to disturbance from projects in the Moray

Firth and individuals in SCANS-III block R are vulnerable to disturbance from AHEP and projects in the Forth and Tay. However, the opposite was found to be true for harbour porpoise. Harbour porpoise scenarios in which individuals in SCANS-III block S are vulnerable to disturbance from projects in the Moray Firth and individuals in SCANS-III block R are vulnerable to disturbance from AHEP and projects in the Forth and Tay had more impact on the population in comparison to scenarios in which the whole population is vulnerable to disturbance from all operations.

The overall worst case from the sensitivity analysis was found to be scenario 1 for bottlenose dolphin, grey seal and minke whale and scenario 4 for harbour porpoise. Plots of iPCoD model output for the overall worst-case scenario for each species are presented in the following section.

3.3.1 Overall worst case: Bottlenose dolphin

The mean population size and 95% CI for the impacted and un-impacted population are shown in Figure 11. The mean population size for the impacted population is smaller than the mean population size for the un-impacted population across all years in the simulation. It is important to note that the disturbed population follows the same trajectory as the undisturbed population in the years following construction. However, it is also important to note that the size of the impacted population after 24 years is significantly smaller than the size of the un-impacted population according to a two sample T test ($t = -16.86$, $p < 0.01$). After 24 years, the mean predicted population size for the un-impacted population was 304. The mean predicted population size for the impacted population after 24 years was 287, which is 94.4% of the size of the un-impacted population.

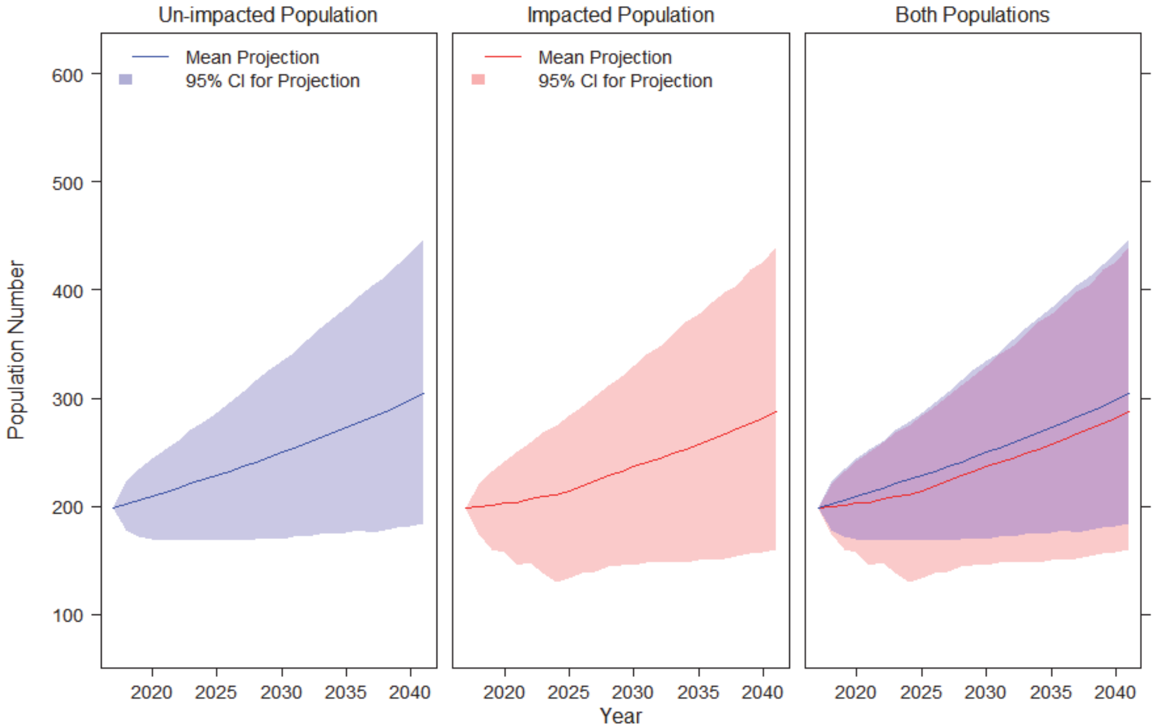

Figure 11. Mean population size for bottlenose dolphins under Scenario 1.

Histograms of the ratio of the impacted population size to the un-impacted population size across all paired simulations are shown in Figure 12 for the end of years 1, 6, 12, 18 and 24. At the end of 24 years, the mean ratio of the impacted and un-impacted population size was 0.946, indicating that the impacted population is generally smaller than the paired un-impacted population.

