MORAY WEST PVA REPORT

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1.1	24 July 2018	Corrected initial population sizes
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CONTENTS

1 OVERVIEW

This document presents the underpinnings of the Population Viability Analyses (PVAs) conducted for NIRAS and for the Moray West Offshore Wind Farm Report to Inform Appropriate Assessment (RIAA). The analysis was performed for breeding colonies of seven species of seabirds in three different Special Protected Areas (SPAs). Stochastic, density independent, age-structured matrix models were used to simulate population trends over time for a range of impacts scenarios. Full details of the analysis, including model specifications and demographic rates used, are provided below.

2 METHODS

The potential impacts of the Moray West wind-farm development on the population growth and size of seven seabird species inhabiting three local SPAs/pSPAs were predicted via population viability analysis (PVA). Table 1 describes the populations and the SPAs analysed.

2.1 Matrix Models and parameterisation

Table 1: Populations and SPAs considered for analysis, and corresponding initial population sizes used in the modelling

Species	SPA	Initial population size (breeding individuals)	Year	Source
Northern Gannet	Troup Head SSSI	7694		pers. comm. I. Ellis (07/03/2018)
Puffin	North Caithness Cliffs	3507	2016	Marine Scotland Scoping Opinion, Appendix A
Razorbill †	East Caithness Cliffs	40256	2015	Marine Scotland Scoping Opinion, Appendix A
	North Caithness Cliffs	4699	2015	Marine Scotland Scoping Opinion, Appendix A
Common Guillemot †	East Caithness Cliffs	199966	2015	Marine Scotland Scoping Opinion, Appendix A
	North Caithness Cliffs	52076	2016	Marine Scotland Scoping Opinion, Appendix A
Black-legged Kittiwake	East Caithness Cliffs	48920		Marine Scotland Scoping Opinion, Appendix A
	North Caithness Cliffs	11146		Marine Scotland Scoping Opinion, Appendix A
Herring gull	East Caithness Cliffs	6534	2015	Marine Scotland Scoping Opinion, Appendix A
Great Black-Backed Gull	East Caithness Cliffs	532	2015	Marine Scotland Scoping Opinion, Appendix A

† For Razorbill and Guillemot populations, displayed numbers of breeding individuals in the initial population were obtained from correcting the counts provided in the source document using a multiplying factor of 1.34.

For each species, an age-structured matrix model (Caswell, 2001) was built to simulate the population's progress through time in terms of abundance and age distribution, based on species-specific demographic rates and count estimates. The model assumes individuals to be grouped into discrete year age-classes, and all members of an age-class are considered equal with respect to their demographic vital rates (i.e. survival, growth and reproduction). The model dynamics involves predicting the population numbers at age in the next year given its previous year's numbers and vital rates.

The generic population model can be written in compact form as

$$\mathbf{n}_{y+1} = \mathbf{L}\mathbf{n}_y$$

where $\mathbf{n}_y$ is the population vector with elements $n_{a,y}$ denoting the number of individuals at each age-dass $a = 1, \dots, A$ at year y, $\mathbf{n}_{y+1}$ is the numbers at age-class in the following year, and $\mathbf{L}$ represents the $A \times A$ projection matrix (also known as the Leslie matrix). The projection matrix $\mathbf{L}$ defines the expected contribution of individuals in each age-dass in a given year to each age-class in the subsequent year.

Models used in this analysis were built under the following assumptions, for all considered species:

- models represent an annual post-breeding census over a period of $y = 1, \dots, Y$ year steps. Therefore, the model annual cycle comprises a census immediately after fledging on the first day of the biological year, with the first age-dass ($a = 1$) containing newly hatched birds, followed by a 12 months period of survival. Then, on the first day of the subsequent year, surviving animals increment in age, adult age-classes reproduce and resultant newborns fledge, and the next census is carried out.
- reproduction is considered to be confined to adult birds, with age of first breeding being species-specific.
- population size is density independent, and therefore projections will either increase to infinity or decrease to extinction.
- population is considered to be closed system, i.e. age distributions are not affected by migration exchanges between neighbouring colonies
- the final age-class A is a aggregated age group, representing A years-old birds and older. This implies the absence of senescence, i.e. the survival and reproductive performances of the oldest animals remain constant over time. The value of A, and hence the size of the projection matrix, of each species is determined by either the age of first breeding or the oldest adult age-class for which survival data is available (the largest of the two values).

Based on the above assumptions, the expanded version of the generic population model used in this analysis can be expressed as

$$\begin{bmatrix} n_{1,t+1} \\ n_{2,t+1} \\ n_{3,t+1} \\ \vdots \\ n_{A,t+1} \end{bmatrix} = \begin{bmatrix} 0 & \cdots & 0 & P_{A-1}(0.5)S_{A-1\to A} & P_A(0.5)S_A \\ S_{1\to 2} & 0 & 0 & \cdots & 0 \\ 0 & S_{2\to 3} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & 0 & S_{A-1\to A} & S_A \end{bmatrix} \times \begin{bmatrix} n_{1,t} \\ n_{2,t} \\ n_{3,t} \\ \vdots \\ n_{A,t} \end{bmatrix}$$

where P_A denotes the annual productivity rate of age-class A, expressed as the annual average number of fledged young per breeding pair; and $S_{a\to a+1}$ represents the annual survival transition rate of animals of age-class a, i.e. the average proportion of birds in age-dass a that will survive the whole year and trasition to age-class $a + 1$. Elements in the top row of the projection matrix $\mathbf{L}$ (i.e. half of the produtivity rate multiplied by the survival rate) reflect the annual fecundity rate per capita of each adult age-class.

Environmental stochasticity, which accounts for the variation arising from environmental changes affecting individuals in the same group (e.g. between-year differences in weather conditions), was incorporated in the models at the level of productivity and survival rates. For each simulated year, a value for each demographic rate was randomly generated from a probability distribution defined by the mean and standard deviation estimates of that rate for the population under consideration.

Random survival rates, which are theoretically bounded at 0 and 1, were drawn from beta distributions. Stretched beta distributions were used to generate productivity rates as it allows an upper limit greater than one, which was set based on the maximum number of eggs laid per pair per year for each species. These two distributions are considered to provide biologically reasonable random values of each vital rate (Morris and Doak, 2002).

Demographic stochasticity, which accounts for individual-level variation affecting transition probabilities between age-classes, was not included in the models. For large populations, like the ones considered in this analysis (Table 1), the effects of environmental stochasticity are deemed more important than those associated with demographic stochasticity (Morris and Doak, 2002).

Table 2 provides the demographic parameters used to specify the models for each species. With exception of maximum number of eggs per pair (taken from Snow and Perrins, 1998), all remaining parameter were obtained from Horswill and Robinson (2015).

Table 2: Species features and demographic rates used in the population models (Snow & Perrins, 1998; Horswill & Robinson, 2015).

	Reproduction				Survivals						Productivities	
Species	Age first breeding	Final age (A)	Eggs/pair		$S_{1\to2}$	$S_{2\to3}$	$S_{3\to4}$	$S_{4\to5}$	$S_{5\to6}$	S_A	P_{A-1}	P_A
Gannet	5.01	5	2	**Mean**	0.424	0.829	0.891	0.895		0.919	0	0.698
				SD	0.007	0.004	0.003	0.003		0.042	0	0.071
Puffin	5	6	3	**Mean**	0.892	0.892	0.892	0.76	0.805	0.906	0.617	0.617
				SD	0.009	0.009	0.009	0.019	0.017	0.083	0.151	0.151
Razorbill	5	5	1	**Mean**	0.794	0.794	0.895	0.895		0.895	0	0.459
				SD	0.134	0.134	0.067	0.067		0.067	0	0.236
Guillemot	6	6	1	**Mean**	0.56	0.792	0.917	0.939	0.939	0.939	0	0.629
				SD	0.013	0.034	0.022	0.015	0.015	0.015	0	0.174
Black-legged Kittiwake	4	4	2	**Mean**	0.79	0.854	0.854			0.854	0	0.819
				SD	0.092	0.051	0.051			0.051	0	0.332
Herring Gull	5	5	3	**Mean**	0.798	0.798	0.834	0.834		0.834	0	0.92
				SD	0.092	0.092	0.034	0.034		0.034	0	0.477
Great Black-Backed Gull	5	5.	2	**Mean**	0.82	0.885	0.885	0.885		0.885	0	1.139
				SD	0.022	0.022	0.022	0.022		0.022	0	0.533

Annual productivity rates were selected from regional-specific estimates available in Horswill and Robinson (2015). Thus, for the Moray West site, U.K. north-eastern productivity estimates were used whenever possible (Table 3). Single survival estimates attributed to multiple age-classes (e.g. Puffin) were split evenly into annual survival rates, with associated standard deviations computed via simulation (Table 3).

Table 3: Comments on values selected for demographic rates

Species	Demographic Rate	Comments
Gannet	Productivity	Eastern UK figures. Suggested experience-specific productivity not applied
Puffin	Productivity	Average UK rates
	Survivals $S_{1\to2}$, $S_{2\to3}$ & $S_{3\to4}$	Literature provides a single mean (0.709) and SD (0.022) for the first 3 age-classes. Corresponding annual mean rate computed as exp(log(0.709)/3) = 0.892. Approximate annual SD (0.009) derived from 1000 draws from a beta distribution with mean=0.709 and SD=0.022.
Razorbill	Productivity	Northern UK figures
	Survivals $S_{1\to2}$ & $S_{2\to3}$	Literature provides a single mean (0.630) and SD (0.209) for the first 2 age-classes. Corresponding annual mean rate computed as exp(log(0.63)/2) = 0.794. Approximate annual SD (0.134) derived from 1000 draws from a beta distribution with mean=0.63 and SD=0.209.
Guillemot	Productivity	Northern UK figures
Black-legged Kittiwake	Productivity	Eastern UK figures
Herring Gull	Productivity	Age-specific productivity rates available, but data quality noted as being poor. No figures available for colonies in the Moray Firth. Average UK rates used instead.
Great Black-Backed Gull	Productivity	Average UK rates
	All survivals	Survival rates largely unknown for this species. Following Horswill and Robinson's (2015) advice, survival rates from the Lesser Black-backed Gull used instead

For each model, assuming the population was at equilibrium before the windfarm development, the initial population size in terms of breeding individuals (Table 1) was converted to total size (i.e. number of birds in the whole population) using the proportion of breeders under the population's stable age distribution (i.e. the proportion of individuals per age-class). The stable age distribution was provided by the right eigenvector associated with the dominant eigenvalue of the population projection matrix using the mean of the demographic rates (Table 2). The (average) stable age

distribution for each species is provided in Table 4. The initial population vector ($\mathbf{n_1}$) was then obtained by multiplying the initial total size by the stable age distribution vector.

Starting with the initial population vector for the first simulated year, new population vectors were calculated by multiplying the previous year's population vector by a new projection matrix generated from sampling each demographic rate (i.e. different projection matrices prevailing in each simulated year).

Models were run for 50 years, representing the likely lifespan of the wind farm developments. Each 50-year simulation was run 1000 times to obtain indicative population trends and estimates of uncertainty surrounding those trends. Models were run for each SPA separately based on population size estimates.

Table 4: Stable age structure for each species under analysis

Age-class	Gannet	Puffin	Razorbill	Guillemot	Kittiwake	Herring Gull	Great Black-backed Gull
1	0.192	0.143	0.127	0.162	0.187	0.18	0.199
2	0.081	0.124	0.101	0.088	0.143	0.143	0.15
3	0.067	0.108	0.08	0.068	0.118	0.114	0.122
4	0.059	0.094	0.072	0.06	0.553	0.095	0.099
5	0.602	0.069	0.619	0.055		0.469	0.43
6		0.463		0.566			

Wind farm impacts from collision and displacement effects were incorporated in the models in terms of additional mortalities. Displacement effects were assumed to have no impact on productivity rates. Additional mortalities were assumed to be applied to all age classes in proportion to their presence (i.e. the likelihood of a bird being killed due to wind farm effects assumed to be independent of its age).

A range of absolute additional adult mortalities per annum, from 0 to a species-specific maximum value by incremental steps of 50, were used as impact scenarios. The related absolute number of additional deaths over all ages was derived via the stable age distribution. While impact scenarios are expressed in terms of absolute annual deaths, this is not expected to remain constant as population sizes change over time. As such, the absolute number of additional deaths only strictly applies in the first year of simulation. It is converted to per-capita mortality rate for projection forwards i.e. the number of additional deaths in a year will increase proportionately with an increase in the simulated population size and vice-versa.

2.2 Implementation

All modelling was done in the R statistical programming environment v3.3.x (R Core Team, 2017). All code was bespoke.

2.3 Key outputs

Outputs here focus on reference points indicated in the relevant scoping document[1]. The principal metrics indicated in the scoping document follow recommendations by Jitlal *et al.* (2017)[2] and are the:

1. median of the ratio of impacted to unimpacted annual growth rate.
2. median of the ratio of impacted to unimpacted population size.
3. centile for unimpacted population that matches the 50th centile for impacted population.

Where annual population growth rate was required, this was calculated as the average over years 5 to 50 of the simulations, as per scoping recommendations – the first 5 years being discarded to mitigate against effects of starting conditions.

Furthermore, each unimpacted to impacted metric was derived following a matched runs approach (Green, 2014), whereby stochasticity is applied to the population before wind farm impacts are applied (i.e. survival and productivity rates sampled at each time step are the same for the unimpacted and impacted populations, with additional impact mortalities being subsequently deducted from sampled survivals).

[1] Marine Scotland - Licensing Operations Team (16 June 2017) Scoping Opinion Addendum: Ornithology. SCOPING OPINION FOR THE PROPOSED SECTION 36 CONSENT AND ASSOCIATED MARINE LICENCE APPLICATION FOR THE MORAY EAST OFFSHORE WINDFARM ALTERNATIVE DESIGN PARAMETERS – ORNITHOLOGY ASPECTS ONLY

[2] Jitlal, M., Burthe, S., Freeman, S. and Daunt F. 2017 Testing and validating metrics of change produced by Population Viability Analysis (PVA) – Marine Scotland Science commissioned report (currently unpublished)

3 REFERENCES

Caswell, H. 2001. Matrix Population models, Second Edition. Sinauer Associates, Inc. Sunderland, MA.

Horswill, C. & Robinson R. A. 2015. Review of seabird demographic rates and density dependence. JNCC Report No. 552. Joint Nature Conservation Committee, Peterborough.

Marine Scotland - Licensing Operations Team (16 June 2017) Scoping Opinion Addendum: Ornithology. Scoping opinion for the proposed section 36 consent and associated marine licence application for the moray east offshore windfarm alternative design parameters – ornithology aspects only.

Morris, W.F. and Doak, D.F. 2002. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer, MA.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Snow, D.W. & Perrins, C.M. 1998. The birds of the western Palearctic, Concise editon. Oxford University Press.

4 APPENDIX

The following are selected outputs for the simulations run for:

- Gannets: Troup Head
- Puffin: North Caithness Cliffs
- Razorbill: North/East Caithness Cliffs
- Guillemot: North/East Caithness Cliffs
- Kittiwake: North/East Caithness Cliffs
- Herring gull: East Caithness Cliffs
- Great Black-backed Gull: East Caithness Cliffs

Outputs from VPAs can be voluminous and may be summarised in many ways. Outputs here focus on reference points indicated in the relevant scoping document[3], as well as over-arching views of the simulations. The principal metrics indicated in the scoping document follow recommendations by Jitlal *et al.* (2017)[4] and are the:

4. median of the ratio of impacted to unimpacted annual growth rate
5. median of the ratio of impacted to unimpacted population size
6. centile for unimpacted population that matches the 50th centile for impacted population

Here for each species/population we present:

1. Plots of the distributions of simulated final population sizes after 50 years. Unimpacted distributions are presented in each, along with a range of impact scenarios, in terms of varying additional adult mortalities.
2. Plots of the population size projections through time, 0 - 50 years post-construction. A range of impact scenarios are presented in terms of varying additional adult mortalities, ranging from 0 (unimpacted) to a species/population-specific upper limit.
3. Plots comparing the 50th percentile points of the simulated impacted and unimpacted populations sizes through time (two representations are given).
4. Plots comparing the growth rates of simulated impacted and unimpacted populations, for a range of impact sizes.
5. A table of growth rates under varying impact scenarios, with several reference points expressed: the 2.5%, 50% & 97.5% points of the distribution of simulated rates.

[3] Marine Scotland - Licensing Operations Team (16 June 2017) Scoping Opinion Addendum: Ornithology. SCOPING OPINION FOR THE PROPOSED SECTION 36 CONSENT AND ASSOCIATED MARINE LICENCE APPLICATION FOR THE MORAY EAST OFFSHORE WINDFARM ALTERNATIVE DESIGN PARAMETERS – ORNITHOLOGY ASPECTS ONLY

[4] Jitlal, M., Burthe, S., Freeman, S. and Daunt F. 2017 Testing and validating metrics of change produced by Population Viability Analysis (PVA) – Marine Scotland Science commissioned report (currently unpublished)

