BERWICK BANK WIND FARM **OFFSHORE ENVIRONMENTAL IMPACT ASSESSMENT**

APPENDIX 10.4: MARINE MAMMALS IPCOD MODELLING REPORT

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CONTENTS

TABLES

FIGURES

1. INTRODUCTION

1. Berwick Bank Wind Farm Limited (BBWFL), a wholly owned subsidiary of SSE Renewables Limited (hereafter be referred to as 'the Applicant'), is proposing the development of the Berwick Bank Wind Farm (hereafter referred to as the 'Proposed Development'), an offshore wind farm off the east coast of Scotland. The Proposed Development array area is located in the outer Firth of Forth and Forth of Tay, approximately 37.8 km east of the Scottish Borders coastline (St Abb's Head) and 47.6 km from the East Lothian coastline. The Proposed Development array area will be connected to a SP Energy Networks (SPEN) substation at Branxton via a Proposed Development export cable corridor.

2. An Environmental Impact Assessment was (EIA) was carried out to determine the potential effects of the Proposed Development on sensitive marine mammal receptors from a range of different impacts. A key impact assessed was the potential for elevations in subsea noise during piling activities to lead to injury and behavioural disturbance to individuals. Subsea noise modelling was conducted to predict the potential spatial scale of the effect. In particular, for behavioural disturbance, the assessment predicted that the elevations in subsea noise leading to disturbance could extend over a considerable area and potentially affect a large number of individuals of the key species identified within the marine mammal study area.

3. Population modelling was therefore carried out to determine the potential for a short to medium term effects (piling could occur over a total duration of 372 days intermittently within a 52 month piling period during the eight year offshore construction timeframe) to result in long term population level effects on any species. The interim Population Consequences of Disturbance (iPCoD) model1 (developed by Sea Mammal Research Unit (SMRU) Consulting, collaborating 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 explained within this report.

1.1. IPCOD

4. The iPCoD model simulates the changes in a population over time, for both a disturbed and an undisturbed population. This provides a comparison of the type of changes that could occur resulting from natural environmental variation, demographic stochasticity (i.e. variability in population growth rates) and disturbance (Harwood *et al.,* 2014; King *et al.,* 2015).

5. 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). In the case of the iPCoD model, the marine mammal experts 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 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). 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 a 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.

6. A potential limitation of the iPCoD model is that no form of density dependence has been incorporated due to the uncertainties as to how this may occur. As discussed in Harwood *et al*. (2014), the concept of density-dependence is fundamental to understanding how animal populations respond to a reduction in their size. In population biology, density-dependant 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-dependant factors become limiting again (i.e. population remains at carrying capacity). The limitations for assuming a simple linear ratio between the maximum net productivity level and carrying capacity have been highlighted by Taylor and Master (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.

2. METHODOLOGY

2.1. PILING PARAMETERS

2.1.1. MAXIMUM DESIGN SCENARIO

7. The maximum design scenario for piling at the Proposed Development assumes that 5.5 m diameter piled jacket foundations will be installed using a maximum hammer energy of 4,000 kJ. This represents the absolute maximum energy likely to be required at any point across foundation installation. Taken as an average, the maximum hammer energy is likely to be no greater than 3,000 kJ. For the purposes of population modelling, the assessment focussed only on the absolute maximum of 4,000 kJ as this represented the maximum adverse design (as agreed by consultees at Marine Mammal Road Map Meeting 3, 18 January 2022).

8. Piling will be required at up to 179 wind turbine foundations and ten offshore substation platform (OSP)/Offshore convertor station platform foundations. The maximum design scenario was based on concurrent piling at wind turbine foundations with the largest separation between piling locations. Although piling could occur concurrently at a wind turbine and OSP/Offshore convertor station platform foundation these locations would be closer together compared to two wind turbine foundations. Therefore, piling at OSPs/Offshore convertor station platforms was considered as a single piling event and modelled as a separate operation within iPCoD but not coincident with concurrent piling at the wind turbine foundations (since this would represent three concurrent piling events which is not proposed as part of the Proposed Development design). Using the maximum number of hours of piling per pile, the number of piles likely to be installed within 24 hours and the number of concurrent installation vessels, it was possible to estimate the maximum number of days (24 hours) within which piling could occur on the basis of two piling operations:

[1] https://smruconsulting.com/?page_id=12050

- 287 piling days (concurrent vessel) for the 179 wind turbines; and
- 85 piling days (single vessel) for the ten OSPs/Offshore convertor station platforms.

9. It is estimated that piling activity at the Proposed Development will take place in three campaigns and an indicative piling construction schedule is provided in Table 2.1. Piling could potentially take place at any point within the foundation installation phases; however, for the purposes of developing the piling programme for iPCoD (a requirement of the model) an indicative programme has been developed based on a realistic installation approach. Therefore, within each campaign, a realistic scenario has been assumed where there are nine months of piling followed by 12 months where jackets are installed over the piles.

2.1.2. NOISE MODELLING (CONVERSION FACTORS)

10. Subsea noise modelling was undertaken to predict the potential spatial scale of the effect of subsea noise. Potential injury, in the form of a PTS was determined using published and peer reviewed thresholds developed by Southall *et al.* (2019) for the dual metrics un-weighted peak Sound Pressure Levels (SPL_{pk}) and marine mammal hearing-weighted cumulative Sound Exposure Level (SEL_{cum}). For behaviour disturbance a dose-response approach was undertaken using the metric single strike Sound Exposure Level (SEL_{ss}) with contours modelled in 5 dB increments based on Graham *et al.* (2017). A full description of subsea noise modelling is provided in volume 3, appendix 10.1 and summarised in section 10.11.1 of volume 2, chapter 10. Further to discussion via the marine mammal Road Map process, the subsea noise modelling investigated the sensitivity of using different conversion factors to determine the amount of energy converted into received sound. In this respect, three conversion factors were modelled: 10% reducing to 1% as piling progresses, 4% reducing to 0.5% as piling progresses and a constant conversion factor of 1% throughout piling.

11. A detailed study of existing literature was undertaken by Seiche Ltd, including exploration of published data from pile driving at other wind farms. Subsequently, the subsea noise modelling report recommended that the 4% reducing to 0.5% conversion factor was an appropriate conservative approach. This was evaluated alongside the 1% conversion factor in the full marine mammal assessment of effects.

12. Whilst 10% reducing to 1% was not included in the marine mammal assessment of effects (as it was determined to be overly conservative and therefore an inaccurate representation of potential impact), for completeness the results of all conversion factor scenarios have been analysed and the estimated numbers of animals potentially affected for all scenarios are presented in an appendix to the marine mammal chapter (volume 3, appendix 10.5).

13. For the purposes of population modelling, all three conversion factors were included to provide a comparison. For reasons described above, only the results of the 4% reducing to 0.5% conversion factor and 1% constant conversion factor have been taken forward to present in the marine mammal chapter (volume 3, appendix 10.5). The iPCoD modelling results are presented in order of the largest potential quantitative effect to the smallest:

- 10% reducing to 1% conversion factor;
- 1% constant conversion factor throughout the piling period; and
- 4% reducing to 0.5% conversion factor.

14. Note that in terms of behavioural effects, the 1% constant conversion factor was found to result in a higher SEL at any point over the piling sequence compared to the 4% reducing to 0.5% conversion factor and therefore led to a larger potential effect area (see Figure 10.4 in volume 2, chapter 10 and further explanation in volume 4, appendix 10.5).

Table 2.1: Indicative Piling Construction Programme

Foundations	2026 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind turbines				P	P	P	P	P	P	P	P	P
Wind turbines												
OSP/Offshore convertor station platform	P	P	P	J	J	J	J	J	J	J	J	J
OSP/Offshore convertor station platform												

Foundations	2027 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind turbines	J	J	J	J	J	J	J	J	J	J	J	J
Wind turbines				P	P	P	P	P	P	P	P	P
OSP/Offshore convertor station platform												
OSP/Offshore convertor station platform	P	P	P	J	J	J	J	J	J	J	J	J

Foundations	2028 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind turbines												
Wind turbines	J	J	J	J	J	J	J	J	J	J	J	J
OSP/Offshore convertor station platform												
OSP/Offshore convertor station platform												

Foundations	2029 Jan-Dec	2030 Jan-Dec
Wind turbines		
Wind turbines		
OSP/Offshore convertor station platform		
OSP/Offshore convertor station platform		

Foundations	2031 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind turbines				P	P	P	P	P	P	P	P	P
Wind turbines												
OSP/Offshore convertor station platform	P	P	P	J	J	J	J	J	J	J	J	J
OSP/Offshore convertor station platform												

Foundations	2032 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind turbines	J	J	J	J	J	J	J	J	J	J	J	J
Wind turbines												
OSP/Offshore convertor station platform												
OSP/Offshore convertor station platform												

Foundation installation using concurrent vessels **Foundation installation using single vessels** **Period with no foundation installation**

P =indicative scheduling for piling within piling campaign programme; J =indicative installation of jackets over installed piles

2.2. KEY SPECIES

15. Key species to be included in the population modelling were discussed as part of the marine mammal Road Map consultation process and stakeholders requested inclusion of the following species:

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

16. The first version of the iPCoD model was considered to be suitable for all species above with the exception of harbour seal since data on trends in the abundance of harbour seal were limited when iPCoD was initially developed. Subsequent count data has, however, allowed a better understanding of the demographics of this population. In the Firth of Tay and Eden Estuary Special Area of Conservation (SAC), the population declined between 2002 and 2017 by 18.6%, however, data from the 2016 counts suggested that the SAC represents only 15% of the East of Scotland Seal Management Area (SMA). When including counts from the wider Firth of Forth, the total East of Scotland SMA population appears to be more stable in recent years. Despite the potential limitations of the model for harbour seal, the consultees requested (25 February 2022) that this species was included in the population modelling due to concerns over the historic decline of harbour seal on the east coast of Scotland.

2.3. MODEL INPUTS

17. The iPCoD model v5.2[2] was set up using the program R v4.1.2 (2021) with RStudio as the user interface. To enable the iPCoD model to be run, the following data were provided:

- demographic parameters for the key species;
- user specified input parameters:
  - vulnerable subpopulations; and
  - residual days of disturbance.
- number of animals predicted to experience PTS and/or disturbance during piling; and
- estimated piling schedule during the proposed construction programme.

2.3.1. DEMOGRAPHIC PARAMETERS

18. Demographic parameters for the key species assessed in the population model are presented in Table 2.2.

Table 2.2: Demographic Parameters Recommended for Each Species for the Relevant Management Unit (MU)/SMAs (Sinclair *et al.,* 2019)

Species	MU/SMA	Age Calf/Pup Becomes Independent	Age of First Birth	Calf/Pup Survival	Juvenile Survival	Adult Survival	Fertility	Growth Rate
Parameter Code		**Age1**	**Age2**	**Surv[1]**	**Surv[2]**	**Surv[13]**	**Fertility**	**Growth Rate**
Harbour porpoise	North Sea	1	5	0.8455	0.85	0.925	0.34	1.000
Bottlenose dolphin	Coastal East	3	9	0.925	0.962	0.98	0.24	1.0365
Minke whale	European waters	1	9	0.70	0.77	0.96	0.91	1.000
Grey seal	All SMAs	1	6	0.222	0.94	0.94	0.84	1.010
Harbour seal	East Coast Scotland	1	4	0.4	0.78	0.92	0.85	1.000

2.3.2. REFERENCE POPULATIONS

19. MU populations and vulnerable sub-populations were specified in the model as reference populations against which the effects (i.e. number of animals suffering PTS/disturbed) were assessed. The MUs and vulnerable subpopulations were agreed with stakeholders as part of the Road Map process (25 February 2022). Vulnerable subpopulations were requested for harbour porpoise and minke whale only. The results of the assessment using vulnerable subpopulations should, however, be interpreted with caution as the relevant area used to delineate the subpopulation (SCANS-III block R) are survey units rather than representing a biologically meaningful area. Table 2.3 provides the reference populations used in the iPCoD.

Table 2.3: Reference Populations Used in the iPCoD

Species	MU Population		Vulnerable Subpopulation	
	MU	**Population**	**Relevant Area**	**Population**
Harbour porpoise	North Sea	346,601	SCANS-III block R	38,646 (11.1% of MU)
Bottlenose dolphin	Coastal East Scotland	224	N/A	N/A
Minke whale	Celtic and Greater North Seas	20,118	SCANS-III block R	2,498 (12.4% of MU)
Grey seal	East Scotland plus Northeast England	42,600	N/A	N/A
Harbour seal	East Scotland[1]	476	N/A	N/A

1 The offshore EIA Report considers the reference population as East Scotland plus Northeast England MU, however, further to discussions with NatureScot and Marine Scotland Licencing Operations Team during the Marine Mammal Road Map consultation it was requested that the iPCoD model was run against the East Scotland population only.

[2] https://smruconsulting.com/?page_id=13194

2.3.3. RESIDUAL DAYS DISTURBANCE

20. Empirical evidence from constructed wind farms (e.g. Graham *et al*., 2019; Brandt *et al*., 2011) suggests that the detection of animals returns to baseline levels in the hours following a 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. Due to the potential duration of piling occurring at the Proposed Development (up to 10 hours for installation of a single wind turbine jacket pile and up to five piles installed per 24 hours using two vessels), piling could occur for most of the 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.

2.3.4. NUMBER OF ANIMALS (PTS/DISTURBANCE)

21. The number of animals predicted to experience PTS and/or disturbance was based on the density values provided as part of the baseline assessment (volume 3, appendix 10.2). For each species studied, the density values – including a mean and a maximum - were provided and these were used to quantify the number of animals affected, based on the modelled noise contours. For the purposes of this population modelling, the maximum density values were adopted to provide a conservative assessment (Table 2.4).

Table 2.4: Maximum Density Values Applied to the Calculation of Number of Animals Potentially Affected and Taken Forward for the iPCoD Model

Species	Density (Animals per km^2)	Notes
Harbour porpoise	0.826	Average density taken as summer peak from site-specific aerial survey data.
Bottlenose dolphin (coastal population)	0.294 (Firth of Tay) 0.197 (all other areas)	Contours overlaid with bottlenose dolphin coastal areas with higher density in Firth of Tay (FoT) segment compared to other segments where a conservative average was provided.
Minke whale	0.0387	SCANS-III block R density estimate.
Grey seal	1.2	Density taken from Carter *et al.* (2020) updated seal density maps.
Harbour seal	0.002	Density taken from Carter *et al.* (2020) updated seal density maps.

22. The number of animals predicted to be injured or disturbed were calculated using these maximum densities and were estimated from the piling locations that gave rise to the largest potential impact ranges. Therefore, the highest numbers of animals potentially affected at any one time are assessed.

23. For all scenarios, mitigation will be applied (see volume 2, chapter 10), including:

- pre-start monitoring using Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM);
- Acoustic Deterrent Device (ADD) for a period of 30 minutes prior to commencement of piling;
- low energy hammer initiation;
- soft start for a period of 30 minutes; and
- a gradual ramp up to full hammer.

24. With these measures in place, the residual number of individuals potentially affected by PTS was zero for all species. The exception to this was for the scenario of 10% reducing to 1% conversion factor where for minke whale, a residual estimate of one individual could potentially experience PTS during piling.

25. The total number of individuals affected by piling at any one time are provided in the Table 2.5 and represent the number disturbed (with exception of minke whale for the 10% reducing to 1% conversion factor scenario). Where residual PTS is predicted after application of mitigation measures, as outlined in paragraph 23, this is show in parenthesis.

Table 2.5: Estimated Number of Animals Predicted to be Disturbed at any one Time During Piling Using Different Conversion Factors

Species	Number of Animals Affected: Concurrent Piling Wind Turbine			Number of Animals Affected: Single Piling OSP/Offshore Convertor Station Platform		
	10% to 1%	**1%**	**4% to 0.5%**	**10% to 1%**	**1%**	**4% to 0.5%**
Harbour porpoise	3,591	2,815	2,133	2,383	1,828	1,131
Bottlenose dolphin (coastal population)	8	5	4	6	4	3
Minke whale	168 (1)	132	100	112	86	60
Grey seal	1,940	1,450	977	1,035	720	453
Harbour seal	4	3	2	2	1	1

Piling schedule

26. The piling schedule was developed from the project design envelope which provided an estimate of the number of days piling for the wind turbine and OSP/Offshore convertor station platform foundations within a defined piling phase, which is scheduled to take place within an overall offshore piling construction window of March 2026 to October 2028 (Table 2.1).

27. A total of 287 days (24-hour periods) on which piling could occur (based on the maximum design scenario) was estimated for concurrent piling at the wind turbines. A total of 85 days of piling (24-hour periods) on which piling could occur was estimated for single piling at the OSPs/Offshore convertor station platforms. The number of piling days was allocated evenly across months (Table 2.6). The scenario of number of consecutive days piling followed by non-piling days was considered to be typical of a piling construction programme which would allow for weather downtime, breakdowns and/or return of vessel to port.

28. The first two time points in the model were selected to coincide with key periods of the piling schedule. Subsequent time points were selected up to year 25 as follows:

- time point 4: end of first two piling campaigns which run sequentially between 2026 and 2027;
- time point 8: end of third piling campaign which ends December 2031;
- time point 13: 13 years after the start of the offshore construction phase;
- time point 19: 19 years after the start of the offshore construction phase; and
- time point 25: 25 years after the start of the offshore construction phase.

Table 2.6: Piling Schedule Assessed within the iPCoD Model

Location	Total Duration of Piling Campaign	Phasing of Piling Within the Offshore Construction Phase	Number of Days Piling per Phase	Assumptions
Wind Turbines	52 months	Apr 2026 to Dec 2026	97 days	Piling days distributed evenly across months with typical scenario of ~5 days on and ~10 days off.
		Apr 2027 to Dec 2027	95 days	
		Apr 2031 to Dec 2031	95 days	
OSPs/Offshore convertor station platforms	4 months	Jan 2026 to Mar 2026	34 days	Piling days distributed evenly across months with typical scenario of ~ 2/3 days on and ~3/4 days off for first two phases, then 1 day on and 5 days off for last phase.
		Mar 2027 to Dec 2027	34 days	
		Mar 2031 to Dec 2031	17 days	

2.4. CUMULATIVE PROJECTS

29. Population modelling was run for cumulative scenarios based on the scheduling of offshore construction for projects within the relevant study areas for each species. For harbour porpoise and minke whale the cumulative assessment considered the MU reference populations only and not the vulnerable subpopulations (defined within SCANS block R) as cumulative projects fell outside this SCANS block and therefore this subpopulation was not relevant with respect to the cumulative assessment. Details of piling schedules were unknown as offshore wind farm assessments typically only provide indicative offshore construction times (Table 2.7). The maximum design scenario for each project was based on the maximum adverse consented or proposed design for each project.

Table 2.7: Indicative Offshore Construction Schedules for Each of the Cumulative Projects

Project	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Berwick Bank Wind Farm					P	P				P		
Seagreen 1A												
Inch cape												
Moray West												
Dogger Bank Creyke Beck A												
Dogger Bank Creyke Beck B												
Dogger Bank Teesside A												
Sofia												
Hornsea Project Three												
Hornsea Project Four												

P = Indicative piling campaign at the Proposed Development

30. The iPCoD model was set up as described above in terms of the demographic parameters (section 2.3.1), reference populations (section 2.3.2) and with the same days of residual disturbance specified (section 2.3.3). The number of animals affected for each of the key species and number of days on which piling occurred was taken from the maximum design scenario for each of the projects and has been referenced in the following sections. As piling schedules were unknown, the piling days were spread evenly throughout the offshore construction phases shown in Table 2.7.

31. Time points in the model were selected to coincide with the following periods:

- time point 2: start of 2023, piling commences at four projects;
- time point 3: start of 2024, piling continues with a total of eight projects potentially piling;
- time point 4: start of 2025, piling continues with a total of seven projects potentially piling;
- time point 5: start of 2026, piling continues at six projects plus start of offshore construction phase at the Proposed Development (just prior to start of piling at the Proposed Development);
- time point 7: start of year 2028, piling continues at cumulative projects and is completed after the first two piling campaigns at the Proposed Development;
- time point 11: start of year 2032, piling continues at cumulative projects and is completed after the third piling campaign at the Proposed Development;
- time point 19: start of year 2040, 8 years after completion of piling at all projects; and
- time point 25: start of year 2046, 14 years after completion of piling at all projects.

32. For the cumulative projects only the 1% conversion factor was modelled for the Proposed Development as this represented the maximum spatial effect range compared to the 4% reducing conversion factor. A conversion factor of 10% reducing was not used as this was deemed to be unrepresentative (see section 2.1.2).

2.4.1. HARBOUR PORPOISE

33. Cumulative projects for harbour porpoise were considered across the regional marine mammal study area which encompassed the northern North Sea. A summary of the number of harbour porpoise affected and number of piling days for each of cumulative projects is provided below (Table 2.8).