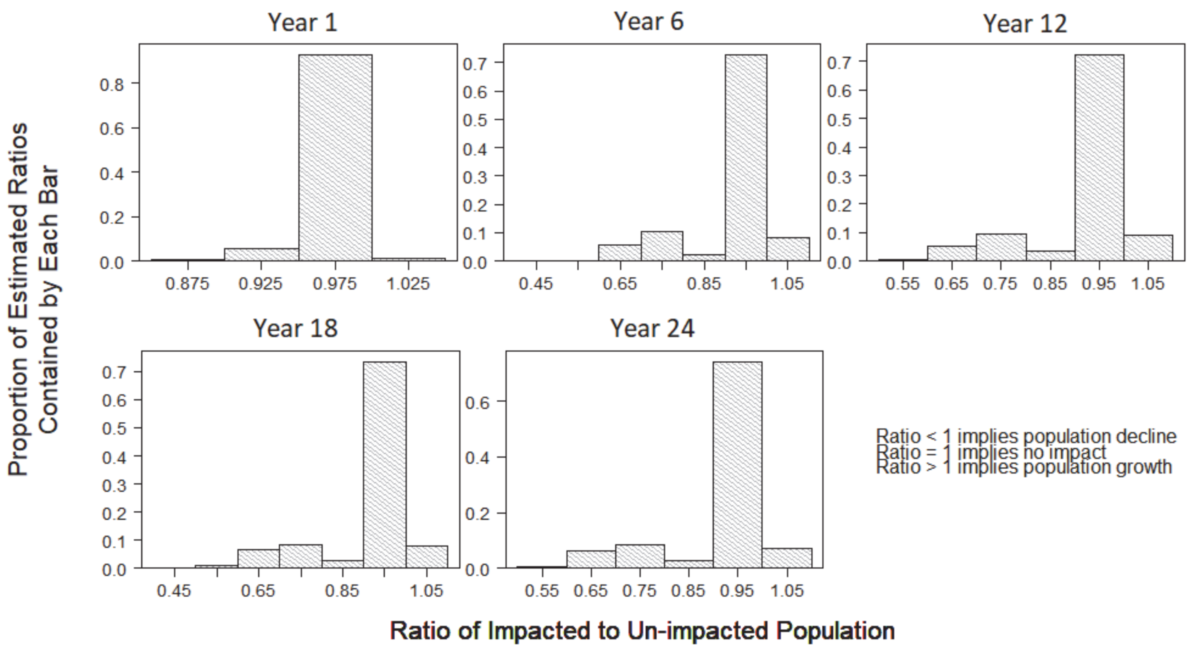

Figure 12. Ratio of impacted to un-impacted population size at the end of years 1, 6, 12, 18 and 24 for bottlenose dolphins in Scenario 1.

Histograms of the ratio of the impacted population growth rate to the un-impacted population growth rate across all paired simulations are shown in Figure 13 for the end of years 1, 6, 12, 18 and 24. The mean ratio of the impacted and un-impacted population annual growth rate at the end of 24 years was 0.997. A small number of simulations therefore resulted in a change in growth rate that was lower for the impacted population compared to the paired un-impacted population. However, this difference is very small.

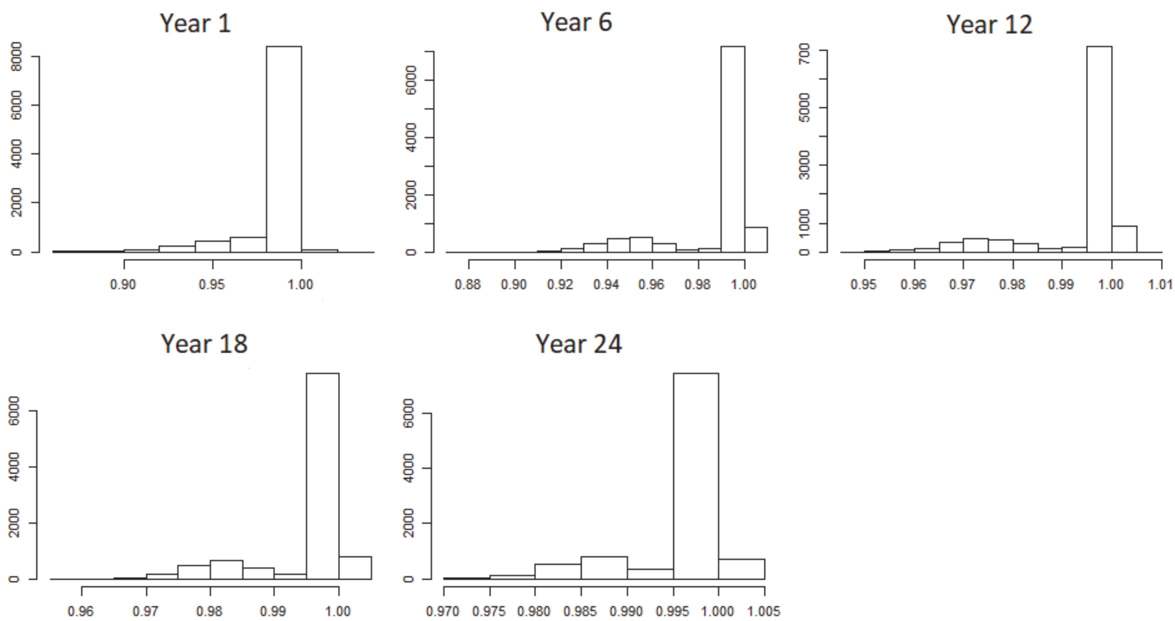

Figure 13. Ratio of impacted to un-impacted annual growth rate at the end of years 1, 6, 12, 18 and 24 for bottlenose dolphins in Scenario 1.

3.3.2 *Overall worst case: Grey seals*

The mean population size and 95% CI for the impacted and un-impacted population are shown in Figure 14. There is a very large overlap in confidence intervals for the impacted and un-impacted population. The results of a two-sample T test show no significant difference between the size of the impacted and un-impacted population after 24 years (t = -0.43, p = 0.66). The mean predicted population size for the un-impacted population after 24 years was 18,683. The mean predicted population size for the impacted population after 24 years was 18,665, which is 99.9% of the size of the un-impacted population.