4.1 Gannets – Troup Head

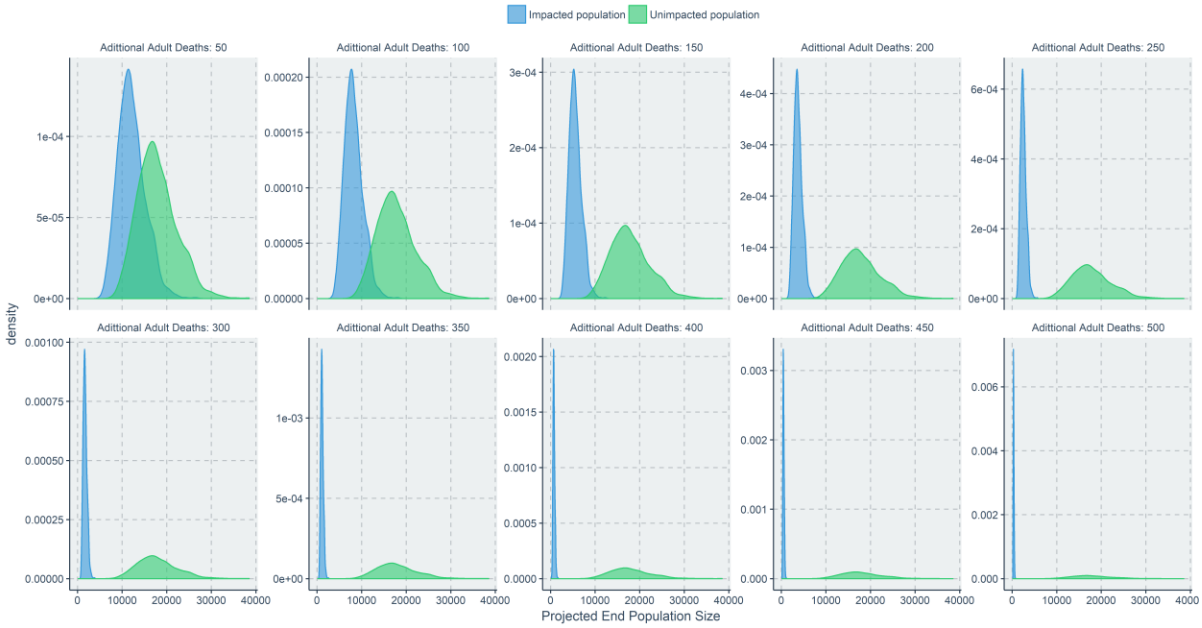

Figure 1: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

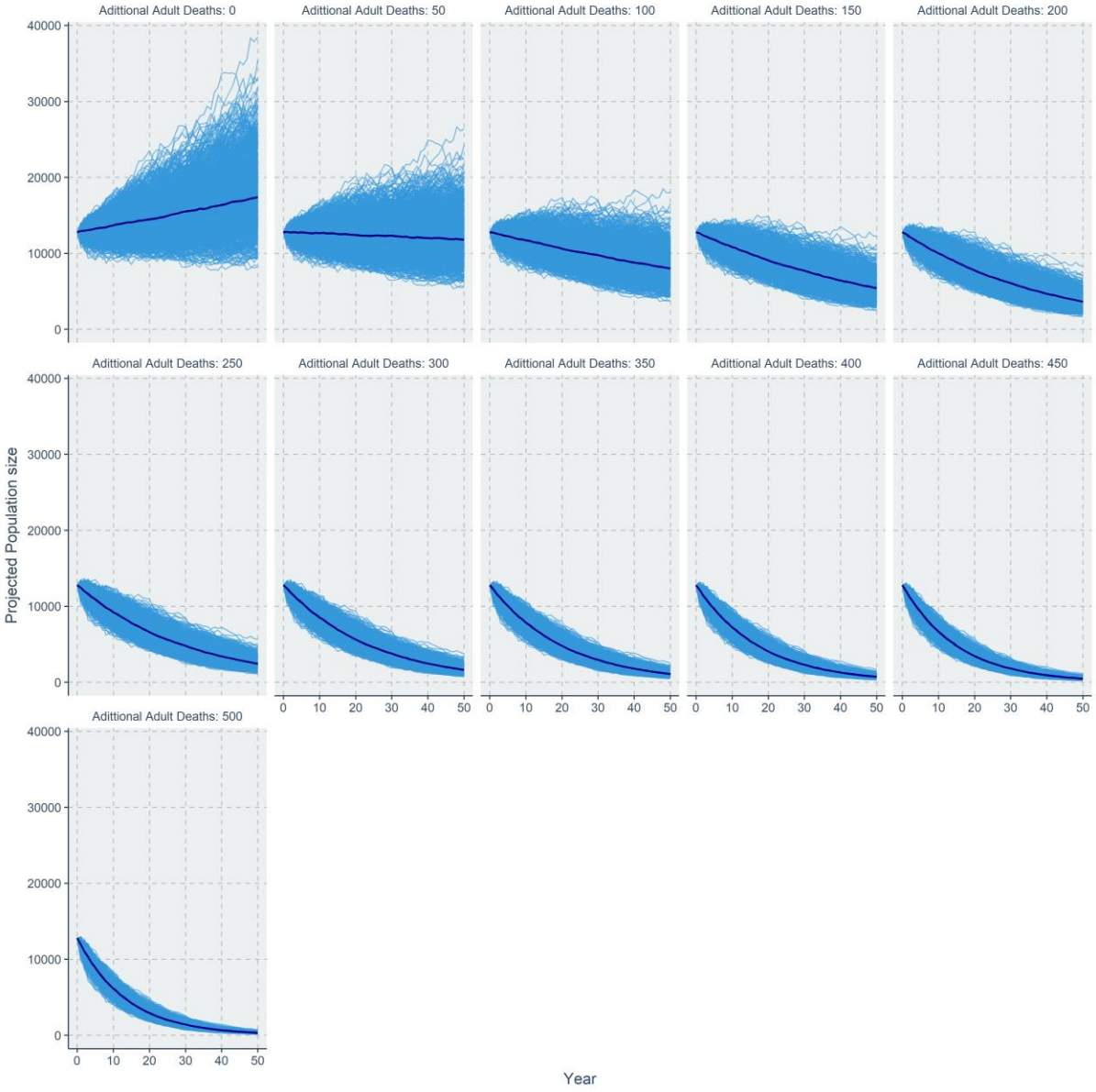

Figure 2: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

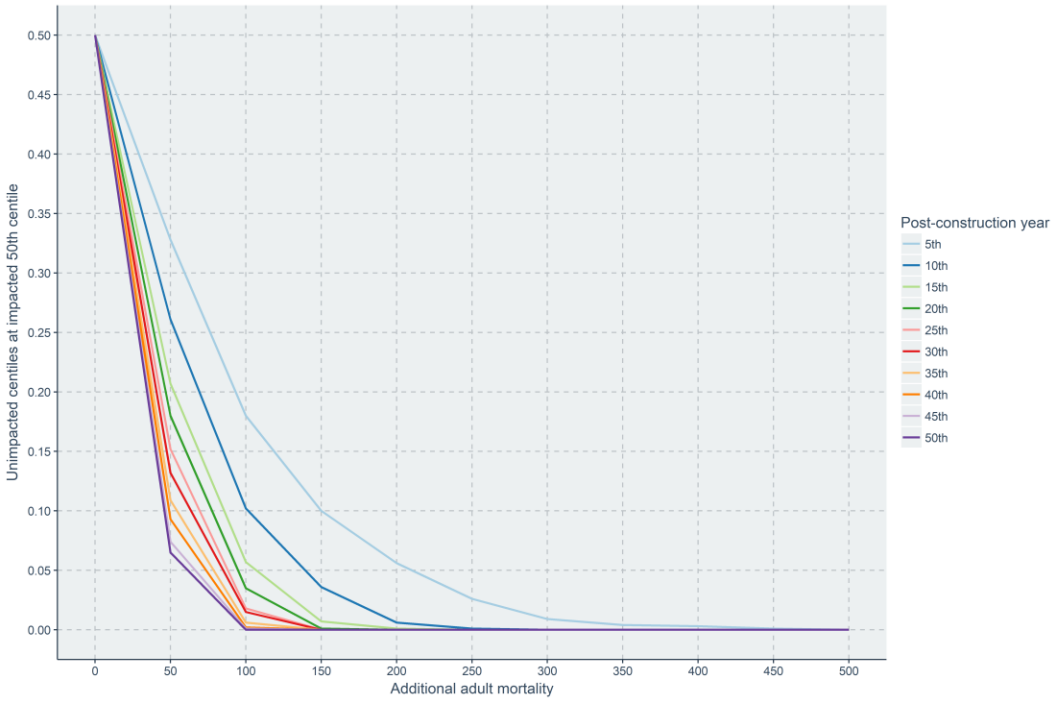

Figure 3: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

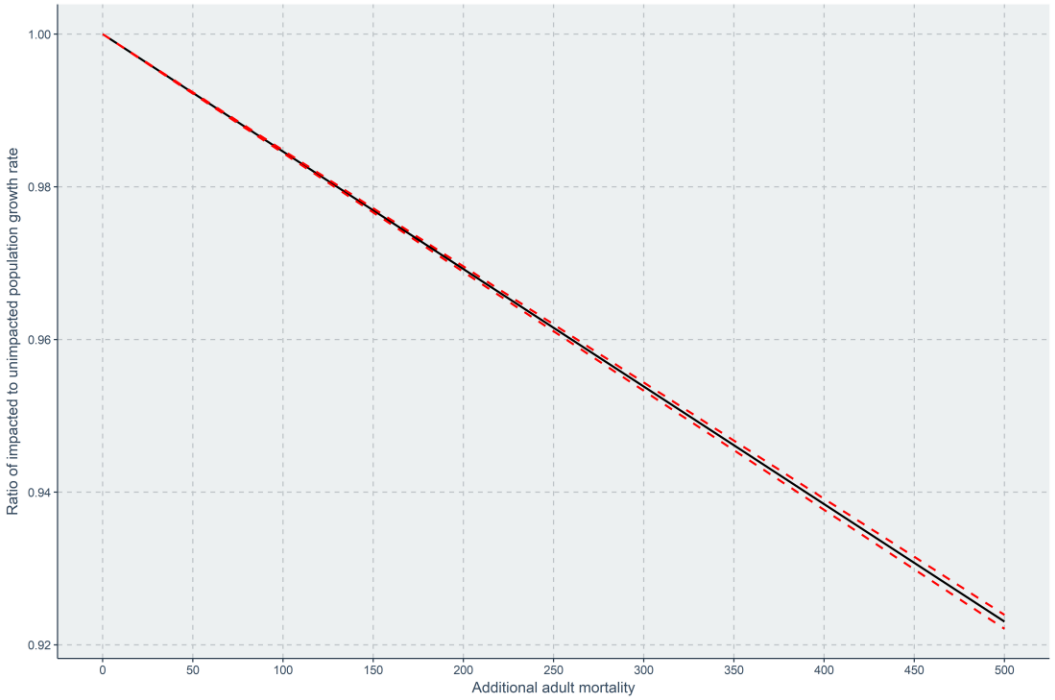

Figure 4: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

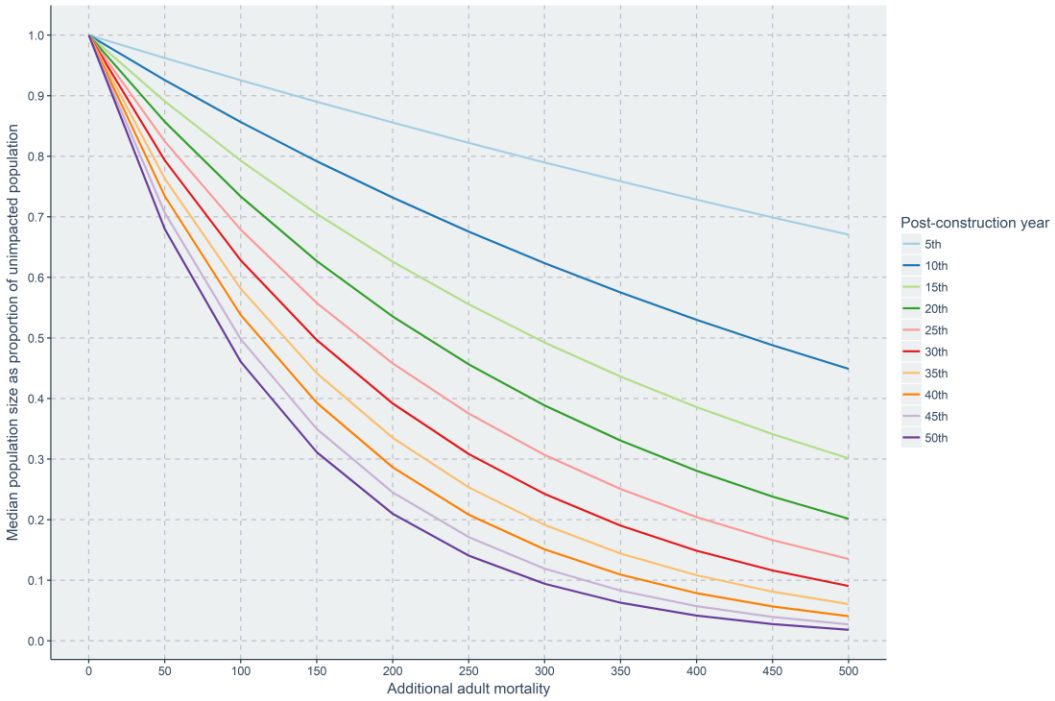

Figure 5: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 5: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.006	0.996	1.016
50	0.998	0.988	1.008
100	0.991	0.980	1.000
150	0.983	0.973	0.993
200	0.975	0.965	0.985
250	0.968	0.957	0.977
300	0.960	0.949	0.970
350	0.952	0.942	0.962
400	0.944	0.934	0.954
450	0.937	0.926	0.946
500	0.929	0.918	0.939

4.2 Puffin – North Caithness Cliffs

Figure 6: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of addition al adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

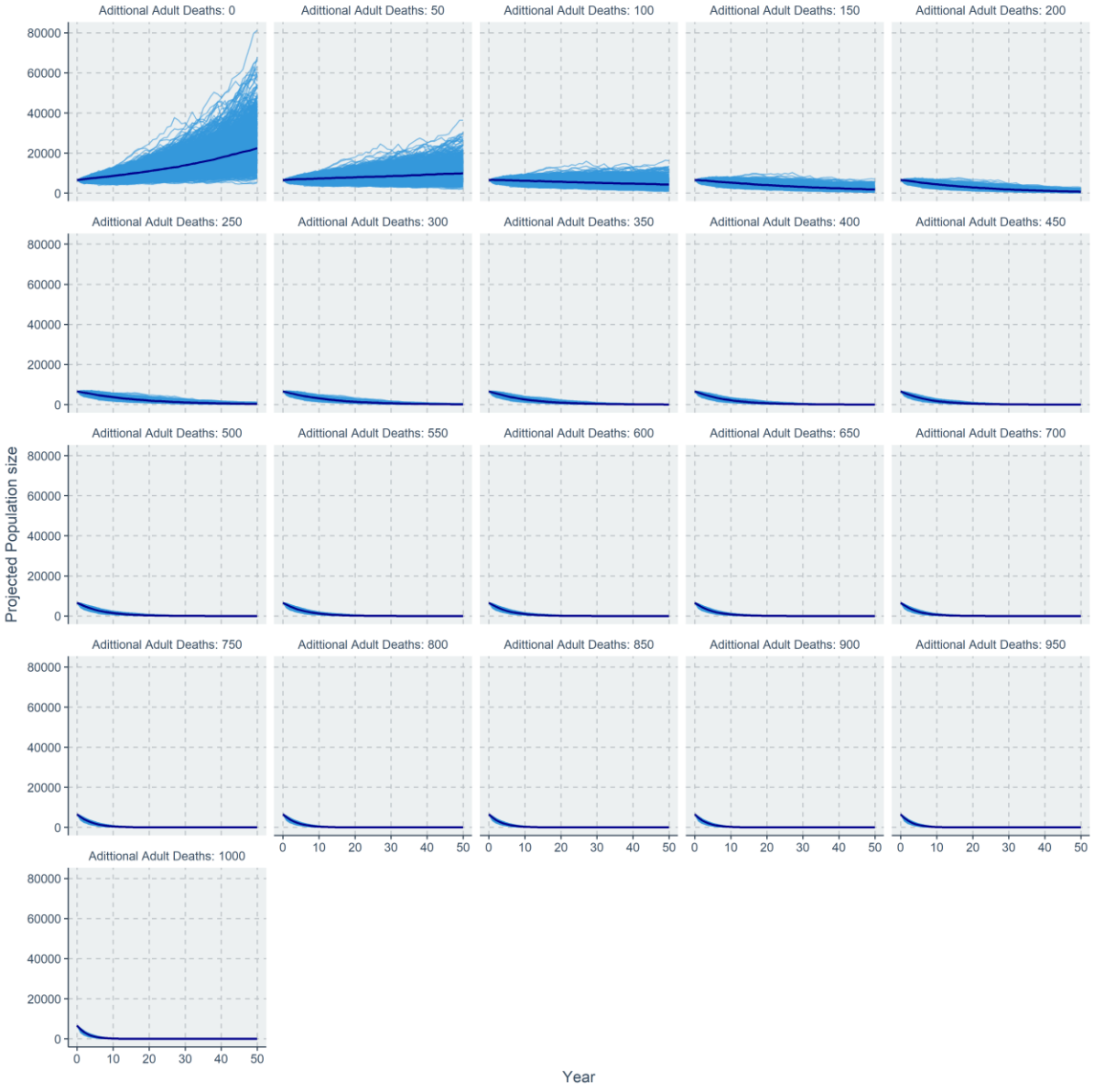

Figure 7: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

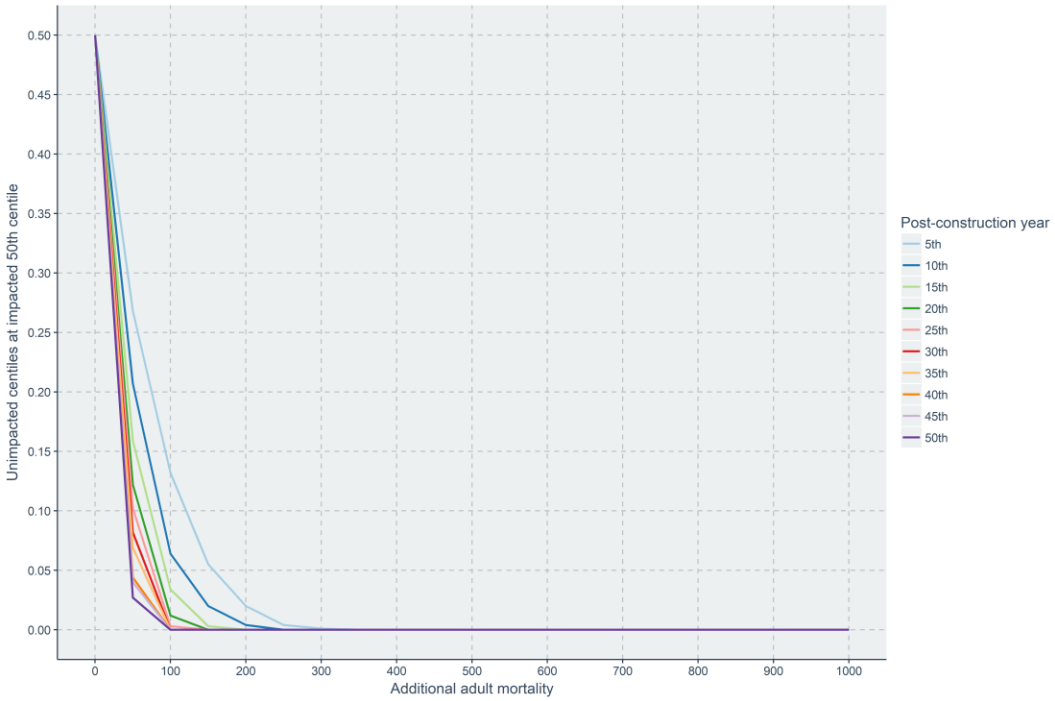

Figure 8: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

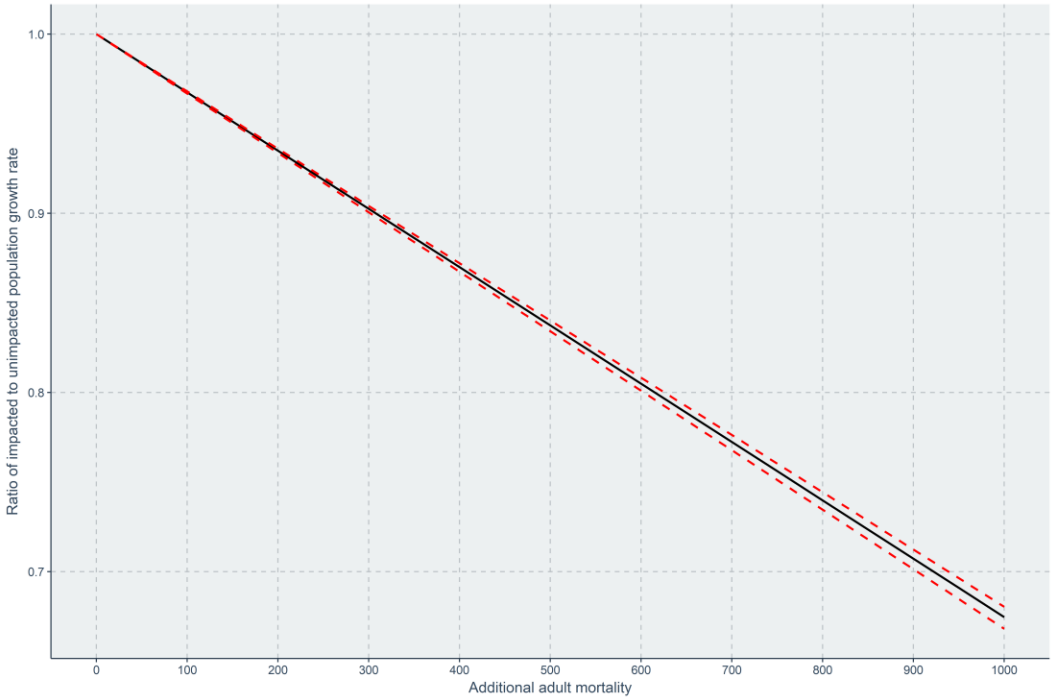

Figure 9: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

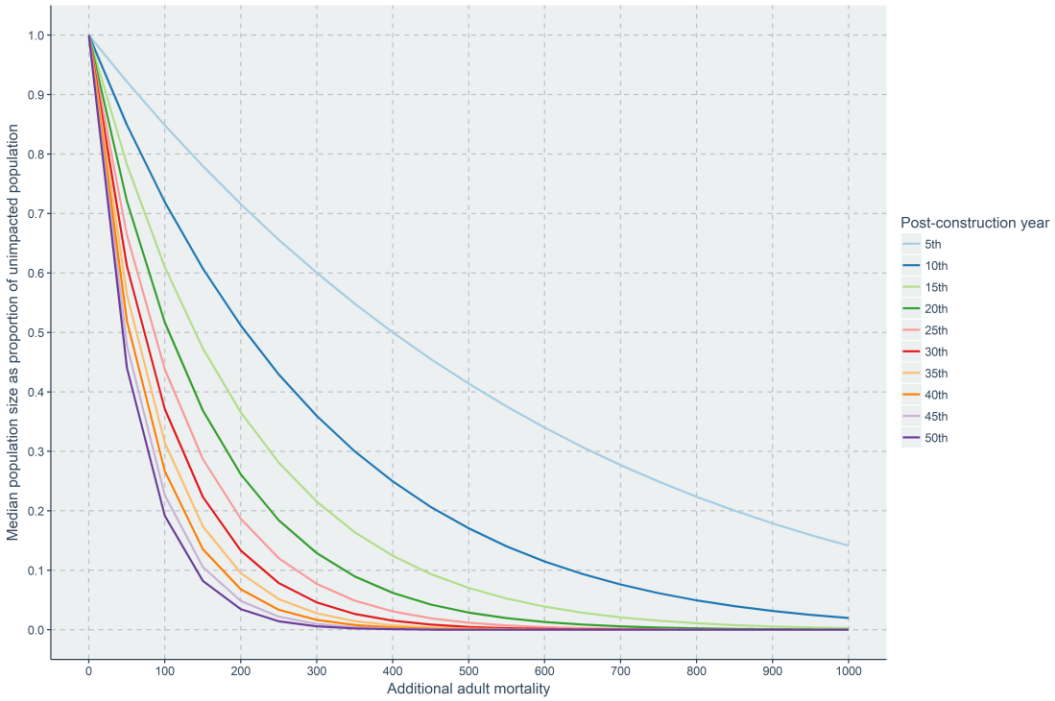

Figure 10: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 6: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.025	1.005	1.042
50	1.008	0.988	1.025
100	0.991	0.971	1.008
150	0.975	0.955	0.992
200	0.958	0.938	0.975
250	0.941	0.921	0.959
300	0.925	0.905	0.942
350	0.908	0.888	0.925
400	0.892	0.872	0.908
450	0.875	0.855	0.892
500	0.858	0.838	0.875
550	0.842	0.822	0.858
600	0.825	0.805	0.842
650	0.808	0.788	0.825
700	0.792	0.772	0.808
750	0.775	0.755	0.792
800	0.758	0.738	0.775
850	0.741	0.722	0.758
900	0.725	0.705	0.742
950	0.708	0.688	0.725
1000	0.691	0.672	0.708