Table 2.8: Summary of Cumulative Projects Included in iPCoD for Harbour Porpoise

Project	Number of Piled Foundations	Scenario	Total Piling Duration (hours)	Number of Piling Days	Number of Animals Disturbed	% Reference Population	Source
Seagreen 1A	36	2,300 kJ single piling	432	36	1,882	0.55	Seagreen Wind Energy Ltd (2020)
Inch Cape	72	5,000 kJ concurrent piling	444	74	302	0.1	Inch Cape Offshore Limited (2018)
Moray West	85	5,000 kJ concurrent piling	1,056	44	1,609	0.49	Moray West (2018)
Dogger Creyke Beck A	300	3,000 kJ concurrent piling	4,858	159	3,119	1.3	Forewind (2013)
Dogger Creyke Beck B	300	3,000 kJ concurrent piling	4,858	159	4,394	1.89	Forewind (2013)
Dogger Bank Teesside A	120	4,000 kJ single piling	420	120	2,148	0.95	Royal HaskoningDHV (2020)
Sofia	200	4,000 kJ single piling	1,100	71	2,263	0.995	Innogy (2020)
Hornsea Project Three	300	3,000 kJ concurrent piling	1,276	219	7,330	2.12	GoBe (2018a)
Hornsea Project Four	180	3,000 kJ concurrent piling	792	232	9,686	2.80	SMRU Consulting (2021)

2.4.2. BOTTLENOSE DOLPHIN

34. Cumulative projects for bottlenose dolphin were considered across the north-east of Scotland which encompassed the region between the northern part of Moray Firth to the southern part of the Firth of Forth. A summary of the number of bottlenose dolphin affected and number of piling days for each of cumulative projects is provided below (Table 2.9).

Table 2.9: Summary of Cumulative Projects Included in iPCoD for Bottlenose Dolphin

Project	Number of Piled Foundations	Scenario	Total Piling Duration (hours)	Number of Piling days	Number of Animals Disturbed	% Reference Population	Source
Seagreen 1A	36	2,300 kJ single piling	432	36	4	2.1	Seagreen Wind Energy Ltd (2020)
Inch Cape	72	5,000 kJ concurrent piling	444	74	8	4.1	Inch Cape Offshore Limited (2018)
Moray West	85	5,000 kJ concurrent piling	1,056	44	15	7.5	Moray West (2018)

2.4.3. MINKE WHALE

35. Cumulative projects for minke whale were considered across the regional marine mammal study area which encompassed the northern North Sea. A summary of the number of minke affected and number of piling days for each of cumulative projects is provided below (Table 2.10).

Table 2.10: Summary of Cumulative Projects Included in iPCoD for Minke Whale

Project	Number of Piled Foundations	Scenario	Total Piling Duration (hours)	Number of Piling Days	Number of Animals Disturbed	% Reference Population	Source
Seagreen 1A	36	2,300 kJ single piling	432[1]	36[1]	297[2]	313[2]	Seagreen Wind Energy Ltd (2012) Seagreen Wind Energy Ltd (2020)
Inch Cape	72	5,000 kJ concurrent piling	444	74	444	158	Inch Cape Offshore Limited (2018)
Moray West	85	5,000 kJ concurrent piling	1,056	44	1,056	30	Moray West (2018)
Dogger Creyke Beck A	300	3,000 kJ concurrent piling	4,858	159	4,858	14	Forewind (2013)
Dogger Creyke Beck B	300	3,000 kJ concurrent piling	4,858	159	4,858	22	Forewind (2013)
Dogger Bank Teesside A	120	4,000 kJ single piling	420	120	420	35	Royal HaskoningDHV (2020)
Sofia	200	4,000 kJ single piling	1,100	71	1,100	39	Innogy (2020)
Hornsea Project Three	300	3,000 kJ concurrent piling	1,276	219	1,276	51	GoBe (2018a)
Hornsea Project Four	180	3,000 kJ concurrent piling	792	232	792	60	SMRU Consulting (2021)

1 The number of days of piling is based on the 2020 Seagreen 1A Piling Strategy (Seagreen Wind Energy Ltd, 2020) as the number of piled foundations has been reduced since the original EIA (Seagreen Wind Energy Ltd, 2012).

2 The number of minke whale potentially disturbed at any one time is based on impacts of piling at Seagreen Bravo presented in the original EIA (Seagreen Wind Energy Ltd, 2012), as it represents the worst-case number when compared with numbers presented in later documents.

2.4.4. GREY SEAL

36. Cumulative projects for grey seal were considered across the north-east of Scotland which encompassed the region between the northern part of Moray Firth to the southern part of the Firth of Forth. A summary of the number of grey seals affected and number of piling days for each of cumulative projects is provided below (Table 2.11).

Table 2.11: Summary of Cumulative Projects Included in iPCoD for Grey Seal

Project	Number of Piled Foundations	Scenario	Total Piling Duration (hours)	Number of Piling Days	Number of Animals Disturbed	% Reference Population	Source
Seagreen 1A	36	2,300 kJ single piling	432[1]	36[1]	465[2]	8.0[2]	Seagreen Wind Energy Ltd (2012) Seagreen Wind Energy Ltd (2020)
Inch Cape	72	5,000 kJ concurrent piling	444	74	1,236	7.7	Inch Cape Offshore Limited (2018)

1 The number of days of piling is based on the 2020 Seagreen 1A Piling Strategy (Seagreen Wind Energy Ltd, 2020) as the number of piled foundations has been reduced since the original EIA (Seagreen Wind Energy Ltd, 2012).

2 The number of grey seal potentially disturbed at any one time is based on impacts of piling at Seagreen Bravo presented in the original EIA (Seagreen Wind Energy Ltd, 2012), as it represents the worst-case number when compared with numbers presented in later documents.

2.4.5. HARBOUR SEAL

37. Cumulative projects for harbour seal were considered across the north-east of Scotland which encompassed the region between the northern part of Moray Firth to the southern part of the Firth of Forth. A summary of the number of harbour seal affected and number of piling days for each of cumulative projects is provided below (Table 2.12).

Table 2.12 Summary of Cumulative Projects Included in iPCoD for Harbour Seal

Project	Number of Piled Foundations	Scenario	Total Piling Duration (hours)	Number of Piling Days	Number of Animals Disturbed	% Reference Population	Source
Seagreen 1A	36	2,300 kJ single piling	432[1]	36[1]	51[2]	9.0[2]	Seagreen Wind Energy Ltd (2012) Seagreen Wind Energy Ltd (2020)
Inch Cape	72	5,000 kJ concurrent piling	444	74	20	3.9	Inch Cape Offshore Limited (2018)

1 The number of days of piling is based on the 2020 Seagreen 1A Piling Strategy (Seagreen Wind Energy Ltd, 2020) as the number of piled foundations has been reduced since the original EIA (Seagreen Wind Energy Ltd, 2012).

2 The number of harbour seal potentially disturbed at any one time is based on impacts of piling at Seagreen Bravo presented in the original EIA (Seagreen Wind Energy Ltd, 2012), as it represents the worst-case number when compared with numbers presented in later documents.

2.5. SUMMARY OF SCENARIOS MODELLED IN IPCOD

38. Table 2.13 presents a summary of the scenarios modelled through iPCoD for each species for the Proposed Development alone and for cumulative projects.

Table 2.13: Summary of Scenarios Modelled for Each Species in iPCoD for the Proposed Development

Scenario (Reference)		Hammer Energy	Conversion Factor	Population Size	Vulnerable Subpopulation
Harbour Porpoise					
1	Berwick Bank Wind Farm	4,000 kJ	10% reducing to 1%	346,601	100%
1a		4,000 kJ	10% reducing to 1%		11.1%
2		4,000 kJ	1% constant		100%
2a		4,000 kJ	1% constant		11.1%
3		4,000 kJ	4% reducing to 0.5%		100%
3a		4,000 kJ	4% reducing to 0.5%		11.1%
4	Cumulative projects	4,000 kJ	1% constant	100%	
Bottlenose Dolphin					
1	Berwick Bank Wind Farm	4,000 kJ	10% reducing to 1%	224	100%
2		4,000 kJ	1% constant		100%
3		4,000 kJ	4% reducing to 0.5%		100%
4	Cumulative projects	4,000 kJ	1% constant		100%
Minke Whale					
1	Berwick Bank Wind Farm	4,000 kJ	10% reducing to 1%	20,118	100%
1a		4,000 kJ	10% reducing to 1%		12.4%
2		4,000 kJ	1% constant		100%
2a		4,000 kJ	1% constant		12.4%
3		4,000 kJ	4% reducing to 0.5%		100%
3a		4,000 kJ	4% reducing to 0.5%		12.4%
4	Cumulative projects	4,000 kJ	1% constant		100%
Grey Seal					
1	Berwick Bank Wind Farm	4,000 kJ	10% reducing to 1%	42,600	100%
2		4,000 kJ	1% constant		100%
3		4,000 kJ	4% reducing to 0.5%		100%
4	Cumulative projects	4,000 kJ	1% constant		100%
Harbour Seal					
1	Berwick Bank Wind Farm	4,000 kJ	10% reducing to 1%	586	100%
2		4,000 kJ	1% constant		100%
3		4,000 kJ	4% reducing to 0.5%		100%
4	Cumulative projects	4,000 kJ	1% constant		100%

3. RESULTS

3.1. HARBOUR PORPOISE

39. Results of the iPCoD modelling for harbour porpoise using the maximum adverse design of 10% reducing to 1% conversion factor for the MU population (Scenario 1) are presented in Table 3.1 and Figure 3.1. Results are expressed as the predicted difference in the mean population size of an undisturbed population versus a disturbed population and is provided as the median of the ratio of impacted to unimpacted

population size (also referred to as the ‘median counterfactual of population size’; Sinclair *et al.,* 2020). Thus, for a ratio of one there is no difference between the trajectories of disturbed versus undisturbed populations. Conversely, for a ratio of <1 the median impacted population size is smaller than the median unimpacted population size.

40. The results show that for the 10% reducing to 1% conversion factor the median counterfactual of population size was 99.9% at a time point of the start of year eight (coinciding with the end of the third piling campaign at the Proposed Development) onwards until the maximum 25-year time point. Therefore, given that the differences in disturbed to undisturbed populations approaches a ratio of one there is not considered to be a potential for a long-term effect on this species. This was also the case when considered against the SCANS Block R as a vulnerable subpopulation (Scenario 1a) (Table 3.1, Figure 3.2).

41. When using the 1% conversion factor throughout the piling phase scenario for the MU population (Scenario 2), the median counterfactual of population size was also 99.9% at the start of year eight (end of the third piling campaign at the Proposed Development) onwards until the maximum 25-year point (Table 3.1, Figure 3.3). As before there is not considered to be a potential for a long-term effect on this species. This was also the case when considered against the SCANS Block as a vulnerable subpopulation (Scenario 2a) (Figure 3.4).

42. When using the 4% reducing to 0.5% conversion factor scenario for the MU population (Scenario 3), the median counterfactual of population size was also 99.9% at start of year eight onwards until the maximum 25-year point (Table 3.1,Figure 3.5). As before there is not considered to be potential for a long-term effect on this species. This was also the case when considered against the SCANS Block as a vulnerable subpopulation (Scenario 3a) (Table 3.1,Figure 3.2).

43. For the cumulative scenario assessed against the MU population (Scenario 4), where multiple projects may be piling either sequentially or concurrently within the regional marine mammal study area, the population modelling suggested a slight decrease in the median counterfactual of population size with a median ratio 99.8 at time point 5 (just before piling starts at the Proposed Development) (Table 3.1, Figure 3.7:). This reduces slightly to a median counterfactual of population size of 99.2% after the first two piling campaigns at the Proposed Development and remains at this ratio up to time point 25.

Table 3.1: Population Trajectory of Harbour Porpoise Showing the Mean and Upper and Lower Confidence Limits at Different Time Points (Years After Start of Offshore Construction Phase[3]).

Time Point (Years Following Commencement of Piling)	Unimpacted Population			Impacted Population			Median Ratio of Population Size
	Mean	Lower 2.5%	Upper 97.5%	Mean	Lower 2.5%	Upper 97.5%	
Scenario 1: 10% to 1% Conversion Factor (no Vulnerable Subpopulation)							
4	348037	305075	389459	347647	304464	388892	0.999874
8	347206	292261	410287	346770	292211	410204	0.999902
13	348211	278136	432803	347665	277637	430471	0.999871
19	350140	263254	457930	349585	263254	456423	0.999862
25	350174	251710	464881	349619	251710	463390	0.999865
Scenario 1a: 10% to 1% Conversion Factor (11.1% Vulnerable Subpopulation)							
4	345995	302448	389615	345289	302081	388577	0.998480
8	347087	288463	413769	346310	287988	412890	0.998359
13	346919	274797	433715	345965	274685	433193	0.997911
19	347297	262189	443565	346329	261851	442893	0.997886
25	348204	252171	471586	347232	251613	470194	0.997872
Scenario 2: 1% Conversion Factor (no Vulnerable Subpopulation)							
4	346554	303423	388494	346275	303345	387730	0.999934
8	348122	288196	406988	347813	288178	406335	0.999943
13	347843	276552	432406	347458	276476	431231	0.999929
19	348423	259554	457068	348031	258606	455797	0.999929
25	348614	258220	472244	348225	258211	471163	0.999930
Scenario 2a: 1% Conversion Factor (11.1% Vulnerable Subpopulation)							
4	345995	302448	389615	345289	302081	388577	0.998488
8	347087	288463	413769	346310	287988	412890	0.998359
13	346919	274797	433715	345965	274685	433193	0.997911
19	347297	262189	443565	346329	261851	442893	0.997886
25	348204	252171	471586	347232	251613	470194	0.997872
Scenario 3: 4% to 0.5% Conversion Factor (no Vulnerable Subpopulation)							
4	345698	304357	389590	345494	304306	389590	0.999969
8	345746	286880	406707	345514	286799	406505	0.999973
13	346807	273806	441622	346522	273806	441054	0.999966
19	348895	267304	458832	348602	267300	457743	0.999964
25	349709	251072	471885	349416	251072	469630	0.999962
Scenario 3: 4% to 0.5% Conversion Factor (11.1% Vulnerable Subpopulation)							
4	345091	303431	384642	344751	303417	384335	0.999367
8	345289	291141	405616	344909	290872	405305	0.999345
13	345298	276698	425563	344826	276682	424177	0.999176
19	343719	260099	440625	343241	259769	439573	0.999155
25	343243	250264	456858	342765	250222	456591	0.999157
Scenario 4: CUMULATIVE PROJECTS 1% Conversion Factor (no Vulnerable Subpopulation)							
2	347163	319577	372550	347163	319577	372550	1.000000
3	346552	309884	381550	346000	309712	381532	0.999456
4	346782	306842	387222	345198	305106	385529	0.997704
5	346711	298435	391533	345352	297577	389971	0.998052
7	346429	292186	401471	342108	288406	397890	0.992123
11	347473	284059	419678	344005	282889	416580	0.992123
19	349104	270496	452426	345375	267803	447414	0.992123
25	349064	253686	467646	345331	251355	464689	0.992123

[3] Note: Year 4 = Start of 2028 (After Completion of First Two Piling Campaigns) and Year 8 = Start of 2032 (After Completion of Third and Final Piling Campaign).

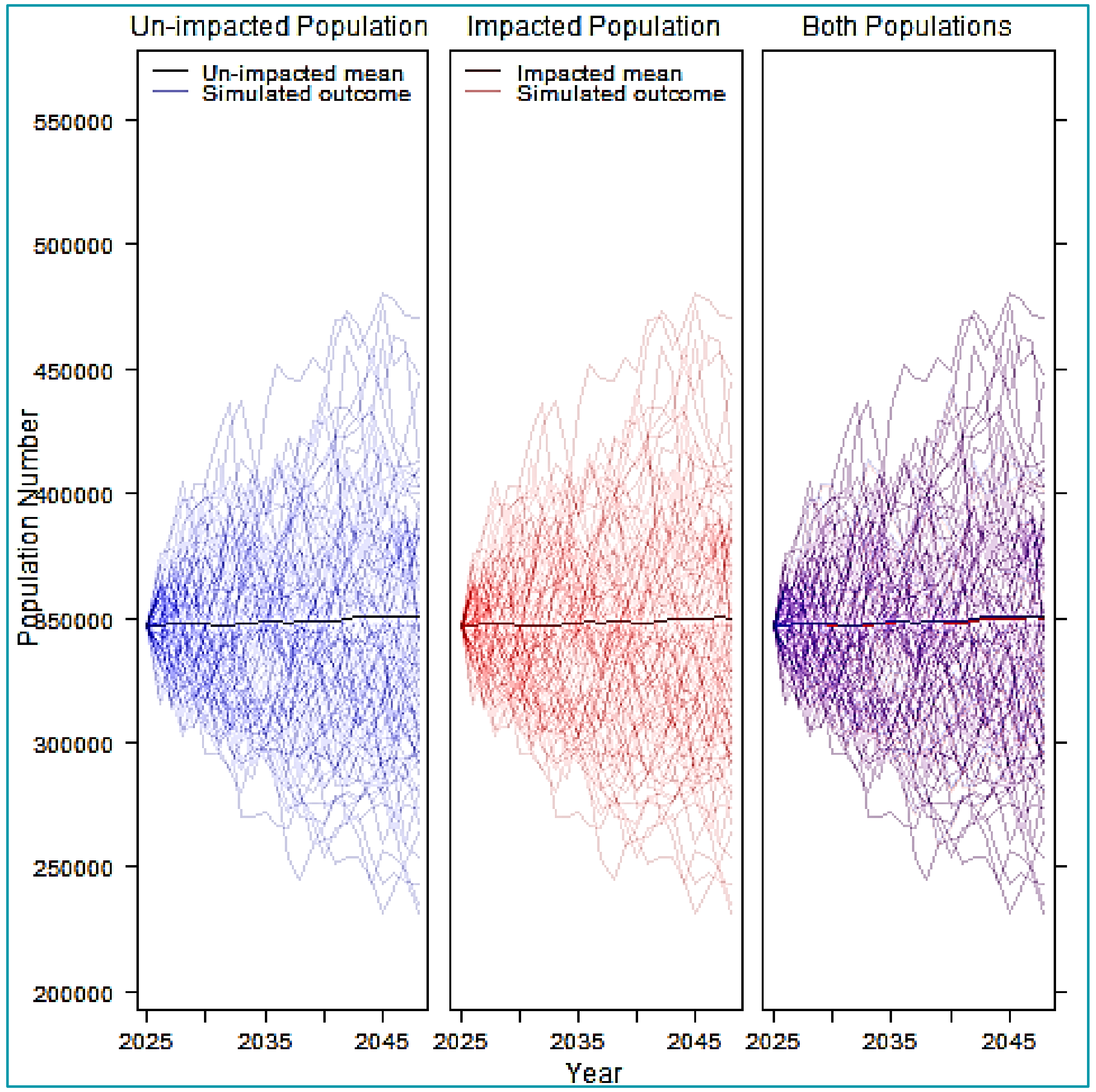

Figure 3.1: Harbour Porpoise Scenario 1: 10% Reducing to 1% Conversion Factor, no Vulnerable Subpopulation