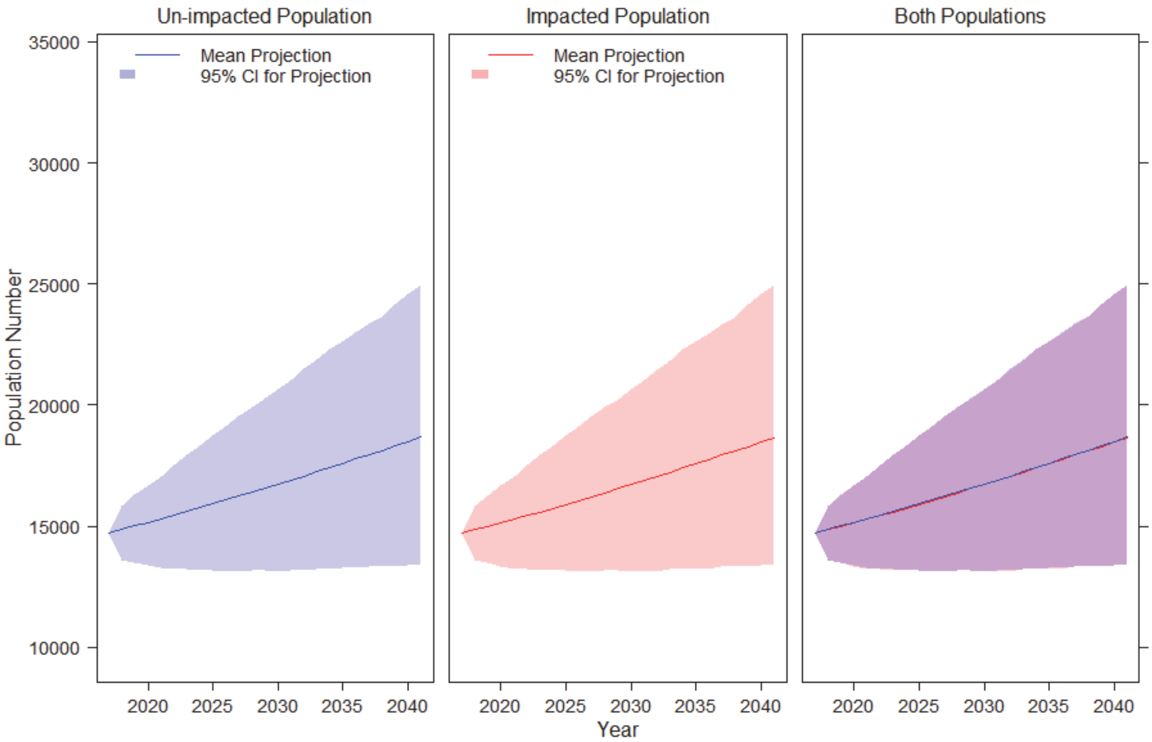

Figure 14. Mean population size for grey seals under Scenario 1.

Histograms of the ratio of the impacted population size to the un-impacted population size across all paired simulations are shown in Figure 15 for the end of years 1, 6, 12, 18 and 24. The mean ratio of the impacted population size to un-impacted population size is very close to 1 across all years examined, indicating that the differences between the two population sizes are very small.

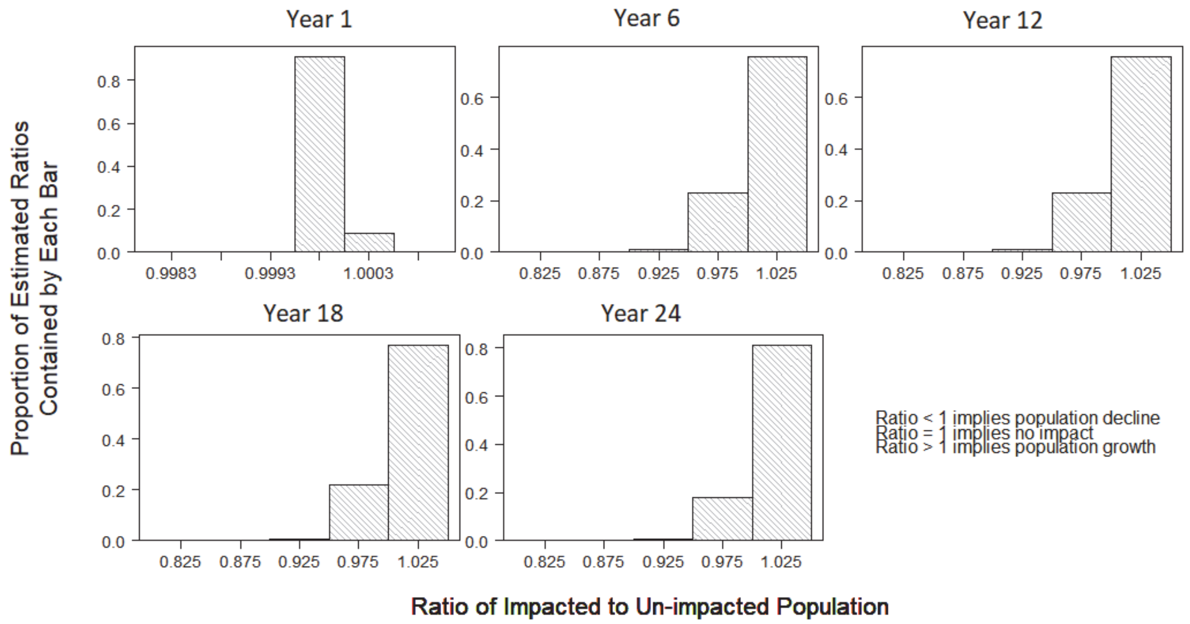

Figure 15. Ratio of impacted to un-impacted population size at the end of years 1, 6, 12, 18 and 24 for grey seals in Scenario 1.

Histograms of the ratio of the impacted population growth rate to the un-impacted population growth rate across all paired simulations are shown in Figure 16 for the end of years 1, 6, 12, 18 and 24. The mean ratio of the impacted and un-impacted population annual growth rate was equal to 1 across all years examined. This indicates that there is no difference in growth rate between the impacted and un-impacted population.