4.3 Razorbill – North Caithness Cliffs

Figure 11: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

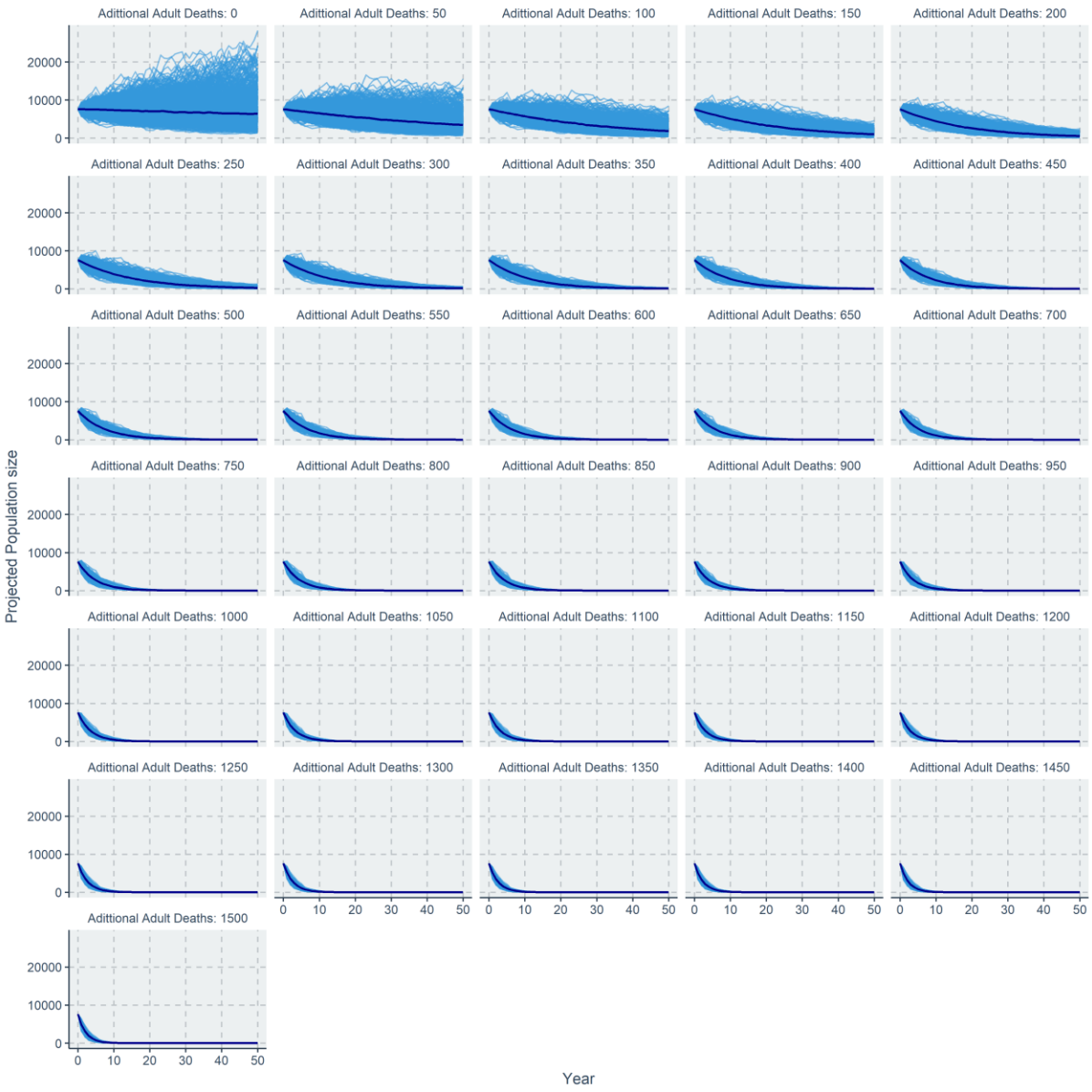

Figure 12: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

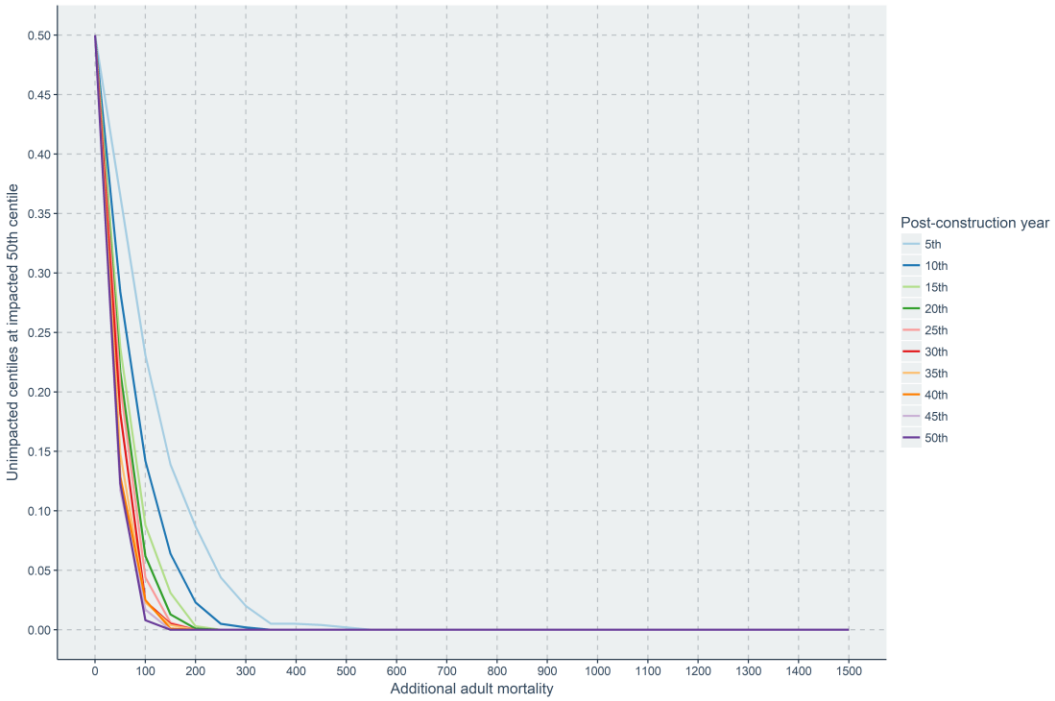

Figure 13: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

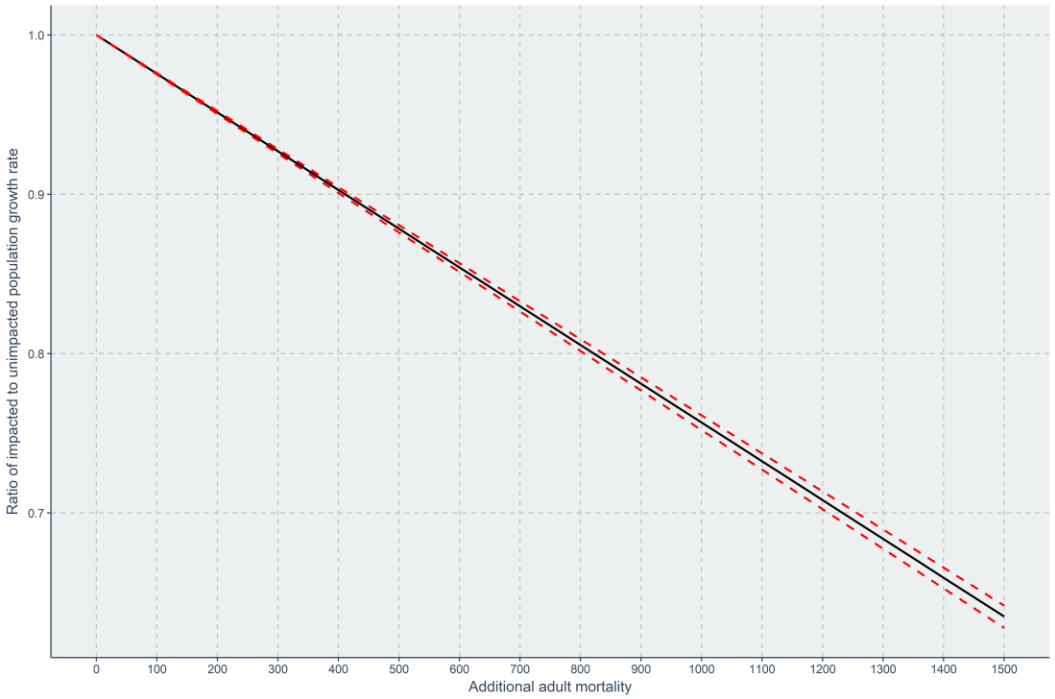

Figure 14: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

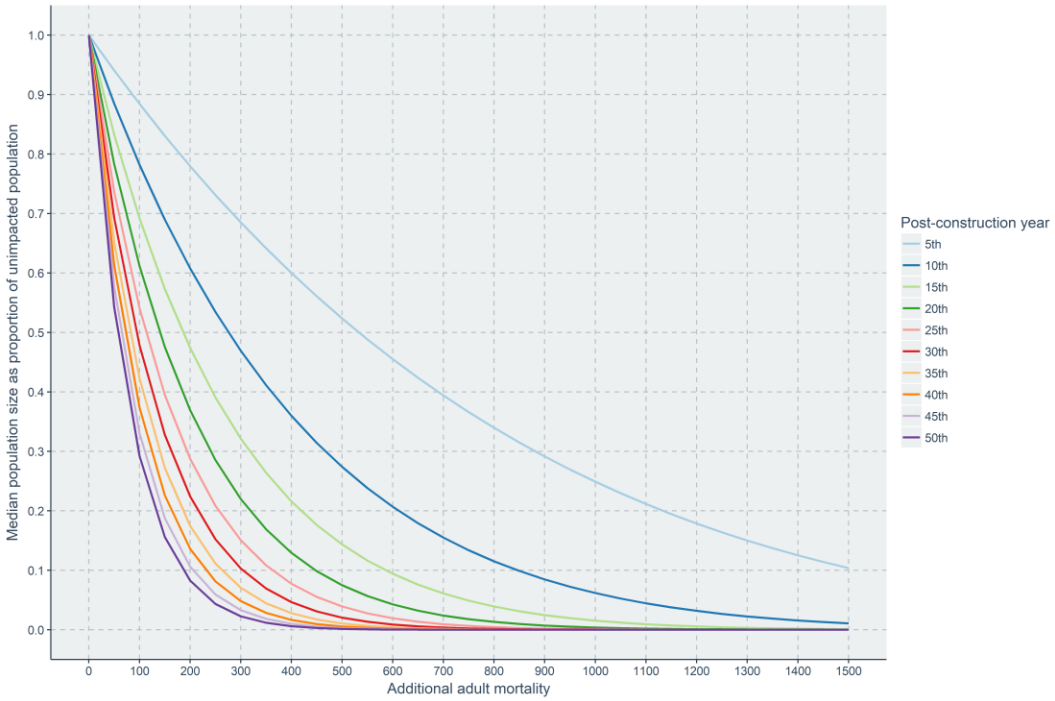

Figure 15: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 7: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	0.997	0.975	1.018
50	0.984	0.963	1.006
100	0.972	0.951	0.994
150	0.960	0.939	0.982
200	0.948	0.927	0.970
250	0.936	0.915	0.957
300	0.924	0.903	0.945
350	0.912	0.891	0.933
400	0.900	0.879	0.921
450	0.888	0.867	0.909
500	0.875	0.855	0.897
550	0.863	0.843	0.884
600	0.851	0.830	0.872
650	0.839	0.818	0.860
700	0.827	0.806	0.848
750	0.815	0.795	0.836
800	0.803	0.782	0.823
850	0.791	0.770	0.811
900	0.778	0.758	0.799
950	0.766	0.746	0.787
1000	0.754	0.734	0.775
1050	0.742	0.722	0.762
1100	0.730	0.710	0.750
1150	0.718	0.698	0.738
1200	0.706	0.686	0.726
1250	0.694	0.673	0.714
1300	0.682	0.661	0.701
1350	0.669	0.649	0.689
1400	0.657	0.637	0.677
1450	0.645	0.625	0.665
1500	0.633	0.613	0.653