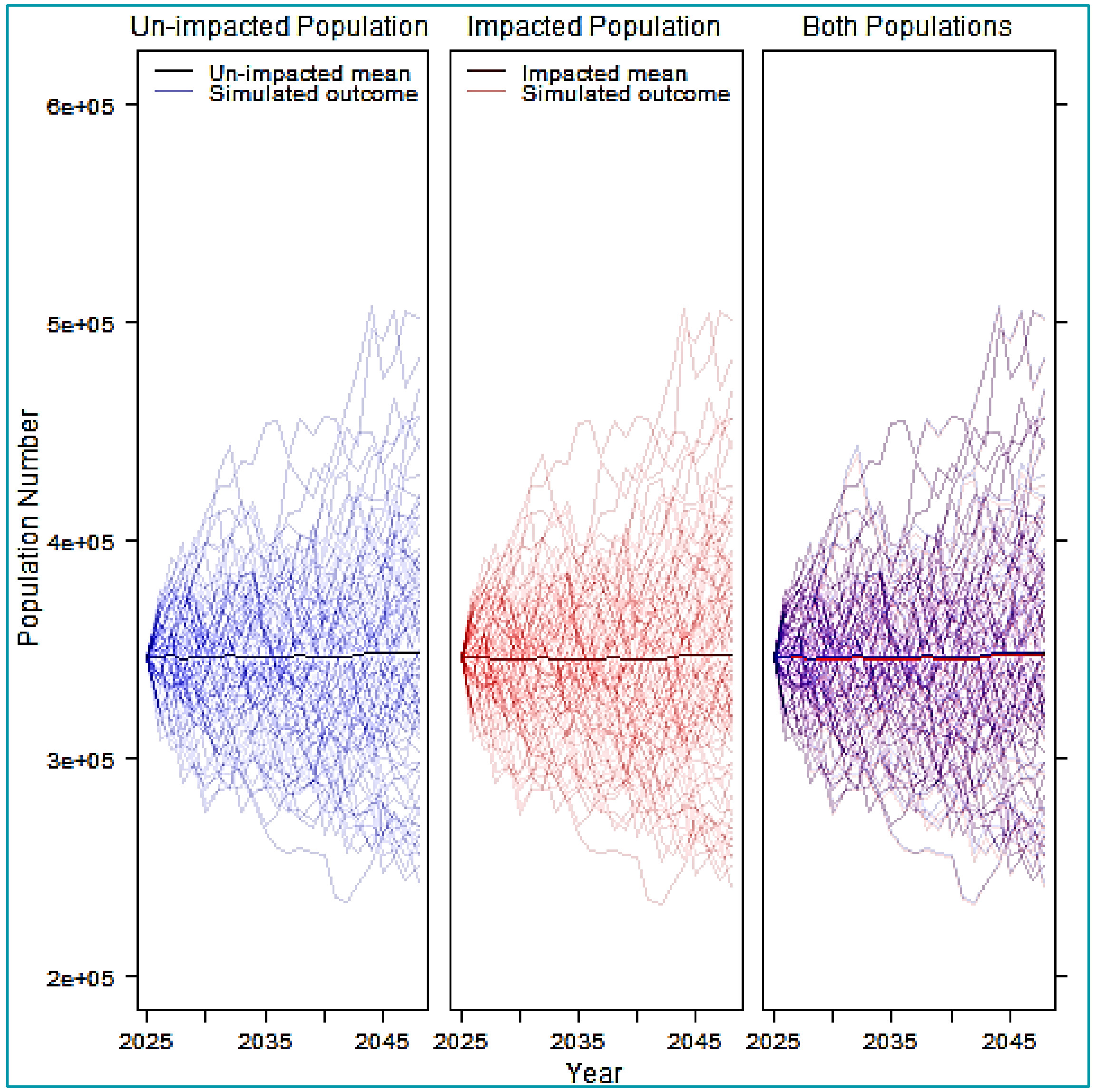

Figure 3.2: Harbour Porpoise Scenario 1a: 10% Reducing to 1% Conversion Factor, 11.1% Vulnerable Subpopulation

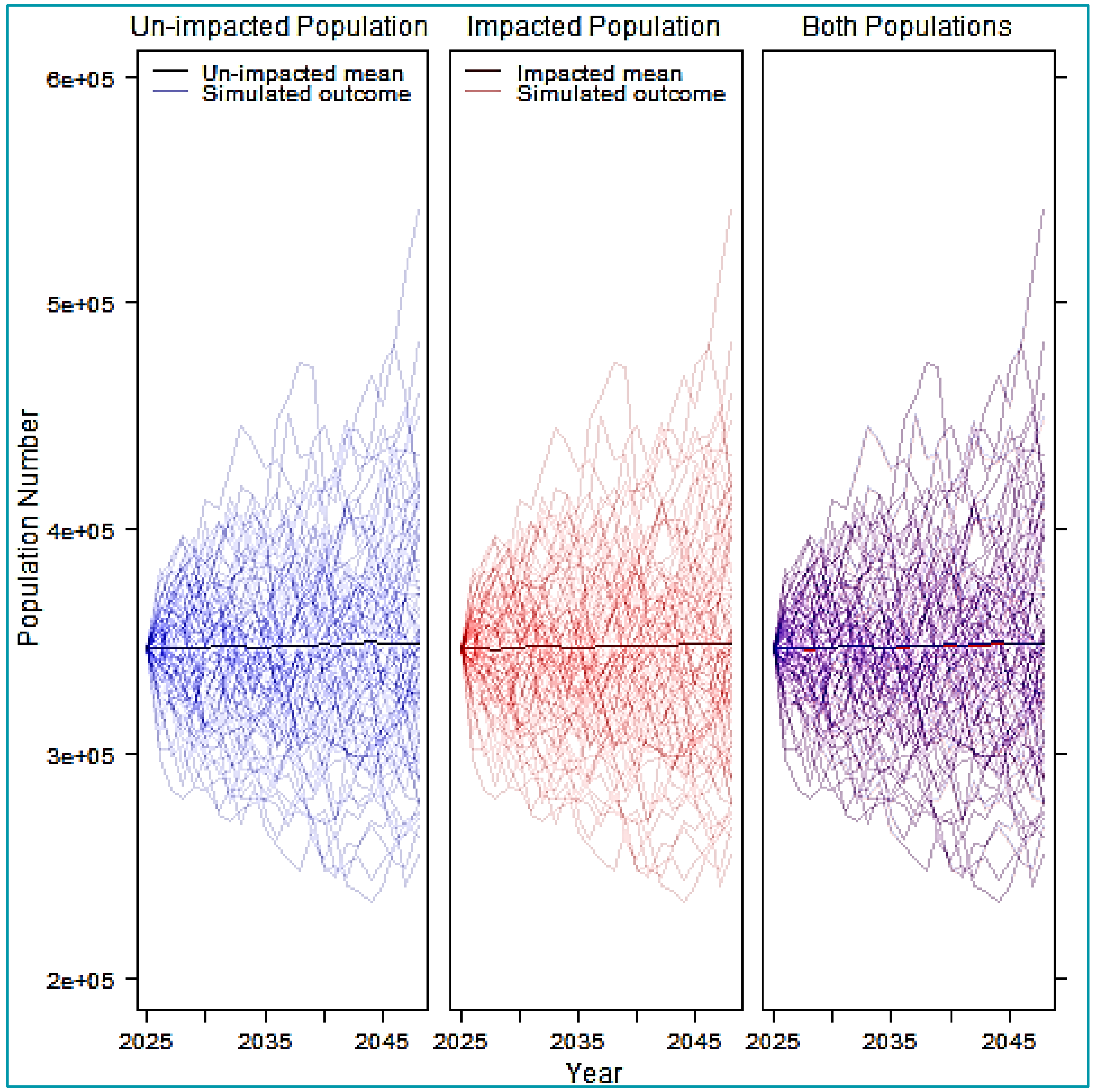

Figure 3.3: Harbour Porpoise Scenario 2: 1% Constant Conversion Factor, no Vulnerable Subpopulation

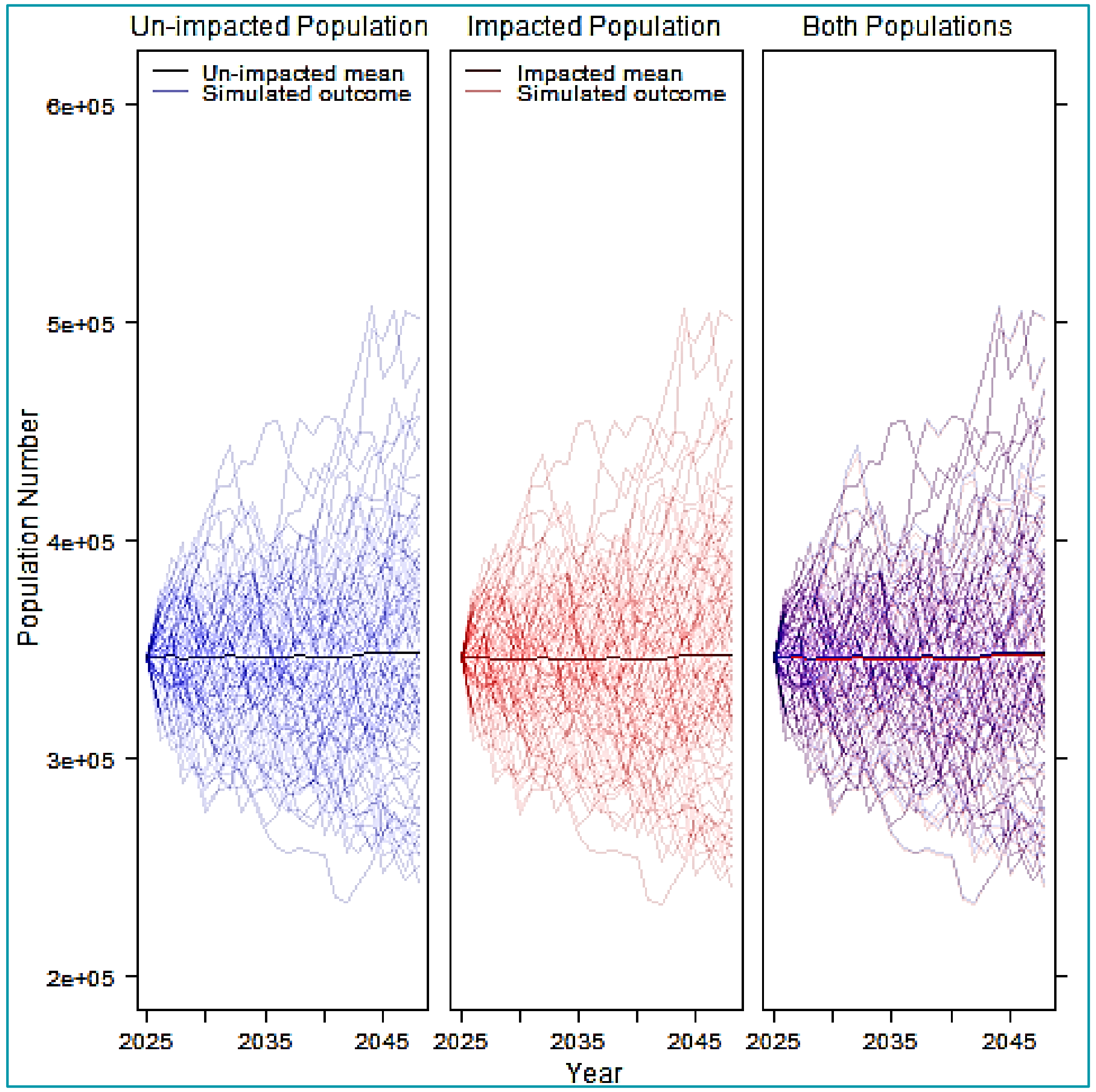

Figure 3.4: Harbour Porpoise Scenario 2a: 1% Constant Conversion Factor, 11.1% Vulnerable Subpopulation

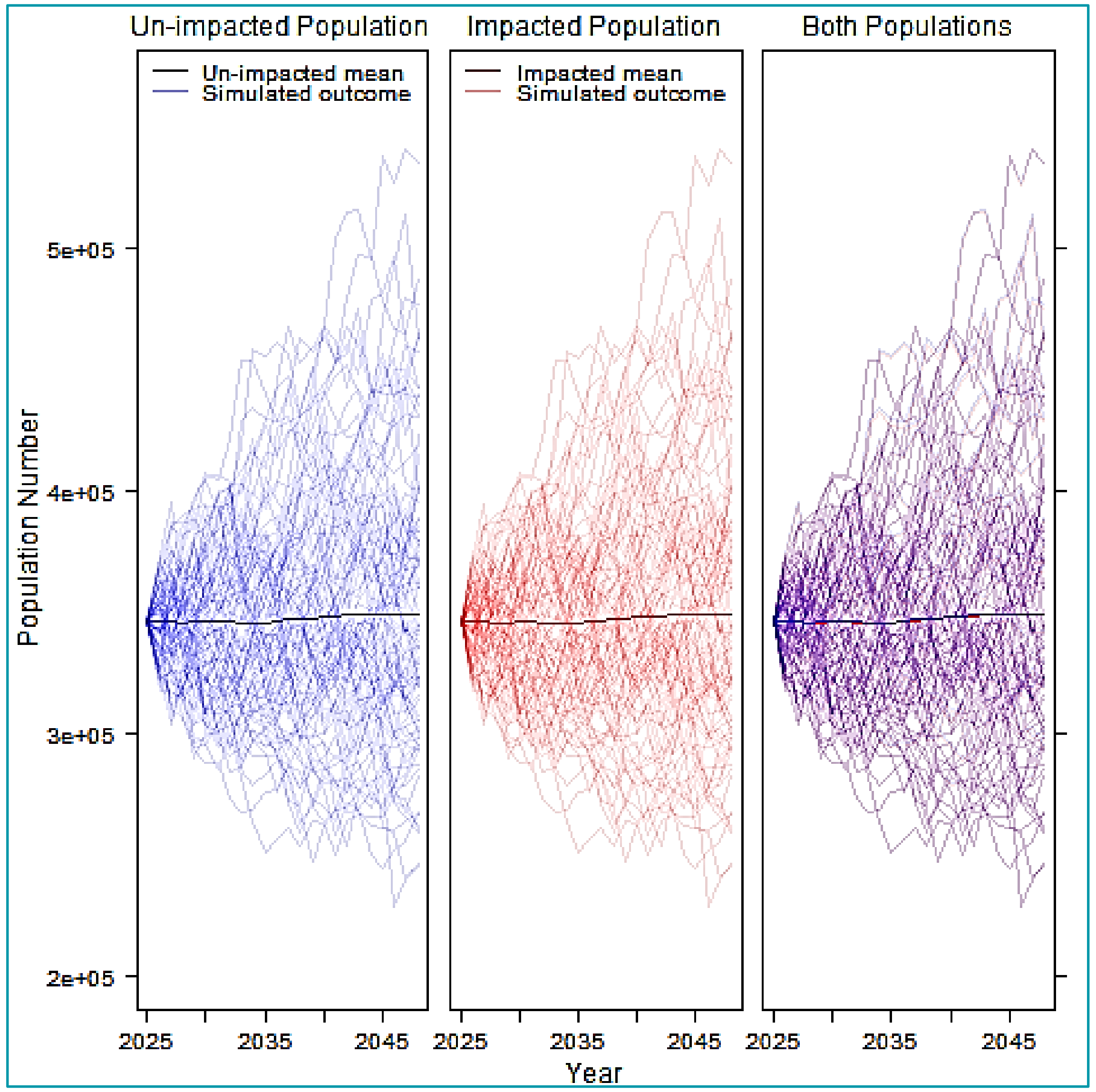

Figure 3.5: Harbour Porpoise Scenario 3: 4% Reducing to 0.5% Conversion Factor, no Vulnerable Subpopulation

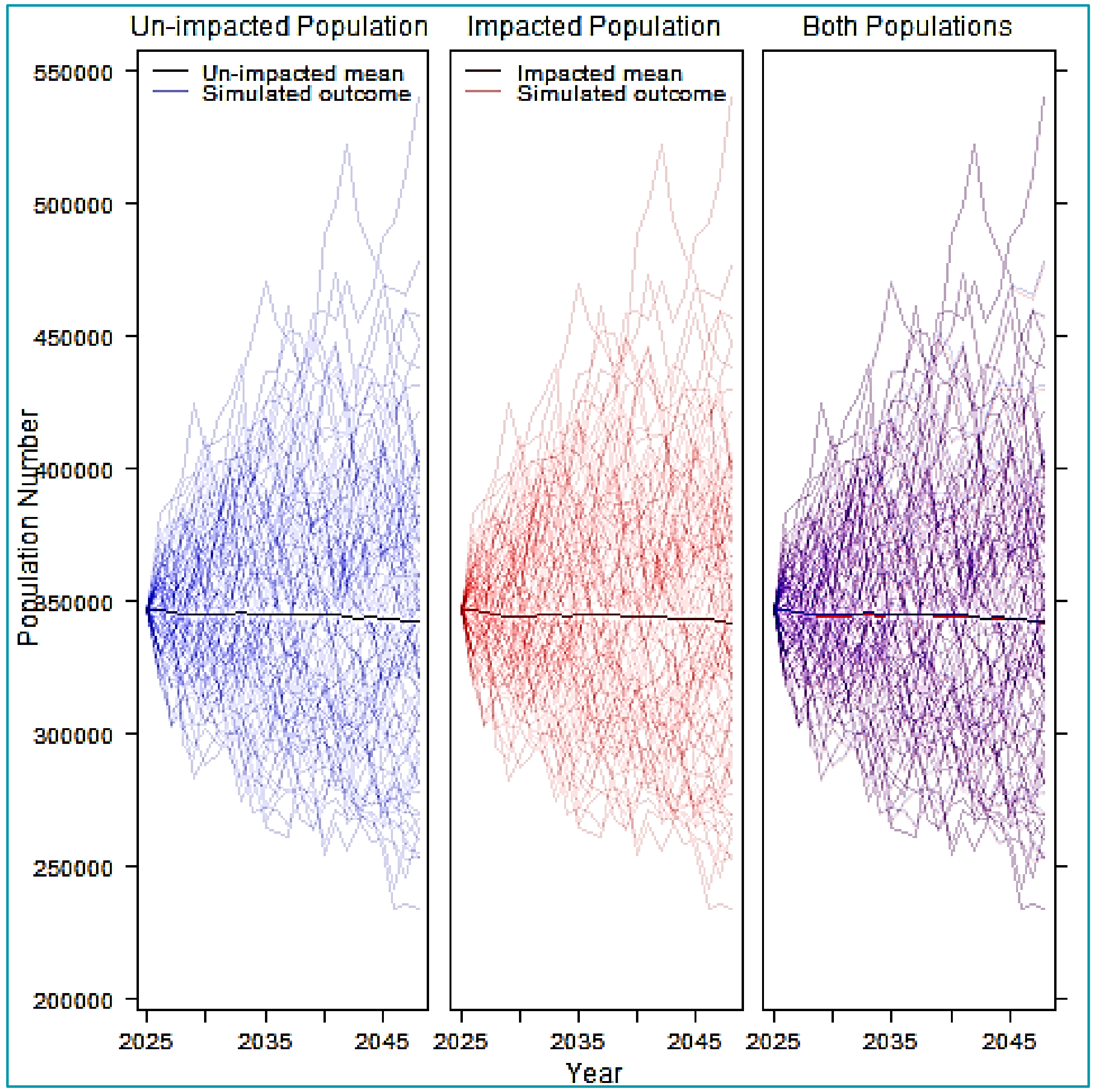

Figure 3.6: Harbour Porpoise Scenario 3a: 4% Reducing to 0.5% Conversion Factor, 11.1% Vulnerable Subpopulation

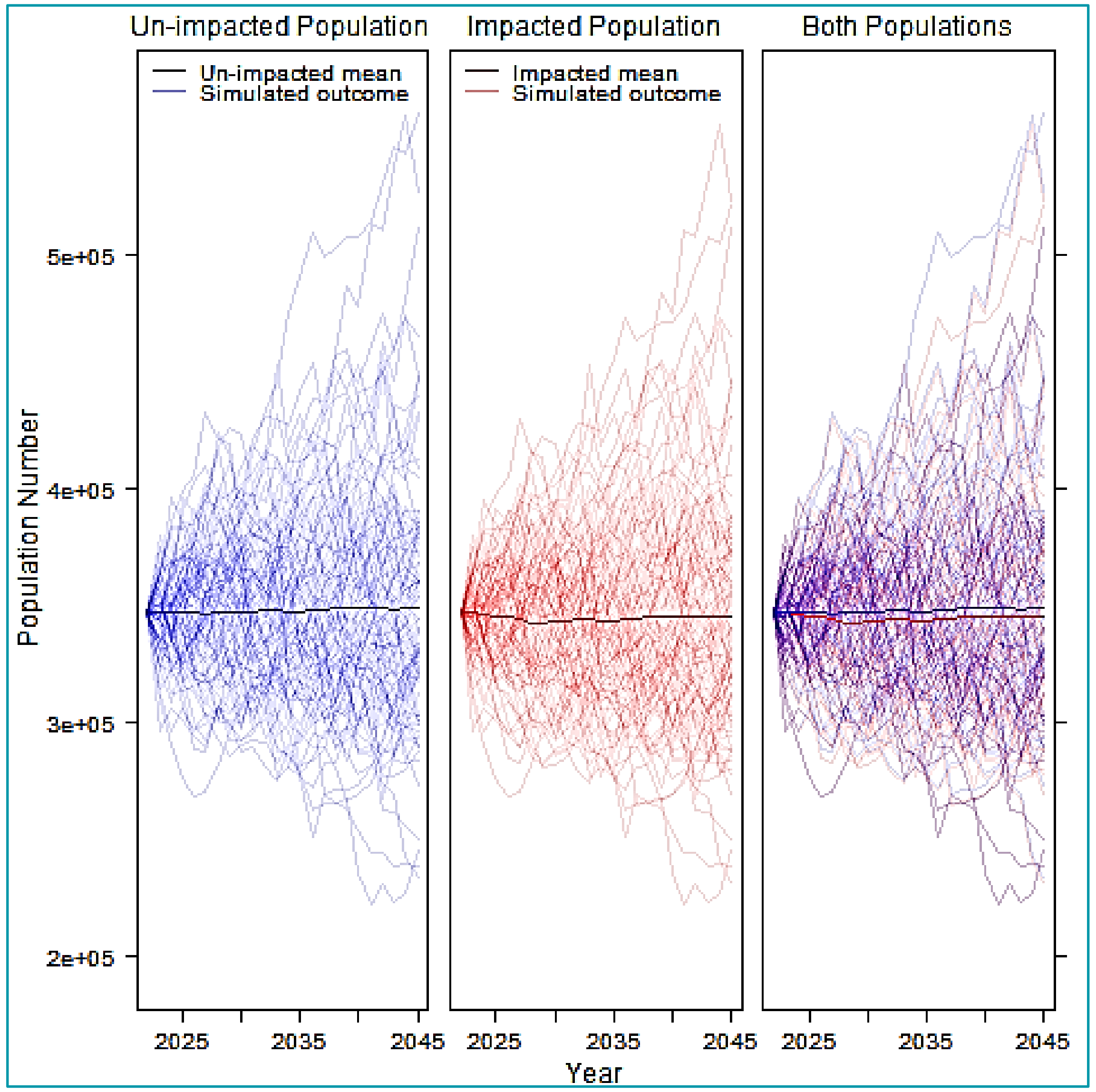

Figure 3.7: **Harbour Porpoise Scenario 4: Cumulative Projects 1% Constant Conversion Factor, no Vulnerable Subpopulation**

3.2. BOTTLENOSE DOLPHIN

44. There appears to be a very small difference in the growth trajectory of bottlenose dolphin, across all three conversion factor scenarios. Comparison of the mean unimpacted population to the impacted population for all three scenarios illustrates this very small alteration and the median counterfactual of population size was 100% in all cases (Table 3.2).