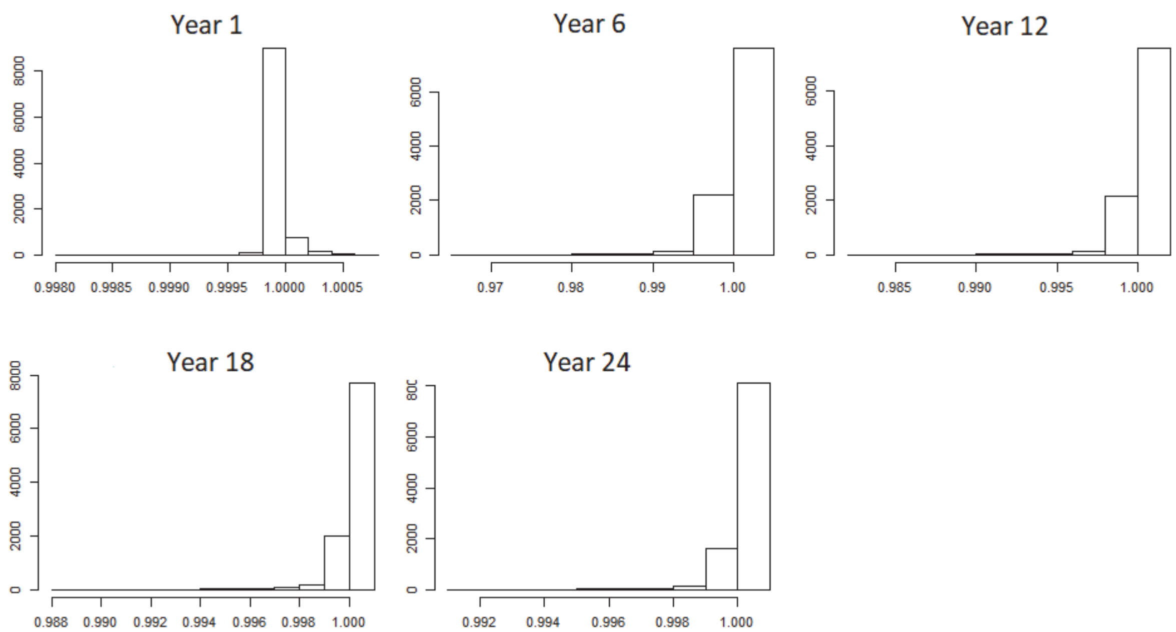

Figure 16. Ratio of impacted to un-impacted annual growth rate at the end of years 1, 6, 12, 18 and 24 for grey seals in Scenario 1.

3.3.3 Overall worst case: Harbour porpoise

The mean population size and 95% CI for the impacted and un-impacted population are shown in Figure 17. The mean size of the impacted population is fractionally smaller than the mean size of the un-impacted population but there is a very large overlap in confidence intervals. The results of a two-sample T test show no significant difference between the size of the impacted and un-impacted population after 24 years (t =-0.16, p = 0.87). At the end of 24 years, the mean predicted population size for the un-impacted population was 226,355. The mean predicted population size for the impacted population after 24 years was 224,032, which is 98.97% of the size of the un-impacted population.

Figure 17. Mean population size for harbour porpoise under Scenario 4.

Histograms of the ratio of the impacted population size to the un-impacted population size across all paired simulations are shown in Figure 18 for the end of years 1, 6, 12, 18 and 24. The mean ratio of the impacted population size to un-impacted population size is very close to 1 across all years examined, indicating that the differences between the two population sizes are very small.

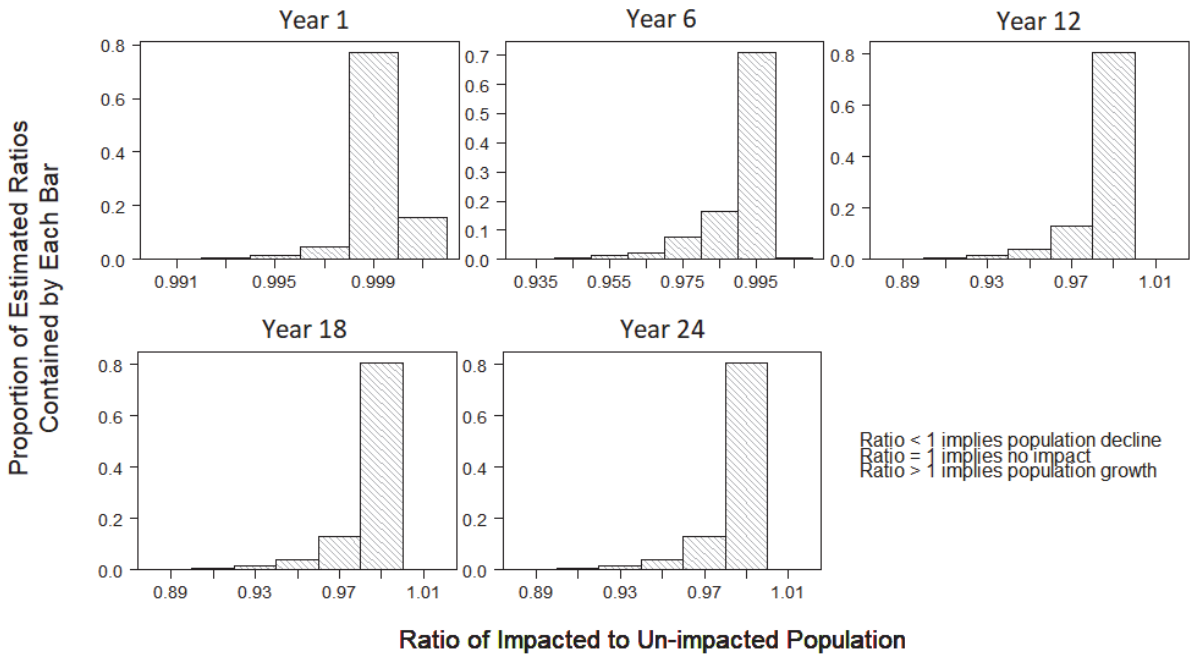

Figure 18. Ratio of impacted to un-impacted population size at the end of years 1, 6, 12, 18 and 24 for harbour porpoise in Scenario 4.