4.4 Razorbill – East Caithness Cliffs

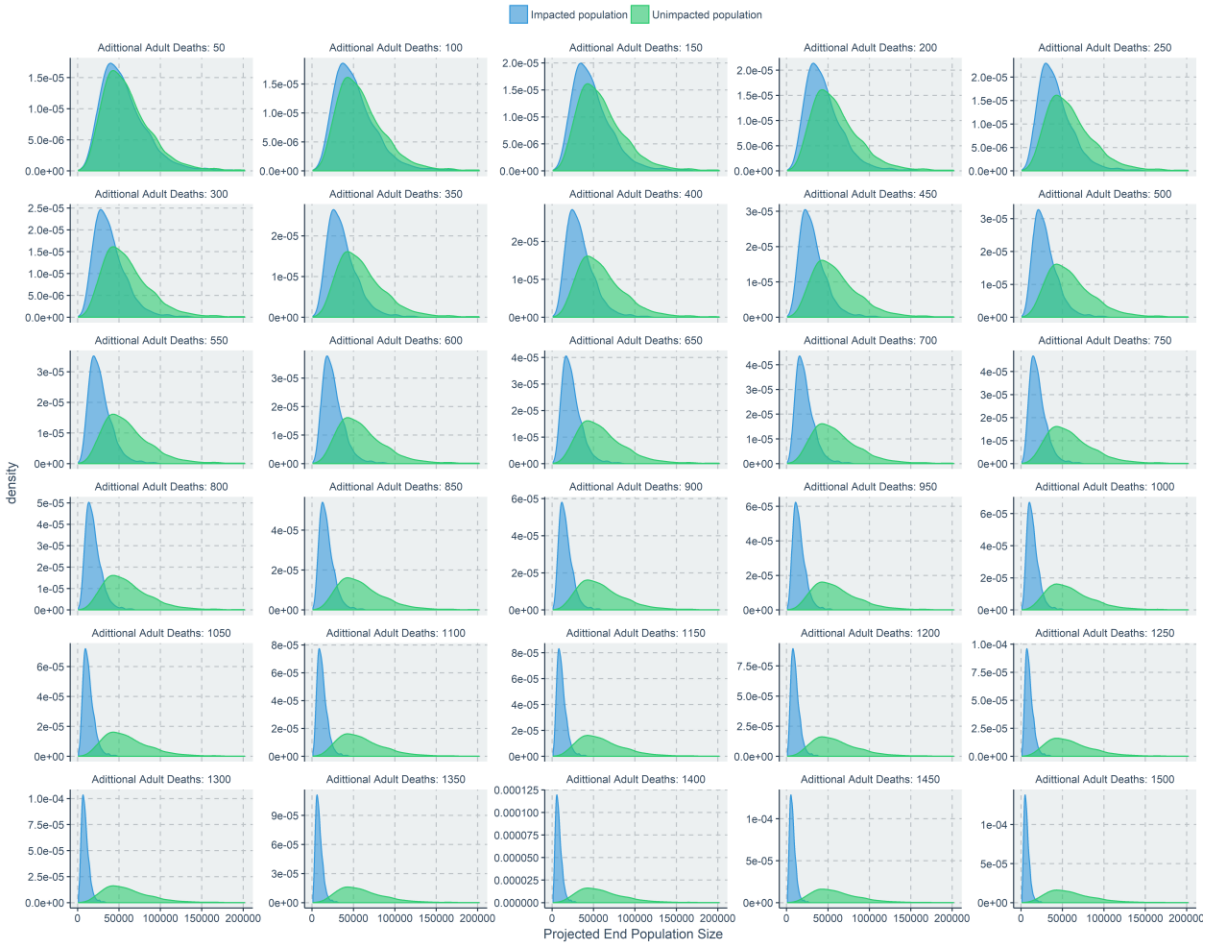

Figure 16: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

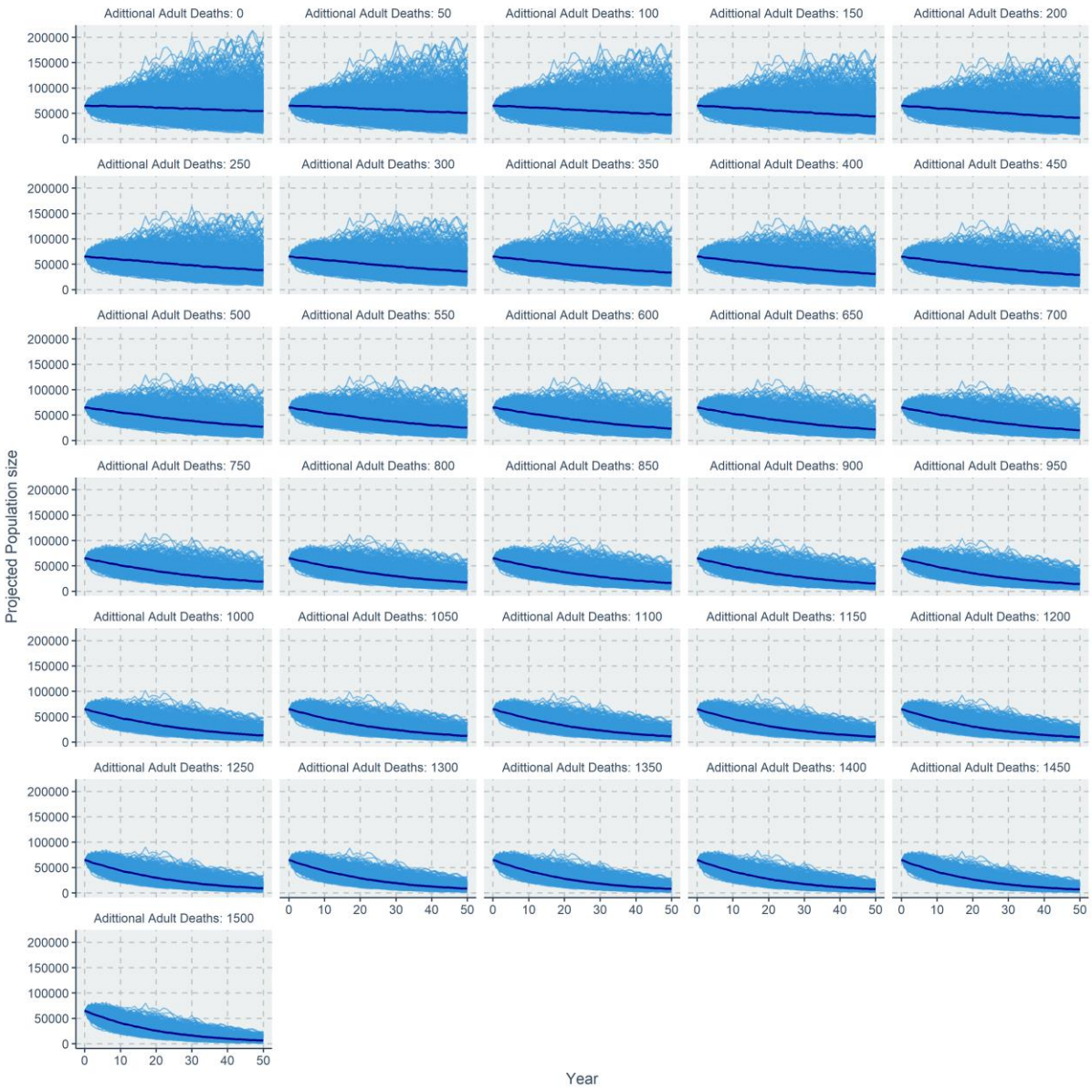

Figure 17: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

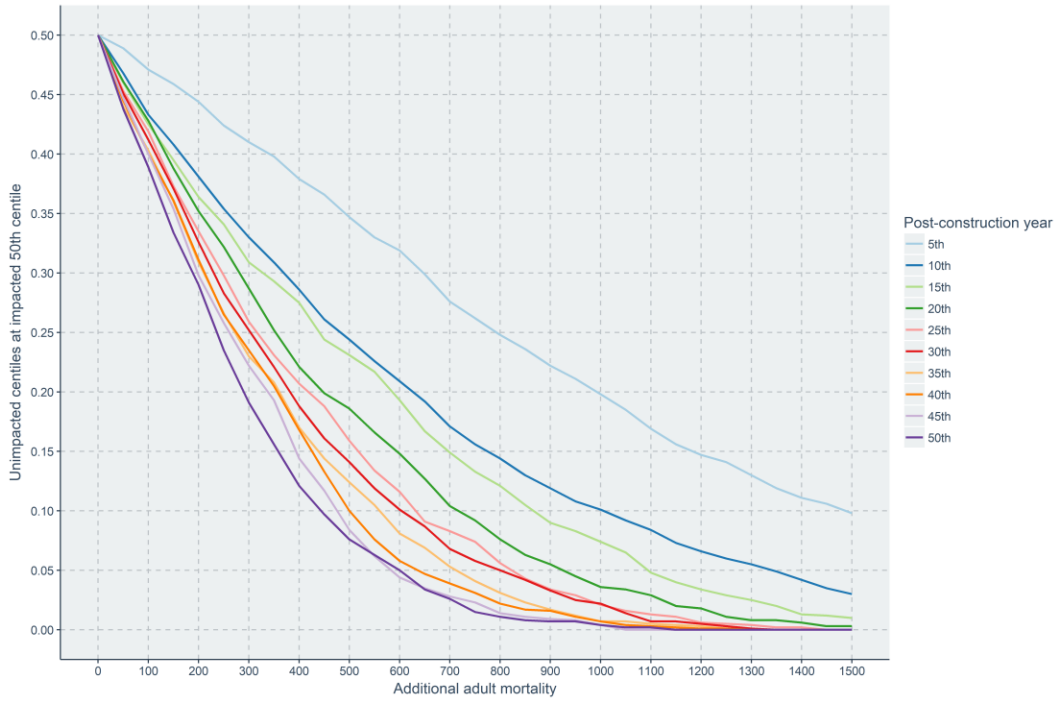

Figure 18: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

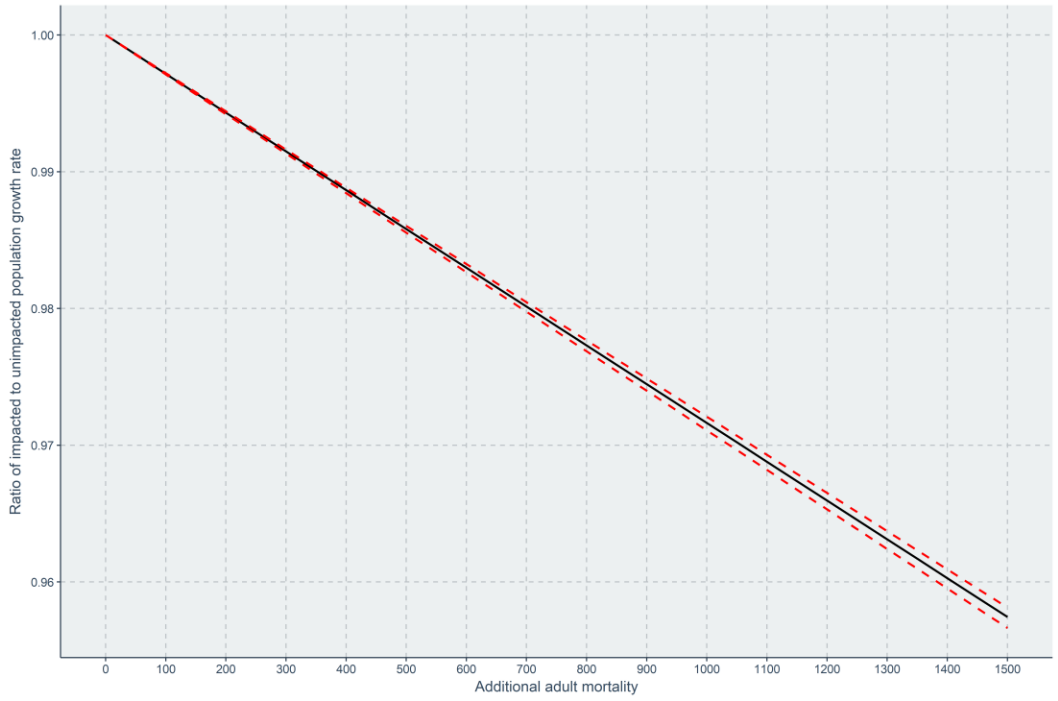

Figure 19: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

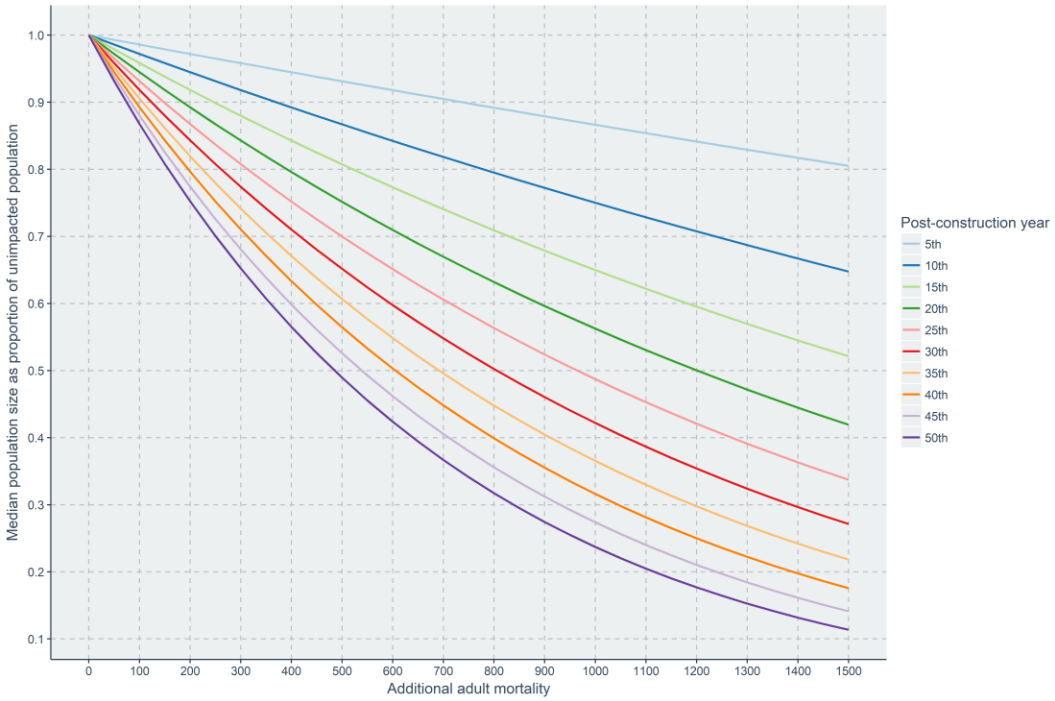

Figure 20: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 8: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	0.996	0.976	1.015
50	0.995	0.975	1.013
100	0.994	0.974	1.012
150	0.992	0.972	1.010
200	0.991	0.971	1.009
250	0.989	0.970	1.008
300	0.988	0.968	1.006
350	0.986	0.967	1.005
400	0.985	0.965	1.003
450	0.984	0.964	1.002
500	0.982	0.962	1.000
550	0.981	0.961	0.999
600	0.979	0.960	0.998
650	0.978	0.958	0.996
700	0.977	0.957	0.995
750	0.975	0.955	0.993
800	0.974	0.954	0.992
850	0.972	0.953	0.991
900	0.971	0.951	0.989
950	0.969	0.950	0.988
1000	0.968	0.948	0.986
1050	0.967	0.947	0.985
1100	0.965	0.946	0.983
1150	0.964	0.944	0.982
1200	0.962	0.943	0.981
1250	0.961	0.941	0.979
1300	0.960	0.940	0.978
1350	0.958	0.939	0.976
1400	0.957	0.937	0.975
1450	0.955	0.936	0.973
1500	0.954	0.934	0.972

4.5 Guillemot – North Caithness Cliffs

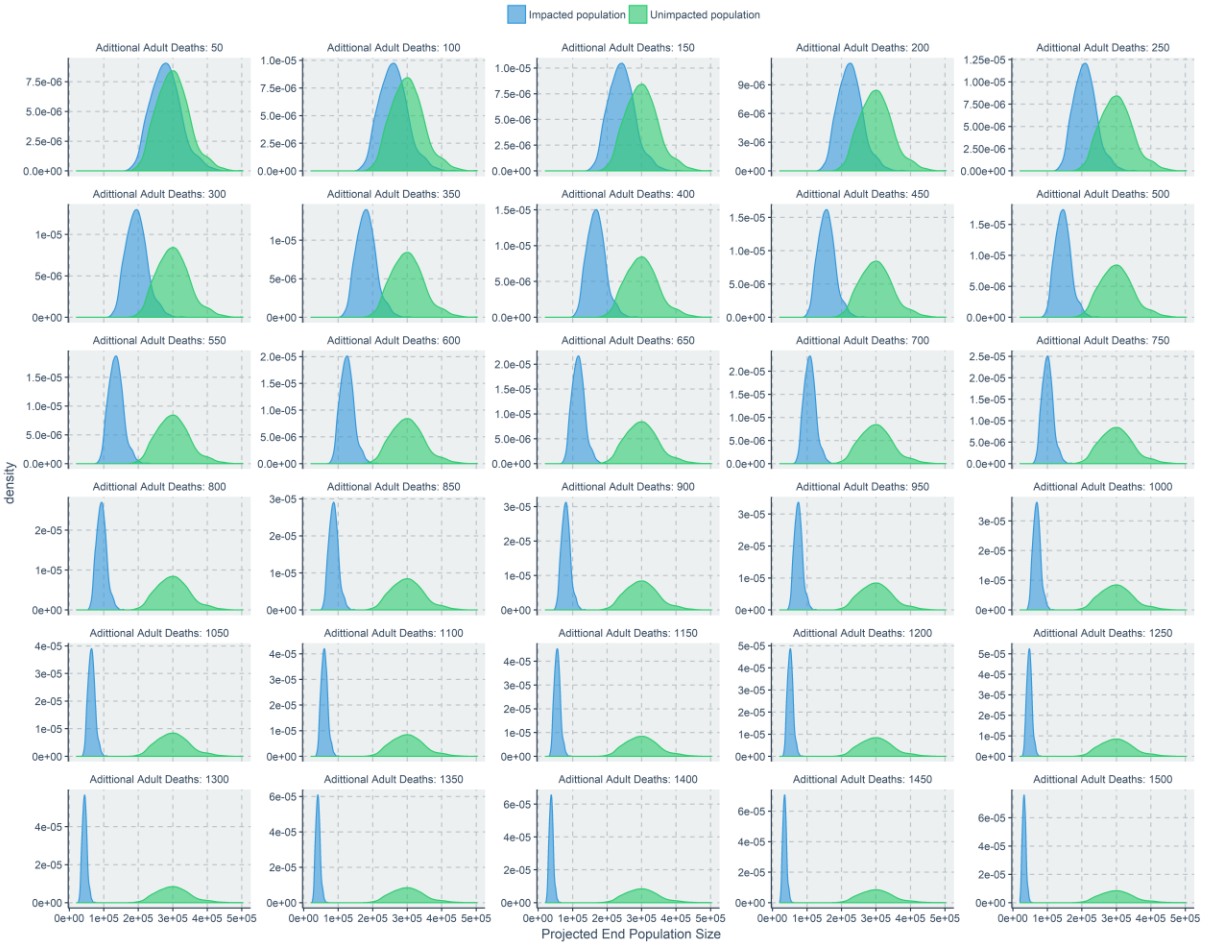

Figure 21: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

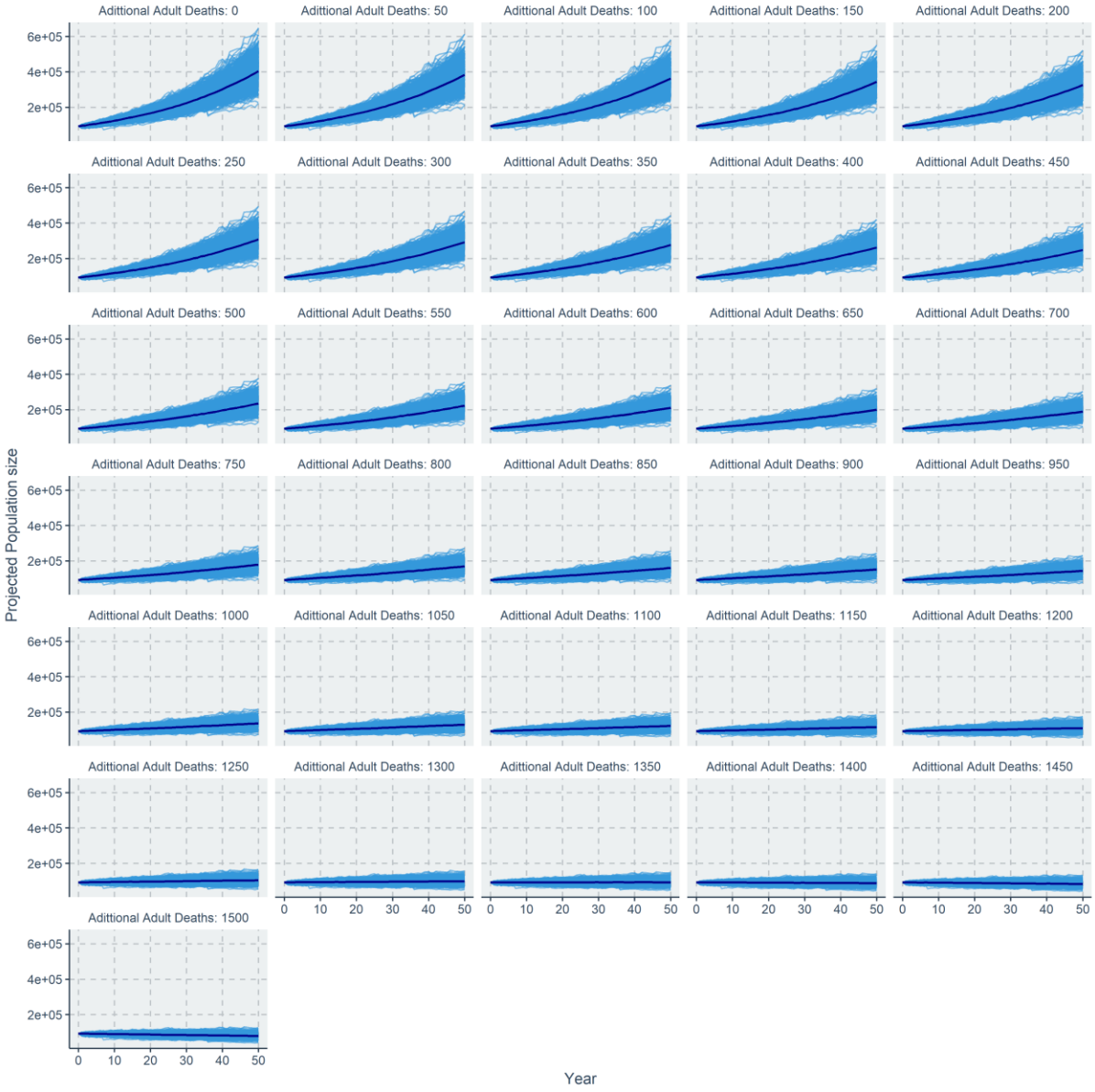

Figure 22: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

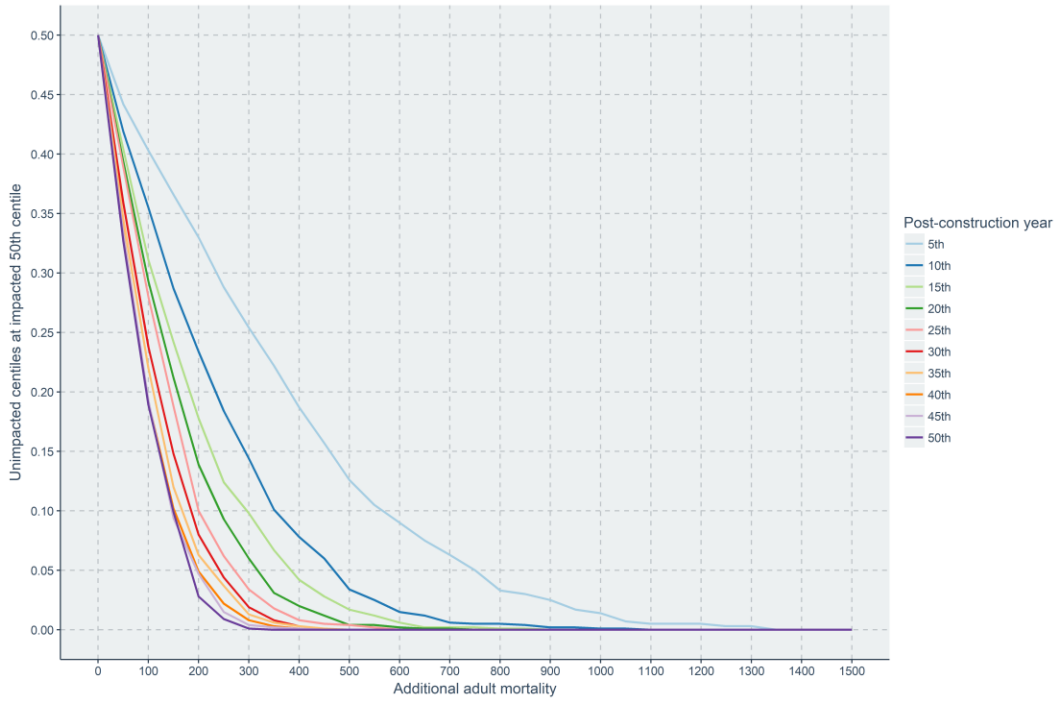

Figure 23: the median of the impacted population as a centile of the unimpacted population, under a range of impacts cenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

