Population modelling of Greenland white-fronted geese: potential impacts of additional mortality on the Scottish population and the Caithness and Kintyre sub-populations

COMMISSIONED REPORT

Commissioned Report No. 632

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COMMISSIONED REPORT
Summary

Population modelling of Greenland white-fronted geese: potential impacts of additional mortality on the Scottish population and the Caithness and Kintyre sub-populations

Background

This report presents outputs from the Greenland white-fronted goose density-independent Population Viability Analysis (Trinder, 2010) using three sets of demographic parameters. The risk, and increase in risk, of population declines due to additional mortality (i.e. in addition to natural mortality) are presented at the level of the Scottish population and the Caithness and Kintyre sub-populations. Estimates of the levels of additional mortality which trigger increases in the risk of population decline of up to 50% are presented.

Main findings

– The probability of populations declining below their existing population sizes was around 8% (predicted by the model when no additional mortality was applied) irrespective of which population was modelled.
– For the Scottish population additional mortality in excess of 25 and 30, 40 or 75 individuals per year increases the probability of a decline below the starting size by 5% depending on the parameter set used.
– For the Caithness sub-population additional mortality in excess of 2 or 3 individuals per year increases the probability of a decline below the starting size by 5% irrespective of the parameter set used.
– For the Kintyre sub-population additional mortality in excess of 10 or 15 individuals per year increases the probability of a decline below the starting size by 5% depending on the parameter set used.
– The figures presented in this report are for illustration purposes only and do not indicate any recommended or acceptable thresholds.

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1. INTRODUCTION

Under a previous SNH Commissioned Research Report (Trinder, 2010), a stochastic population model was developed for the Scottish population of the Greenland white-fronted goose *Anser albifrons flavirostris*. The model was used to predict future trends of this population under two scenarios: maintenance of the shooting moratorium introduced on Iceland in 2006 and a return to previous levels of shooting there.

The demographic parameter set used in Trinder (2010) was calculated on the basis that survival was predicted to improve following the Icelandic shooting moratorium. However, the recent population trend indicates that this has not resulted in the improvements predicted.

The lack of population recovery has led to increasing concern about potential impacts (particularly the risk of collision with wind turbines and power lines) of the expansion of renewable energy developments within important areas for Greenland white-fronted geese. Kintyre and Caithness are currently the geographical areas most likely to be affected. Further, the International Single Species Action Plan for this goose (Stroud *et al*., 2012) includes as an action taking steps to 'minimise additional sources of mortality' citing shooting and collisions with man-made structures as examples.

This report therefore sets out supplementary outputs from the Trinder (2010) population model which explore the impact of additional mortality on the Scottish population as a whole, and on the sub-populations in Caithness and Kintyre. Given that the Scottish population has not recovered as expected, three different demographic parameter sets ranging from optimistic to precautionary are used in the model to illustrate the range of potential impacts.

2. METHODS

Initial population sizes were taken from the winter 2011/12 census: 10,091, 338 and 2,406 geese for Scotland, Caithness and Kintyre respectively (Fox & Francis, 2012; Anon, 2013).

Three alternative sets of demographic parameters (Table 1) were used for the current modelling exercise. These sets allow potential additional mortality impacts to be gauged against different demographic scenarios. The first set was used in the original model (Trinder, 2010). These parameters were estimated on the basis that survival was expected to have increased since the shooting moratorium was introduced in Iceland in 2006 and are considered to be optimistic based on the recent observed population trend.

The second set of parameters was based on the averages of observed values across the period 1982 to 2014 (taken from the annual reporting of the Greenland White-fronted Goose Study Group: http://gwfg-conservation.wikispaces.com). This is considered the most precautionary parameter set.

The third set of parameters used the lower of the two mean brood size values (3.3 from 1982-2014) and intermediate values for survival and breeding proportion. This set was intended to provide guidance on the sensitivity of the results to the parameters used (in particular survival) and also in an effort to 'future-proof' the results should future survival rates average around this value. The reason that intermediate values were used for survival and breeding proportion, but not mean brood size, is that the former two are derived parameters (i.e. calculated from other parameters) while mean brood size is estimated directly from field observations. Variance for the intermediate parameters was assumed to be the higher of the two available on the grounds that this was more precautionary.

Table 1. Sets of demographic parameters used in the Greenland white-fronted goose population model. The 1996-2005 values in set 1 were taken from Trinder (2010).

Parameter set	Period	Mean demographic parameter (standard deviation)		
		Survival	Brood size	Proportion of breeders
1	1996-2005	0.930 (0.086)	3.368 (0.332)	0.0845 (0.02)
2	1982-2014	0.876 (0.074)	3.300 (0.341)	0.112 (0.049)
3	NA	0.9 (0.086)	3.300 (0.341)	0.10 (0.049)

It should be noted that the population model in Trinder (2010) was developed at the level of the Scottish population, with brood size and survival estimates based on data collected across a range of Scottish wintering locations. It is possible that different sub-populations of the wintering population, as defined by the broad regions used here, may experience consistently different levels of (for example) reproductive success. If this is the case then use of these population level parameters may not be wholly appropriate for modelling sub-populations. However, whilst there are variations among the sub-populations in any particular year, these differences are not static and lie within the overall range of variation for the whole population. Consequently the demographic parameters are considered sufficiently reliable for the sub-populations under consideration here. However, the above considerations should be borne in mind when interpreting the model predictions since any consistent regional differences in demography would alter the results obtained.

Trinder (2010) developed two forms of the model, with and without density dependence, which were used to project the population for a period of 25 years. It was not possible to determine which would generate more reliable predictions. As a general rule a density-independent model provides more precautionary predictions, particularly in the face of larger impacts, since there is no mechanism in the model by which reductions in population size can be buffered by compensatory improvements in survival or reproduction. Thus, owing to the more conservative nature of the results generated, the density-independent model was used for the assessment presented here.

As with the modelling presented in Trinder (2010), the rates of survival and the proportion of breeders were estimated taking into account the moratorium on shooting introduced in Iceland in 2006. There remains a modest level of illegal and accidental shooting in Greenland and Iceland (c. 500 per year, Tony Fox pers. comm.), and this is incorporated into the parameters in Table 1. Thus at a modelled mortality level of 0, there is an actual unknown mortality of around 500 implicitly included. This is unchanged from the modelling in Trinder (2010).

Additional mortality was modelled across ranges appropriate to the size of each population; for Scotland between 0 and 1,000 individuals at increments of 25, for Caithness between 0 and 50 individuals at increments of 5 and for Kintyre between 0 and 300 individuals at increments of 10. At each level of mortality, 5,000 simulations were conducted using the demographic parameters in Table 1. The probability of decline at each mortality level was estimated as the proportion of the 5,000 simulations which declined below each percentage reduction threshold (0, 5, 10, 20, 30, 40 and 50%) within a 25 year projection period. These thresholds therefore provide estimates ranging from the probability of any decline (0%) up to a halving in the population size (50%).

The following sections present illustrative levels of increase in the probability of population decline. These do not confer any particular significance to the values used but rather guide the reader through interpretation of the results. As examples, discussion is presented of the level of additional mortality required to increase the risk of any, 10% or 20% decline in population size by 5% or 10%.

3. RESULTS

3.1 Demographic parameter set 1

Using the first set of demographic parameters (Table 1; survival = 0.930, mean brood size = 3.368, proportion breeders = 0.0845) the following results were obtained for each population.

3.1.1 Scottish population

The baseline probability that the population would decline below the initial population size within 25 years was 8.0% (red line Figure 1, Table 2). With increasing additional mortality this rose, reaching around 20% when additional mortality was between 150 and 175 individuals per year. The probability of a 10% decline in the population size was 6.0% (yellow line Figure 1) with no additional mortality, which increased to 10% when additional mortality exceeded 75 individuals per year and 20% when additional mortality was around 200 individuals per year.
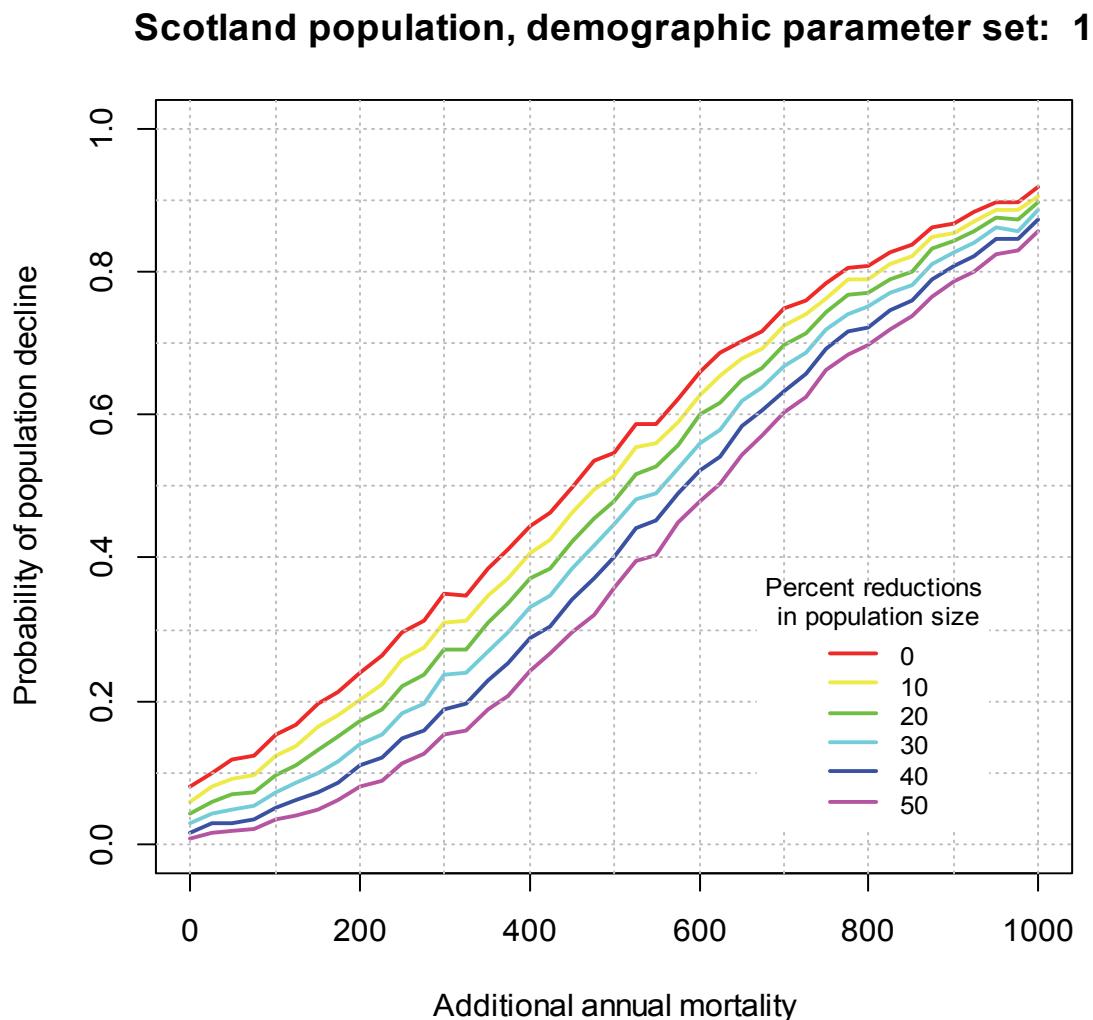
Figure 1. The probability of population decline in relation to increasing annual mortality in the Scottish population of Greenland white-fronted geese using parameter set 1.The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, additional mortality of 75 birds per annum will increase the risk of any population decline by 5% (red line Figure 2). The increase in the risk of a 10% population decline exceeded 10% when additional mortality exceeded 150 individuals per year (yellow line Figure 2). The increase in the risk of a 20% decline exceeded 10% when additional mortality was around 175 individuals per year (green line Figure 2).