Histograms of the ratio of the impacted population growth rate to the un-impacted population growth rate across all paired simulations are shown in Figure 19 for the end of years 1, 6, 12, 18 and 24. The mean ratio of the impacted and un-impacted population annual growth rate was very close to 1 across all years examined. This indicates that there is very little difference in the growth rate between the impacted and un-impacted population.

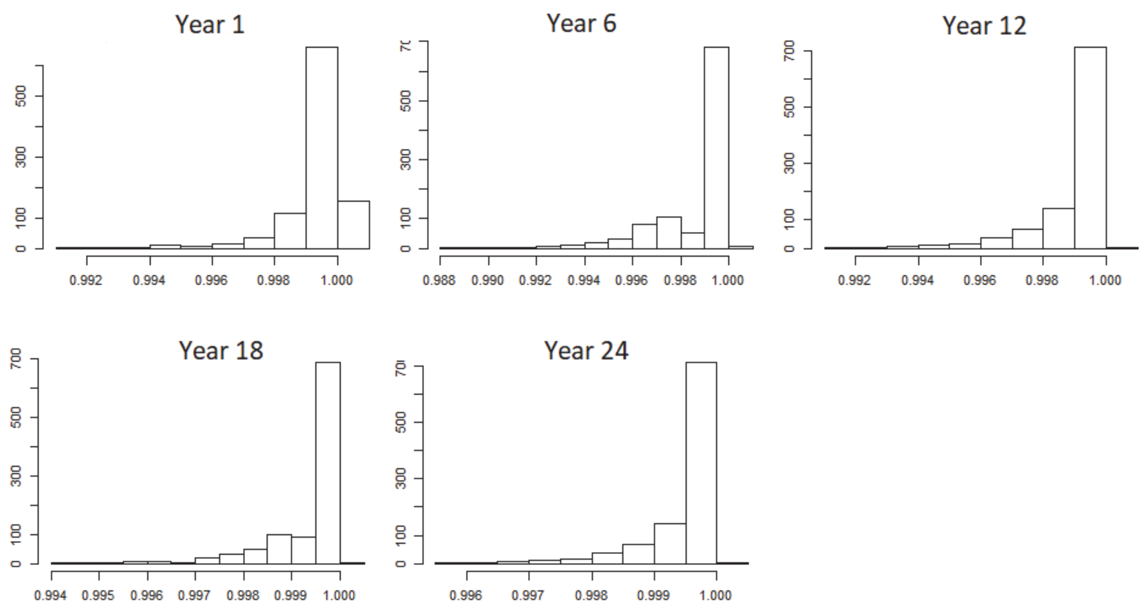

Figure 19. Ratio of impacted to un-impacted annual growth rate at the end of years 1, 6, 12, 18 and 24 for harbour porpoise in Scenario 4.

3.3.4 Overall worst case: Minke whale

The mean population size and 95% CI for the impacted and un-impacted population are shown in Figure 20. At the end of the simulation period the mean population size for the impacted population is substantially smaller than the mean population size for the un-impacted population. At the end of 24 years, the mean predicted population size for the un-impacted population was 23,584. The mean predicted population size for the impacted population after 24 years was 21,676, which is 91.9% of the size of the un-impacted population.

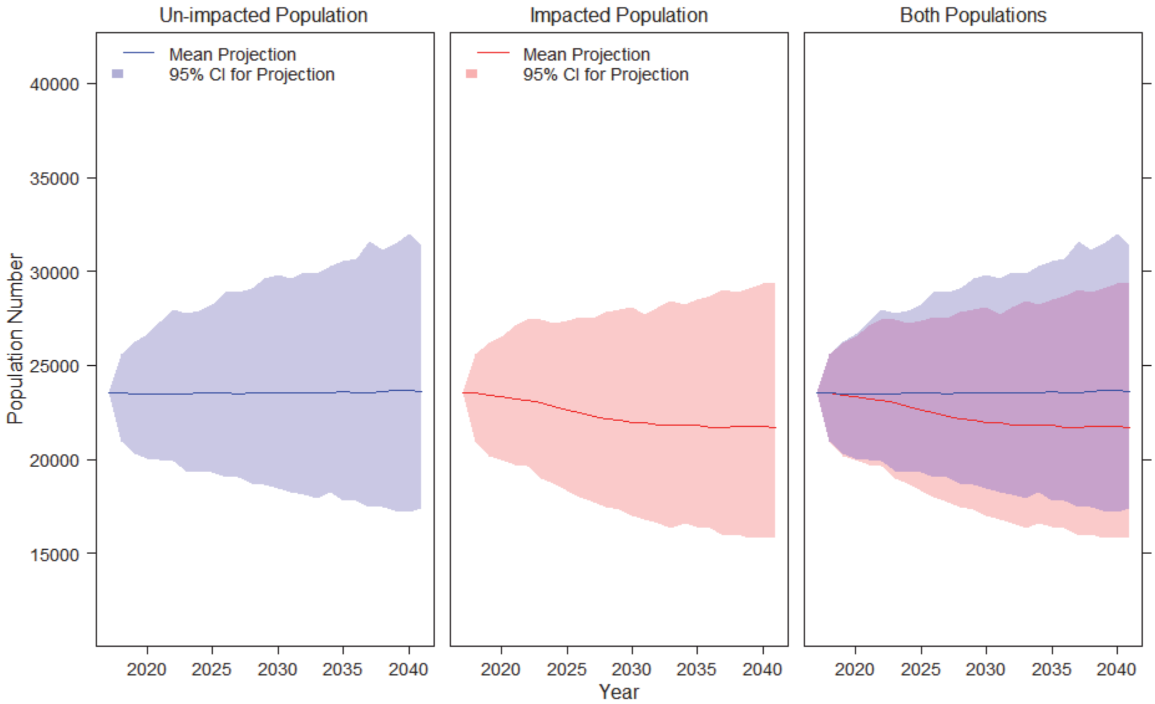

Figure 20. Mean population size for minke whale under Scenario 1.