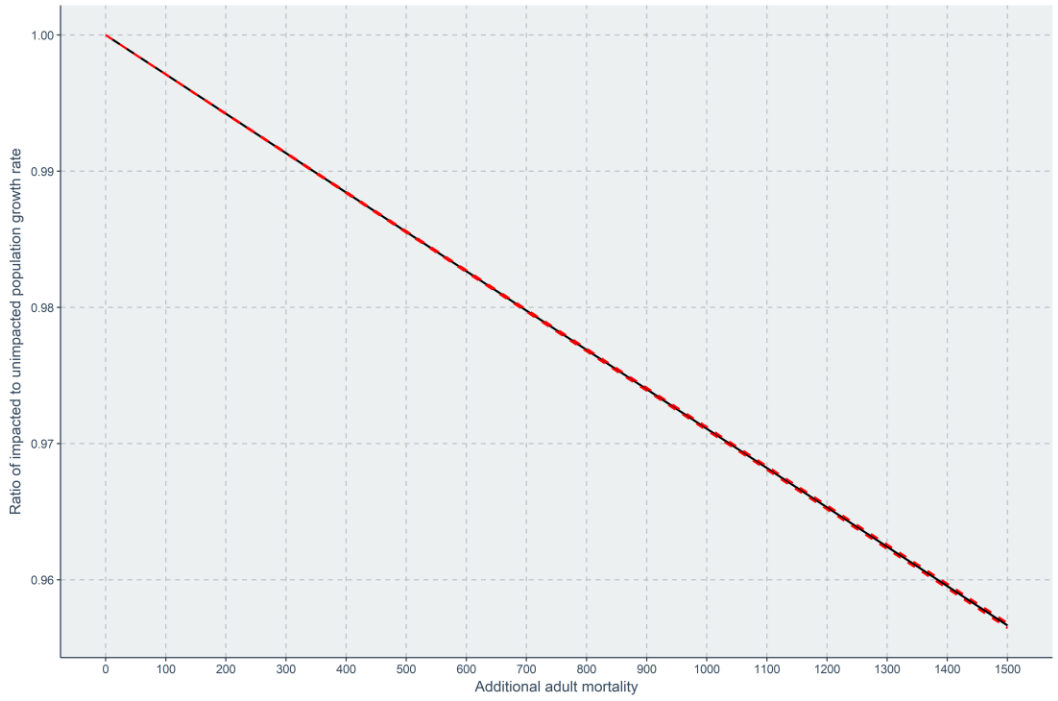

Figure 24: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

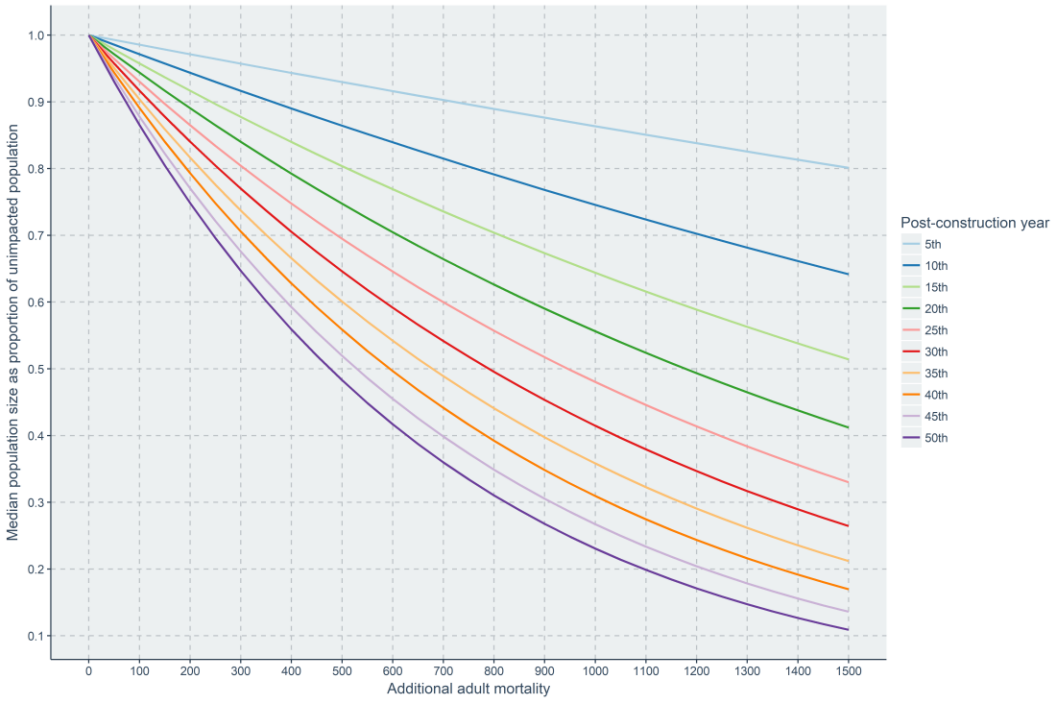

Figure 25: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 9: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.030	1.023	1.037
50	1.029	1.022	1.036
100	1.028	1.020	1.035
150	1.027	1.019	1.033
200	1.026	1.018	1.032
250	1.025	1.017	1.031
300	1.023	1.016	1.030
350	1.022	1.015	1.029
400	1.021	1.014	1.028
450	1.020	1.013	1.027
500	1.019	1.012	1.026
550	1.018	1.010	1.025
600	1.017	1.009	1.023
650	1.016	1.008	1.022
700	1.015	1.007	1.021
750	1.013	1.006	1.020
800	1.012	1.005	1.019
850	1.011	1.004	1.018
900	1.010	1.003	1.017
950	1.009	1.002	1.016
1000	1.008	1.001	1.014
1050	1.007	0.999	1.013
1100	1.006	0.998	1.012
1150	1.005	0.997	1.011
1200	1.003	0.996	1.010
1250	1.002	0.995	1.009
1300	1.001	0.994	1.008
1350	1.000	0.993	1.007
1400	0.999	0.992	1.006
1450	0.998	0.991	1.004
1500	0.997	0.989	1.003

4.6 Guillemot – East Caithness Cliffs

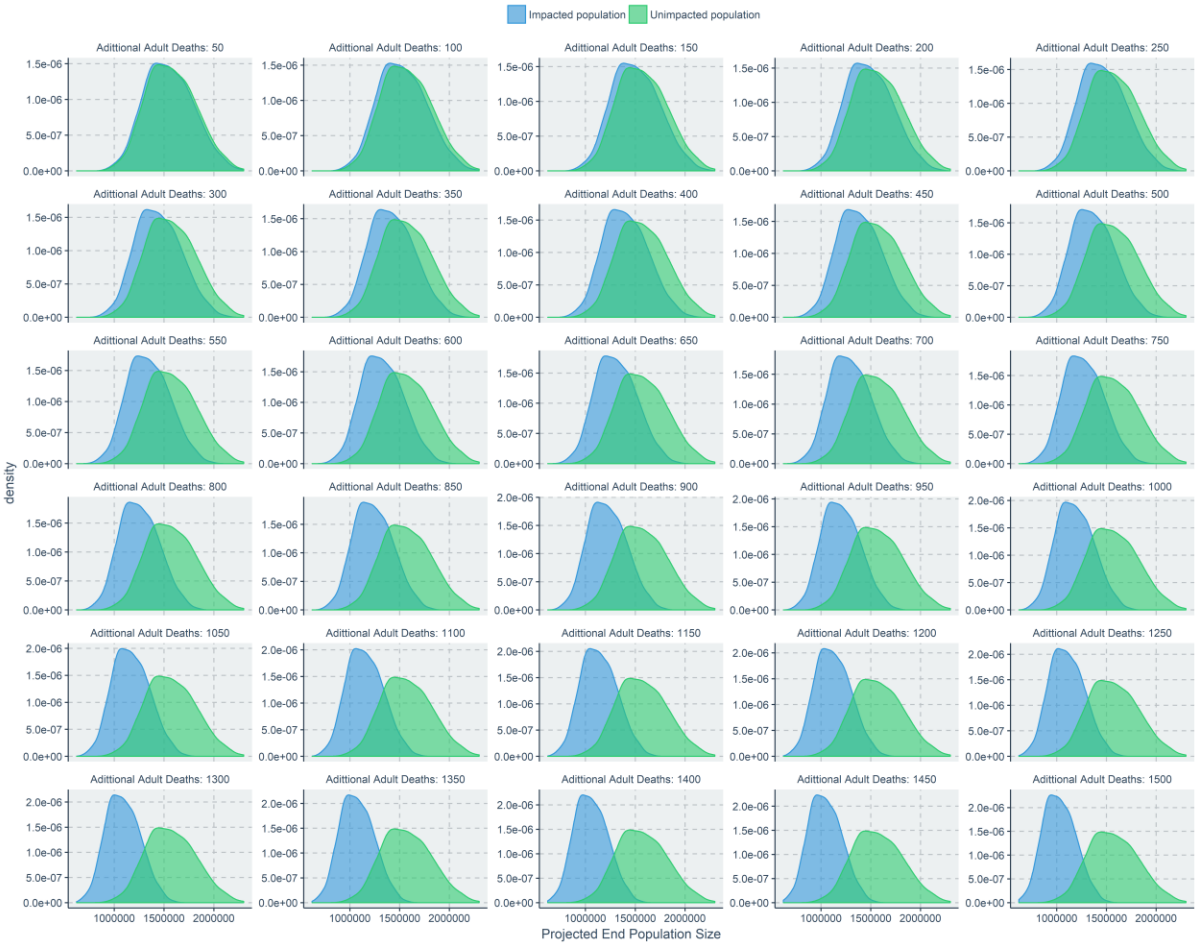

Figure 26: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

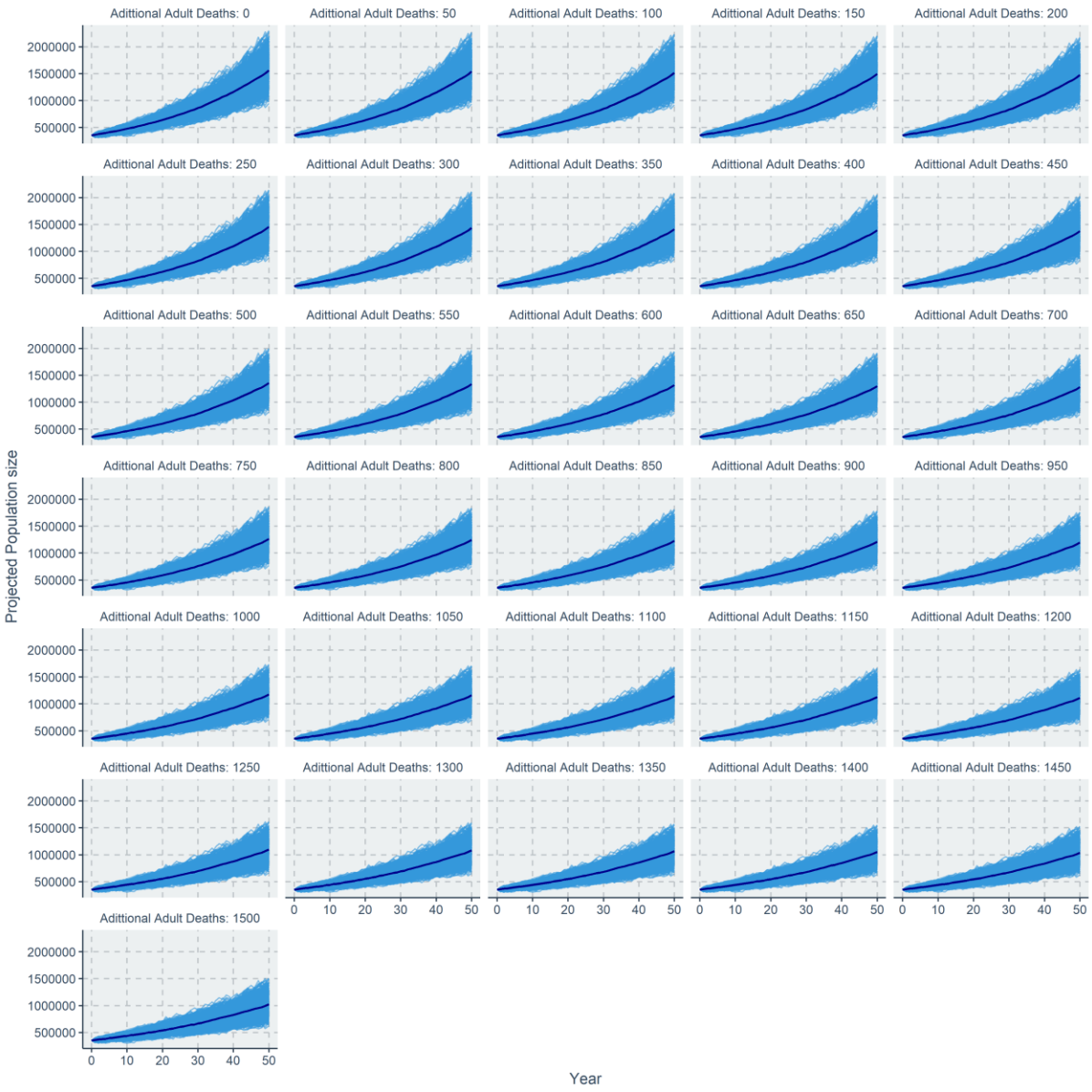

Figure 27: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

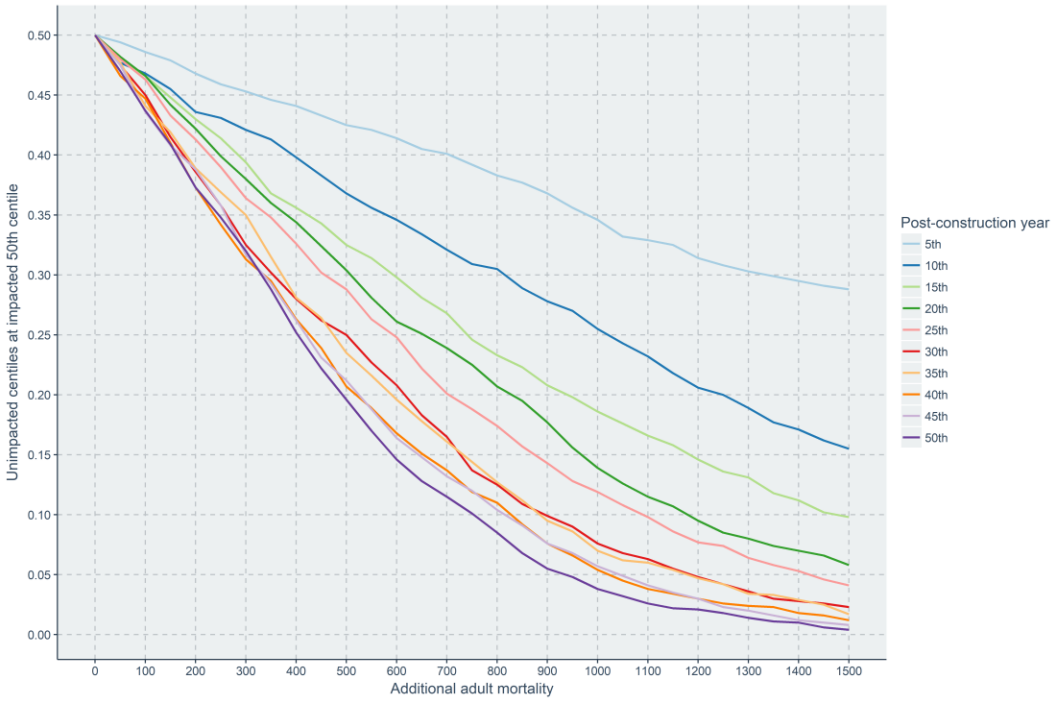

Figure 28: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

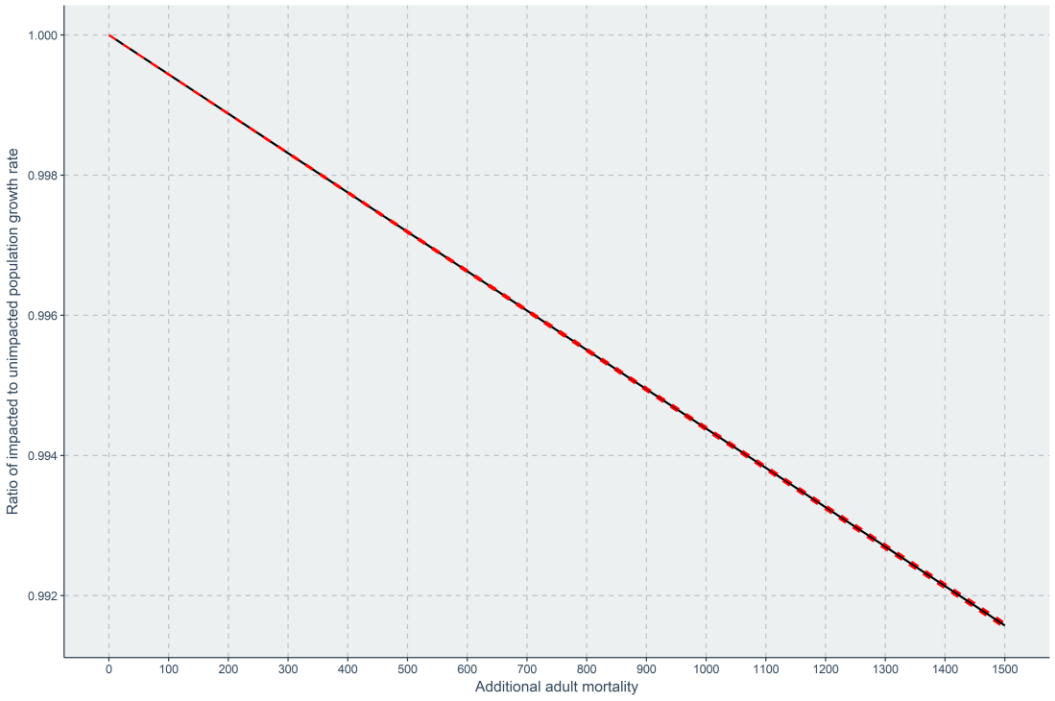

Figure 29: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

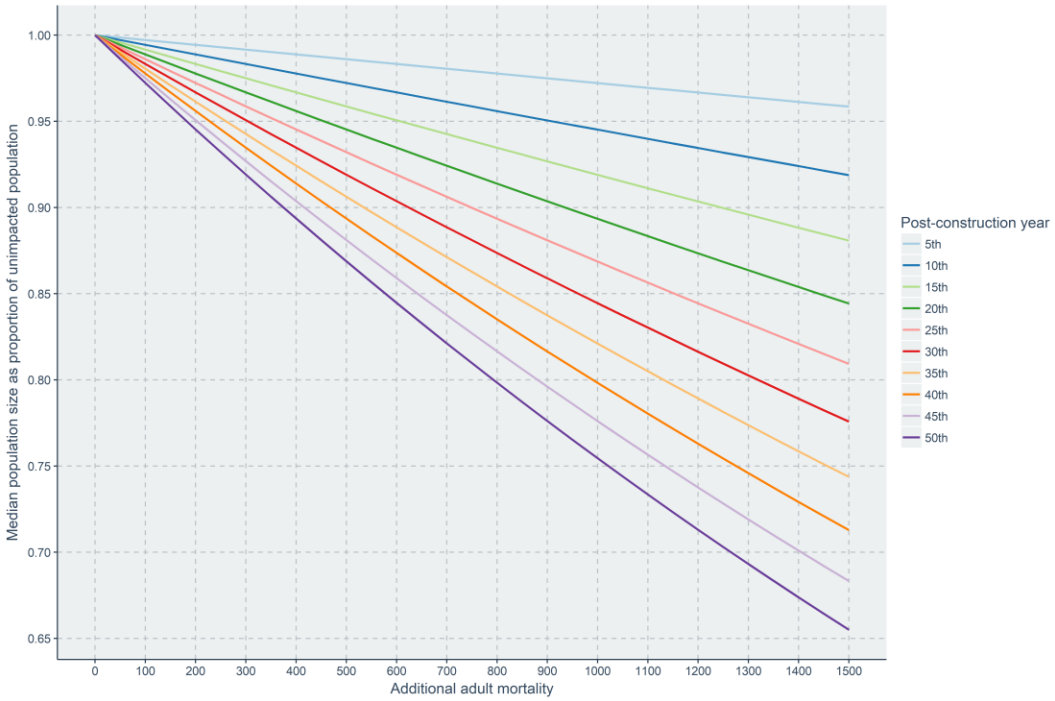

Figure 30: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 10: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.030	1.023	1.037
50	1.030	1.023	1.036
100	1.030	1.023	1.036
150	1.029	1.022	1.036
200	1.029	1.022	1.035
250	1.029	1.022	1.035
300	1.028	1.022	1.035
350	1.028	1.021	1.035
400	1.028	1.021	1.034
450	1.027	1.021	1.034
500	1.027	1.020	1.034
550	1.027	1.020	1.033
600	1.027	1.020	1.033
650	1.026	1.020	1.033
700	1.026	1.019	1.033
750	1.026	1.019	1.032
800	1.025	1.019	1.032
850	1.025	1.018	1.032
900	1.025	1.018	1.031
950	1.025	1.018	1.031
1000	1.024	1.018	1.031
1050	1.024	1.017	1.030
1100	1.024	1.017	1.030
1150	1.023	1.017	1.030
1200	1.023	1.016	1.030
1250	1.023	1.016	1.029
1300	1.023	1.016	1.029
1350	1.022	1.016	1.029
1400	1.022	1.015	1.028
1450	1.022	1.015	1.028
1500	1.021	1.015	1.028