45. Results of the iPCoD modelling for bottlenose dolphin using the maximum adverse design 10% reducing to 1% scenario for the MU population (Scenario 1), show that at a time point of eight years (after the final piling campaign at the Proposed Development) the mean impacted population was predicted to be 282 individuals compared to 289 individuals for the unimpacted population and therefore only a difference of seven individuals (Table 3.2, Figure 3.9). At time point 25, the mean impacted population is 14 animals smaller than the mean unimpacted population. Since there is only small difference in the trajectory of the disturbed versus undisturbed population and this falls within the natural stochasticity of the modelled population there is not considered to be a potential for a long-term effect on this species.

46. When using the 1% conversion factor scenario for the MU population (Scenario 2), at a time point of eight years there were predicted to be four fewer animals in the impacted population compared to the unimpacted population (Table 3.2, Figure 3.10). At time point 25, the mean impacted population is nine animals smaller than the mean unimpacted population. As before there is therefore not considered to be a potential for a long-term effect on this species as the difference falls within the natural stochasticity of the modelled population.

47. When using the 4% to 0.5% conversion factor scenario for the MU population (Scenario 3), at a time point of eight years there were predicted to be four fewer animals in the impacted population compared to the unimpacted population (Table 3.2, Figure 3.11). at time point 25, the mean impacted population is 8 animals smaller than the mean unimpacted population. As before there is therefore not considered to be a potential for a long-term effect on this species as the difference falls within the natural stochasticity of the modelled population.

48. For the cumulative scenario assessed using the 1% conversion factor (Scenario 4), where multiple projects may be piling either sequentially or concurrently within the north-east of Scotland, the population modelling suggested a slight differences in the population size from time point 4 onwards. For example, at time point 5 (just prior to the start of piling at the Proposed Development) the predicted mean population size was 254 animals for the impacted population compared to 260 for the unimpacted population (a difference of six animals). After the end of the first two piling campaigns at the Proposed Development (time point 7) the difference compared to the unimpacted population was nine animals fewer in the impacted population and after the end of the second piling campaign at the Proposed Development (time point 11) 16 animals fewer in the impacted population (Table 3.2, Figure 3.12:). At time point 25 the difference between the impacted and unimpacted population was 19 animals but at all time points the median counterfactual of population size provided a ratio of 100%. These results suggest that whilst there may be a slight decrease in population size resulting from piling at cumulative projects – particularly where the piling phases coincide with piling at the Proposed Development – the population is likely to recover in the long-term and any changes would fall within the natural stochasticity of the modelled population.

49. As mentioned in section 3.1, environmental and demographic stochasticity will cause variation in results. It is also important to highlight that the impacted population will continue to grow at the same rate once the impact has stopped (Figure 3.8), therefore there is essentially no long-term impact predicted and the population remains stable, considering both the Proposed Development alone and cumulative projects.

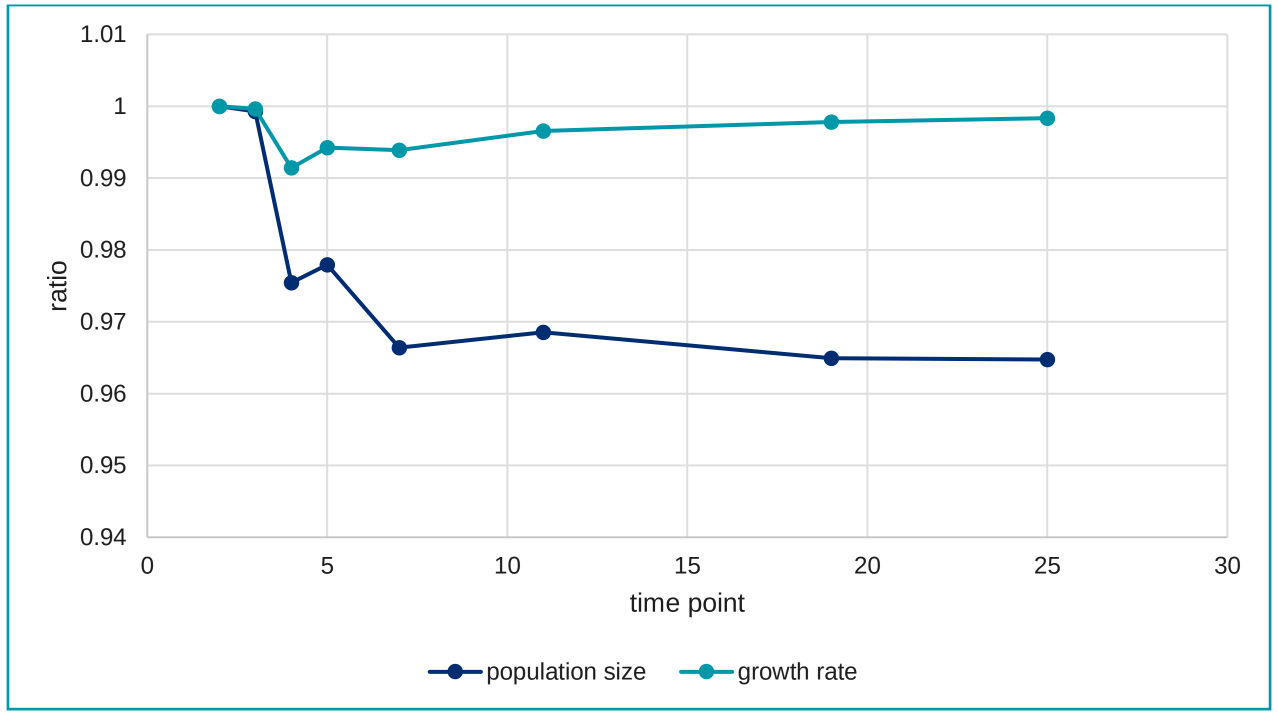

Figure 3.8: Cumulative Assessment: Ratios of the Impacted to Unimpacted Population for Mean Population Size and Mean Growth Rate of Bottlenose Dolphin

50. Furthermore, when modelling for dolphins, expert elicitation results from 2013 were used, as the model had not been updated since the later 2018 elicitation (Booth and Heinis, 2018). The 2013 expert elicitation assumed that for bottlenose dolphin (and minke whale), disturbance would mean foraging ceased for 24 hours, but this is significantly higher than recent response estimates and is likely to lead to highly conservative results in the model. Czapanskiy *et al*. (2021) estimated energetic costs associated with sonar disturbance, and assumed a mild response was one hour of feeding cessation, a strong response was two hours of feeding cessation and an extreme response was eight hours of feeding cessation. Therefore, if results were modelled with extreme disturbance which was assumed to last eight hours (as is in Czapanskiy *et al.* 2021), rather than 24, then the model results are likely to show smaller differences between the disturbed to the undisturbed populations.

Table 3.2: Population Trajectory of Bottlenose Dolphin Showing the Mean and Upper and Lower Confidence Limits at Different Time Points (Years After the Year in Which Piling Commences)

Time Point (Years)	Unimpacted Population			Impacted Population			Median Ratio of Population Size
	Mean	Lower 2.5%	Upper 97.5%	Mean	Lower 2.5%	Upper 97.5%	
Scenario 1: 10% to 1% Conversion Factor							
4	250	208	286	245	198	286	1.000000
8	289	230	344	282	218	344	1.000000
13	344	260	436	335	242	434	1.000000
19	427	300	562	416	280	562	1.000000
25	530	366	704	516	344	698	1.000000
Scenario 2: 1% Conversion Factor							
4	248	206	286	245	202	284	1.000000
8	289	228	348	285	220	346	1.000000
13	344	258	422	338	246	420	1.000000
19	428	306	552	421	290	542	1.000000
25	531	362	710	522	358	696	1.000000
Scenario 3: 4% to 0.5% Conversion Factor							
4	249	210	282	246	206	280	1.000000
8	286	228	340	282	222	338	1.000000
13	344	262	428	339	254	426	1.000000
19	426	304	554	419	292	550	1.000000
25	527	360	698	519	358	686	1.000000
Scenario 4: CUMULATIVE PROJECTS, 1% Conversion Factor							
2	232	212	252	232	212	252	1.000000
3	241	212	270	241	212	270	1.000000
4	250	212	284	243	196	282	1.000000
5	260	218	298	254	204	296	1.000000
7	278	226	328	269	202	324	1.000000
11	322	252	390	311	226	386	1.000000
19	428	304	562	412	278	554	1.000000
25	532	370	728	513	336	722	1.000000

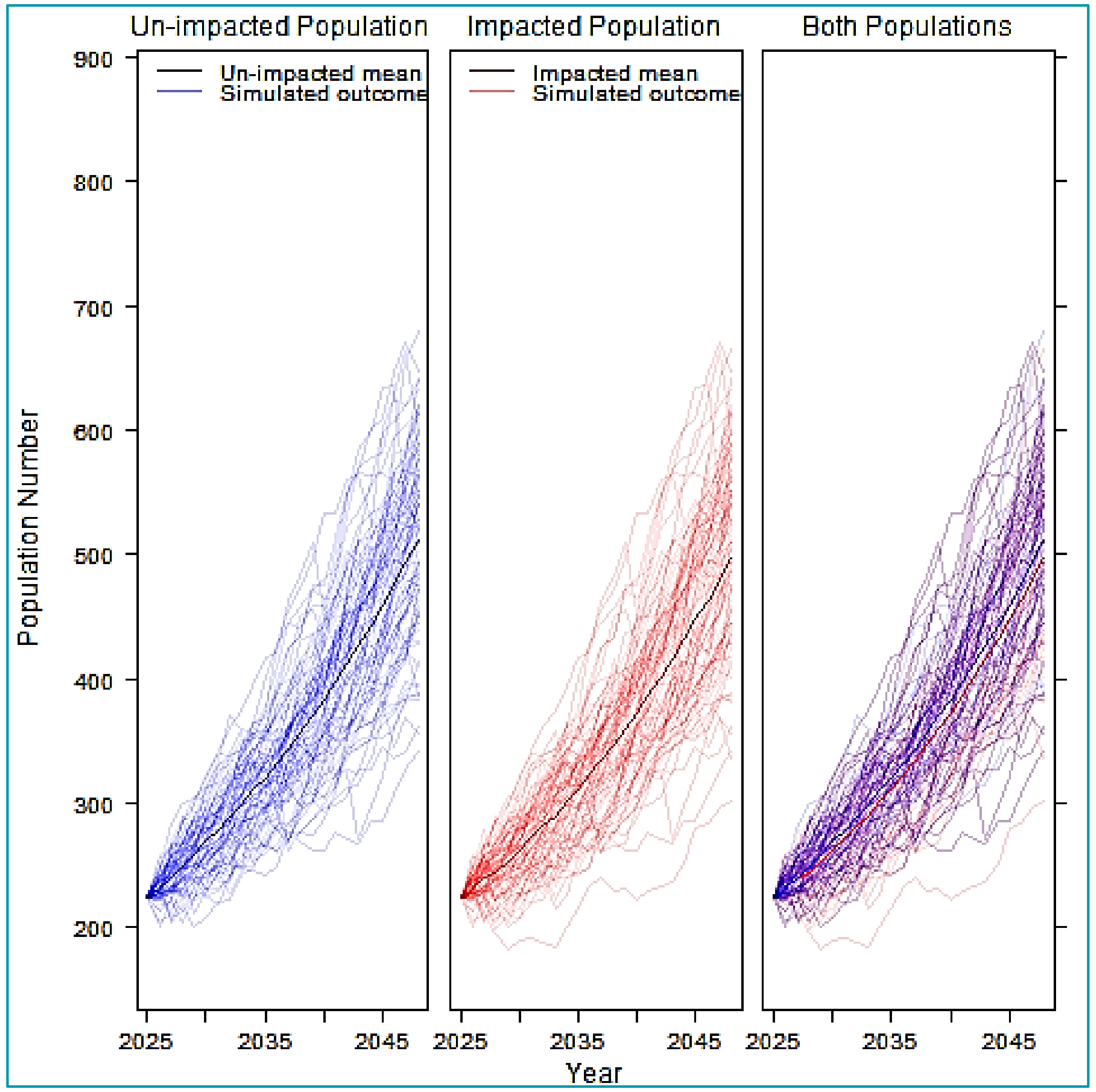

Figure 3.9: Bottlenose Dolphin Scenario 1: 10% Reducing to 1% Conversion Factor, no Vulnerable Subpopulation

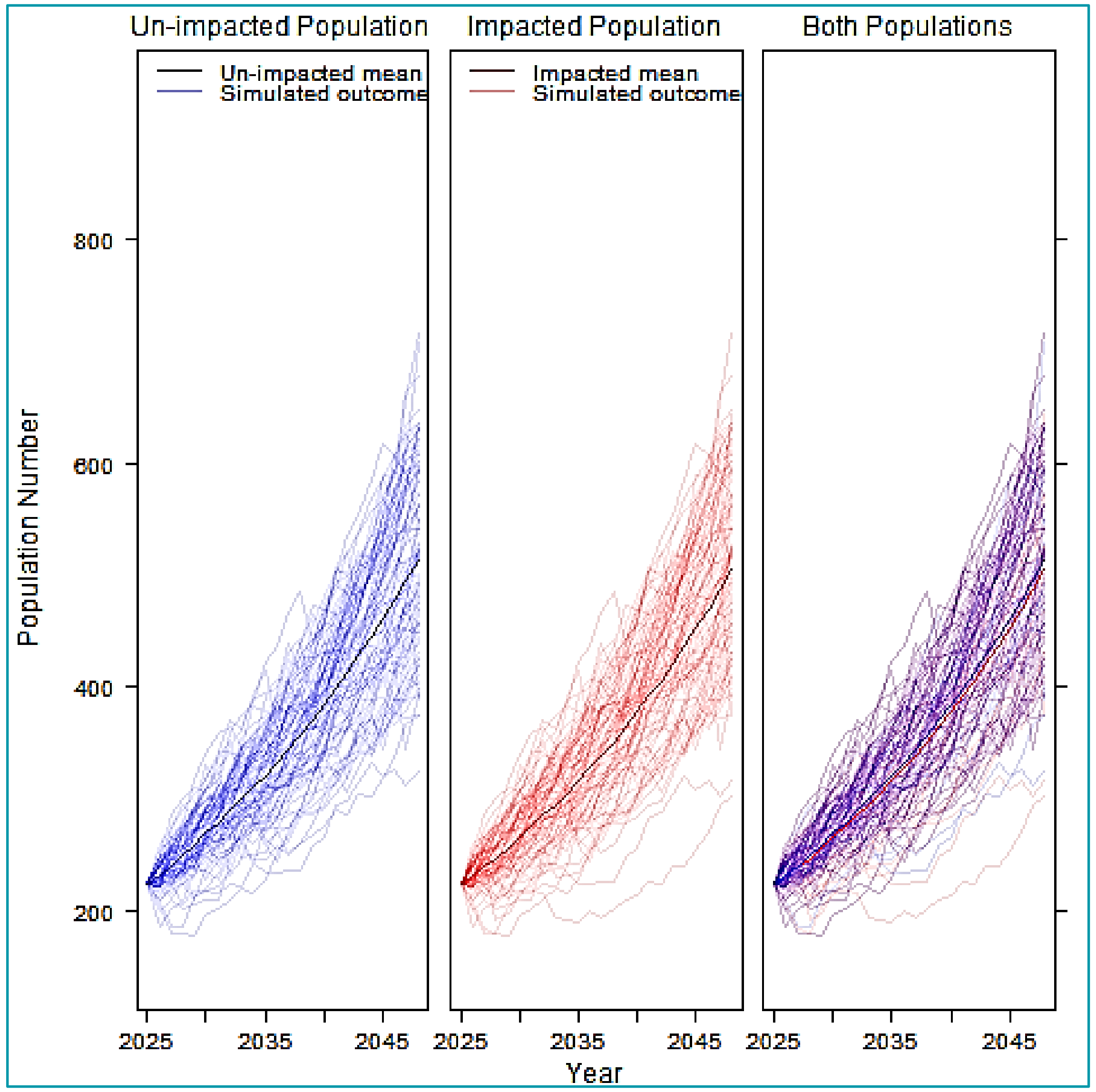

Figure 3.10: Bottlenose Dolphin Scenario 2: 1% Constant Conversion Factor, no Vulnerable Subpopulation

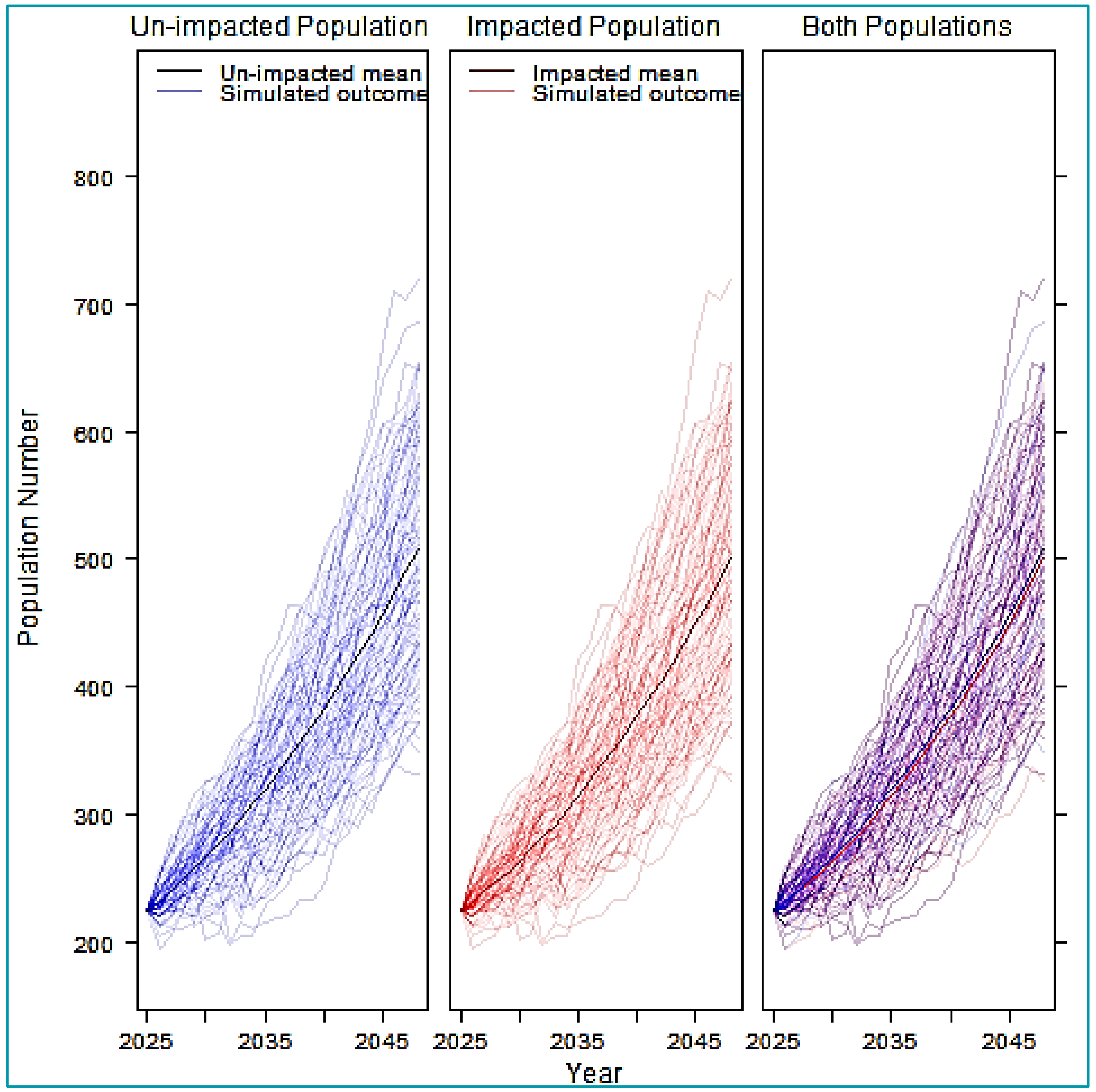

Figure 3.11: Bottlenose Dolphin Scenario 3: 4% Reducing to 0.5% Conversion Factor, no Vulnerable Subpopulation