Histograms of the ratio of the impacted population size to the un-impacted population size across all paired simulations are shown in Figure 21 for the end of years 1, 6, 12, 18 and 24. At the end of 24 years, the mean ratio of the impacted and un-impacted population size was 0.919, indicating that the impacted population is generally smaller than the paired un-impacted population.

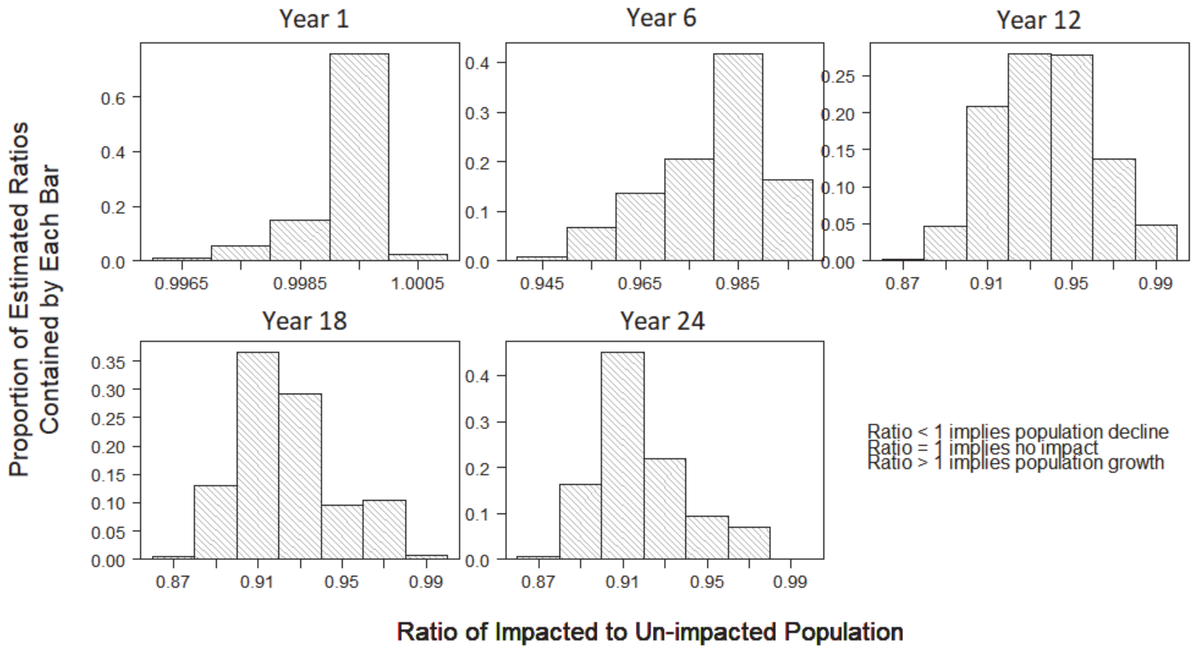

Figure 21. Ratio of impacted to un-impacted population size at the end of years 1, 6, 12, 18 and 24 for minke whale in Scenario 1.

Histograms of the ratio of the impacted population growth rate to the un-impacted population growth rate across all paired simulations are shown in Figure 22 for the end of years 1, 6, 12, 18 and 24. The mean ratio of the impacted and un-impacted population annual growth rate at the end of 24 years was 0.996. This indicates that there is only a small difference in growth rate between the impacted and un-impacted population.

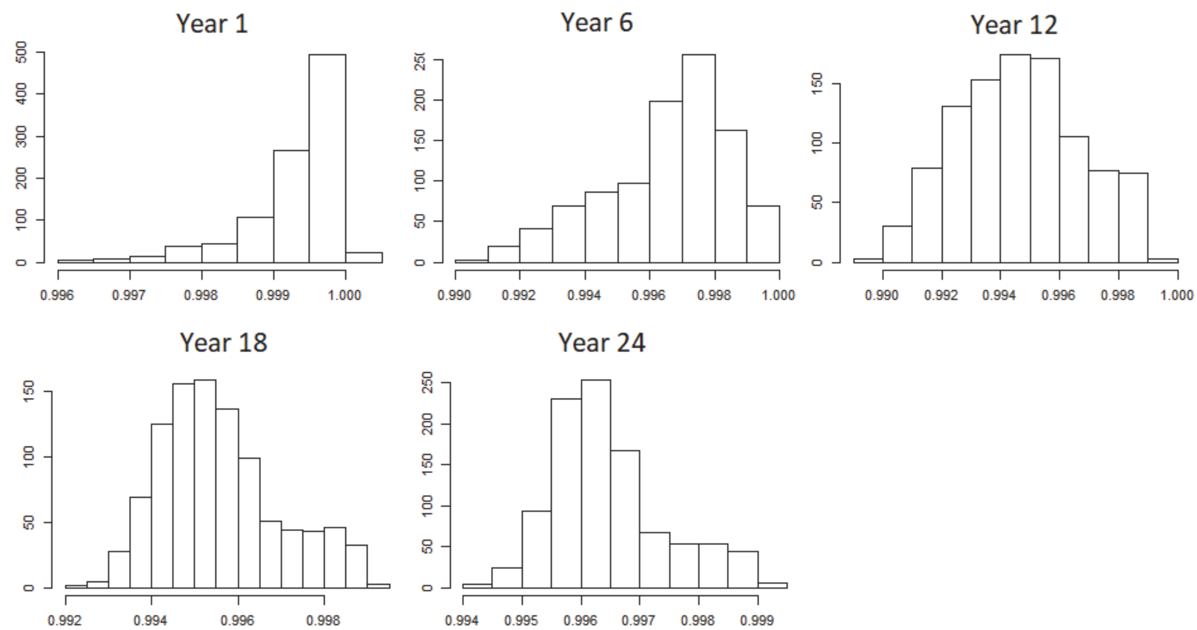

Figure 22. Ratio of impacted to un-impacted annual growth rate at the end of years 1, 6, 12, 18 and 24 for minke whale in Scenario 1.