4.7 Kittiwake – North Caithness Cliffs

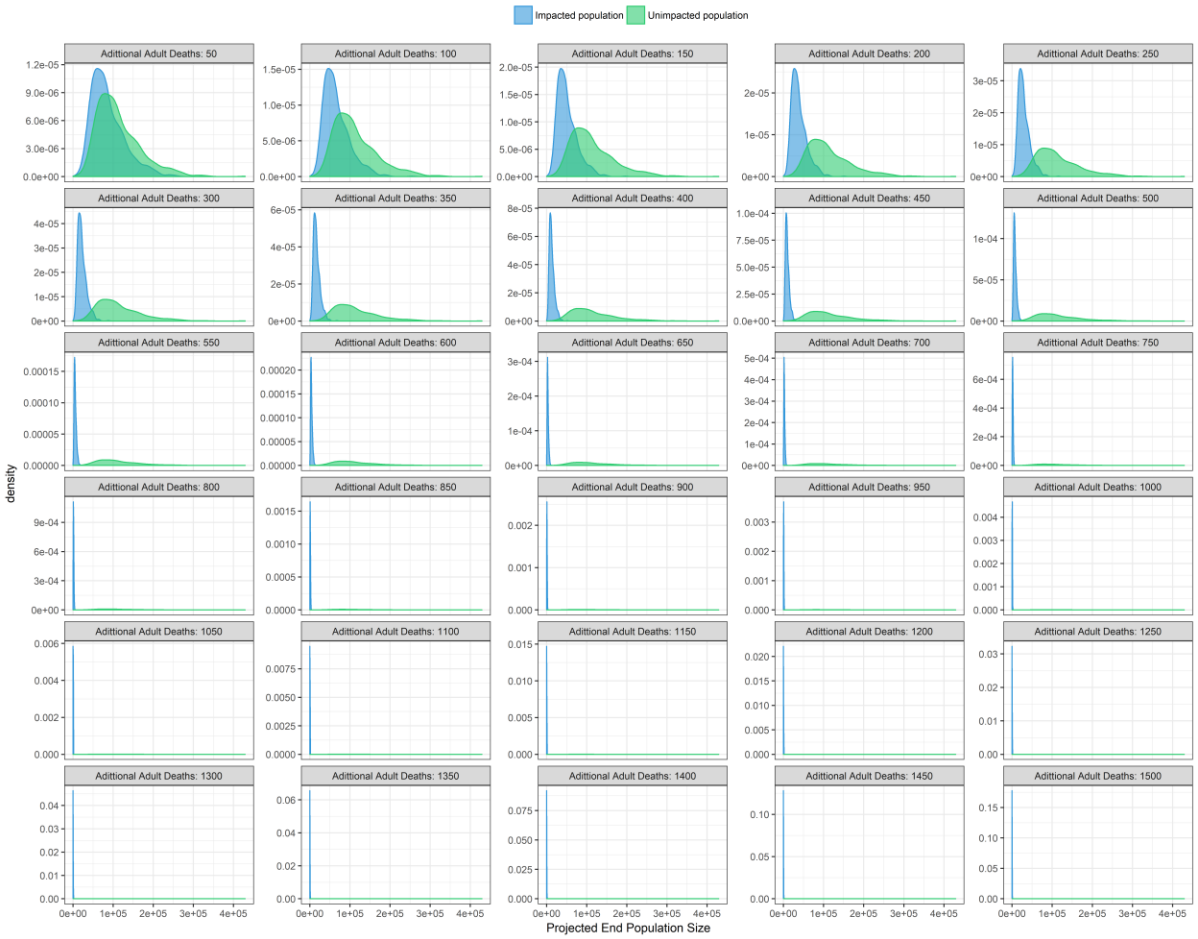

Figure 31: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

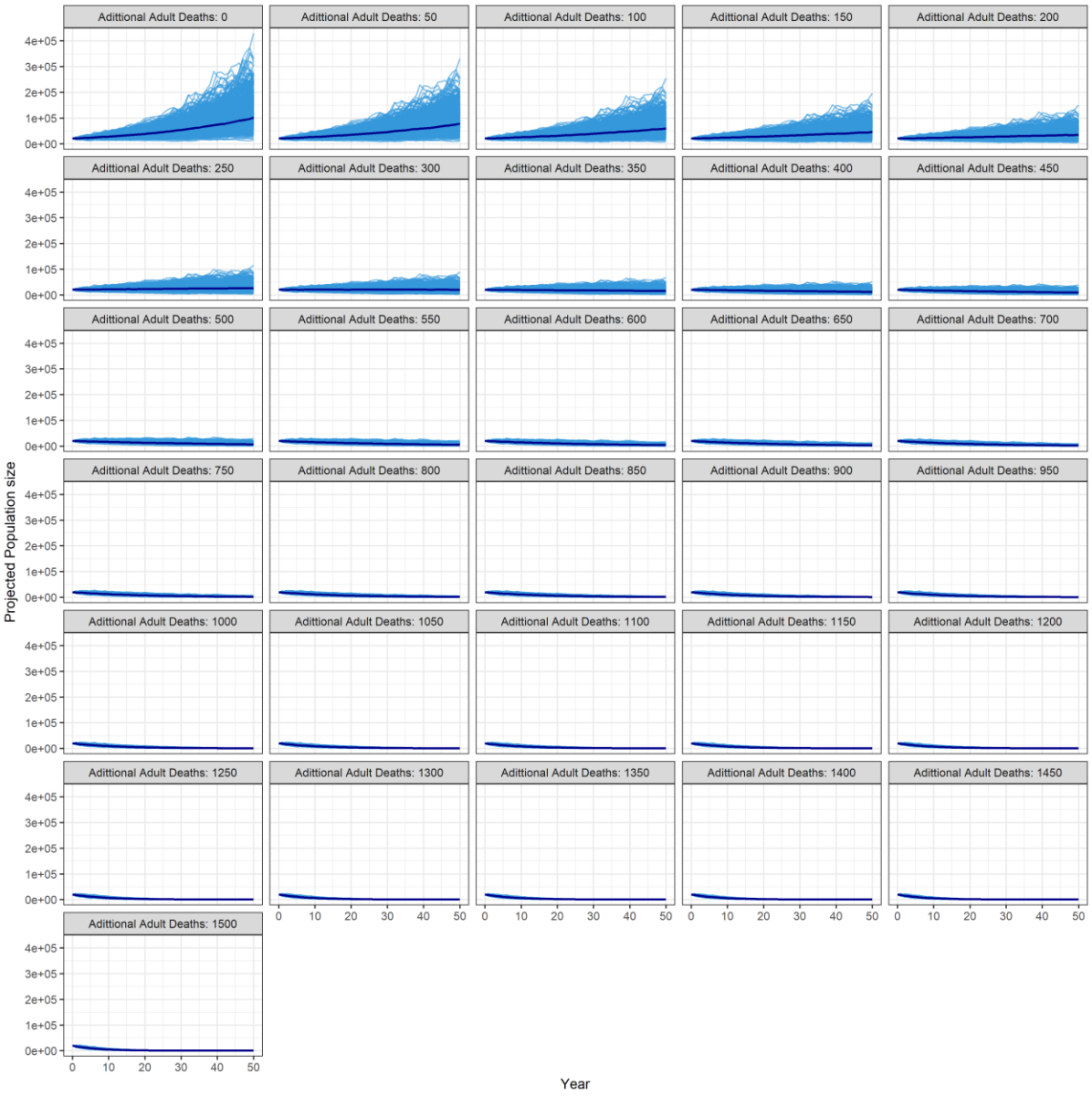

Figure 32: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

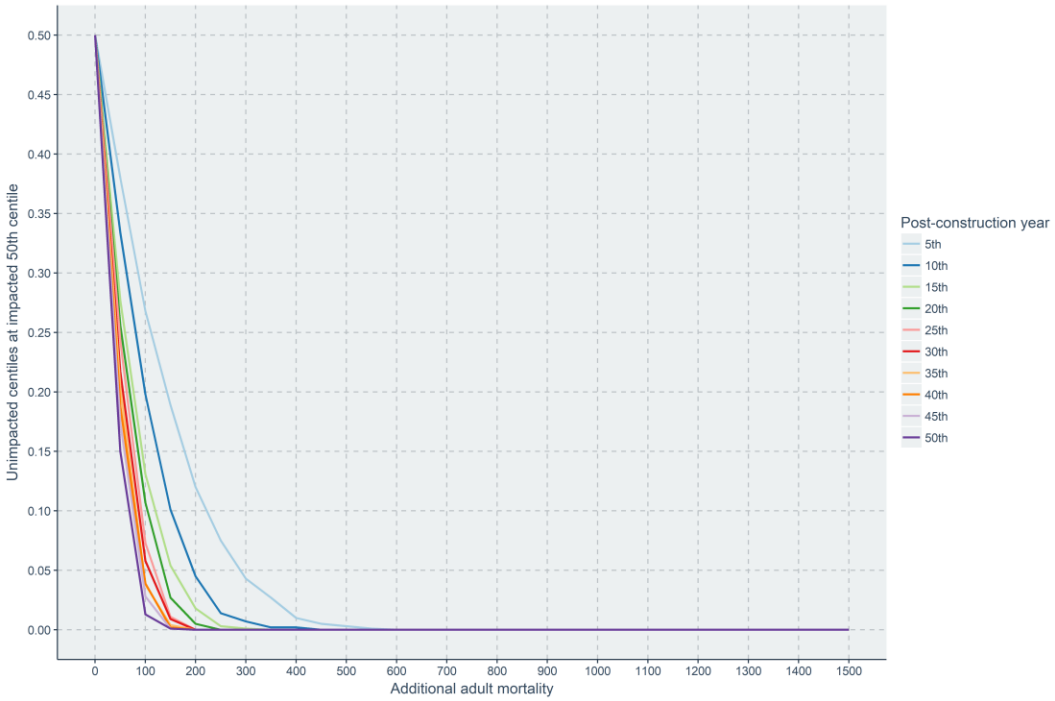

Figure 33: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

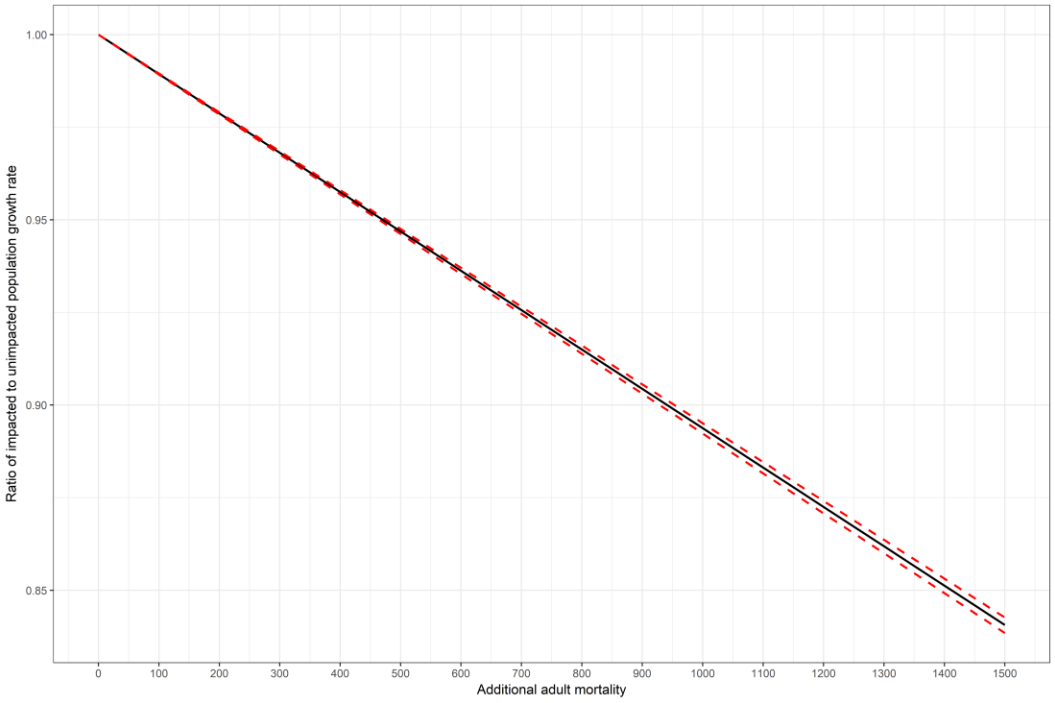

Figure 34: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

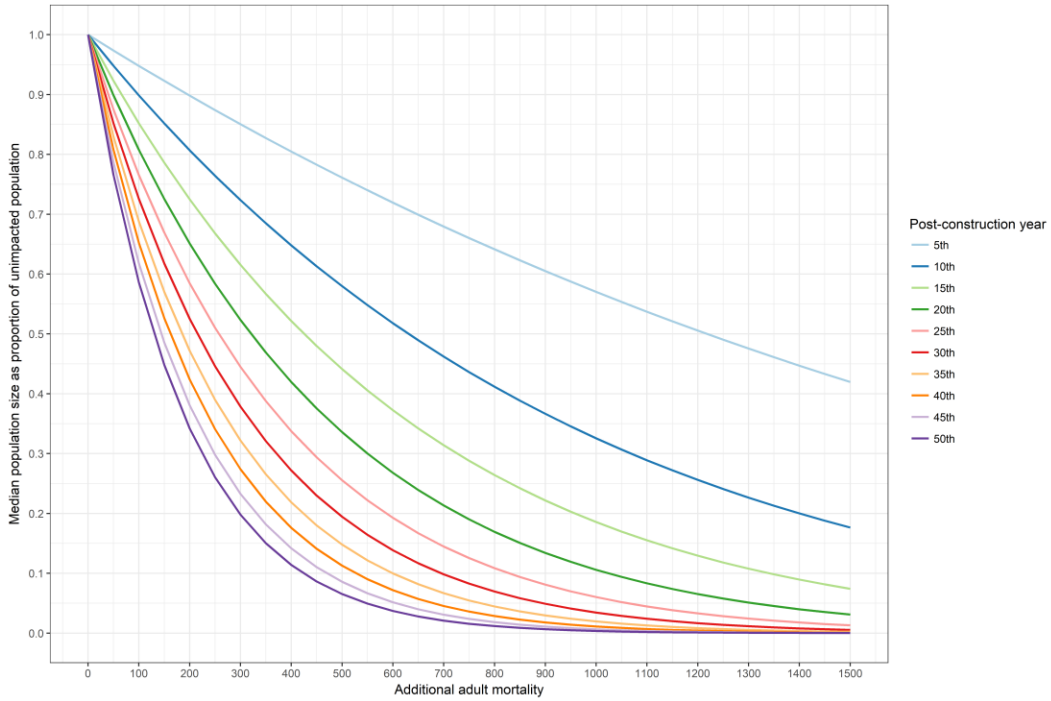

Figure 35: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 11: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.033	1.014	1.053
50	1.028	1.009	1.047
100	1.022	1.003	1.042
150	1.017	0.998	1.036
200	1.011	0.993	1.031
250	1.006	0.987	1.025
300	1.000	0.982	1.020
350	0.995	0.976	1.014
400	0.989	0.971	1.009
450	0.984	0.965	1.003
500	0.978	0.960	0.998
550	0.973	0.955	0.992
600	0.967	0.949	0.987
650	0.962	0.944	0.981
700	0.956	0.938	0.976
750	0.951	0.933	0.970
800	0.945	0.927	0.965
850	0.940	0.922	0.959
900	0.934	0.916	0.954
950	0.929	0.911	0.948
1000	0.923	0.905	0.942
1050	0.918	0.900	0.937
1100	0.912	0.895	0.931
1150	0.907	0.889	0.926
1200	0.901	0.884	0.920
1250	0.896	0.878	0.915
1300	0.890	0.873	0.909
1350	0.885	0.867	0.904
1400	0.879	0.862	0.898
1450	0.874	0.856	0.893
1500	0.868	0.851	0.887