Scotland population, demographic parameter set: 1
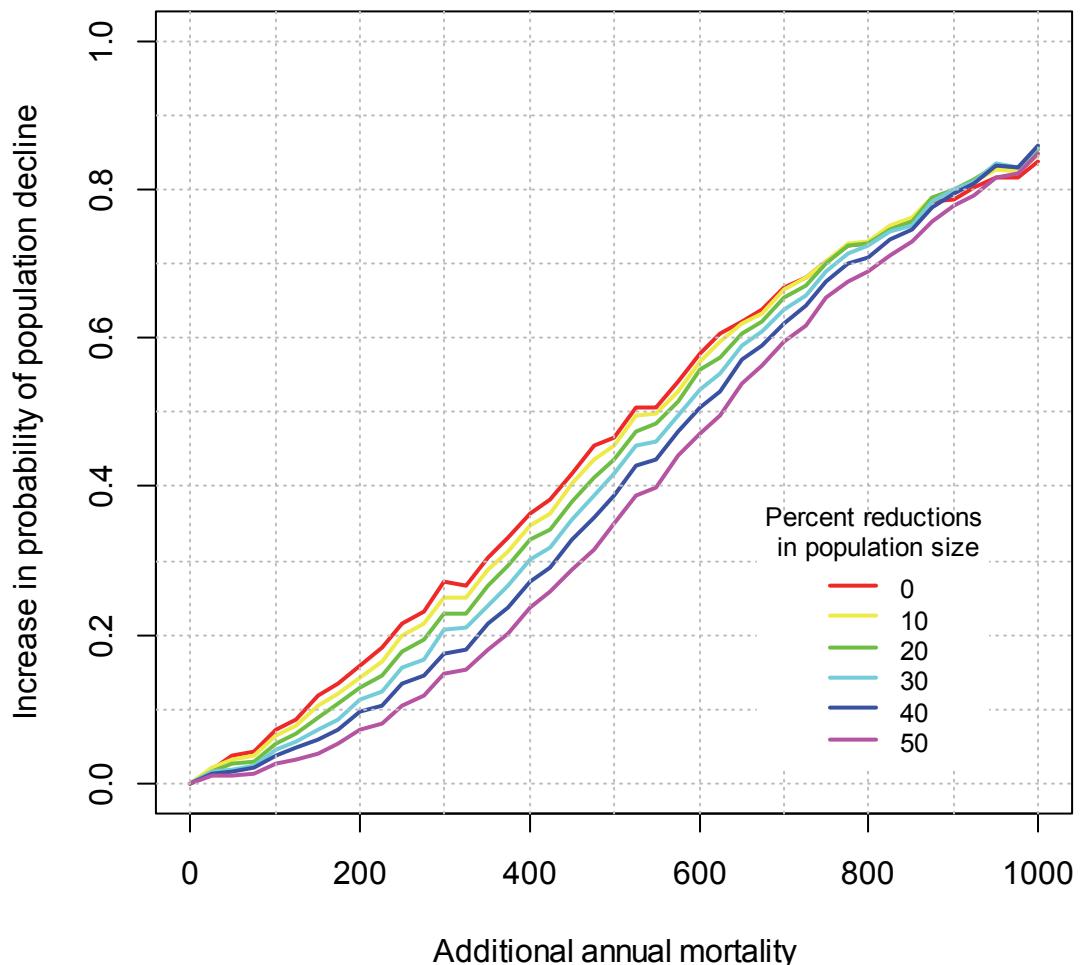
Figure 2. The increase in the probability of population decline in relation to increasing annual mortality in the Scottish population of Greenland white-fronted geese using parameter set 1. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 2. The probabilities of population decline relative to the initial population size in the Scottish population of Greenland white-fronted geese using parameter set 1. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.1710 that an increase in mortality of 200 birds per annum will cause the population to reduce by 20% or more from its starting population size.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.0804	0.0598	0.0430	0.0288	0.0142	0.0074
25	0.0990	0.0800	0.0592	0.0432	0.0278	0.0162
50	0.1174	0.0916	0.0690	0.0472	0.0302	0.0186
75	0.1234	0.0974	0.0726	0.0528	0.0356	0.0212
100	0.1536	0.1244	0.0970	0.0732	0.0516	0.0344
125	0.1672	0.1378	0.1098	0.0846	0.0620	0.0402
150	0.1974	0.1638	0.1306	0.1002	0.0722	0.0478
175	0.2134	0.1806	0.1492	0.1150	0.0866	0.0618
200	0.2386	0.2026	0.1710	0.1406	0.1108	0.0794
225	0.2630	0.2226	0.1876	0.1524	0.1200	0.0890
250	0.2952	0.2596	0.2208	0.1838	0.1490	0.1126
275	0.3112	0.2758	0.2354	0.1962	0.1588	0.1252
300	0.3512	0.3106	0.2728	0.2356	0.1890	0.1542
325	0.3470	0.3110	0.2724	0.2382	0.1952	0.1596
350	0.3840	0.3486	0.3088	0.2690	0.2288	0.1886
375	0.4122	0.3728	0.3370	0.2950	0.2516	0.2082
400	0.4436	0.4058	0.3704	0.3314	0.2872	0.2430
425	0.4634	0.4244	0.3844	0.3460	0.3042	0.2656
450	0.4988	0.4634	0.4240	0.3840	0.3424	0.2948
475	0.5368	0.4948	0.4544	0.4172	0.3728	0.3216
500	0.5468	0.5148	0.4786	0.4458	0.4020	0.3572
525	0.5880	0.5560	0.5176	0.4828	0.4422	0.3960
550	0.5870	0.5594	0.5290	0.4900	0.4516	0.4050
575	0.6232	0.5890	0.5584	0.5252	0.4892	0.4494
600	0.6608	0.6292	0.5996	0.5604	0.5214	0.4792
625	0.6866	0.6552	0.6162	0.5804	0.5422	0.5038
650	0.7032	0.6800	0.6488	0.6190	0.5846	0.5450
675	0.7178	0.6920	0.6660	0.6382	0.6056	0.5700
700	0.7492	0.7244	0.6986	0.6684	0.6342	0.6024
725	0.7610	0.7412	0.7152	0.6860	0.6570	0.6254
750	0.7848	0.7622	0.7426	0.7192	0.6916	0.6622
775	0.8056	0.7884	0.7682	0.7420	0.7162	0.6834
800	0.8090	0.7892	0.7710	0.7526	0.7232	0.6968
825	0.8268	0.8116	0.7890	0.7714	0.7470	0.7202
850	0.8396	0.8220	0.8004	0.7810	0.7612	0.7380
875	0.8634	0.8496	0.8320	0.8118	0.7902	0.7652
900	0.8686	0.8548	0.8438	0.8282	0.8084	0.7868
925	0.8838	0.8706	0.8582	0.8406	0.8224	0.8008
950	0.8976	0.8876	0.8770	0.8632	0.8460	0.8254
975	0.8968	0.8856	0.8738	0.8582	0.8456	0.8292
1000	0.9180	0.9070	0.8968	0.8862	0.8736	0.8574