3.4 Conclusion

In conclusion, outputs from iPCoD suggest that there is unlikely to be any long-term effect of pile driving/blasting during the construction of these developments on the North Sea harbour porpoise population or the grey seal population in the Forth and Tay.

Outputs from iPCoD suggest that the overall worst case pile driving/blasting scenario may affect the Scottish east coast bottlenose dolphin population and the Celtic and Greater North Sea minke whale population.

The overall worst case scenario for bottlenose dolphins showed that the impacted population was statistically smaller than the un-impacted population across all years in the simulation. However, the size of this difference was found to be relatively small, with the growth rate and centile metrics improving over time, suggesting recovery in the post-construction period. The confidence intervals substantially overlap for the simulation, with a small change in predicted growth rate. The worst case scenario considers all individuals are vulnerable to disturbance from all operations. We consider this to be precautionary.

The overall worst case for minke whale showed a significant decrease in the size of the impacted population. However, the expert elicitation process has not yet been updated for minke whale. The results presented in this report for minke whale are likely to be precautionary and should be interpreted with caution.

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ANNEX 1: PARAMETERS USED IN SENSITIVITY ANALYSIS

Parameter Name	Figure 2	Figure 3	Figure 4	Figure 5	Figure 6	Figure 7	Figure 8
nboot	25000	25000	25000	25000	25000	2000	25000
Spec	BND	BND	BND	HS	BND	BND	BND
propfemale	0.5	0.5	0.5	0.5	0.5	0.5	0.5
pmean	195	195	195	200	195	195	195
threshold	500	500	500	500	500	500	500
Surv[1]	0.9	0.9	0.9	0.55	0.9	0.9	0.9
Surv[7]	0.94	0.94	0.94	0.61	0.94	0.94	0.94
Surv[13]	0.9497	0.9497	0.9497	0.9451	0.9497	0.9497	0.9497
Fertility	0.3	0.3	0.3	0.88	0.3	0.3	0.3
age1	2	2	2	1	2	2	2
age2	9	9	9	4	9	9	9
pile_years	2	2	2	10	2	2	3
vulnmean	c(1)	c(1)	c(1)	c(1)	c(1)	c(1)	Varying
days	0	1	1 in (1) and 5 in (b)	0	2	0 in (a) and 1 in (b)	0
prop_dist_days	1	1	1	1	1	1	1
other_days	0	0	0	0	0	0	0
pilesx1	1	1	1	1	2	1	1
vulnpile[1,]	c(1)	c(1)	c(1)	c(1)	c(1,1)	c(1)	c(1)
numDT	c(60)	c(100) in (a) and c(180) in (b)	c(100)	c(20) in (a) and c(100) in (b)	c(60,60) in (a) and c(160,160) in (b)	Varying	c(5)
numPT	c(0)	c(0)	c(0)	c(0)	c(0,0)	0	0
Avoid	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
seasons	1	1	1	1	1	1	1
years	10	10	10	25	15	25	25
Day 1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Ncollisions	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0
K	NA	NA	NA	NA	NA	NA	NA
Fert_0	NA	NA	NA	NA	NA	NA	NA

ANNEX 2: PARAMETER VALUES USED IN SIMULATIONS

Parameter Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
nboot	10000	10000	10000	10000	10000	10000
Spec	BND	BND	BND	BND	BND	BND
propfemale	0.5	0.5	0.5	0.5	0.5	0.5
pmean	195	195	195	195	195	195
threshold	500	500	500	500	500	500
Surv[1]	0.9	0.9	0.9	0.9	0.9	0.9
Surv[7]	0.94	0.94	0.94	0.94	0.94	0.94
Surv[13]	0.9497	0.9497	0.9497	0.9497	0.9497	0.9497
Fertility	0.3	0.3	0.3	0.3	0.3	0.3
age1	2	2	2	2	2	2
age2	9	9	9	9	9	9
pile_years	7	7	7	7	7	7
vulnmean	c(1)	c(1)	c(1)	c(1)	c(1)	c(1)
pilesx1	8	8	8	8	8	8
vulnpile[1,]	c(1,1,1,1,1,1,1,1)	c(1,1,1,1,1,1,1,1)	c(1,1,1,1,1,1,1,1)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)
seasons	1	1	1	1	1	1
numDT	c(19,4,17,2,7,3,2,10)	c(19,4,17,2,7,3,2,10)	c(19,4,17,2,7,3,2,10)	c(19,4,17,2,7,3,2,10)	c(19,4,17,2,7,3,2,10)	c(19,4,17,2,7,3,2,10)
numPT	c(0,0,0,0,0,0,0,0)	c(0,0,0,0,0,0,0,0)	c(0,0,0,0,0,0,0,0)	c(0,0,0,0,0,0,0,0)	c(0,0,0,0,0,0,0,0)	c(0,0,0,0,0,0,0,0)
days	1	1	0	1	1	0
prop_dist_days	1	1	1	1	1	1
other_days	0	0	0	0	0	0
Avoid	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
years	25	25	25	25	25	25
Day1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Ncollisions	0	0	0	0	0	0
z	0	0	0	0	0	0
k	NA	NA	NA	NA	NA	NA
Fert_0	NA	NA	NA	NA	NA	NA