4.8 Kittiwake – East Caithness Cliffs

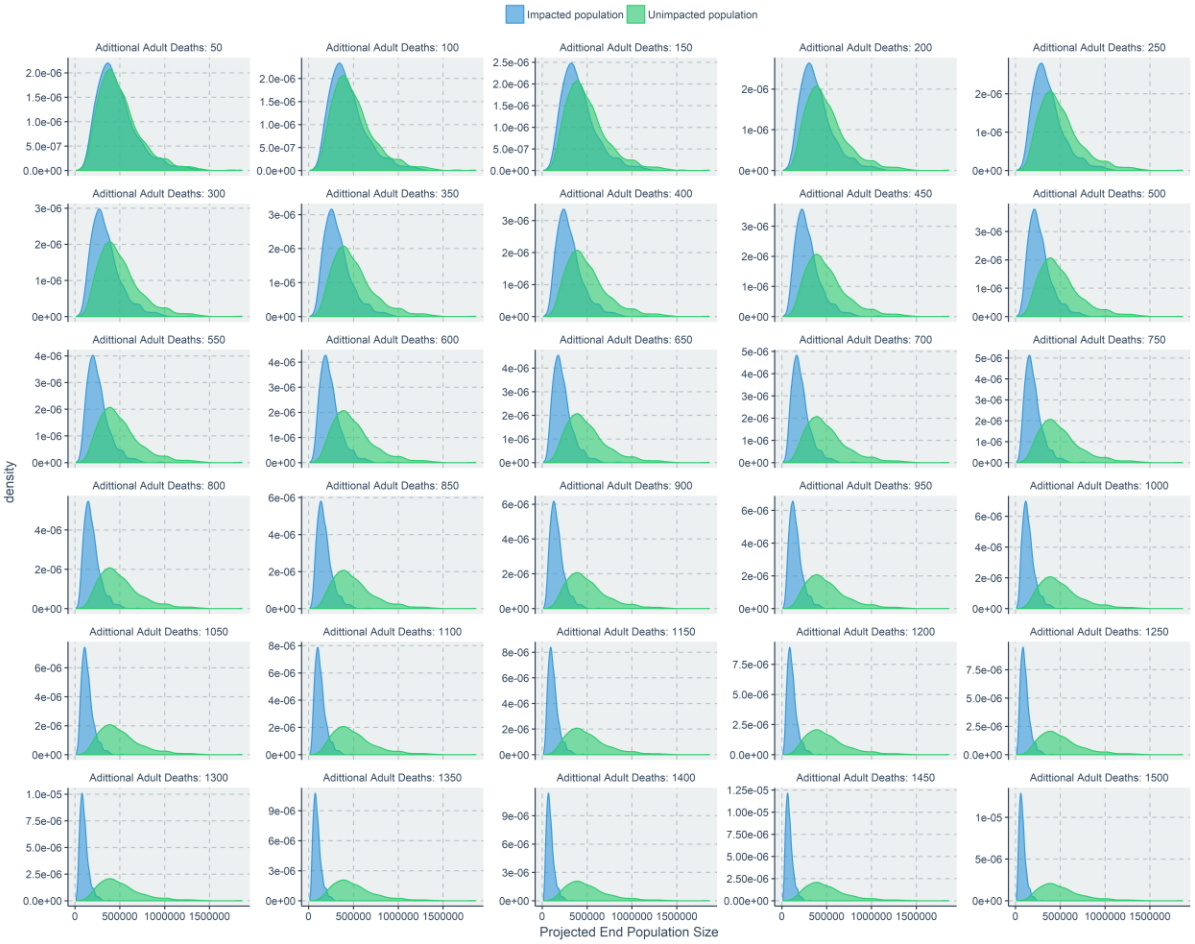

Figure 36: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

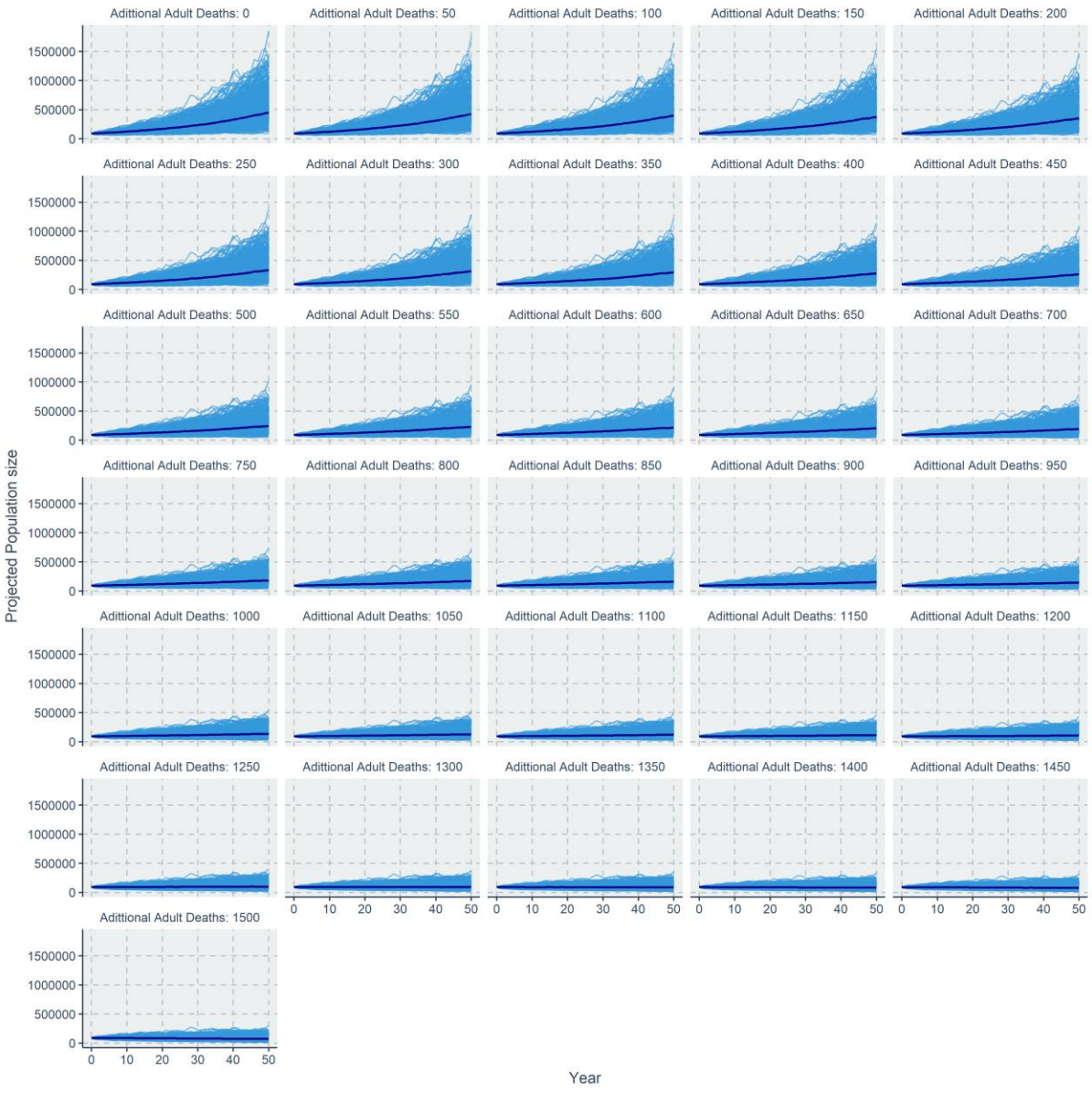

Figure 37: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

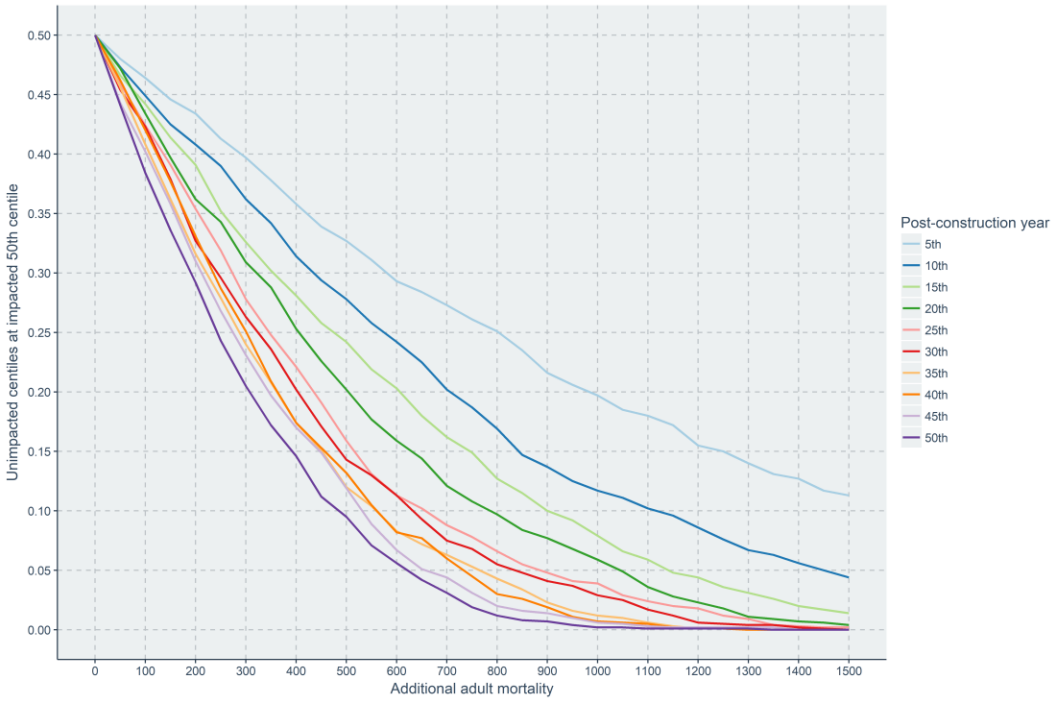

Figure 38: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

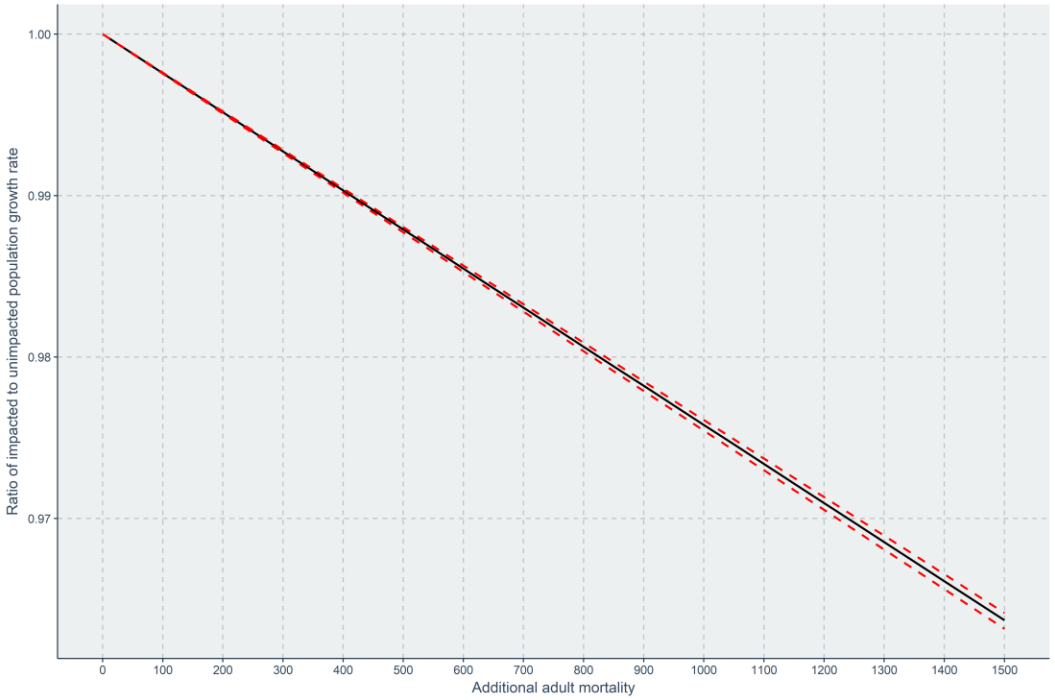

Figure 39: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

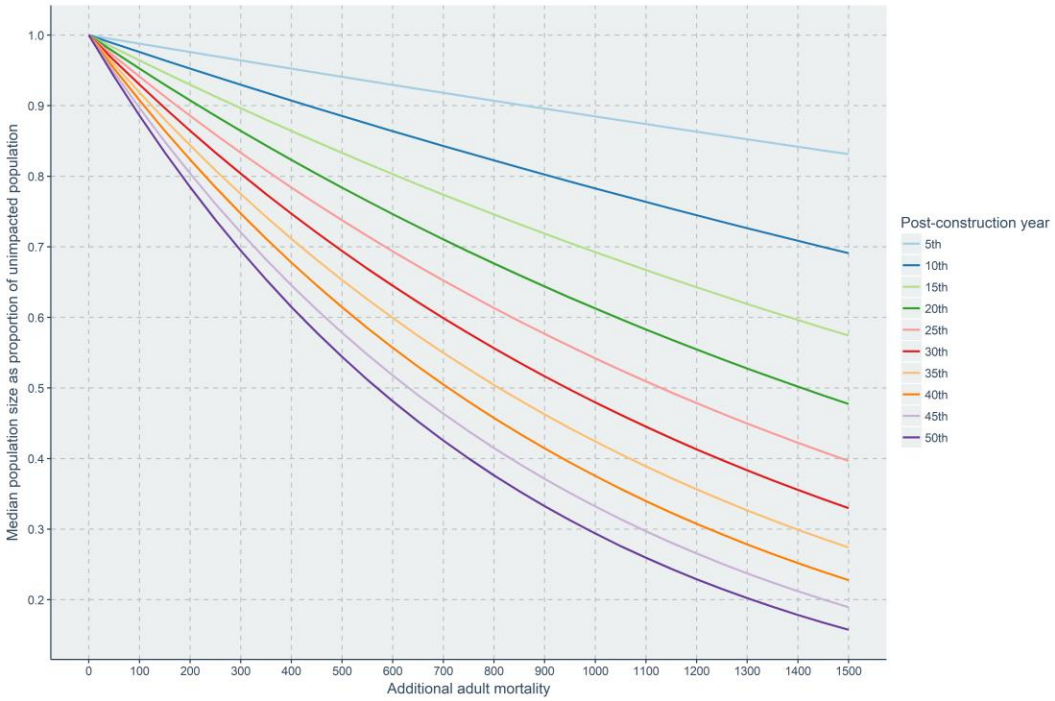

Figure 40: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 12: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.033	1.014	1.053
50	1.032	1.013	1.052
100	1.031	1.012	1.051
150	1.029	1.010	1.050
200	1.028	1.009	1.048
250	1.027	1.008	1.047
300	1.026	1.007	1.046
350	1.024	1.005	1.045
400	1.023	1.004	1.043
450	1.022	1.003	1.042
500	1.021	1.002	1.041
550	1.019	1.000	1.039
600	1.018	0.999	1.038
650	1.017	0.998	1.037
700	1.016	0.997	1.036
750	1.014	0.996	1.034
800	1.013	0.994	1.033
850	1.012	0.993	1.032
900	1.011	0.992	1.031
950	1.009	0.991	1.029
1000	1.008	0.989	1.028
1050	1.007	0.988	1.027
1100	1.006	0.987	1.026
1150	1.004	0.986	1.024
1200	1.003	0.984	1.023
1250	1.002	0.983	1.022
1300	1.001	0.982	1.021
1350	0.999	0.981	1.019
1400	0.998	0.979	1.018
1450	0.997	0.978	1.017
1500	0.996	0.977	1.016

4.9 Herring Gull – East Caithness Cliffs

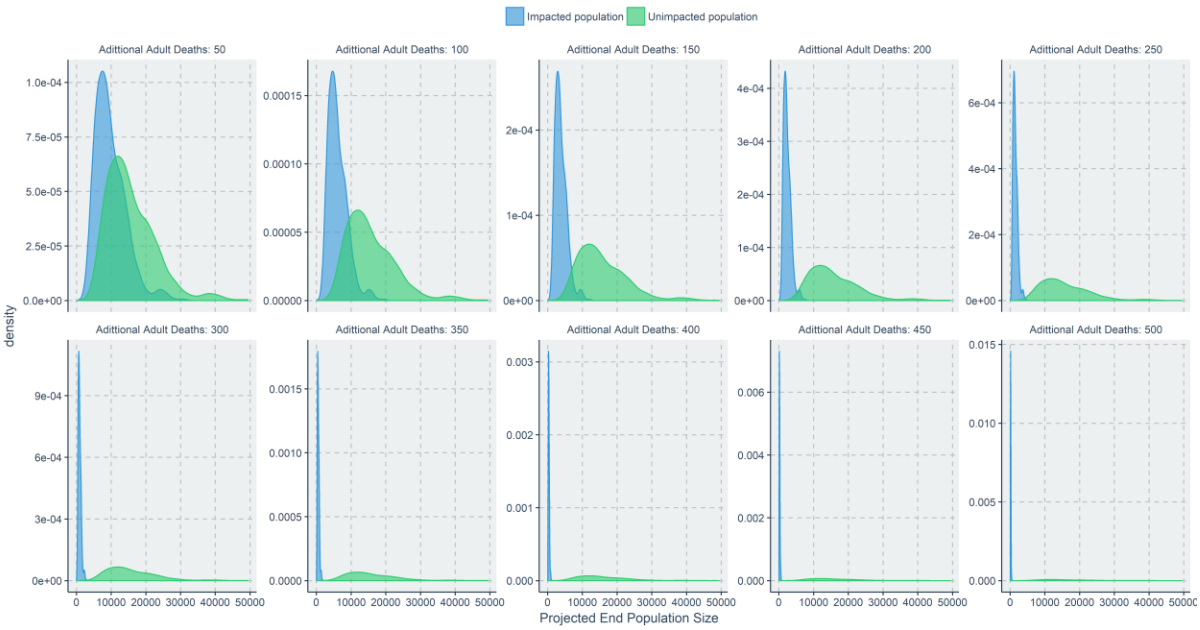

Figure 41: Distributions of end population sizes under simulation. Each plot represents a different impact scenario in terms of additional adult mortalities. The distribution of end population sizes for the unimpacted simulations are given in each.