3.1.2 Caithness population

The baseline probability that the population would decline below the initial population size within 25 years was 8.1% (red line Figure 3, Table 3). With increasing additional mortality this rose, reaching around 20% when additional mortality was a little under 5 individuals per year. The probability of a 10% decline in the population size was 6.1% with no additional mortality (red line Figure 3), which increased to 10% when additional mortality was around 2 individuals per year (yellow line Figure 3) and 20% when additional mortality was around 6 individuals per year (green line Figure 3).
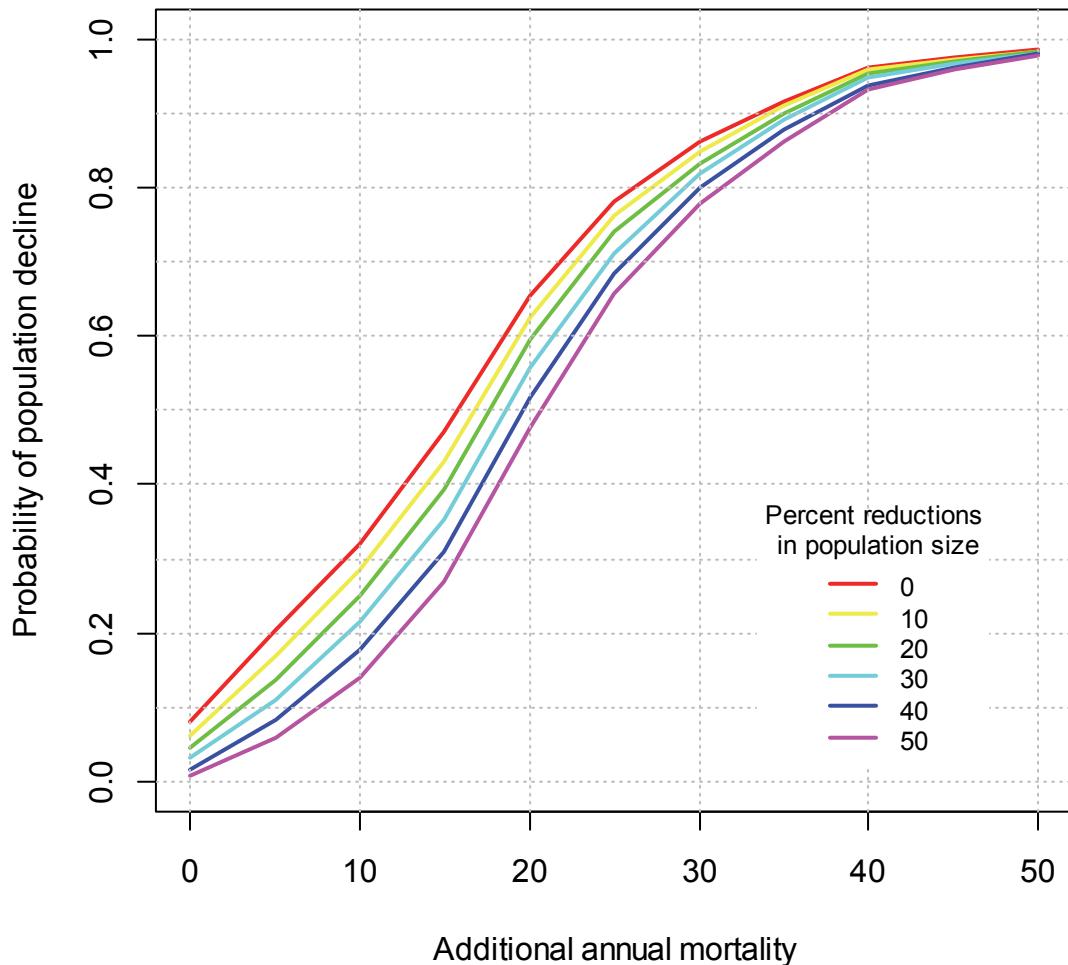
Figure 3. The probability of population decline in relation to increasing annual mortality in the Caithness population of Greenland white-fronted geese using parameter set 1. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, additional mortality of 2 birds per annum will increase the risk of any decline by 5%. The increase in the risk of a 10% population decline exceeded 10% when additional mortality was around 5 individuals per year (yellow line Figure 4). The increase in the risk of a 20% decline exceeded 10% when additional mortality was around 8 individuals per year (green line Figure 4).

Caithness population, demographic parameter set: 1
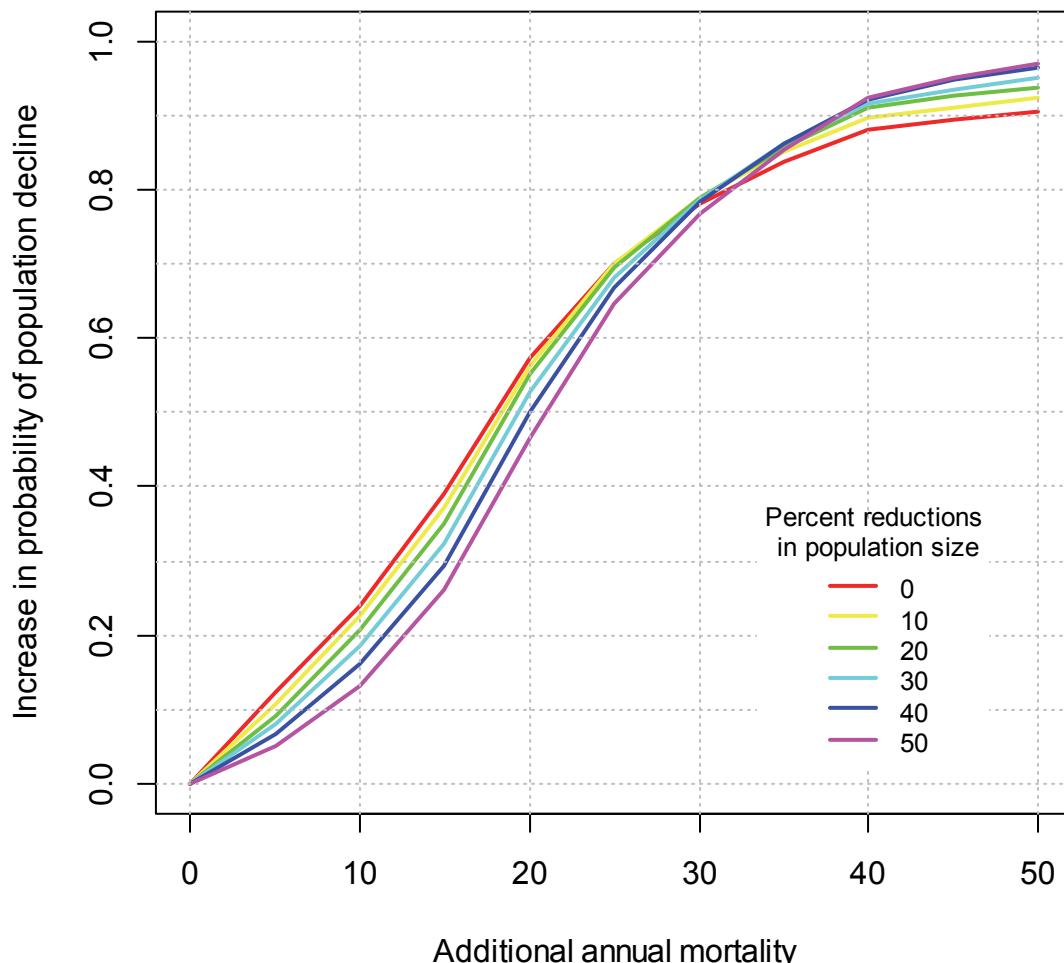
Figure 4. The increase in the probability of population decline in relation to increasing annual mortality in the Caithness population of Greenland white-fronted geese using parameter set 1. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 3. The probabilities of population decline relative to the initial population size in the Caithness population of Greenland white-fronted geese using parameter set 1. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.4320 that increased mortality of 15 birds per annum will give rise to a population reduction of 10% or greater.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.0806	0.0614	0.0440	0.0306	0.0160	0.0084
5	0.2048	0.1688	0.1360	0.1096	0.0830	0.0590
10	0.3212	0.2864	0.2514	0.2158	0.1774	0.1400
15	0.4702	0.4320	0.3938	0.3530	0.3092	0.2700
20	0.6538	0.6258	0.5958	0.5590	0.5170	0.4756
25	0.7822	0.7634	0.7406	0.7120	0.6842	0.6564
30	0.8634	0.8500	0.8340	0.8186	0.7992	0.7776
35	0.9176	0.9122	0.9016	0.8922	0.8786	0.8632
40	0.9632	0.9590	0.9546	0.9482	0.9390	0.9318
45	0.9752	0.9736	0.9702	0.9670	0.9636	0.9590
50	0.9864	0.9852	0.9834	0.9818	0.9810	0.9788

3.1.3 Kintyre population

The baseline probability that the population would decline below the initial population size within 25 years was 8.0% (red line Figure 5, Table 4). With increasing additional mortality this rose, reaching around 20% when additional mortality was approximately 40 individuals per year. The probability of a 10% decline in the population size was 6.0% with no additional mortality, which increased to 10% when additional mortality was between 10 and 20 individuals per year (yellow line Figure 5) and 20% when additional mortality was between 40 and 50 individuals per year (green line Figure 5).

Kintyre population, demographic parameter set: 1
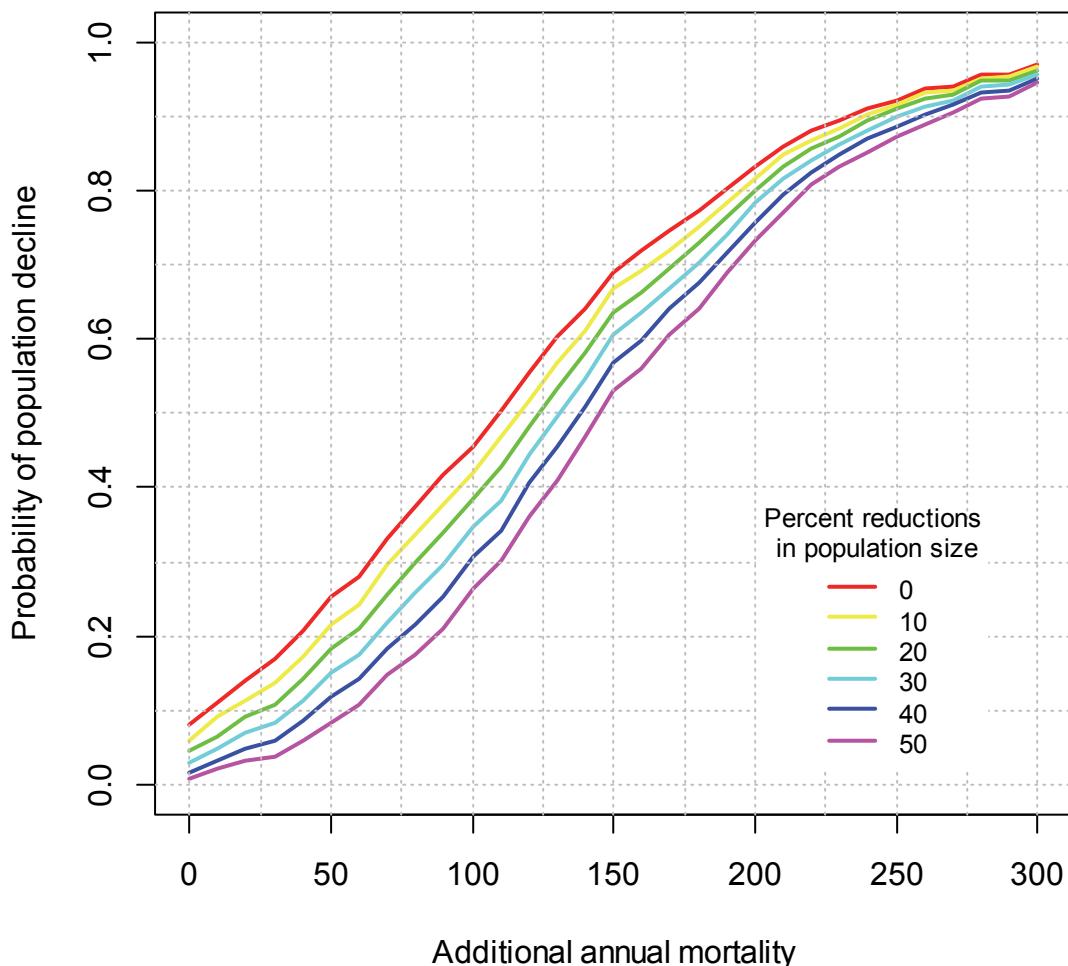
*Figure 5. The probability of population decline in relation to increasing annual mortality in the Kintyre population of Greenland white-fronted geese using parameter set 1. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.*

In terms of the increase in risk of population decline, additional mortality of 15 birds per annum increases the risk of any decline by 5%. The increase in the risk of a 10% population decline exceeded 10% when additional mortality was around 35 individuals per year (yellow line Figure 6). The increase in the risk of a 20% decline exceeded 10% when additional mortality was over 40 individuals per year (green line Figure 6).