Parameter Values Used in the Bottlenose Dolphin Simulations

Parameter Name	Scenario 1	Scenario 2	Scenario 3
nboot	10000	10000	10000
Spec	GS	GS	GS
propfemale	0.5	0.5	0.5
pmean	14,714	14,714	14,714
threshold	500	500	500
Surv[1]	0.222	0.222	0.222
Surv[7]	0.94	0.94	0.94
Surv[13]	0.94	0.94	0.94
Fertility	0.84	0.84	0.84
age1	1	1	1
age2	5	5	5
pile_years	3	3	3
vulnmean	c(1)	c(1)	c(1)
pilesx1	4	4	4
vulnpile[1,]	c(1,1,1,1)	c(1,1,1,1)	c(1,1,1,1)
seasons	1	1	1
numDT	c(821,1058,27,14)	c(821,1058,27,14)	c(821,1058,27,14)
numPT	c(1,0,0,0)	c(1,0,0,0)	c(1,0,0,0)
days	1	1	0
prop_dist_days	1	1	1
other_days	0	0	0
Avoid	FALSE	TRUE	FALSE
years	25	25	25
Day1	FALSE	FALSE	FALSE
Ncollisions	0	0	0
z	0	0	0
k	NA	NA	NA
Fert_0	NA	NA	NA

Parameter Values Used in the Grey Seal Simulations

Parameter Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
nboot	1000	1000	1000	1000	1000	1000
Spec	HP	HP	HP	HP	HP	HP
propfemale	0.5	0.5	0.5	0.5	0.5	0.5
pmean	227,298	227,298	227,298	227,298	227,298	227,298
threshold	500	500	500	500	500	500
Surv[1]	0.6	0.6	0.6	0.6	0.6	0.6
Surv[7]	0.85	0.85	0.85	0.85	0.85	0.85
Surv[13]	0.85	0.85	0.85	0.85	0.85	0.85
Fertility	0.958	0.958	0.958	0.958	0.958	0.958
age1	1	1	1	1	1	1
age2	5	5	5	5	5	5
pile_years	7	7	7	7	7	7
vulnmean	c(1)	c(1)	c(1)	c(1)	c(1)	c(1)
pilesx1	8	8	8	8	8	8
vulnpile[1,]	c(1,1,1,1,1,1,1,1)	c(1,1,1,1,1,1,1,1)	c(1,1,1,1,1,1,1,1)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)
seasons	1	1	1	1	1	1
numDT	c(1205,61,2933,1177, 261,971,1103,1377)	c(1205,61,2933,1177 ,261,971,1103,1377)	c(1205,61,2933,1177, 261,971,1103,1377)	c(1205,61,2933,1177, 261,971,1103,1377)	c(1205,61,2933,1177, 261,971,1103,1377)	c(1205,61,2933,1177, 261,971,1103,1377)
numPT	c(0,0,7,77,0,0,0,0)	c(0,0,7,77,0,0,0,0)	c(0,0,7,77,0,0,0,0)	c(0,0,7,77,0,0,0,0)	c(0,0,7,77,0,0,0,0)	c(0,0,7,77,0,0,0,0)
days	1	1	0	1	1	0
prop_dist_days	1	1	1	1	1	1
other_days	0	0	0	0	0	0
Avoid	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
years	25	25	25	25	25	25
Day1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Ncollisions	0	0	0	0	0	0
z	0	0	0	0	0	0
k	NA	NA	NA	NA	NA	NA
Fert_0	NA	NA	NA	NA	NA	NA

Parameter Values Used in the Harbour Porpoise Simulations

Parameter Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
nboot	1000	1000	1000	1000	1000	1000
Spec	MW	MW	MW	MW	MW	MW
propfemale	0.5	0.5	0.5	0.5	0.5	0.5
pmean	23,528	23,528	23,528	23,528	23,528	23,528
threshold	500	500	500	500	500	500
Surv[1]	0.72	0.72	0.72	0.72	0.72	0.72
Surv[7]	0.77	0.77	0.77	0.77	0.77	0.77
Surv[13]	0.96	0.96	0.96	0.96	0.96	0.96
Fertility	0.9	0.9	0.9	0.9	0.9	0.9
age1	1	1	1	1	1	1
age2	9	9	9	9	9	9
pile_years	7	7	7	7	7	7
vulnmean	c(1)	c(1)	c(1)	c(1)	c(1)	c(1)
pilesx1	8	8	8	8	8	8
vulnpile[1,]	c(1,1,1,1,1,1,1,1)	c(1,1,1,1,1,1,1,1)	c(1,1,1,1,1,1,1,1)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)	c(1,0,1,0,0,0,0,1) c(0,1,0,1,1,1,1,0)
seasons	1	1	1	1	1	1
numDT	c(106,4,,168,77, 138,63,71,23)	c(106,4,,168,77, 138,63,71,23)	c(106,4,,168,77, 138,63,71,23)	c(106,4,,168,77, 138,63,71,23)	c(106,4,,168,77, 138,63,71,23)	c(106,4,,168,77, 138,63,71,23)
numPT	c(0,0,13,14,0,0,0,0)	c(0,0,13,14,0,0,0,0)	c(0,0,13,14,0,0,0,0)	c(0,0,13,14,0,0,0,0)	c(0,0,13,14,0,0,0,0)	c(0,0,13,14,0,0,0,0)
days	1	1	0	1	1	o
prop_dist_days	1	1	1	1	1	1
other_days	0	0	0	0	0	0
Avoid	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE
years	25	25	25	25	25	25
Day1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Ncollisions	0	0	0	0	0	0
z	0	0	0	0	0	0
k	NA	NA	NA	NA	NA	NA
Fert_0	NA	NA	NA	NA	NA	NA

Parameter Values Used in the Minke Whale Simulations

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