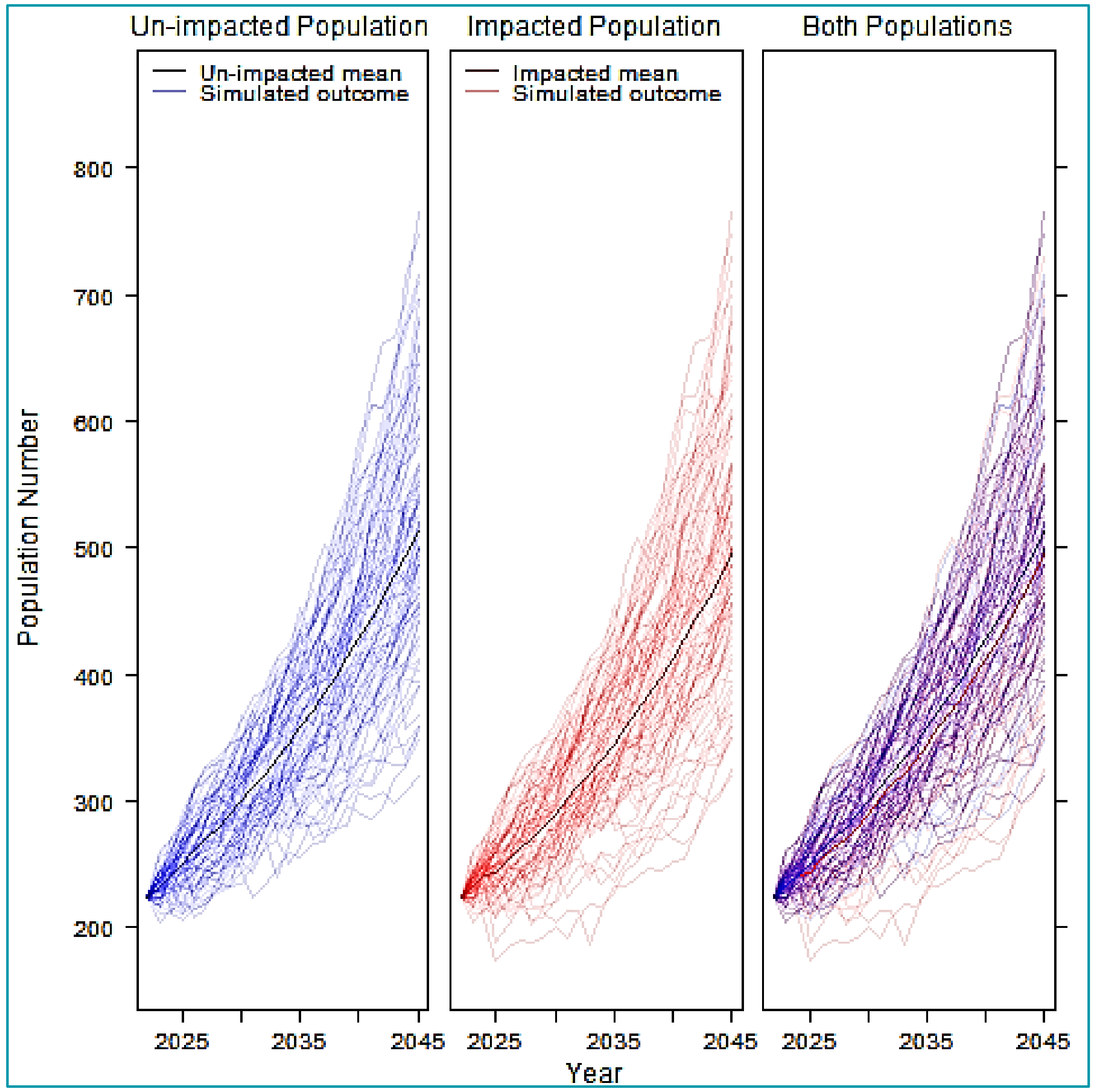

Figure 3.12: Bottlenose Dolphin Scenario 4: Cumulative Projects, 1% Conversion Factor, no Vulnerable Subpopulation

3.3. MINKE WHALE

51. Results of the iPCoD modelling for minke whale using the maximum adverse scenario 10% to 1% scenario for the MU population (Scenario 1) are presented in Table 3.3, Figure 3.14). The results show that for the 10% reducing to 1% conversion factor, the median counterfactual of population size was 99.5% at a time point of the start of year 8 (coinciding with the end of the second piling campaign) and there were predicted to be 105 fewer minke whale in the impacted population compared to the unimpacted population. However, given that the differences in disturbed to undisturbed populations approaches a ratio of one there is not considered to be a potential for a long-term effect on this species. This was also the case when considered against the SCANS Block R as a vulnerable subpopulation (Scenario 1a) where the median of the ratio was 99.1% (Table 3.3, Figure 3.15). In this scenario, the mean impacted vulnerable subpopulation is 102 animals smaller than the mean unimpacted vulnerable subpopulation and as described above is likely to fall within the natural variation of the population over this timescale.

52. When using the 1% conversion factor scenario for the MU population (Scenario 2), the median counterfactual of population size was 99.5% at time point eight with a difference of 100 animals (Table 3.3, Figure 3.16). Again, the results were similar when considered against the SCANS Block as a vulnerable subpopulation (Scenario 2a) (Figure 3.17).

53. When using the 4% reducing to 0.5% conversion factor scenario for the MU population (Scenario 3), the median counterfactual of population size was 99.6% at time point eight with a difference of 105 animals (Table 3.3, Figure 3.18). Results were similar when considered against the SCANS Block as a vulnerable subpopulation (Scenario 3a) (Table 3.3, Figure 3.20).

54. Therefore, a significant impact to the minke whale population due to the Proposed Development alone is not expected as, in the long term, it maintains a stable population trajectory. As mentioned in section 3.1, environmental and demographic stochasticity will cause considerable variability in results.

55. For the cumulative scenario assessed against the MU population (Scenario 4), where multiple projects may be piling either sequentially or concurrently within the regional marine mammal study area, the population modelling suggested a slight decrease in the ratio of the mean impacted to unimpacted population at time point eight (after the first two piling campaigns at the Proposed Development) (Table 3.3, Figure 3.20). However, the median counterfactual of population size was predicted as 100% at all time points and growth rate remains constant suggesting that such declines would not be discernible in the context of natural population stochasticity (Figure 3.13:).

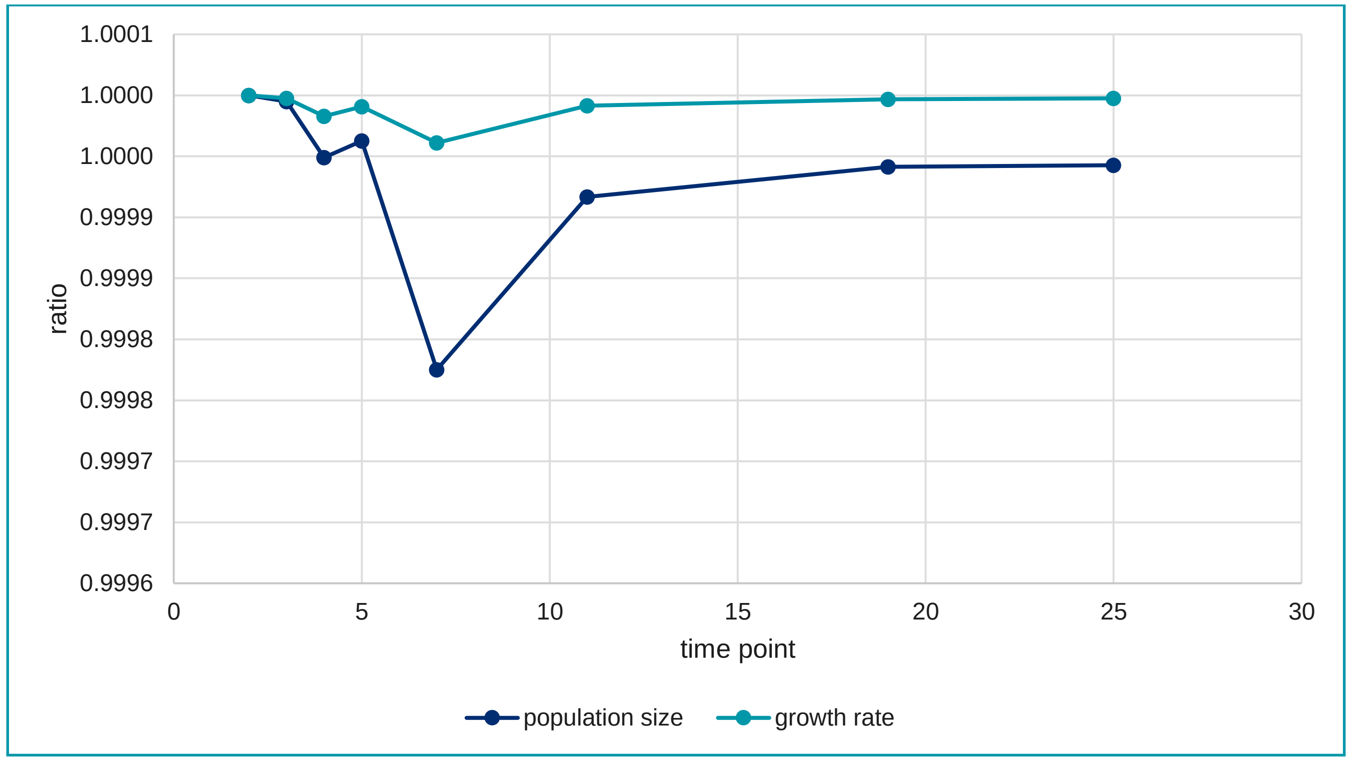

Figure 3.13: Ratios of the Impacted to Unimpacted Population for Mean Population Size and Mean Growth Rate of Minke Whale Based on the Cumulative Projects iPCoD Model

Table 3.3: Population Trajectory of Minke Whale Showing the Mean and Upper and Lower Confidence Limits at Different Time Points (Years After the Year in Which Piling Commences)

Time Point (Years)	Unimpacted Population Mean	Unimpacted Population Lower 2.5%	Unimpacted Population Upper 97.5%	Impacted Population Mean	Impacted Population Lower 2.5%	Impacted Population Upper 97.5%	Median Ratio of Population Size
Scenario 1: 10% to 1% Conversion Factor (no Vulnerable Subpopulation)							
4	20084	17234	23114	20059	17198	23075	0.999235
8	20082	16797	24112	19977	16614	24076	0.995804
13	19982	15756	24826	19787	15550	24582	0.991828
19	19973	15310	26076	19738	14914	25645	0.990068
25	19905	14574	26632	19657	14383	26121	0.989193
Scenario 1a: 10% to 1% Conversion Factor (11.1% Vulnerable Subpopulation)							
4	20166	17272	23303	20141	17272	23293	0.999192
8	20058	16655	23863	19956	16546	23736	0.995831
13	19933	15946	24991	19748	15884	24608	0.991944
19	19890	15140	26032	19668	15008	25774	0.990166
25	19812	14432	26327	19579	14295	26089	0.989455
Scenario 2: 1% Conversion Factor (no Vulnerable Subpopulation)							
4	20090	17253	22944	20066	17159	22911	0.999205
8	20005	16583	23983	19898	16422	23922	0.995554
13	20021	15954	24802	19823	15818	24525	0.991502

Time Point (Years)	Unimpacted Population Mean	Unimpacted Population Lower 2.5%	Unimpacted Population Upper 97.5%	Impacted Population Mean	Impacted Population Lower 2.5%	Impacted Population Upper 97.5%	Median Ratio of Population Size
19	20013	15233	25822	19775	15012	25606	0.989674
25	19989	14599	26826	19736	14451	26475	0.988957
Scenario 2a: 1% Conversion Factor (11.1% Vulnerable Subpopulation)							
4	20034	17220	22952	20010	17193	22924	0.999240
8	20008	16589	24237	19908	16487	24066	0.995949
13	19922	15675	25692	19740	15580	25531	0.992101
19	19900	14881	26536	19680	14686	26370	0.990179
25	19958	14345	27259	19724	14107	27105	0.989424
Scenario 3: 4% to 0.5% Conversion Factor (no Vulnerable Subpopulation)							
4	20033	17194	22780	20009	17186	22760	0.999237
8	19979	16666	24009	19874	16570	23974	0.995888
13	19859	15701	24899	19666	15574	24687	0.991957
19	19784	15167	26033	19553	15001	25760	0.990109
25	19767	14551	27116	19524	14374	26805	0.989313
Scenario 3a: 4% to 0.5% Conversion Factor (11.1% Vulnerable Subpopulation)							
4	20093	17306	22949	20070	17282	22929	0.999243
8	20079	16606	23981	19980	16470	23857	0.995993
13	20004	15867	25283	19822	15685	25082	0.991963
19	19926	15159	26280	19707	15010	25933	0.989966
25	19862	14286	27289	19632	14154	27096	0.989292
Scenario 4: CUMULATIVE PROJECTS, 1% Conversion Factor							
2	20123	18001	21802	20123	18001	21802	1.000000
3	20133	17514	22550	20133	17514	22550	1.000000
4	20108	17044	22998	20107	17044	22998	1.000000
5	20091	17008	23296	20090	17008	23296	1.000000
7	20071	16592	23944	20067	16532	23944	1.000000
11	19990	15998	24630	19988	15998	24630	1.000000
19	20025	14912	26256	20024	14912	26256	1.000000
25	19950	14717	27409	19948	14717	27409	1.000000

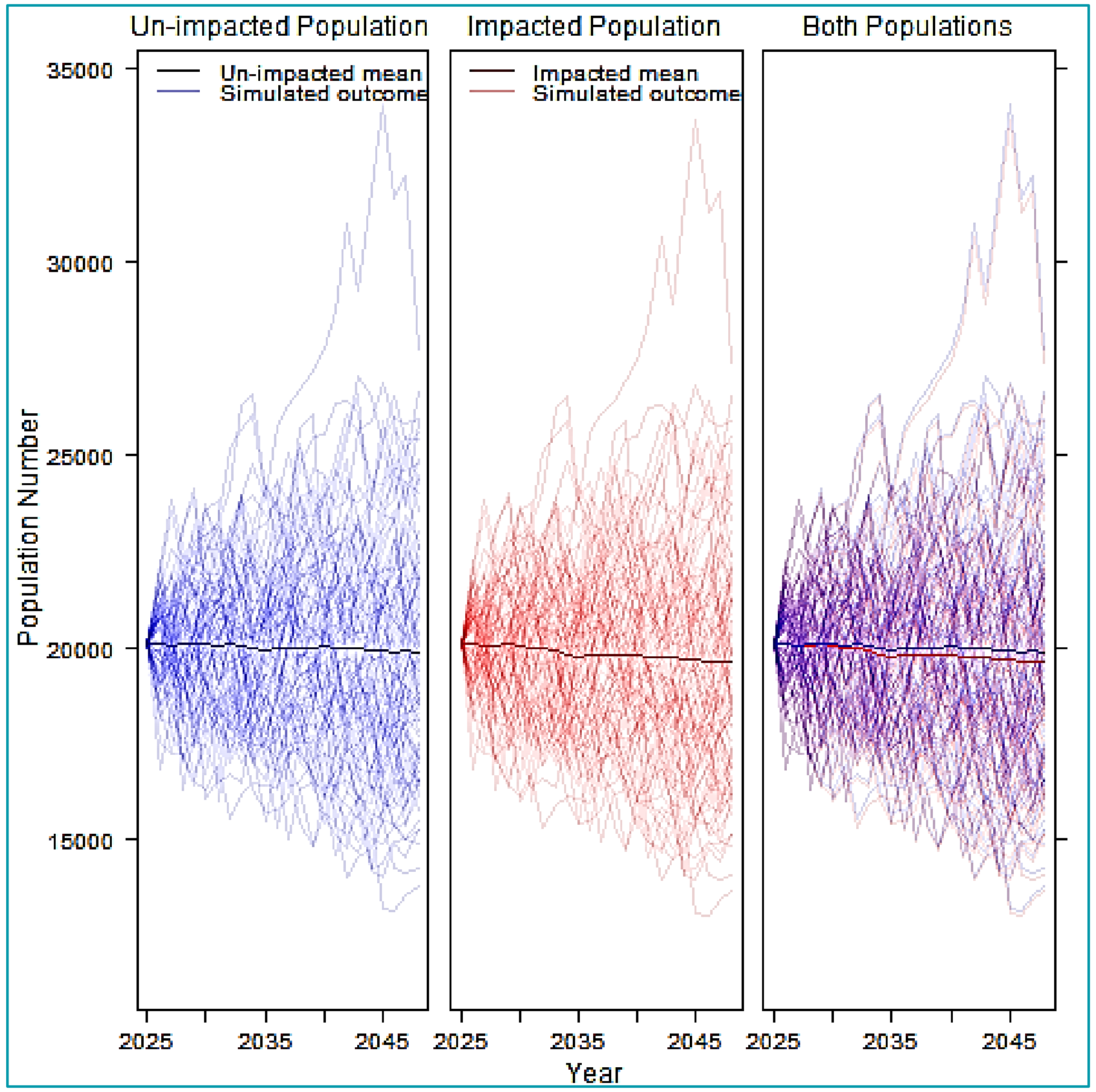

Figure 3.14: Minke Whale Scenario 1: 10% Reducing to 1% Conversion Factor, no Vulnerable Subpopulation

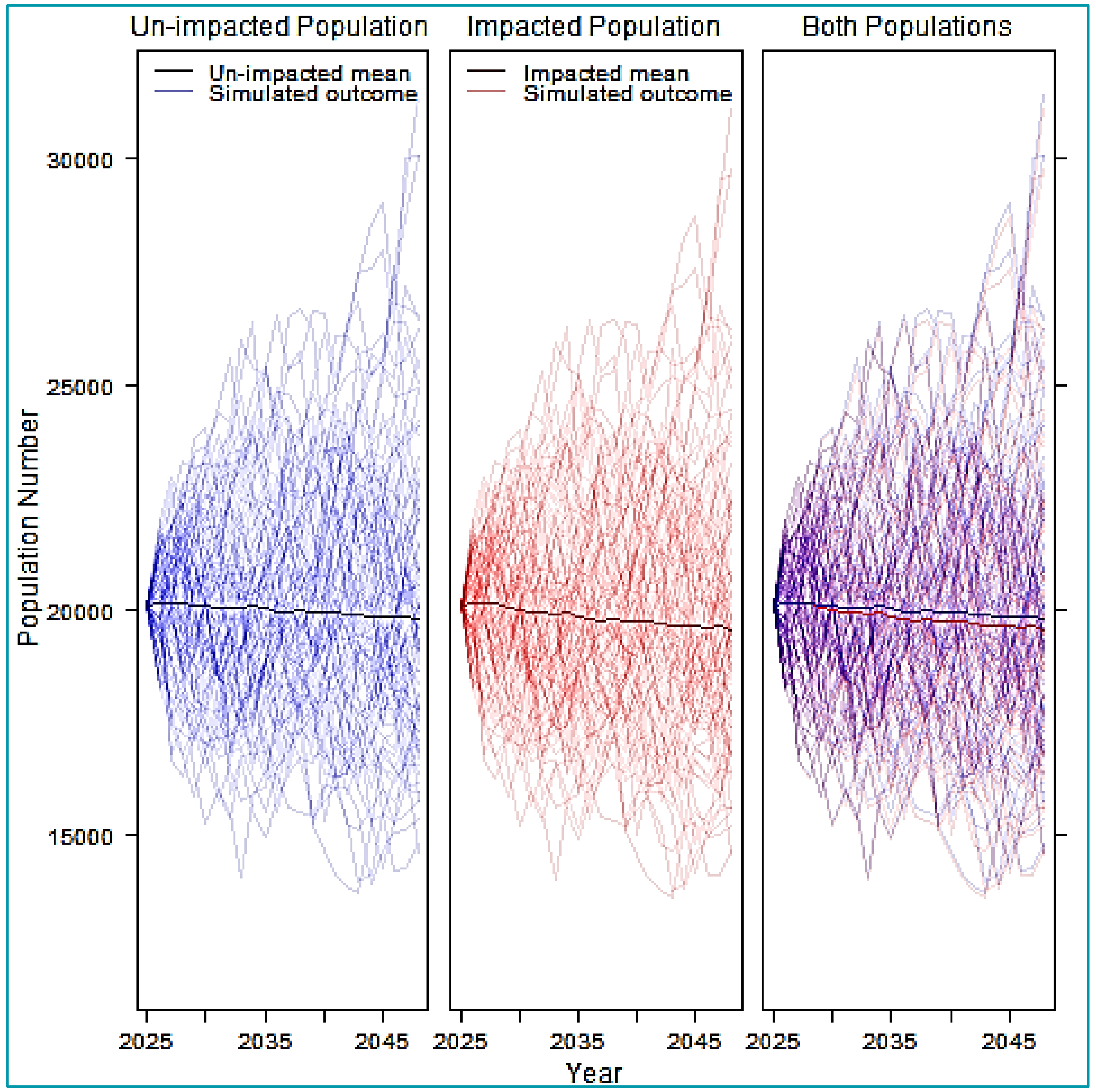

Figure 3.15: Minke Whale Scenario 1a: 10% Reducing to 1% Conversion Factor, 11.1% Vulnerable Subpopulation