Kintyre population, demographic parameter set: 1
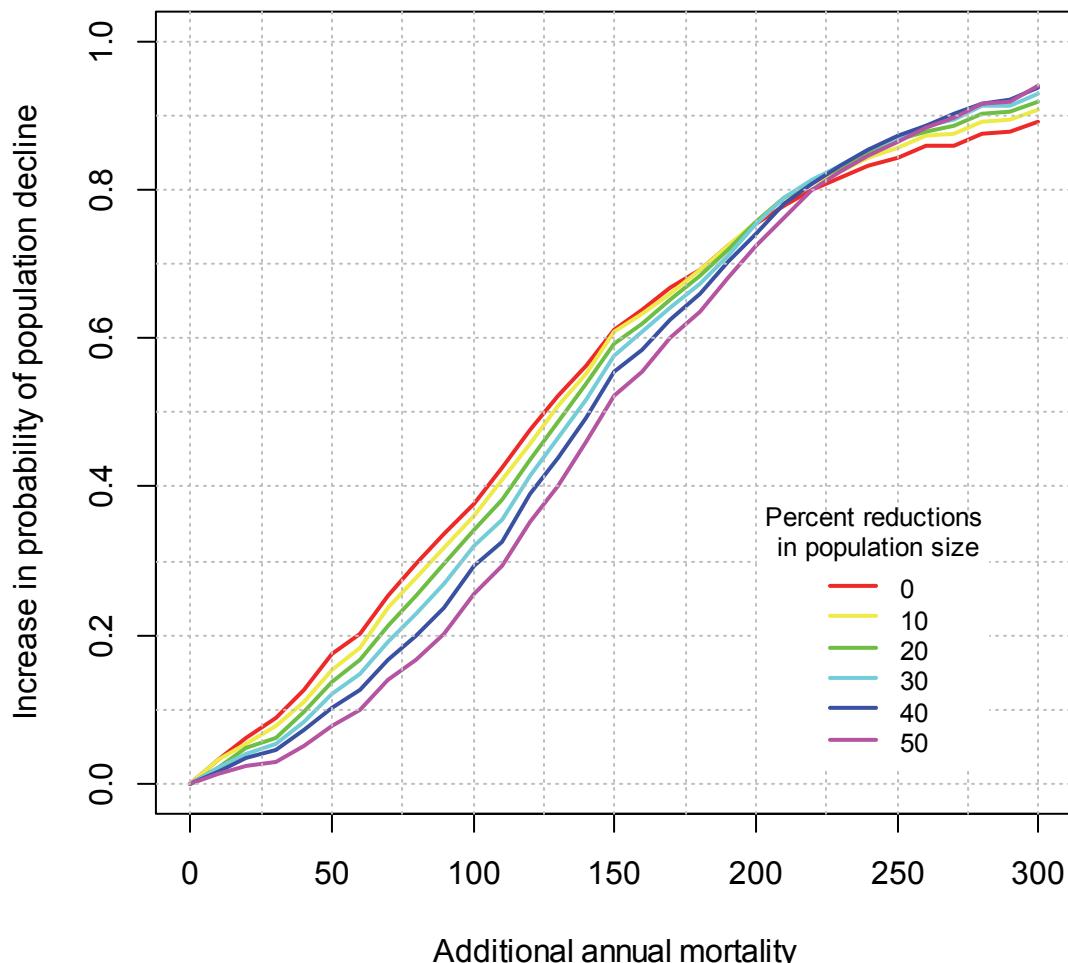
Figure 6. *The increase in the probability of population decline in relation to increasing annual mortality in the Kintyre population of Greenland white-fronted geese using parameter set 1. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.*

Table 4. The probabilities of population decline relative to the initial population size in the Kintyre population of Greenland white-fronted geese using parameter set 1. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.2140 that increased mortality of 50 birds per annum will give rise to a population reduction of 10% or greater.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.0796	0.0598	0.0440	0.0284	0.0150	0.0074
10	0.1100	0.0902	0.0654	0.0490	0.0304	0.0196
20	0.1404	0.1138	0.0908	0.0686	0.0490	0.0308
30	0.1688	0.1364	0.1064	0.0822	0.0594	0.0374
40	0.2060	0.1710	0.1410	0.1122	0.0864	0.0582
50	0.2538	0.2140	0.1816	0.1502	0.1170	0.0842
60	0.2802	0.2416	0.2094	0.1754	0.1412	0.1060
70	0.3320	0.2954	0.2554	0.2184	0.1816	0.1466
80	0.3744	0.3376	0.2982	0.2578	0.2148	0.1744
90	0.4162	0.3772	0.3390	0.2974	0.2526	0.2096
100	0.4558	0.4204	0.3862	0.3484	0.3076	0.2642
110	0.5050	0.4700	0.4272	0.3836	0.3414	0.3002
120	0.5558	0.5174	0.4816	0.4434	0.4058	0.3612
130	0.6030	0.5696	0.5326	0.4956	0.4540	0.4084
140	0.6414	0.6110	0.5822	0.5458	0.5084	0.4686
150	0.6908	0.6676	0.6358	0.6050	0.5692	0.5300
160	0.7186	0.6934	0.6638	0.6370	0.5990	0.5612
170	0.7474	0.7200	0.6952	0.6692	0.6402	0.6072
180	0.7722	0.7526	0.7298	0.7028	0.6756	0.6422
190	0.8042	0.7854	0.7646	0.7410	0.7176	0.6898
200	0.8332	0.8162	0.8006	0.7830	0.7572	0.7322
210	0.8594	0.8482	0.8338	0.8172	0.7954	0.7698
220	0.8808	0.8680	0.8564	0.8416	0.8248	0.8082
230	0.8950	0.8854	0.8742	0.8622	0.8478	0.8322
240	0.9114	0.9030	0.8936	0.8822	0.8698	0.8528
250	0.9232	0.9178	0.9112	0.8998	0.8872	0.8720
260	0.9390	0.9318	0.9238	0.9148	0.9024	0.8904
270	0.9402	0.9360	0.9300	0.9228	0.9168	0.9044
280	0.9562	0.9516	0.9482	0.9414	0.9324	0.9250
290	0.9570	0.9536	0.9496	0.9434	0.9360	0.9278
300	0.9710	0.9670	0.9636	0.9580	0.9518	0.9474

3.2 Demographic parameter set 2

Using the second set of demographic parameters (Table 1; survival = 0.876, mean brood size = 3.30, proportion breeders = 0.112) the following results were obtained for each population.

3.2.1 Scottish population

The baseline probability that the population would decline below the initial population size within 25 years with no additional mortality was 33.4% (red line Figure 7, Table 5). The probability of a 10% decline in the population size with no additional mortality was 27.4% (yellow line Figure 7).

Scotland population, demographic parameter set: 2
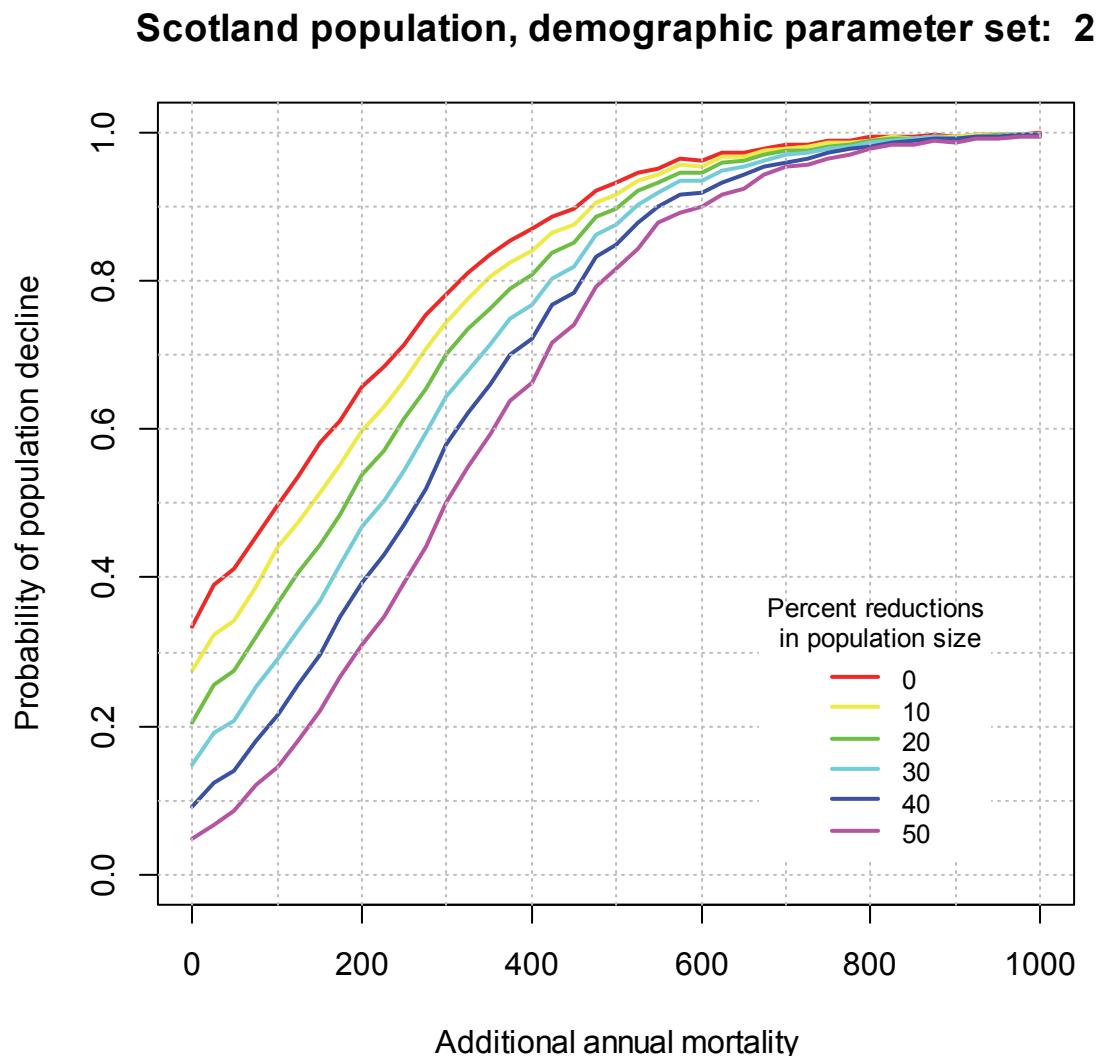
Figure 7. The probability of population decline in relation to increasing annual mortality in the Scottish population of Greenland white-fronted geese using parameter set 2. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, the increase in the risk of a 10% population decline exceeded 10% when additional mortality was between 50 and 75 individuals per year (yellow line Figure 8). The increase in the risk of a 20% decline also exceeded 10% (green line Figure 8) when additional mortality was between 50 and 75 individuals per year.