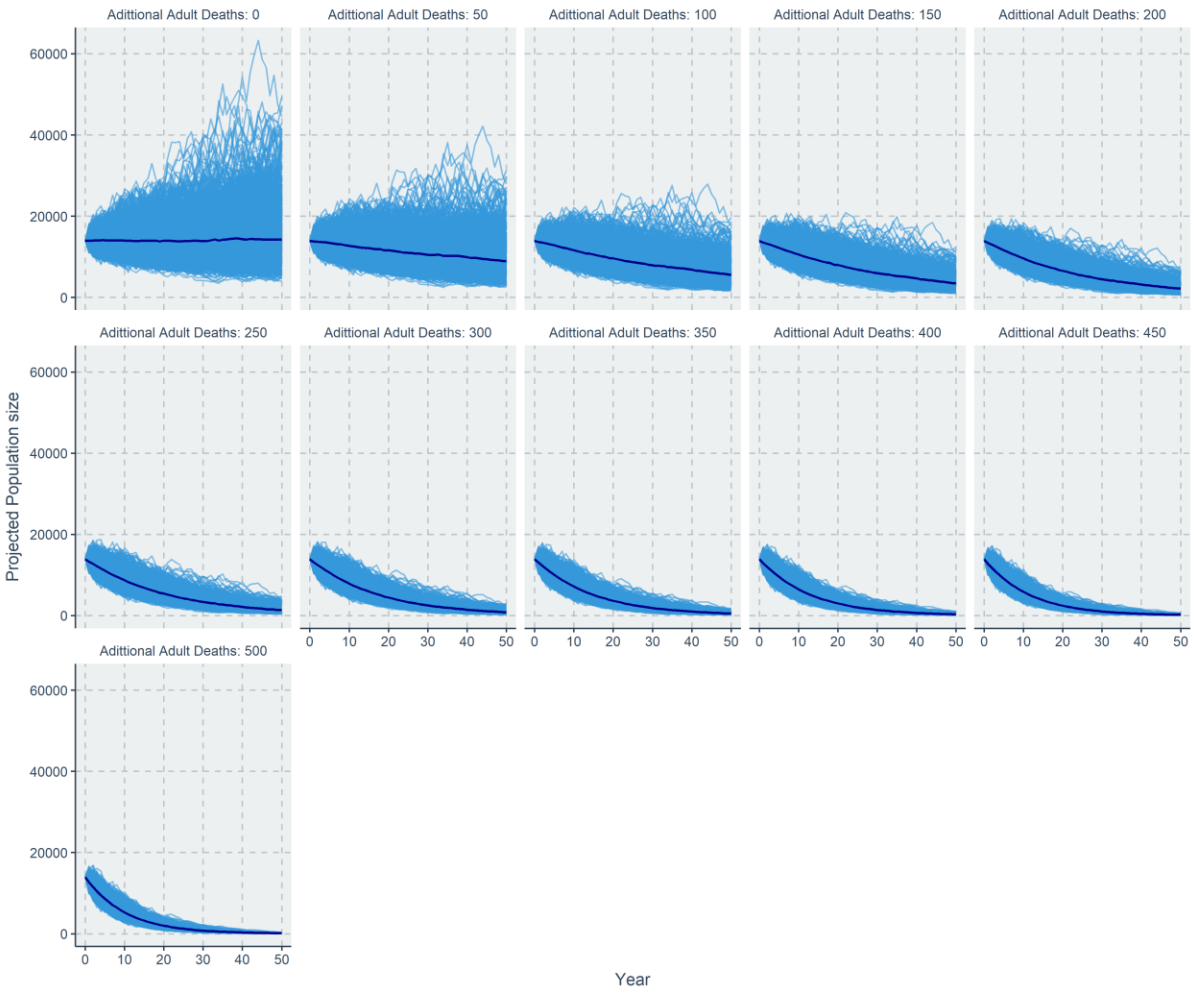

Figure 42: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

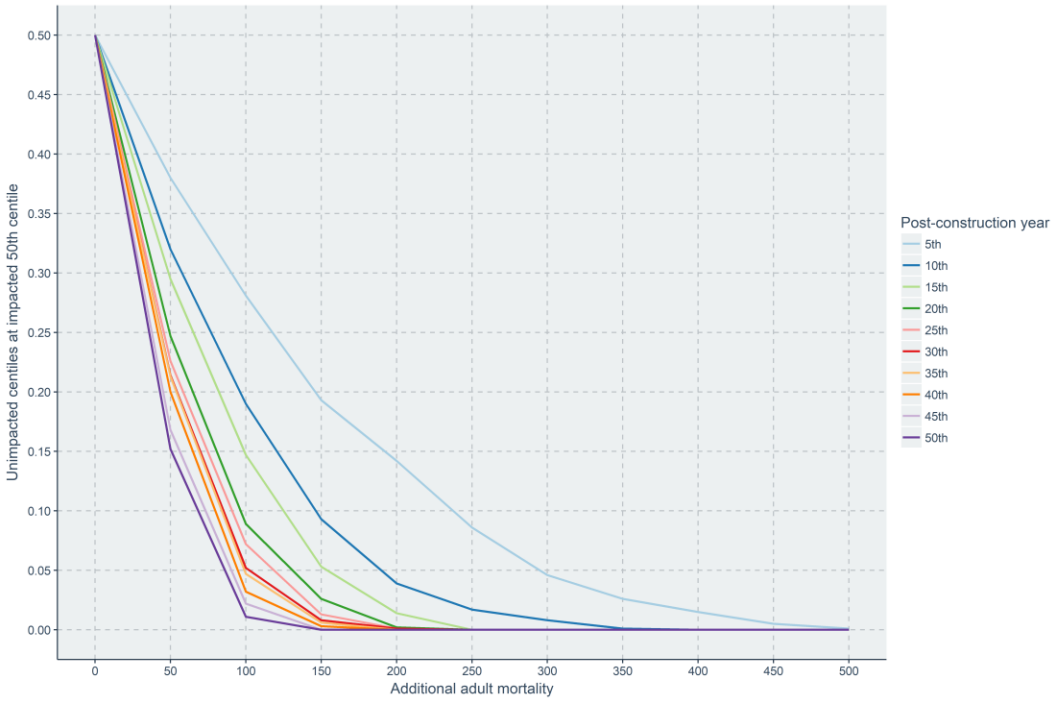

Figure 43: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

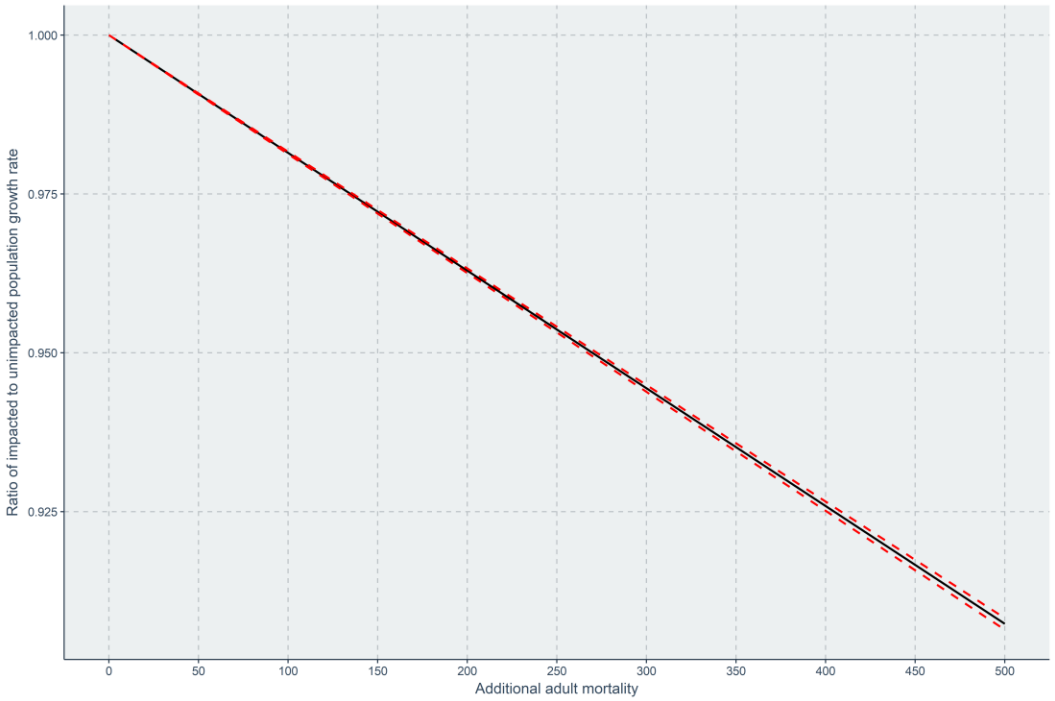

Figure 44: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

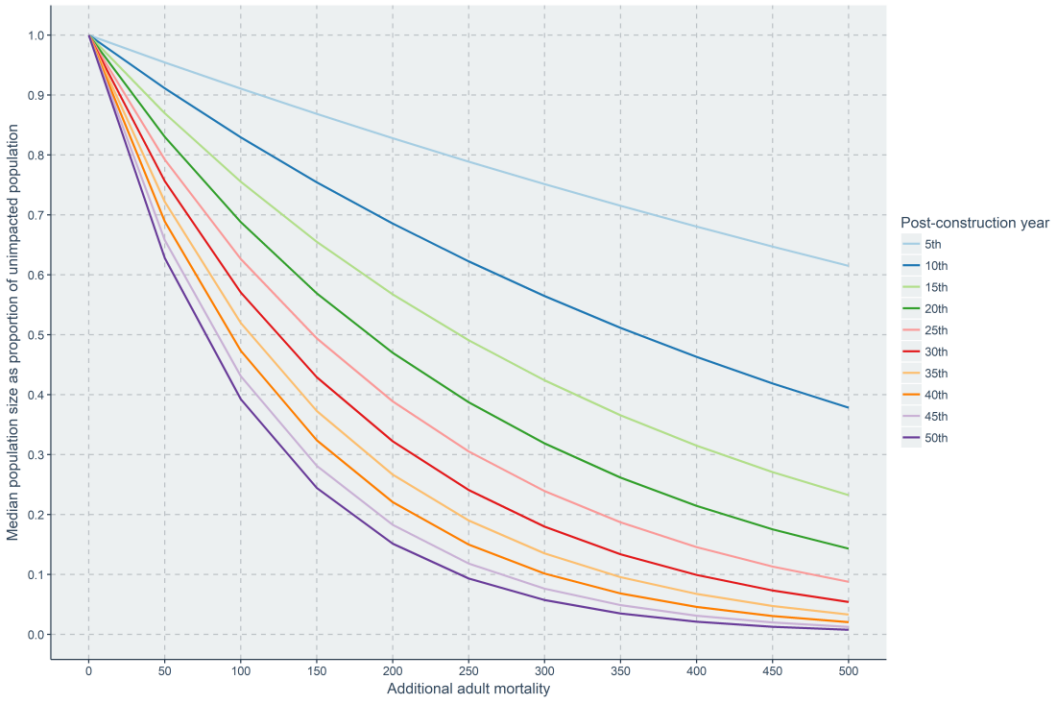

Figure 45: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 13: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.001	0.983	1.019
50	0.991	0.974	1.009
100	0.982	0.965	1.000
150	0.973	0.956	0.991
200	0.964	0.946	0.981
250	0.954	0.937	0.972
300	0.945	0.928	0.962
350	0.936	0.919	0.953
400	0.926	0.910	0.944
450	0.917	0.901	0.934
500	0.908	0.891	0.925

4.10 Great Black-Backed Gull – East Caithness Cliffs

Due to almost immediate extinction of the population under impact, plots of the comparative distributions impacted/unimpacted are not presented.

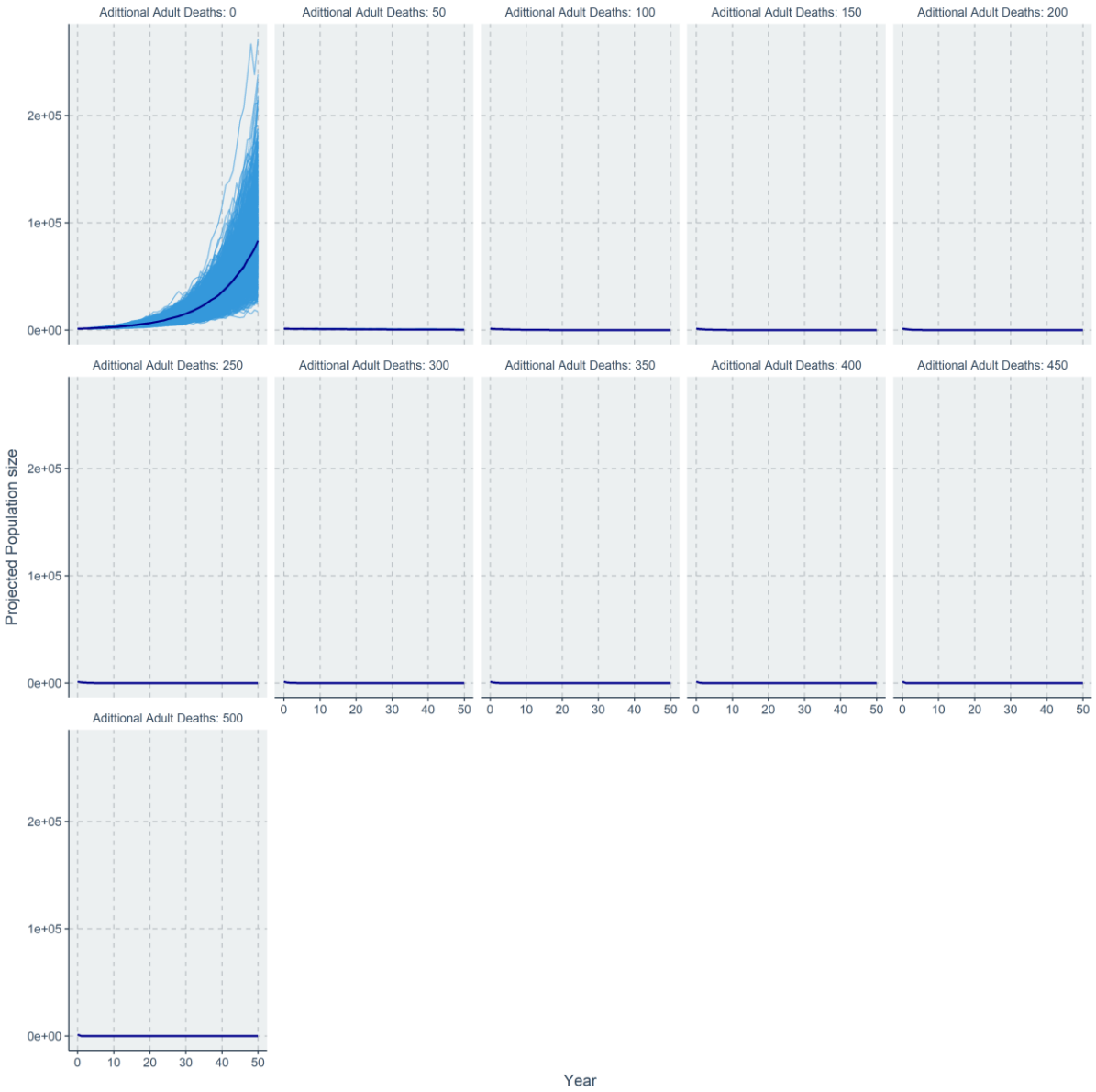

Figure 46: projections of population sizes over a 50-year time-frame. Each plot represents a different impact scenario in terms of additional adult mortalities (starting at 0 i.e. unimpacted). Individual blue lines are different realisations of the population trajectory, when population parameters are sampled from their distributions. The dark blue line is the median at each time point.

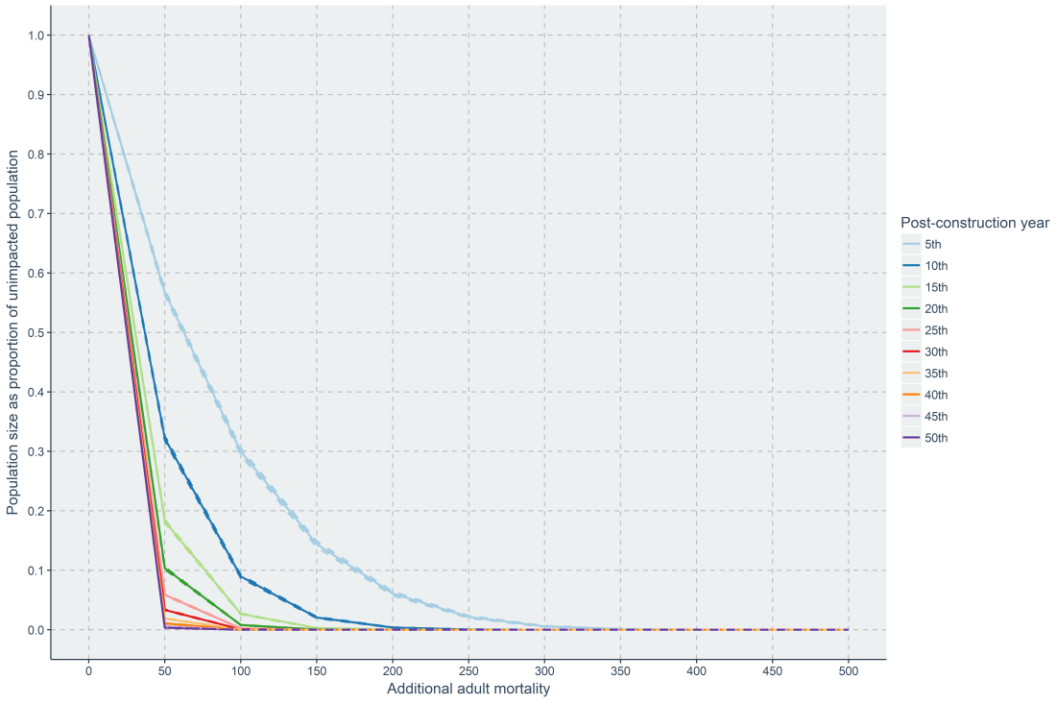

Figure 47: the median of the impacted population as a centile of the unimpacted population, under a range of impact scenarios (additional adult mortalities – x-axis). For example, 0.3 means the median (50th percentile) of the impacted projections sits at the 30th percentile of the unimpacted projections. Individual lines represent years post-construction (0-50 years).

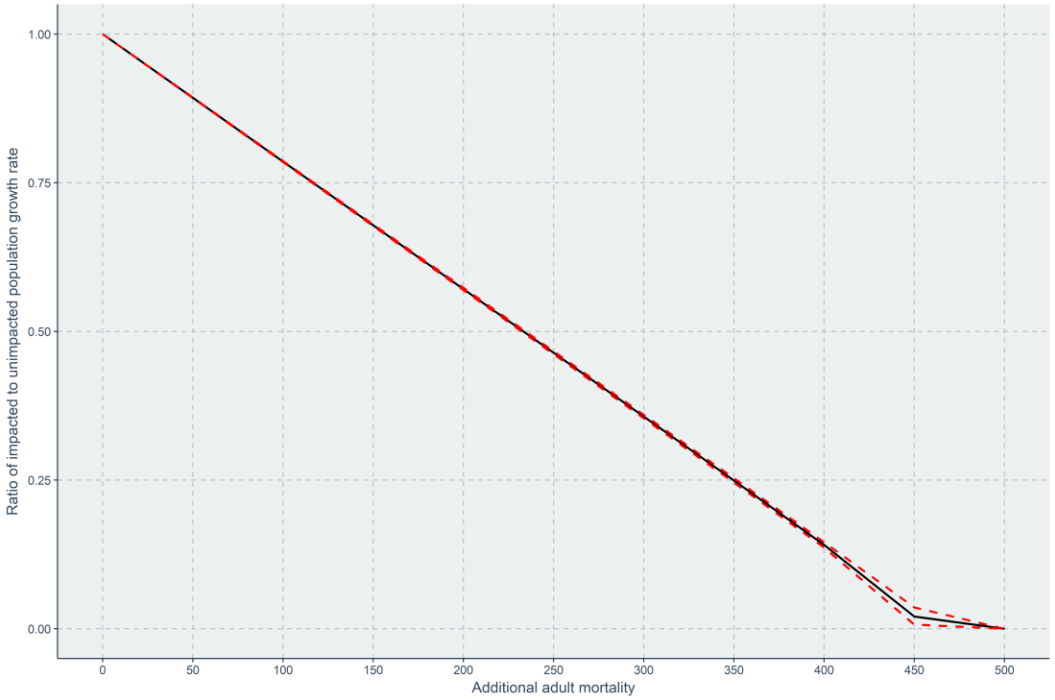

Figure 48: ratio of impacted and unimpacted growth rates under a range of impact scenarios (additional adult mortalities – x-axis) i.e. 0.9 means a 10% decrease in the growth rate under the impact scenario. Figures are based on paired simulations for the impacted and unimpacted populations i.e. based on the same sampled population parameters. The black line represents the 50th percentile (median), red lines give the central 95% of simulated values (2.5% and 97.5% reference points).

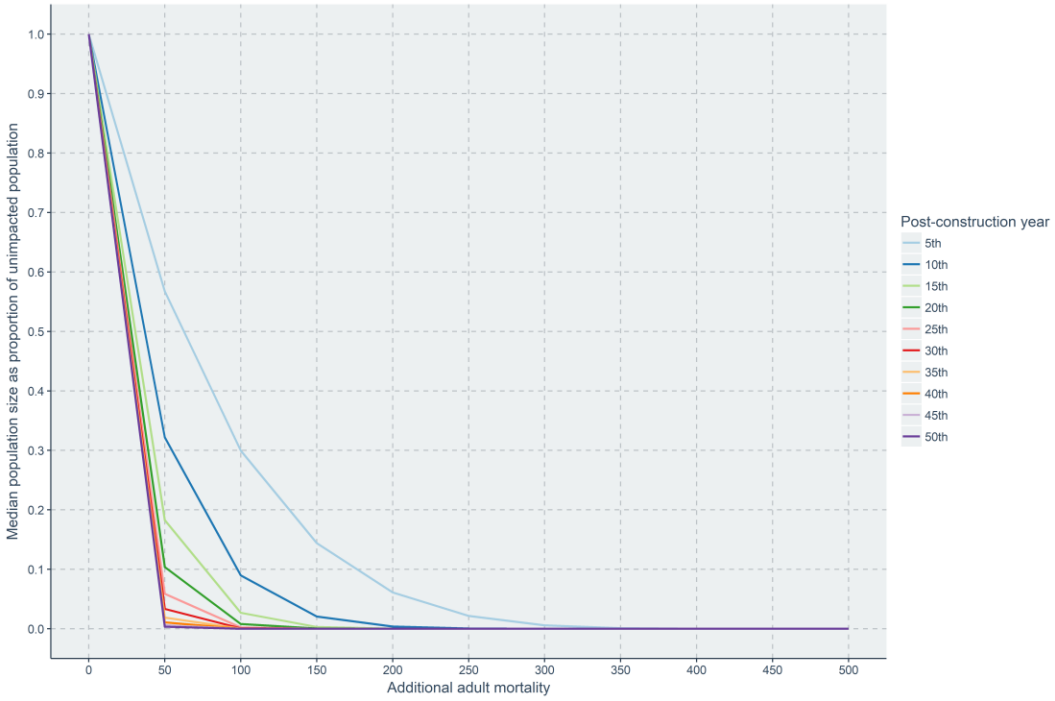

Figure 49: the ratio of the median impacted and median unimpacted population sizes from the simulations i.e. 0.5 means the median impacted population size is one-half the median unimpacted population size. Impact scenarios, in terms of additional adult mortalities, are given on the x-axis. Individual lines represent post-construction time points (projected 0 – 50 years).

Table 14: Growth rates of simulated populations under different impact scenarios. Reference points are 2.5%, 50% (median) and 97.5% of the distribution of simulated growth rates.

Additional adult mortalities	Median growth rates	2.5 percentile of simulated growth rates	97.5 percentile of simulated growth rates
0	1.088	1.069	1.104
50	0.971	0.954	0.986
100	0.855	0.840	0.867
150	0.738	0.725	0.749
200	0.621	0.610	0.631
250	0.505	0.495	0.513
300	0.388	0.380	0.395
350	0.271	0.264	0.277
400	0.153	0.148	0.159
450	0.022	0.007	0.041
500	0.000	0.000	0.000