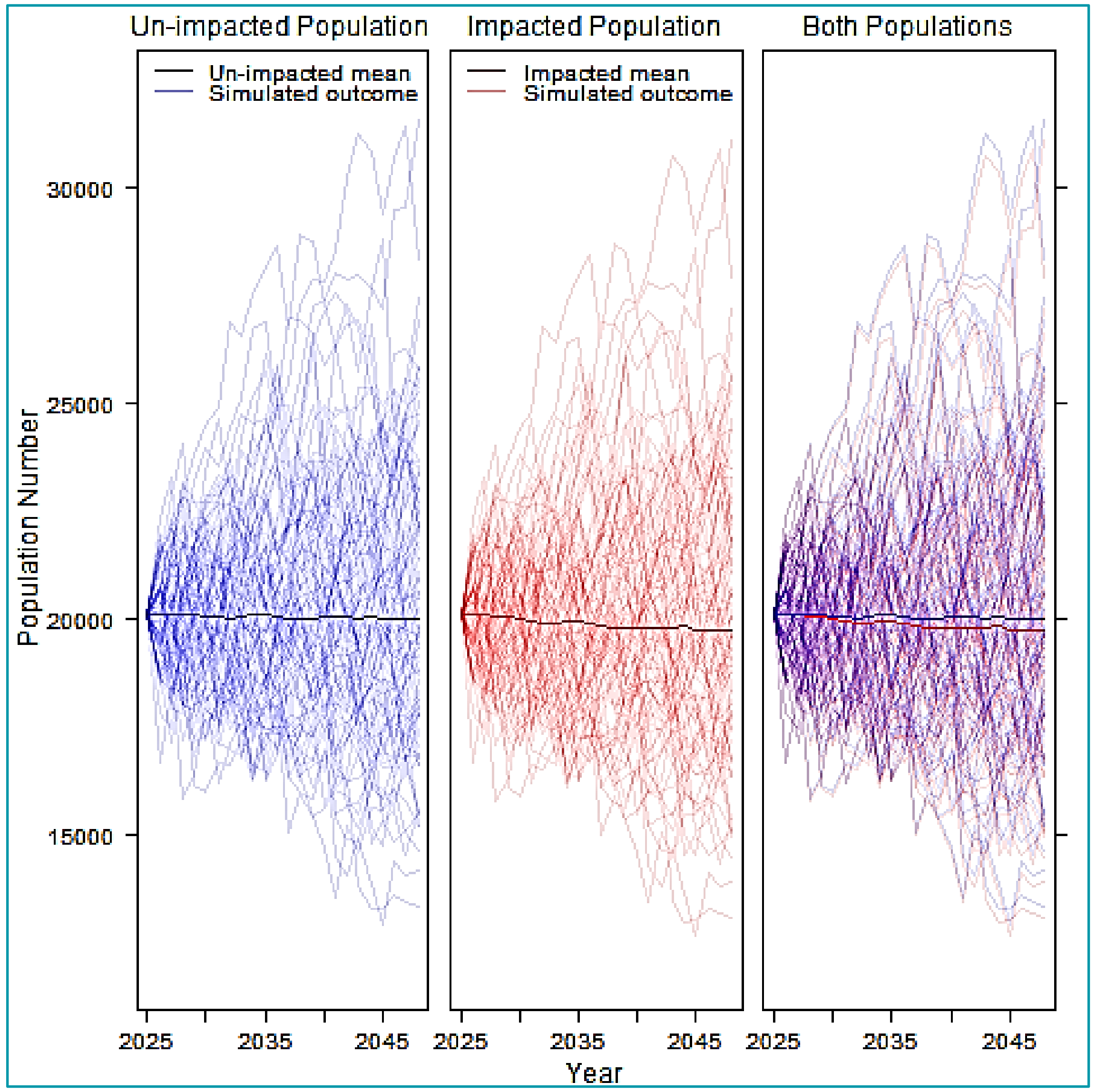

Figure 3.16: Minke Whale Scenario 2: 1% constant Conversion Factor, No Vulnerable Subpopulation

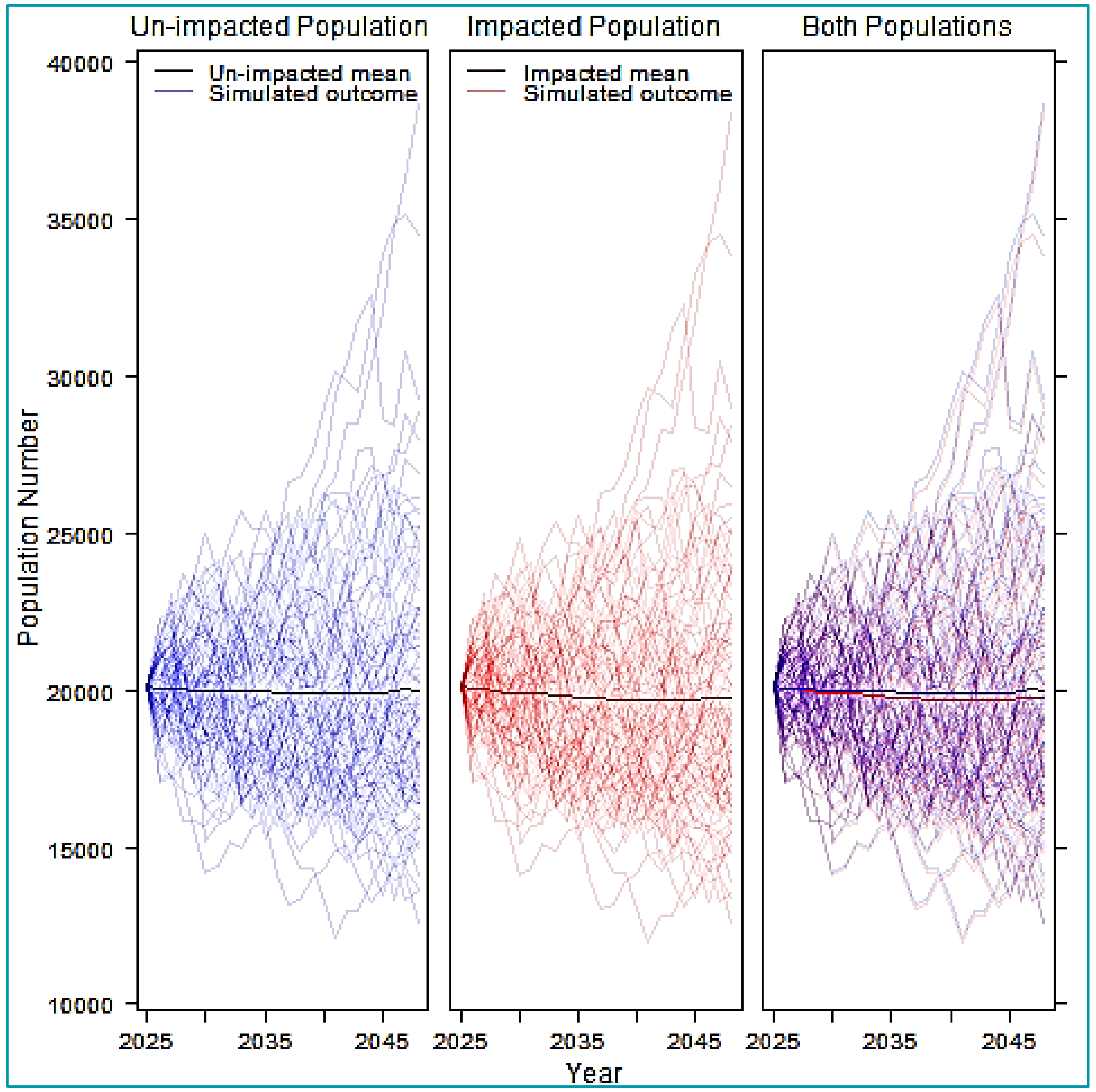

Figure 3.17: **Minke Whale Scenario 2a: 1% Constant Conversion Factor, 11.1% Vulnerable Subpopulation**

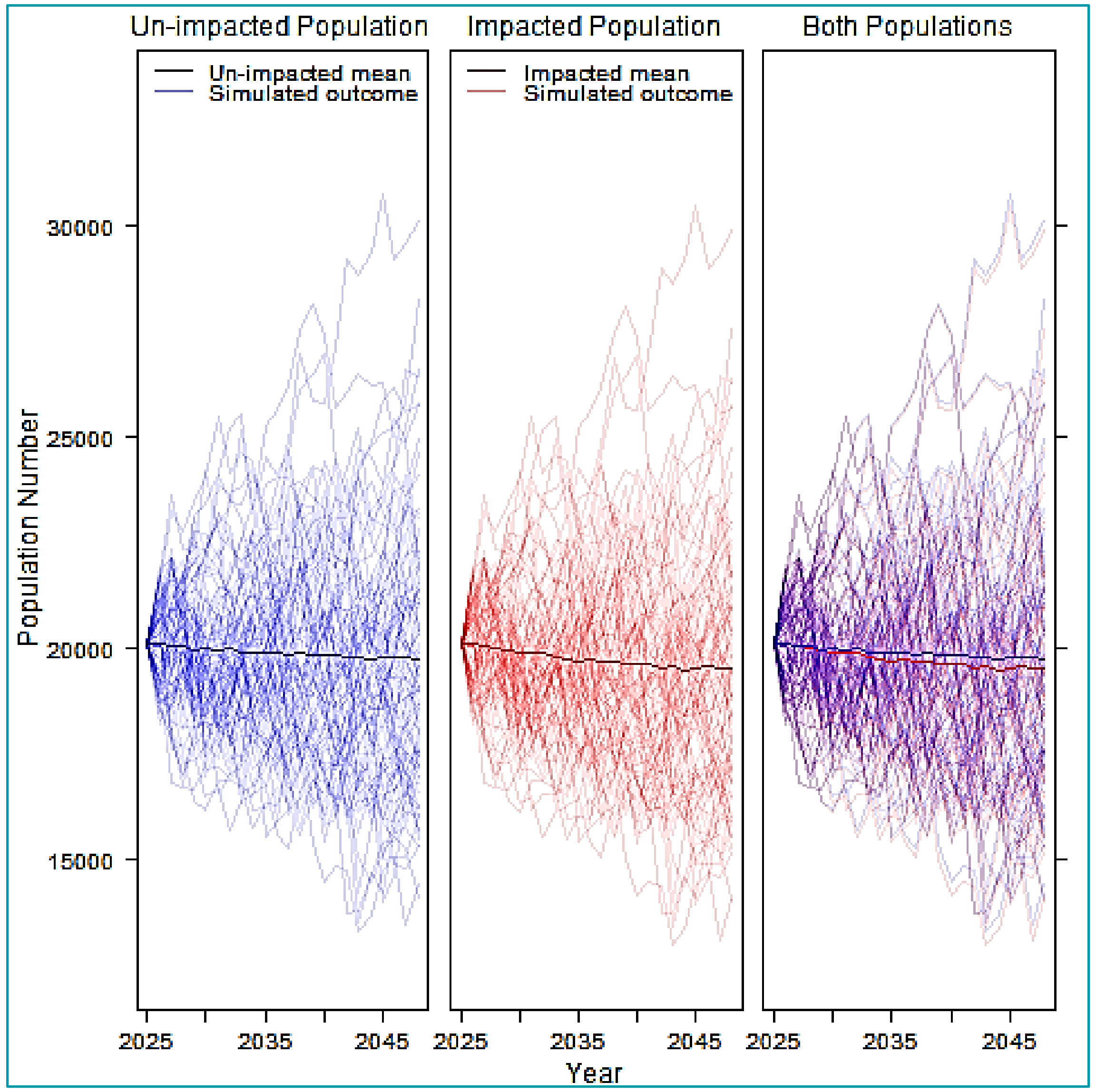

Figure 3.18: **Minke Whale Scenario 3: 4% Reducing to 0.5% Conversion Factor, no Vulnerable Subpopulation**

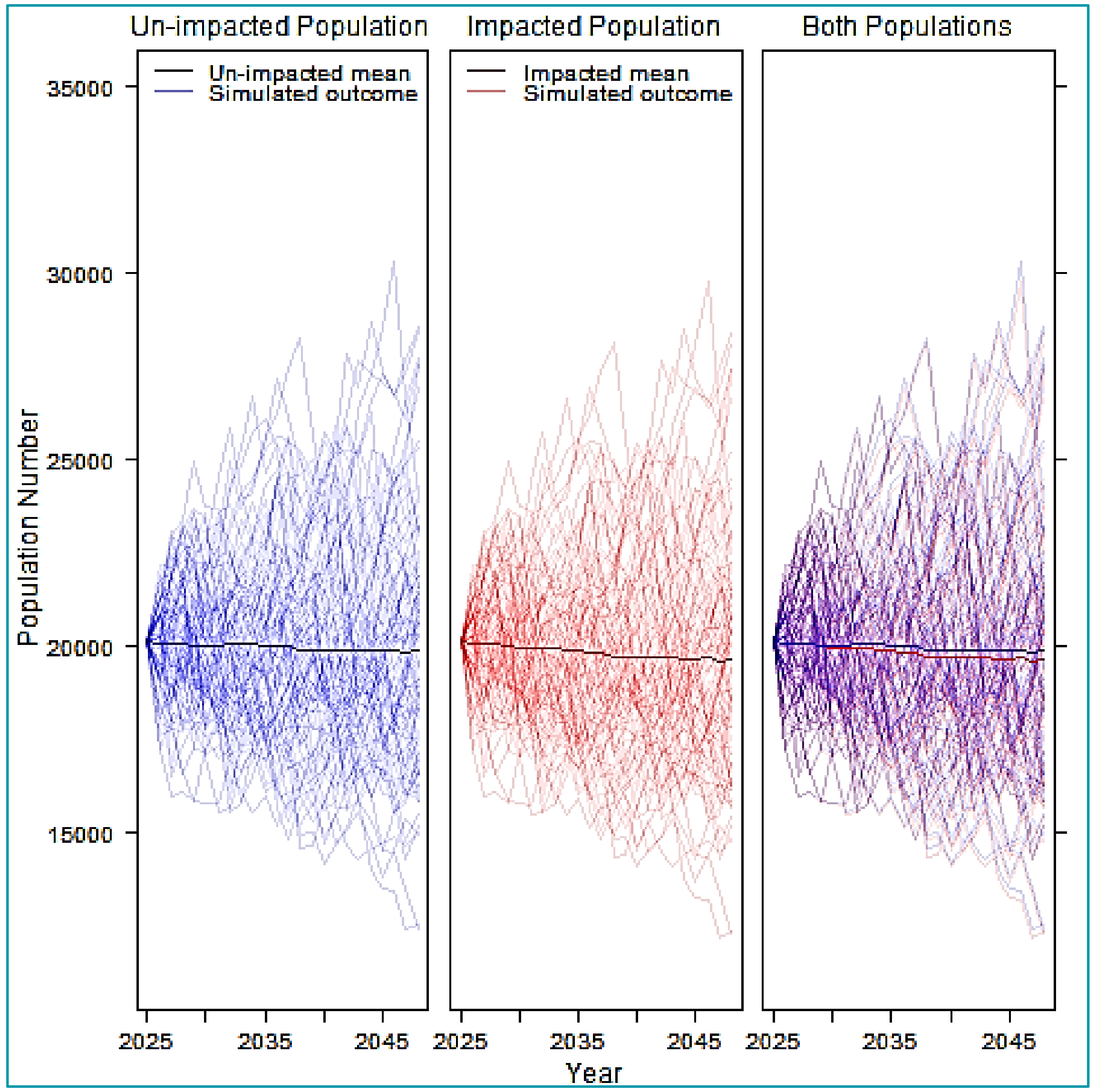

Figure 3.19: Minke Whale Scenario 3: 4% Reducing to 0.5% Conversion Factor, 11.1% Vulnerable Subpopulation

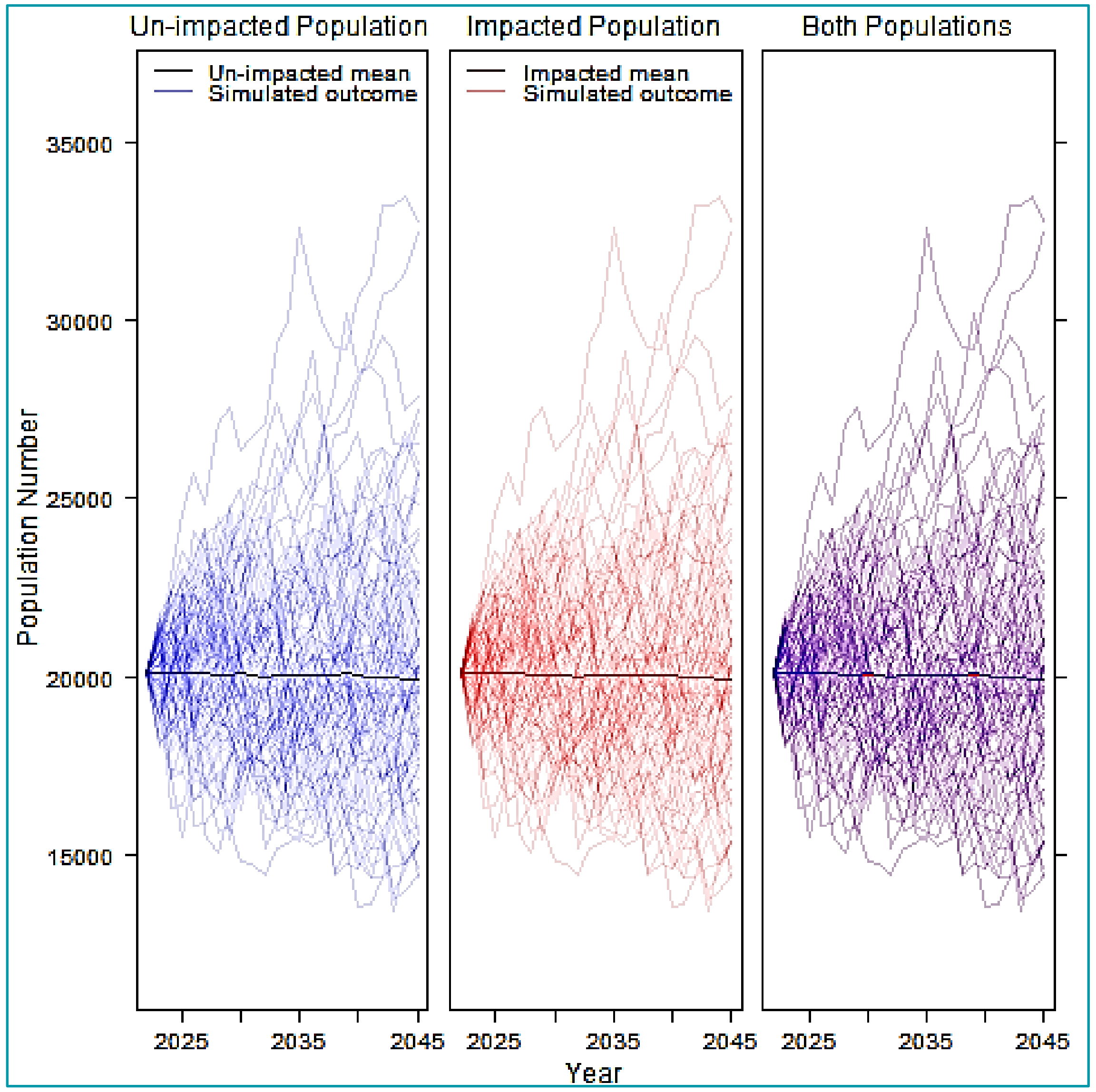

Figure 3.20: Minke Whale Scenario 4: Cumulative Projects, 1% Conversion Factor, no Vulnerable Subpopulation

3.4. GREY SEAL

56. There appears to be negligible alteration to the growth trajectory of grey seal, regardless of which of the conversion factor scenarios were explored for the Proposed Development alone (Figure 3.21, Figure 3.22, Figure 3.23). Comparison of the size of the unimpacted population to the impacted population for all three scenarios showed no difference in the number of animals with the median of the ratio predicted to be 100% at all time points and for all scenarios. Given these very small changes there is not considered to be a potential for long term effects on this species as the difference falls within the natural stochasticity of the modelled population.