Scotland population, demographic parameter set: 2

Figure 8. The increase in the probability of population decline in relation to increasing annual mortality in the Scottish population of Greenland white-fronted geese using parameter set 2. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 5. The probabilities of population decline relative to the initial population size in the Scottish population of Greenland white-fronted geese using parameter set 2. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.5376 that an increase in mortality of 200 birds per annum will cause the population to reduce by 20% or more from its starting population size.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.3340	0.2740	0.2054	0.1466	0.0910	0.0486
25	0.3916	0.3232	0.2550	0.1898	0.1244	0.0672
50	0.4126	0.3420	0.2758	0.2076	0.1408	0.0848
75	0.4564	0.3884	0.3192	0.2526	0.1814	0.1200
100	0.4996	0.4422	0.3664	0.2904	0.2152	0.1446
125	0.5374	0.4750	0.4066	0.3294	0.2550	0.1804
150	0.5808	0.5142	0.4452	0.3676	0.2962	0.2210
175	0.6120	0.5534	0.4842	0.4182	0.3464	0.2676
200	0.6568	0.5980	0.5376	0.4688	0.3936	0.3092
225	0.6850	0.6298	0.5714	0.5046	0.4306	0.3482
250	0.7134	0.6654	0.6136	0.5442	0.4722	0.3938
275	0.7536	0.7080	0.6546	0.5946	0.5200	0.4426
300	0.7812	0.7430	0.7002	0.6450	0.5796	0.5014
325	0.8124	0.7770	0.7364	0.6798	0.6222	0.5492
350	0.8352	0.8060	0.7614	0.7154	0.6606	0.5916
375	0.8554	0.8252	0.7910	0.7484	0.6994	0.6400
400	0.8696	0.8400	0.8092	0.7680	0.7220	0.6640
425	0.8870	0.8660	0.8372	0.8032	0.7694	0.7158
450	0.8982	0.8750	0.8516	0.8192	0.7852	0.7416
475	0.9230	0.9056	0.8864	0.8630	0.8322	0.7932
500	0.9322	0.9168	0.8968	0.8762	0.8480	0.8172
525	0.9470	0.9360	0.9224	0.9024	0.8774	0.8450
550	0.9518	0.9440	0.9334	0.9186	0.9012	0.8778
575	0.9652	0.9576	0.9474	0.9348	0.9164	0.8924
600	0.9634	0.9556	0.9452	0.9342	0.9198	0.9004
625	0.9732	0.9672	0.9598	0.9476	0.9334	0.9174
650	0.9738	0.9684	0.9616	0.9544	0.9424	0.9244
675	0.9796	0.9752	0.9698	0.9630	0.9556	0.9422
700	0.9836	0.9798	0.9752	0.9700	0.9610	0.9530
725	0.9850	0.9818	0.9772	0.9722	0.9662	0.9582
750	0.9882	0.9854	0.9802	0.9778	0.9730	0.9648
775	0.9906	0.9878	0.9846	0.9816	0.9776	0.9706
800	0.9936	0.9904	0.9884	0.9860	0.9816	0.9778
825	0.9956	0.9934	0.9918	0.9892	0.9860	0.9834
850	0.9934	0.9932	0.9924	0.9914	0.9888	0.9846
875	0.9968	0.9956	0.9942	0.9938	0.9918	0.9888
900	0.9954	0.9948	0.9928	0.9920	0.9908	0.9878
925	0.9970	0.9966	0.9958	0.9948	0.9938	0.9922
950	0.9972	0.9970	0.9964	0.9958	0.9938	0.9924
975	0.9986	0.9984	0.9980	0.9976	0.9968	0.9954
1000	0.9990	0.9984	0.9980	0.9974	0.9964	0.9954

3.2.2 Caithness population

The baseline probability that the population would decline below the initial population size within 25 years with no additional mortality was 33.8% (red line Figure 9, Table 6). The probability of a 10% decline in the population size was 27.9% (yellow line Figure 9) with no additional mortality.

Caithness population, demographic parameter set: 2
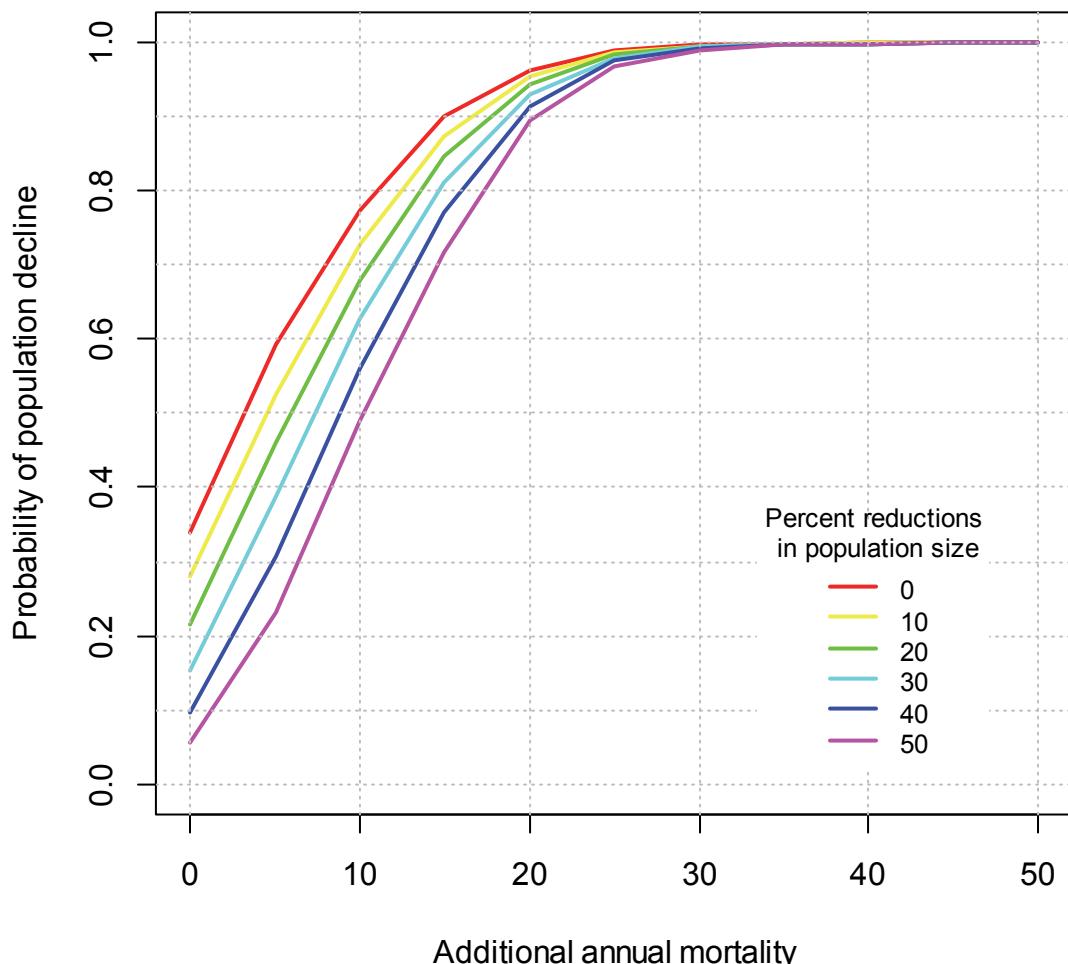
Figure 9. The probability of population decline in relation to increasing annual mortality in the Caithness population of Greenland white-fronted geese using parameter set 2. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, the increase in the risk of a 10% population decline exceeded 10% when additional mortality was around 2 individuals per year (yellow line Figure 10). The increase in the risk of a 20% decline also exceeded 10% when additional mortality was between 2 and 3 individuals per year (green line Figure 10).
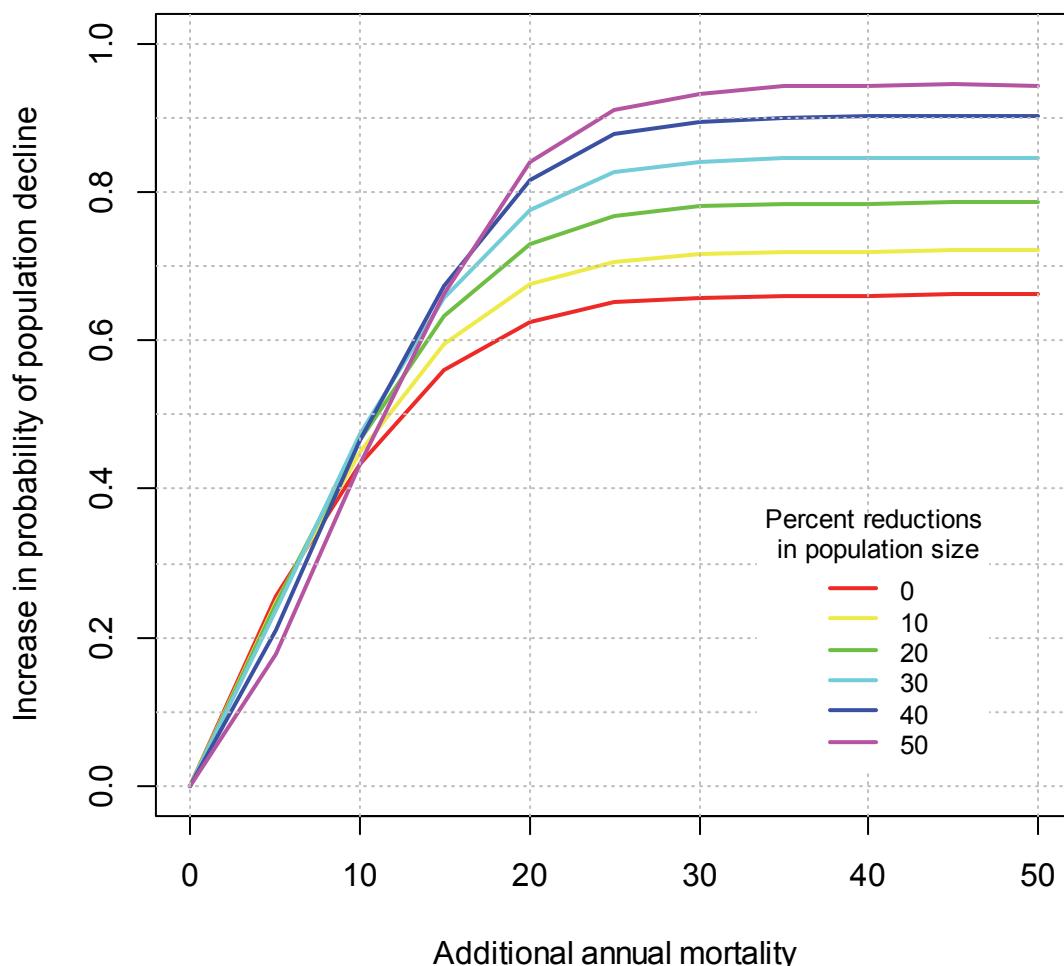
Figure 10. The increase in the probability of population decline in relation to Increasing annual mortality in the Caithness population of Greenland white-fronted geese using parameter set 2. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by10, 20, 30, 40 and 50% from the starting population size.

Table 6. The probabilities of population decline relative to the initial population size in the Caithness population of Greenland white-fronted geese using parameter set 2. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.7288 that increased mortality of 10 birds per annum will give rise to a population reduction of 10% or greater.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.3380	0.2788	0.2140	0.1530	0.0964	0.0550
5	0.5938	0.5254	0.4596	0.3886	0.3058	0.2322
10	0.7722	0.7288	0.6802	0.6278	0.5612	0.4898
15	0.8990	0.8744	0.8468	0.8106	0.7706	0.7180
20	0.9620	0.9554	0.9446	0.9298	0.9140	0.8958
25	0.9892	0.9862	0.9832	0.9798	0.9760	0.9674
30	0.9968	0.9960	0.9958	0.9938	0.9922	0.9890
35	0.9986	0.9982	0.9982	0.9982	0.9978	0.9972
40	0.9988	0.9988	0.9986	0.9986	0.9986	0.9986
45	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
50	1.0000	1.0000	1.0000	1.0000	1.0000	0.9998

3.2.2 Kintyre population

The baseline probability that the population would decline below the initial population size within 25 years with no additional mortality was 33.8% (red line Figure 11, Table 7). The probability of a 10% decline in the population size was 27.4% (yellow line Figure 11) with no additional mortality.

Kintyre population, demographic parameter set: 2
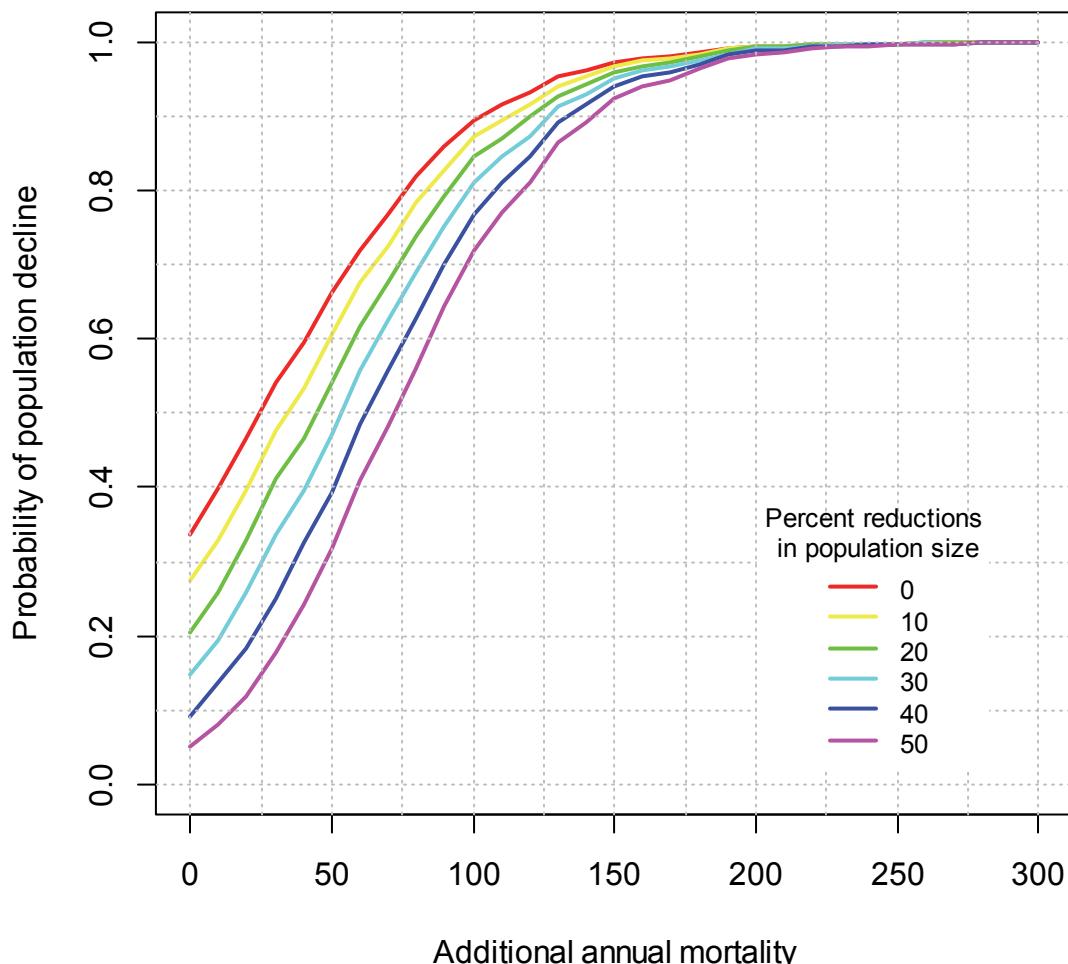
Figure 11. The probability of population decline in relation to increasing annual mortality in the Kintyre population of Greenland white-fronted geese using parameter set 2. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, the increase in the risk of a 10% population decline exceeded 10% when additional mortality was between 10 and 20 individuals per year (yellow line Figure 12). The increase in the risk of a 20% also exceeded 10% when additional mortality was between 10 and 20 individuals per year (green line Figure 12).