57. Similarly for the cumulative scenario assessed within the north-east of Scotland no impacts were predicted on the population of grey seals, resulting from disturbance due to cumulative piling events (Table 3.4, Figure 3.24). This is not unexpected as both Seagreen 1A and Inchcape will finish piling prior to the commencement of piling at the Proposed Development so would not lead to a larger number of animals affected at any one time.

Table 3.4: Population Trajectory of Grey Seal Showing the Mean and Upper and Lower Confidence Limits at Different Time Points (Years After the Year in Which Piling Commences)

Time Point (Years)	Unimpacted Population			Impacted Population			Mean Ratio of Population Size
	Mean	Lower 2.5%	Upper 97.5%	Mean	Lower 2.5%	Upper 97.5%	
Scenario 1: 10% to 1% Conversion Factor							
2	43476	38107	48006	43475	38107	48006	1.000000
7	44582	37358	51522	44582	37358	51470	1.000000
13	45952	36661	56110	45951	36661	56110	1.000000
19	47853	36260	60890	47852	36260	60890	1.000000
25	49958	35366	66287	49957	35366	66287	1.000000
Scenario 2: 1% Conversion Factor							
2	43422	37939	47724	43422	37939	47724	1.000000
7	44549	36819	52131	44548	36819	52131	1.000000
13	45998	35760	55852	45997	35760	55852	1.000000
19	47738	35435	61206	47738	35435	61206	1.000000
25	49506	35291	65782	49506	35291	65782	1.000000
Scenario 3: 4% to 0.5% Conversion Factor							
2	43270	37876	47752	43270	37876	47752	1.000000
7	44504	37125	51984	44504	37125	51984	1.000000
13	45755	36023	56433	45755	36023	56433	1.000000
19	47511	35318	61248	47511	35318	61248	1.000000
25	49259	34974	66783	49259	34974	66783	1.000000
Scenario 4: CUMULATIVE PROJECTS, 1% Conversion Factor							
2	42830	39374	45458	42830	39374	45458	1.000000
3	43008	38496	46691	43008	38496	46691	1.000000
4	43316	38192	47824	43316	38192	47824	1.000000
5	43575	37571	48405	43575	37571	48405	1.000000
7	44198	37367	50471	44198	37367	50471	1.000000
11	45321	36069	54432	45321	36069	54432	1.000000
19	47843	36206	61472	47843	36206	61472	1.000000
25	49798	36151	67403	49798	36151	67403	1.000000

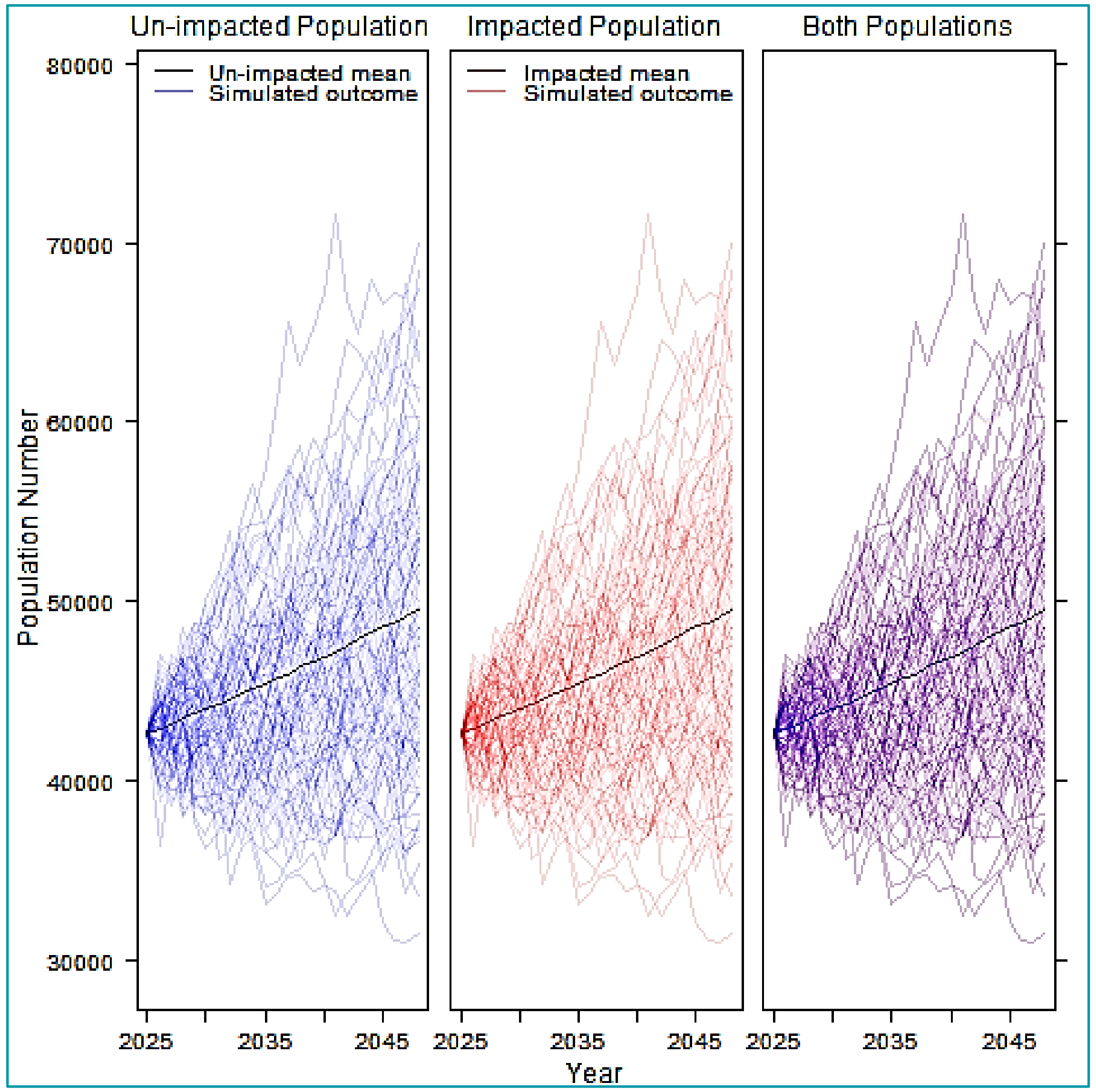

Figure 3.21: Grey Seal Scenario 1: 10% Reducing to 1% Conversion Factor, no Vulnerable Subpopulation

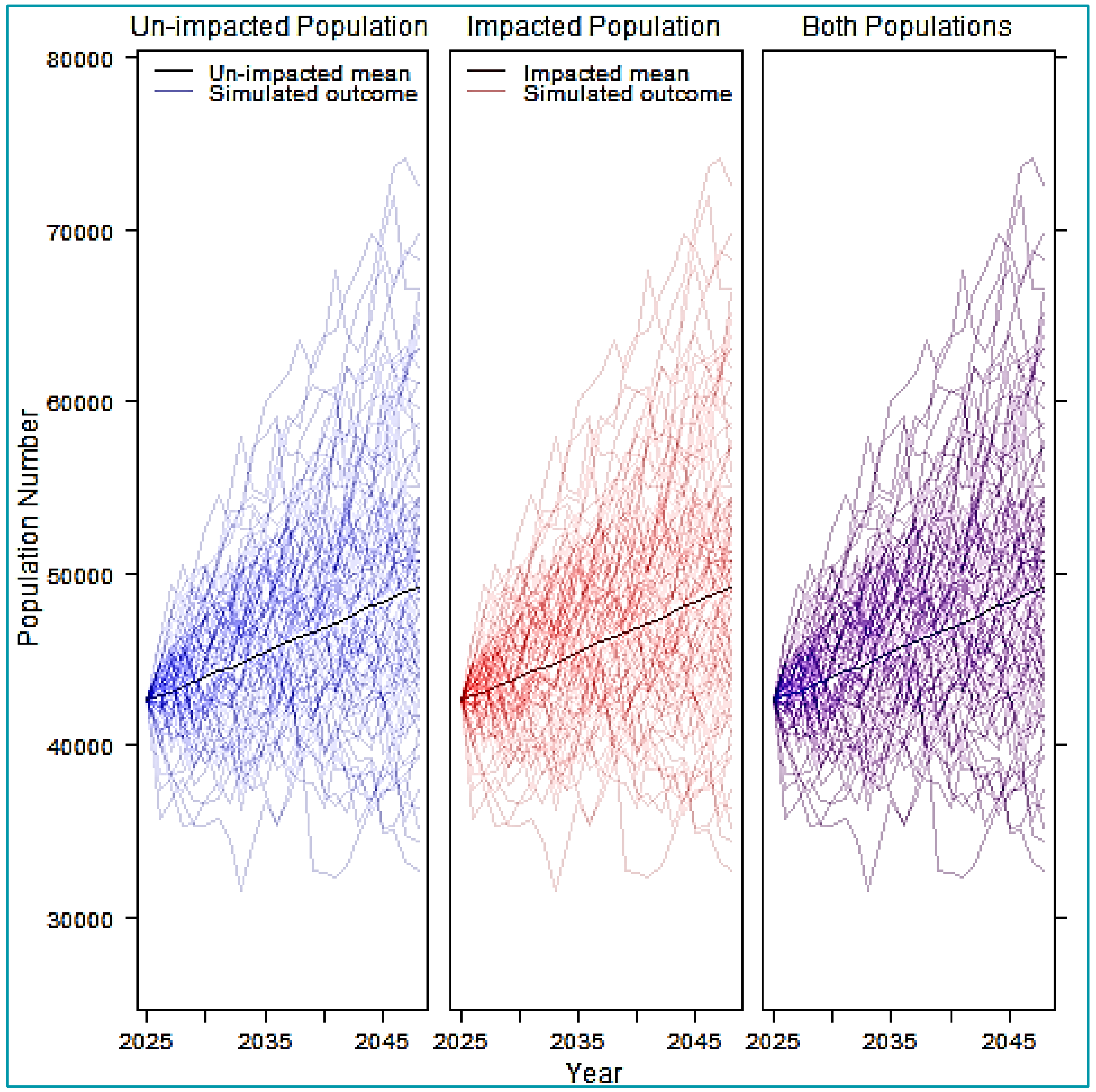

Figure 3.22: **Grey Seal Scenario 2: 1% Constant Conversion Factor, no Vulnerable Subpopulation**

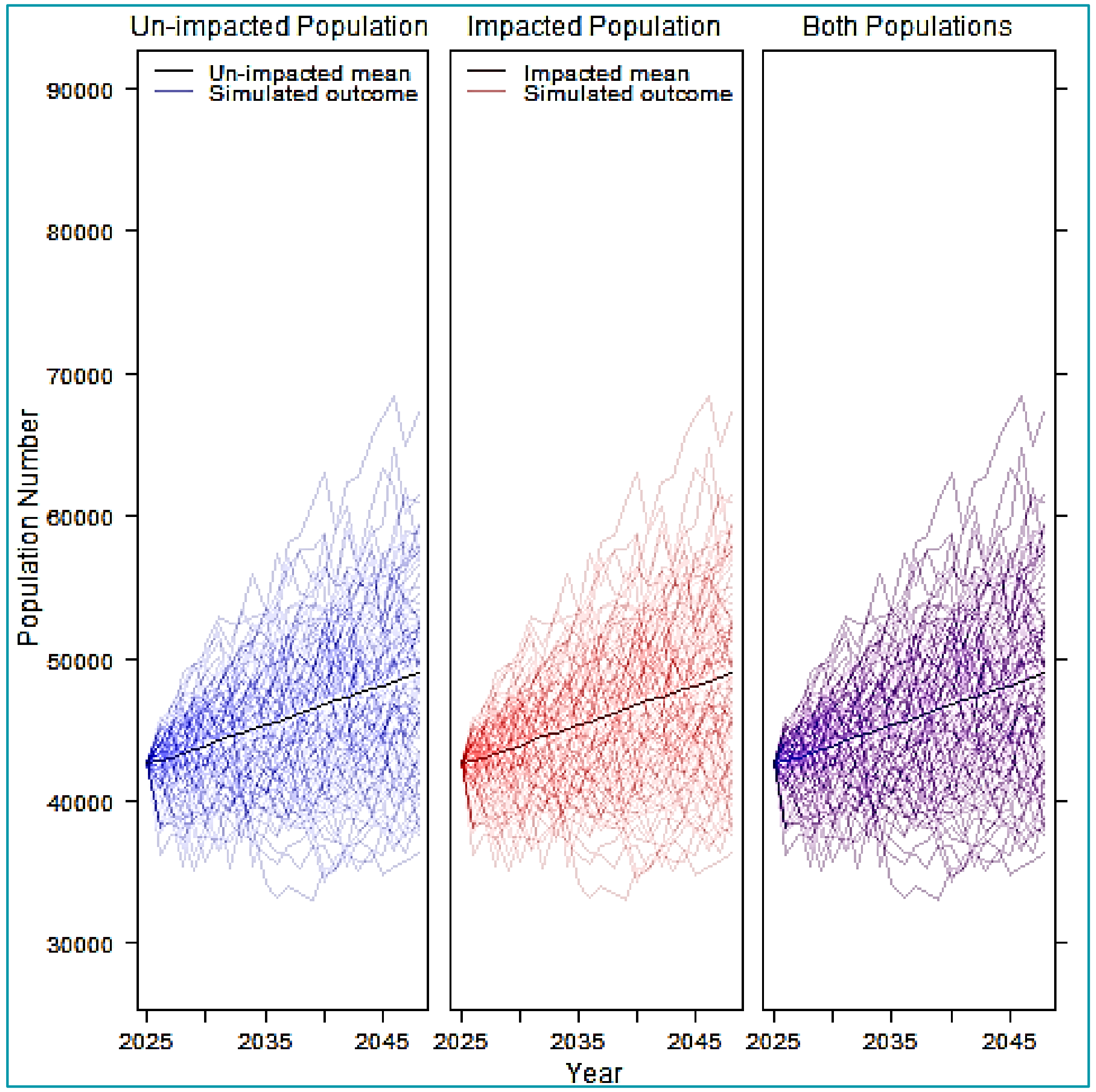

Figure 3.23: **Grey Seal Scenario 3: 4% Reducing to 0.5% Conversion Factor, no Vulnerable Subpopulation**

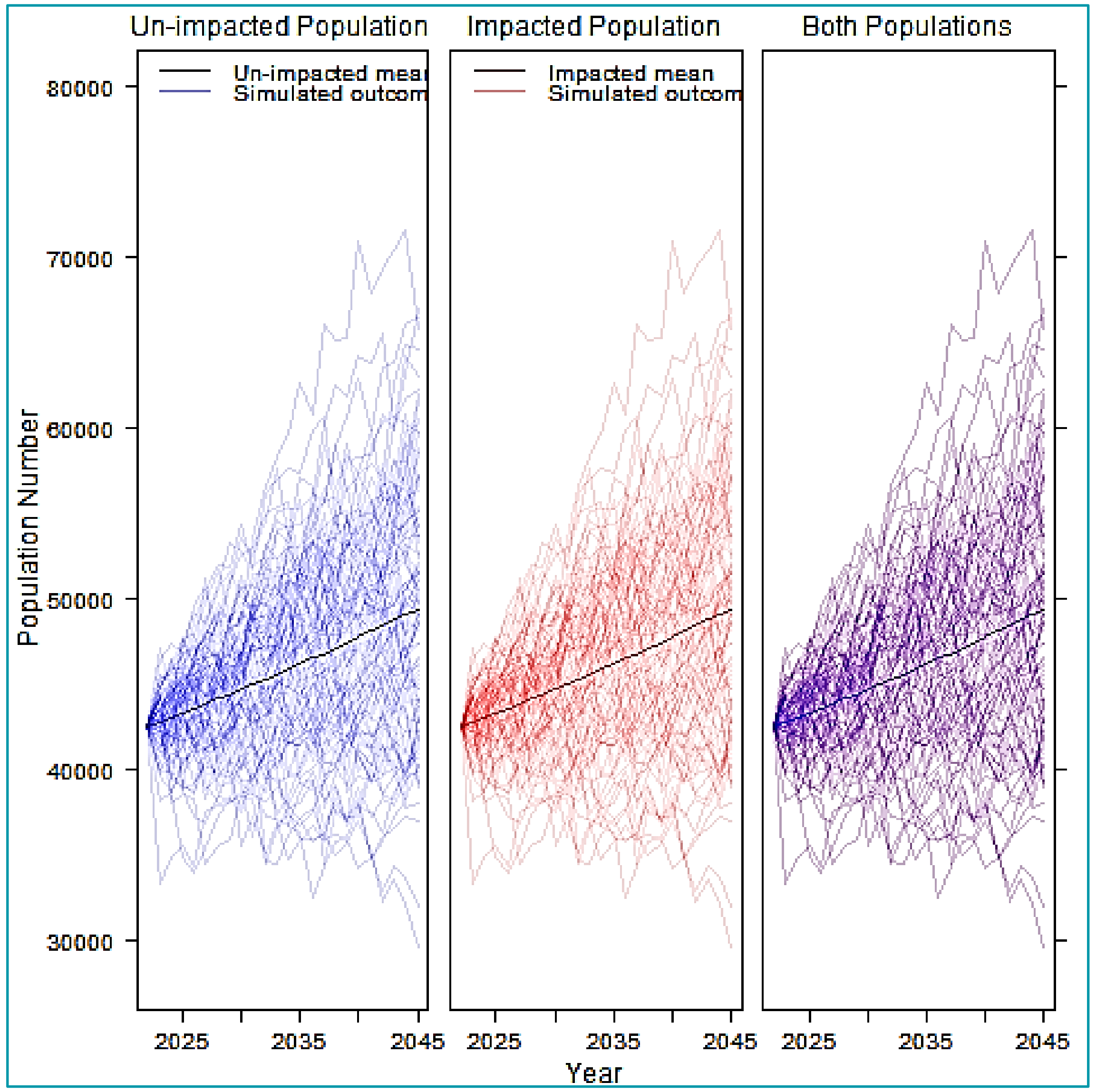

Figure 3.24: Grey Seal Scenario 4: Cumulative Projects, 1% Conversion Factor, no Vulnerable Subpopulation

3.5. HARBOUR SEAL

58. There appears to be negligible alteration to the growth trajectory of harbour seal, regardless of which of the conversion factor scenarios were explored. Comparison of the ratio of unimpacted population to the impacted population for all three scenarios showed no difference (Table 3.5).

59. Results of the iPCoD modelling for harbour seal using the maximum adverse scenario 10% reducing to 1% scenario for the MU population (Scenario 1) show that the median of the ratio of the mean impacted population to the unimpacted population was one at four years (coinciding with the end of the first two piling campaigns) onwards until the maximum 25 year time point (Table 3.5, Figure 3.25). Therefore, there is not considered to be a potential for long-term effects on this species. These results were the same when using the 1% conversion factor scenario for the MU population (Scenario 2, Figure 3.26), and the 4% reducing to 0.5%conversion factor scenario for the MU population (Scenario 3, Figure 3.27), with the mean impacted population the same as the mean unimpacted population at time point 25. Since there is no discernible difference between the impacted and unimpacted populations there is therefore not considered to be a potential for any long-term effects on this species.

60. Similarly for the cumulative scenario assessed within the north-east of Scotland no impacts were predicted on the population resulting from disturbance due to cumulative piling events (Table 3.5, Figure 3.28:). This is not unexpected since both Seagreen 1A and Inchcape will finish piling prior to the commencement of piling at the Proposed Development so would not lead to a larger number of animals affected at any one time.