Kintyre population, demographic parameter set: 2
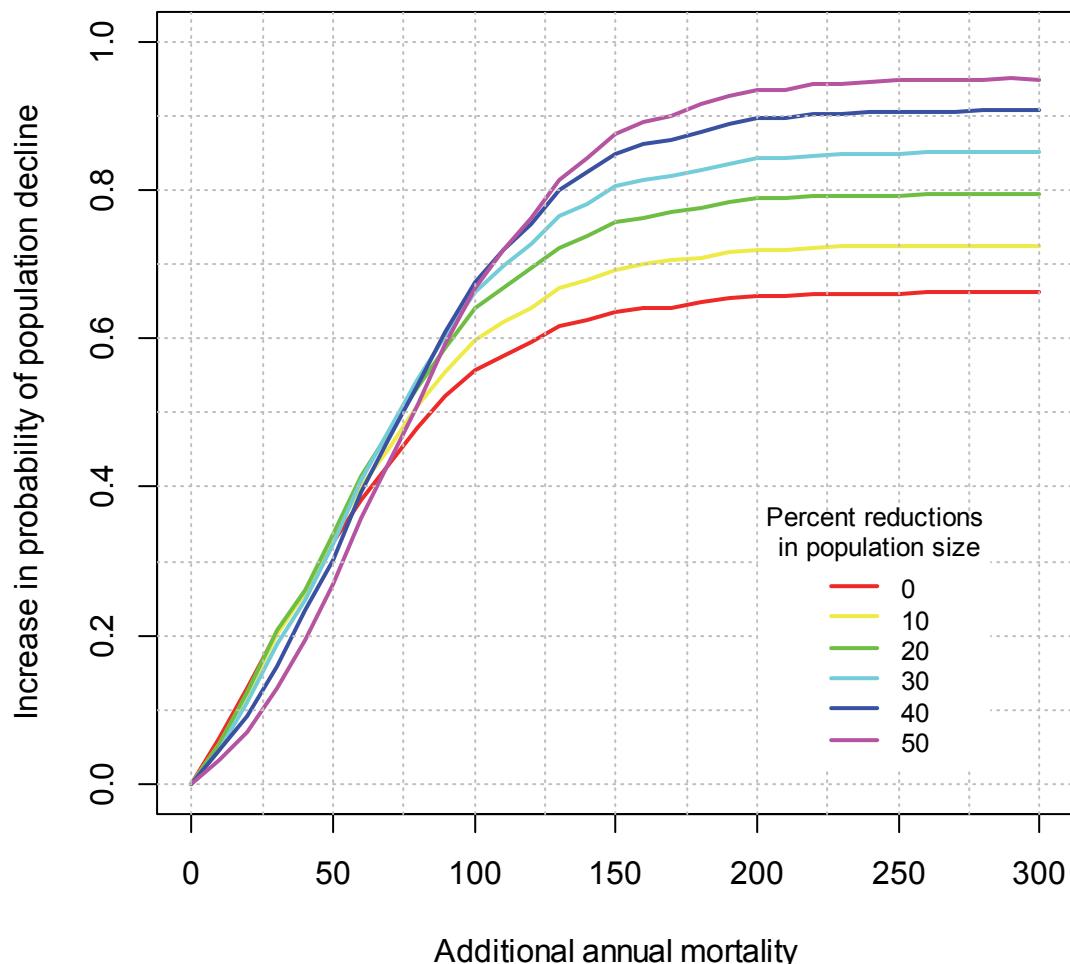
Figure 12. The increase in the probability of population decline in relation to increasing annual mortality in the Kintyre population of Greenland white-fronted geese using parameter set 2. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 7. The probabilities of population decline relative to the initial population size in the Kintyre population of Greenland white-fronted geese using parameter set 2. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.6056 that increased mortality of 50 birds per annum will give rise to a population reduction of 10% or greater.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.3378	0.2740	0.2046	0.1480	0.0918	0.0494
10	0.3994	0.3278	0.2590	0.1944	0.1382	0.0804
20	0.4670	0.3954	0.3274	0.2576	0.1840	0.1192
30	0.5426	0.4764	0.4124	0.3362	0.2500	0.1784
40	0.5952	0.5336	0.4660	0.3968	0.3268	0.2422
50	0.6622	0.6056	0.5420	0.4704	0.3938	0.3176
60	0.7198	0.6756	0.6182	0.5568	0.4842	0.4086
70	0.7692	0.7258	0.6776	0.6242	0.5578	0.4830
80	0.8186	0.7844	0.7388	0.6912	0.6290	0.5592
90	0.8598	0.8278	0.7924	0.7526	0.7014	0.6432
100	0.8960	0.8720	0.8460	0.8122	0.7688	0.7190
110	0.9154	0.8962	0.8716	0.8456	0.8122	0.7698
120	0.9322	0.9166	0.8994	0.8746	0.8452	0.8120
130	0.9536	0.9414	0.9260	0.9138	0.8926	0.8640
140	0.9618	0.9544	0.9440	0.9308	0.9154	0.8918
150	0.9744	0.9674	0.9606	0.9528	0.9398	0.9254
160	0.9792	0.9746	0.9684	0.9628	0.9538	0.9416
170	0.9804	0.9788	0.9744	0.9682	0.9600	0.9494
180	0.9866	0.9838	0.9806	0.9768	0.9716	0.9650
190	0.9930	0.9908	0.9888	0.9848	0.9826	0.9776
200	0.9956	0.9946	0.9938	0.9916	0.9886	0.9852
210	0.9960	0.9948	0.9942	0.9920	0.9894	0.9860
220	0.9986	0.9976	0.9966	0.9956	0.9940	0.9924
230	0.9986	0.9980	0.9972	0.9964	0.9952	0.9940
240	0.9986	0.9986	0.9982	0.9968	0.9962	0.9952
250	0.9986	0.9980	0.9980	0.9980	0.9978	0.9970
260	0.9998	0.9996	0.9994	0.9988	0.9986	0.9986
270	0.9994	0.9994	0.9988	0.9986	0.9984	0.9980
280	0.9996	0.9994	0.9994	0.9994	0.9994	0.9992
290	0.9996	0.9994	0.9994	0.9994	0.9994	0.9992
300	0.9996	0.9994	0.9994	0.9994	0.9994	0.9992

3.3 Demographic parameter set 3

Using the third set of demographic parameters (Table 1; survival = 0.90, mean brood size = 3.30, proportion breeders = 0.10) the following results were obtained for each population.

3.3.1 *Scottish population*

The baseline probability that the population would decline below the initial population size within 25 years with no additional mortality was 21.0% (red line Figure 13, Table 8). The probability of a 10% decline in the population size was 17.0% with no additional mortality (yellow line Figure 13).

Scotland population, demographic parameter set: 3
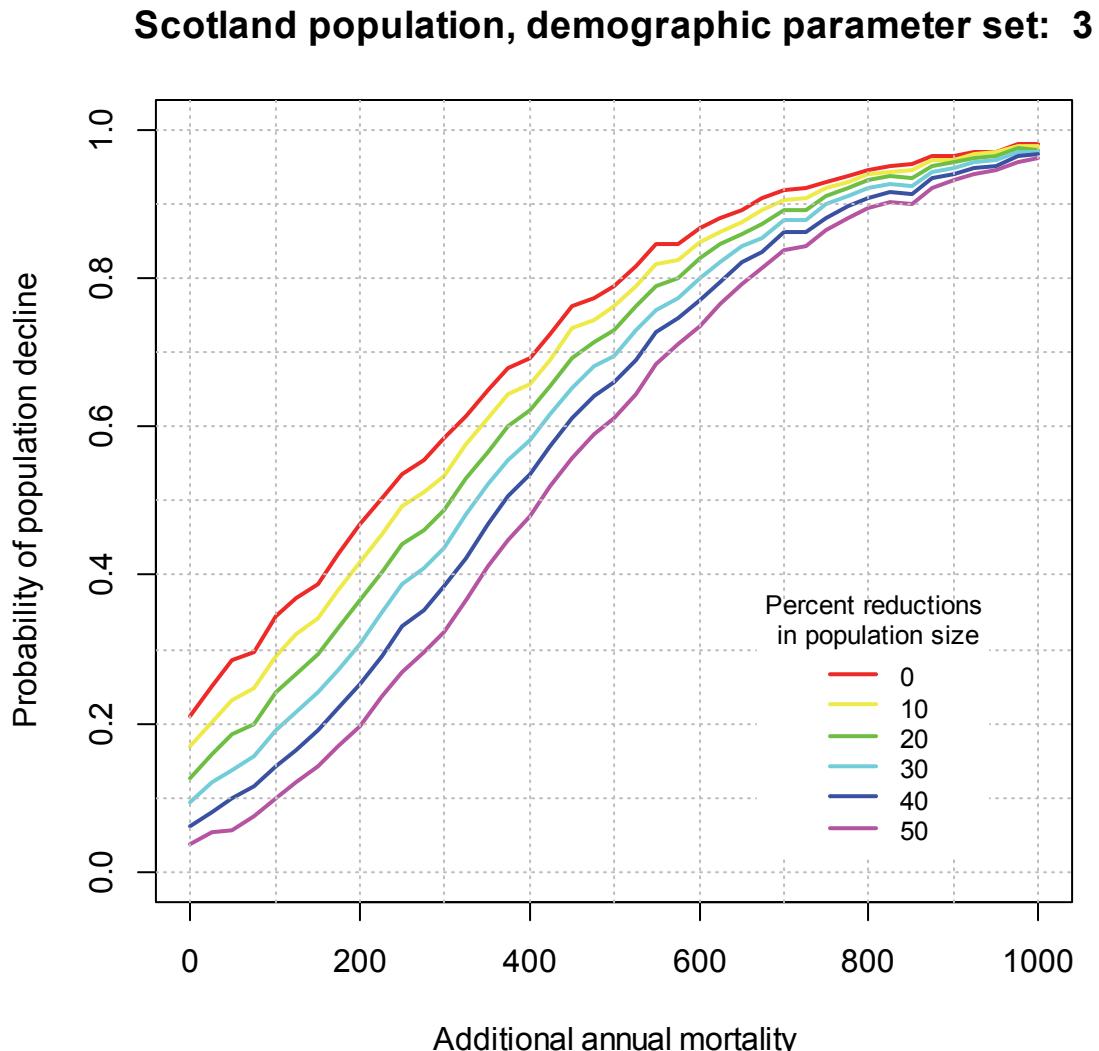
Figure 13. The probability of population decline in relation to increasing annual mortality in the Scottish population of Greenland white-fronted geese using parameter set 3. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, the increase in the risk of a 10% population decline exceeded 10% when additional mortality was between 75 and 100 individuals per year (yellow line Figure 14). The increase in the risk of a 20% decline also exceeded 10% when additional mortality was between 75 and 100 individuals per year.

Scotland population, demographic parameter set: 3

Figure 14. The increase in the probability of population decline in relation to increasing annual mortality in the Scottish population of Greenland white-fronted geese using parameter set 3. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 8. The probabilities of population decline relative to the initial population size in the Scottish population of Greenland white-fronted geese using parameter set 3. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.3666 that an increase in mortality of 200 birds per annum will cause the population to reduce by 20% or more from its starting population size.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.2104	0.1698	0.1268	0.0930	0.0610	0.0358
25	0.2492	0.2016	0.1584	0.1210	0.0802	0.0520
50	0.2852	0.2322	0.1866	0.1366	0.0980	0.0554
75	0.2956	0.2482	0.1998	0.156	0.1156	0.0754
100	0.3448	0.2900	0.2418	0.1908	0.1422	0.0990
125	0.3688	0.3190	0.2656	0.2142	0.1630	0.1204
150	0.3874	0.3408	0.2924	0.2426	0.1906	0.1412
175	0.4282	0.3810	0.3294	0.2726	0.2192	0.1702
200	0.4678	0.4178	0.3666	0.3064	0.2536	0.1950
225	0.5046	0.4556	0.4036	0.3492	0.2908	0.2356
250	0.5354	0.4938	0.4406	0.3878	0.3306	0.2686
275	0.5550	0.5106	0.4614	0.4084	0.3520	0.2966
300	0.5840	0.5338	0.4886	0.4376	0.3838	0.3240
325	0.6152	0.5766	0.5318	0.4830	0.4234	0.3672
350	0.6494	0.6120	0.5660	0.5214	0.4692	0.4132
375	0.6786	0.6448	0.6006	0.5538	0.5056	0.4476
400	0.6938	0.6574	0.6224	0.5820	0.5368	0.4798
425	0.7238	0.6910	0.6550	0.6174	0.5728	0.5196
450	0.7626	0.7324	0.6926	0.6524	0.6114	0.5576
475	0.7734	0.7434	0.7154	0.6820	0.6416	0.5888
500	0.7892	0.7616	0.7292	0.6954	0.6604	0.6108
525	0.8156	0.7902	0.7628	0.7304	0.6894	0.6436
550	0.8460	0.8190	0.7906	0.7568	0.7276	0.6840
575	0.8460	0.8248	0.8016	0.7748	0.7456	0.7120
600	0.8670	0.8484	0.8266	0.8016	0.7702	0.7366
625	0.8822	0.8634	0.8454	0.8214	0.7942	0.7648
650	0.8912	0.8772	0.8606	0.8440	0.8228	0.7924
675	0.9074	0.8926	0.8722	0.8552	0.8348	0.8130
700	0.9190	0.9058	0.8930	0.8788	0.8618	0.8382
725	0.9212	0.9086	0.8932	0.8790	0.8638	0.8434
750	0.9296	0.9216	0.9122	0.8990	0.8818	0.8640
775	0.9384	0.9310	0.9218	0.9106	0.8974	0.8816
800	0.9470	0.9402	0.9336	0.9232	0.9088	0.8954
825	0.9528	0.9448	0.9374	0.9284	0.9158	0.9024
850	0.9546	0.9452	0.9358	0.9242	0.9126	0.9004
875	0.9642	0.9584	0.9528	0.9438	0.9350	0.9224
900	0.9654	0.9608	0.9562	0.9496	0.9416	0.9334
925	0.9710	0.9674	0.9634	0.9574	0.9484	0.9406
950	0.9718	0.9692	0.9648	0.9588	0.9516	0.9466
975	0.9800	0.9778	0.9746	0.9700	0.9654	0.9582
1000	0.9812	0.9778	0.9740	0.9710	0.9672	0.9632