Table 3.5: Population Trajectory of Harbour Seal Showing the Mean and Upper and Lower Confidence Limits at Different Time Points (Years After the Year in Which Piling Commences)

Time Point (Years)	Unimpacted Population			Impacted Population			Median Ratio of Population Size
	Mean	Lower 2.5%	Upper 97.5%	Mean	Lower 2.5%	Upper 97.5%	
Scenario 1: 10% to 1% Conversion Factor							
2	472	398	556	472	398	556	1.000000
7	473	372	584	473	372	584	1.000000
13	474	350	616	474	350	616	1.000000
19	476	324	656	476	324	656	1.000000
25	480	312	694	480	312	694	1.000000
Scenario 2: 1% Conversion Factor							
2	473	402	548	473	402	548	1.000000
7	473	374	576	473	374	576	1.000000
13	474	342	618	474	342	618	1.000000
19	478	322	666	478	322	666	1.000000
25	479	306	696	479	306	696	1.000000
Scenario 3: 4% to 0.5% Conversion Factor							
2	473	398	548	473	398	548	1.000000
7	473	372	580	473	372	580	1.000000
13	475	354	620	475	354	620	1.000000
19	477	326	652	477	326	652	1.000000
25	480	310	682	480	310	682	1.000000
Scenario 4: CUMULATIVE PROJECTS, 1% Conversion Factor							
2	471	422	520	471	422	520	1.000000
3	470	408	530	470	408	530	1.000000

Time Point (Years)	Unimpacted Population			Impacted Population			Median Ratio of Population Size
	Mean	Lower 2.5%	Upper 97.5%	Mean	Lower 2.5%	Upper 97.5%	
4	470	398	538	470	398	538	1.000000
5	470	386	552	470	386	552	1.000000
7	469	378	566	469	378	566	1.000000
11	470	356	604	470	356	604	1.000000
19	471	328	642	471	328	642	1.000000
25	472	312	698	472	312	698	1.000000

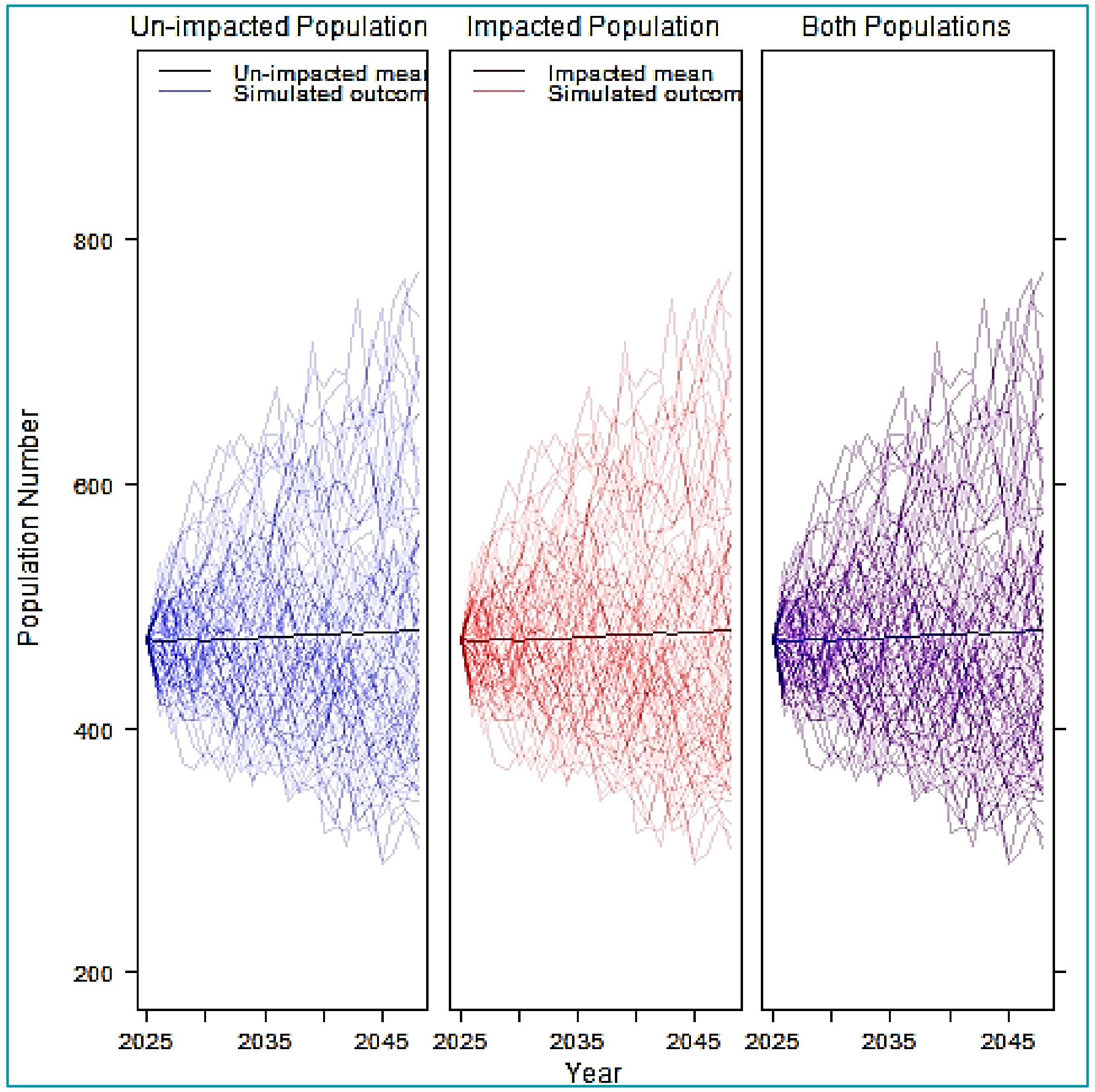

Figure 3.25: Harbour Seal Scenario 1: 10% Reducing to 1% Conversion Factor, no Vulnerable Subpopulation

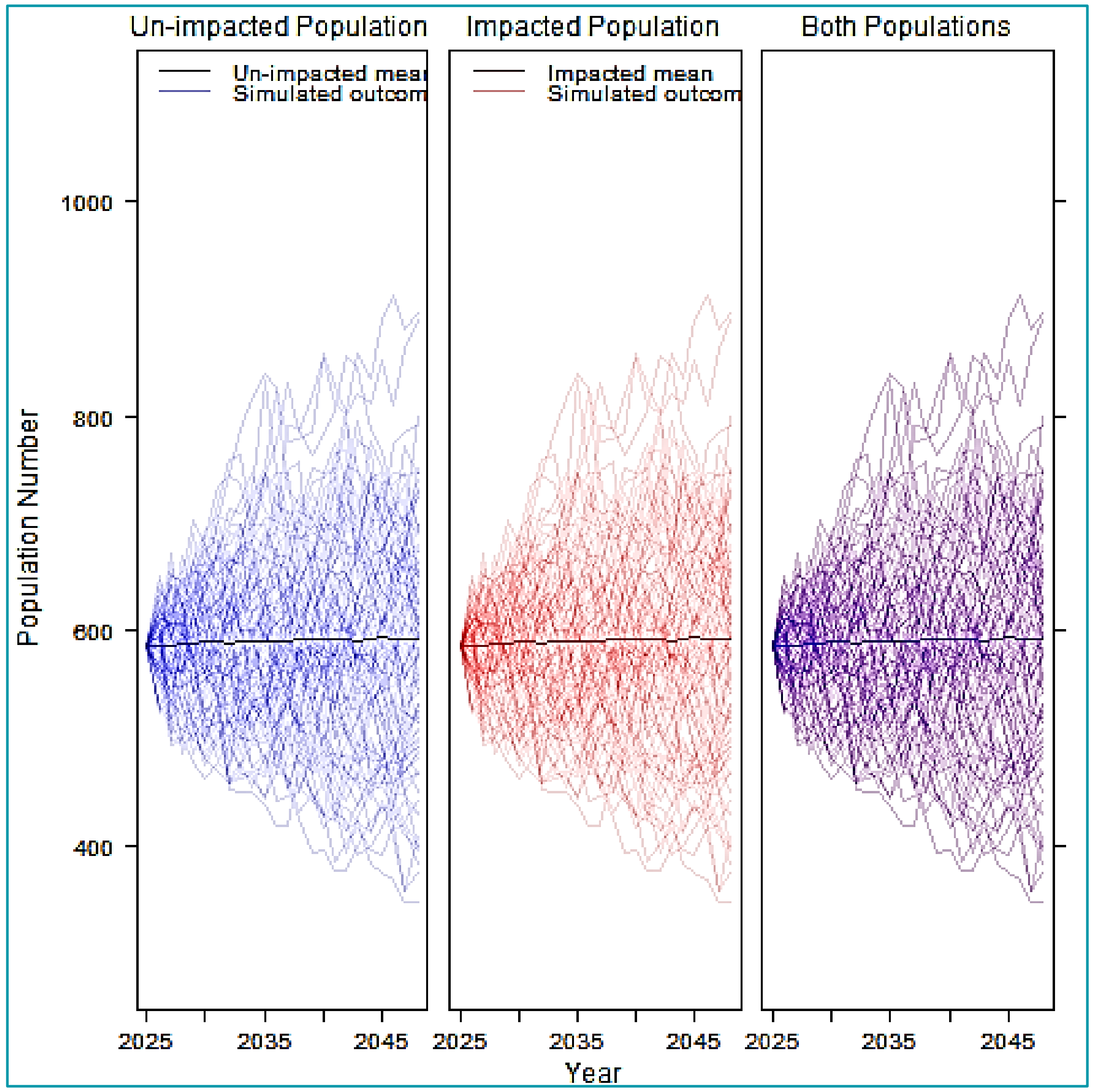

Figure 3.26: Harbour Seal Scenario 2: 1% Constant Conversion Factor, no Vulnerable Subpopulation

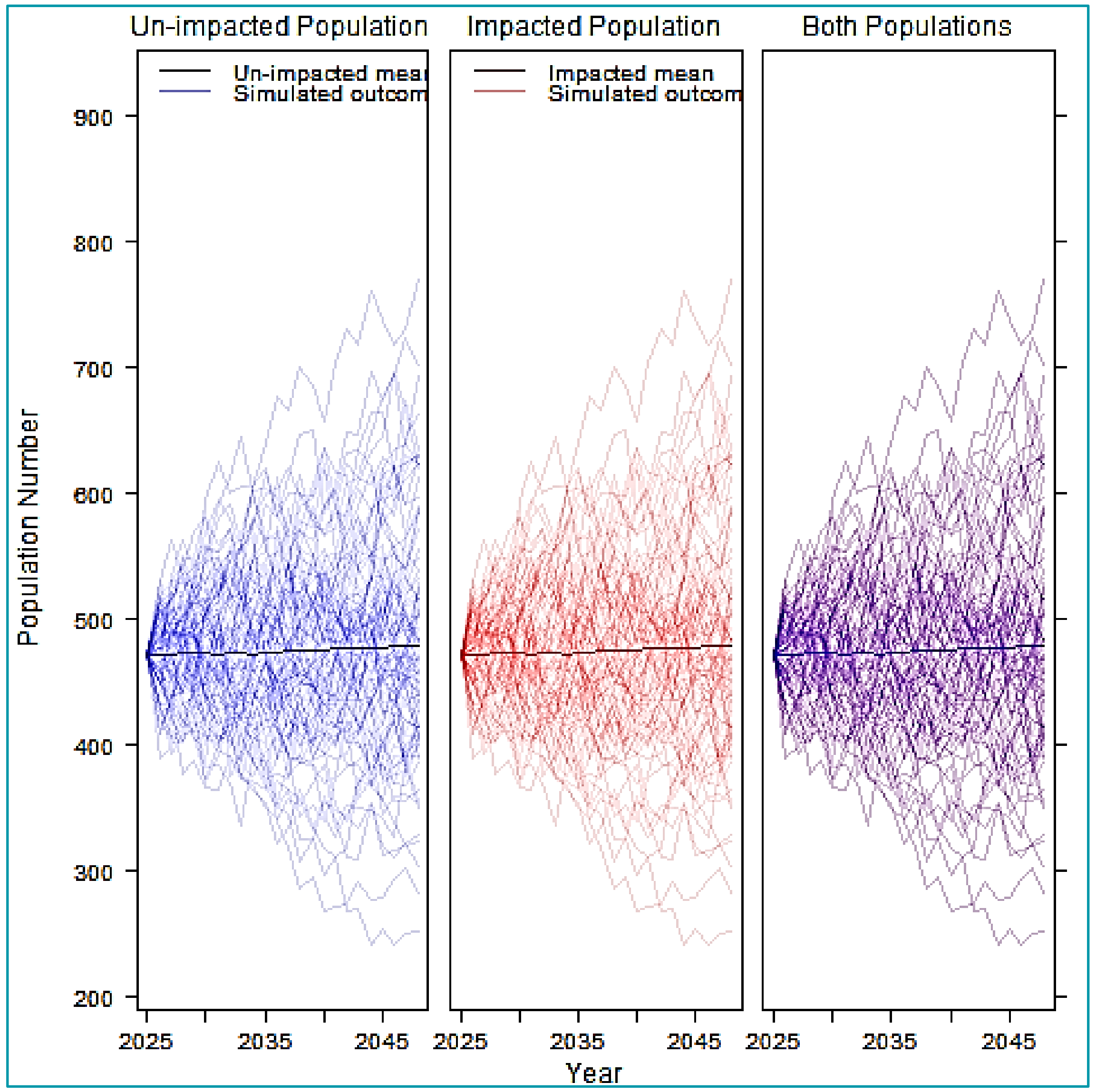

Figure 3.27: Harbour Seal Scenario 3: 4% Reducing to 0.5% Conversion Factor, no Vulnerable Subpopulation

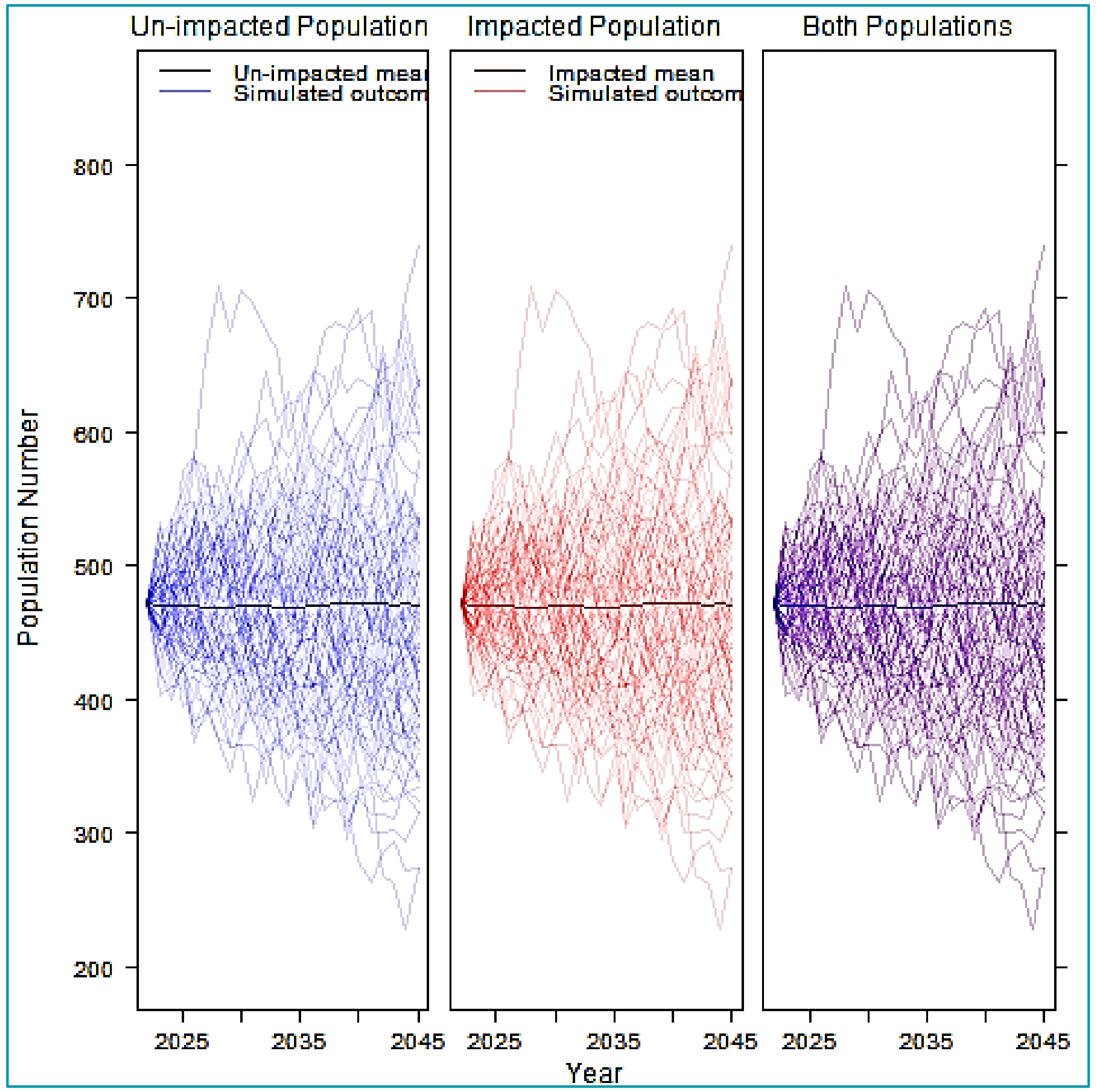

Figure 3.28: Harbour Seal Scenario 4: Cumulative Projects, 1% Conversion Factor, no Vulnerable Subpopulation

4. SUMMARY

61. This report presents the results of the iPCoD population modelling undertaken for key marine mammal species with the potential to be affected by the Proposed Development and for cumulative projects within relevant study areas. Overall, the iPCoD modelling results demonstrate that there is negligible significant effect to any species under any scenario assessed.

62. The population models were run to predict potential changes in population size as a result of piling at the wind turbine locations and offshore substation platforms associated with the Proposed Development. Reference populations were based on the latest estimates of population size for the relevant species' Management Units. The numbers of animals disturbed were based on the maximum design scenario of a 4,000 kJ hammer energy only on the assumption that any population changes would be smaller considering the realistic hammer energy of 3,000 kJ which would affect smaller numbers of animals.

63. The modelling demonstrated that for all species there was predicted to be no long-term decline in the population with negligible to very small differences between the unimpacted to impacted population size. Even where there were notable differences in the number of animals within the undisturbed compared to the disturbed population (i.e. for minke whale using the 10% reducing to 1% conversion factor) it is considered likely that this variation will fall within the natural stochasticity of the population and therefore would not represent a measurable (and significant) difference.

64. Results were similar regardless of the conversion factor used to predict numbers of animals disturbed or assessed against a vulnerable subpopulation (harbour porpoise and minke whale). This suggests that even using the most conservative conversion factor of 10% reducing to 1%, the populations of all species are not predicted to be adversely affected by piling at the Proposed Development in the long term and are therefore likely to recover following cessation of piling. Furthermore, a precautionary assumption has been made for this study that animals are disturbed both on the day of piling and for 24 hours the following day leading to additional conservatism in the model.

65. Similarly, for cumulative projects where piling could occur sequentially and concurrently with the Proposed Development, there were no long-term population level effects predicted for any of the species. The assessment was based on the maximum design scenario for each respective cumulative project (i.e. largest number of animals potentially disturbed at any one time) and therefore represents a conservative approach to the cumulative assessment. Results should, however, be interpreted with caution as there were no details on the actual piling schedules for cumulative projects and it is likely that such activity would be phased due to global availability of piling vessels.

66. Though the iPCoD model attempts to model major sources of uncertainty, results will always vary greatly due to environmental and demographic stochasticity in the model (evidenced in the 95% confidence limits in population size; Table 3.1 to Table 3.5). Whilst the model shows no evidence of population change from the Proposed Development, there are sources of uncertainty. Variation in demographic rates among years may exist as a result of changes in environmental conditions, or as a result of random processes or chance events which impact vital rates (e.g. survival, fertility, etc.). In two, otherwise identical populations that experience exactly the same sequence of environmental conditions, demographic stochasticity will mean populations will follow slightly different trajectories over time. The model assumes 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 data around the mean trajectories Figure 3.1 to Figure 3.28:). In addition, the model assumes that survival and fertility rates are not affected by population size (i.e. that there is no density dependent response).

67. In summary, whilst it is understood that iPCoD is a relatively simple population model (which links days of disturbance to changes in individual vital rates), the most obvious sources of uncertainty have been captured in the model development. In addition, the marine mammal assessment has adopted a precautionary approach in recognition of the uncertainties in how animals respond to repeated piling over time.

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