3.3.2 Caithness population

The baseline probability that the population would decline below the initial population size within 25 years with no additional mortality was 21.6% (red line Figure 15, Table 9). The probability of a 10% decline in the population size was 17.4% with no additional mortality (yellow line Figure 15).

Caithness population, demographic parameter set: 3
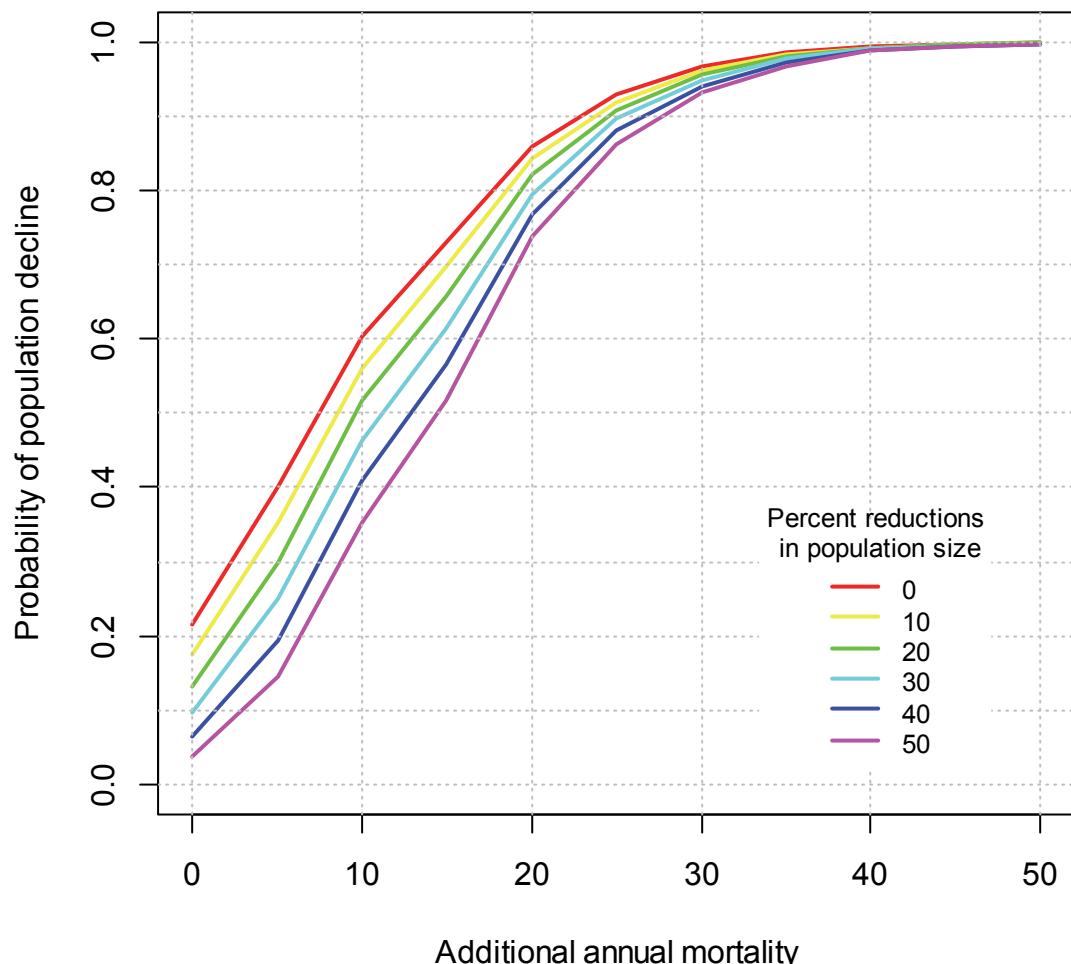
Figure 15. The probability of population decline in relation to increasing annual mortality in the Caithness population of Greenland white-fronted geese using parameter set 3. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, the increase in the risk of a 10% population decline exceeded 10% when additional mortality was between 2 to 3 individuals per year (yellow line Figure 16). The increase in the risk of a 20% decline also exceeded 10% when additional mortality was between 2 to 3 individuals per year (green line Figure 16).

Caithness population, demographic parameter set: 3
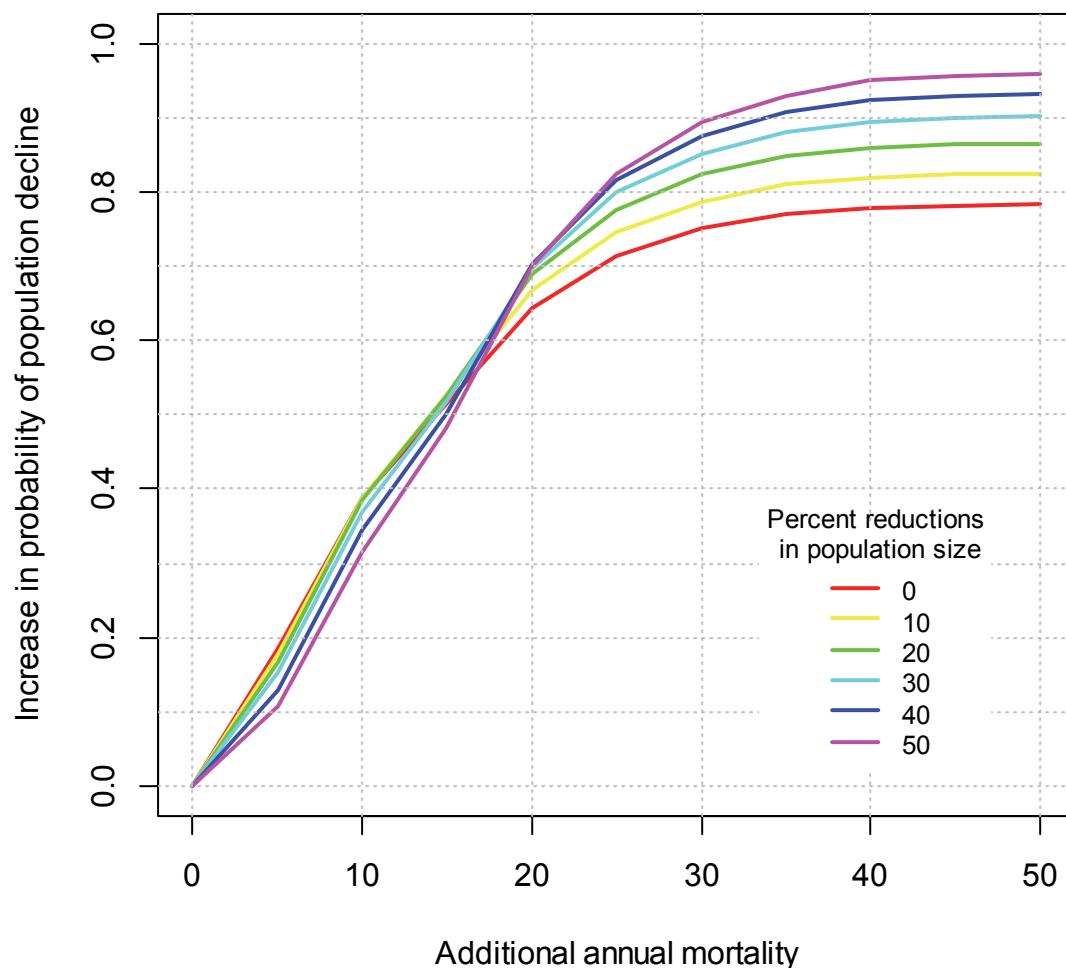
Figure 16. The increase in the probability of population decline in relation to increasing annual mortality in the Caithness population of Greenland white-fronted geese using parameter set 3. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 9. The probabilities of population decline relative to the initial population size in the Caithness population of Greenland white-fronted geese using parameter set 3. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.6984 that increased mortality of 15 birds per annum will give rise to a population reduction of 10% or greater.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.2160	0.1736	0.1322	0.0968	0.0646	0.0370
5	0.4004	0.3516	0.2978	0.2510	0.1940	0.1444
10	0.6034	0.5608	0.5180	0.4646	0.4088	0.3518
15	0.7304	0.6984	0.6572	0.6144	0.5668	0.5180
20	0.8598	0.8426	0.8228	0.7960	0.7680	0.7372
25	0.9300	0.9196	0.9082	0.8970	0.8816	0.8616
30	0.9672	0.9612	0.9566	0.9496	0.9404	0.9330
35	0.9858	0.9836	0.9812	0.9774	0.9732	0.9680
40	0.9944	0.9926	0.9918	0.9912	0.9892	0.9886
45	0.9982	0.9974	0.9970	0.9960	0.9954	0.9944
50	0.9990	0.9988	0.9988	0.9986	0.9980	0.9976

3.3.3   Kintyre population

The baseline probability that the population would decline below the initial population size within 25 years without additional mortality was 21% (red line Figure 17, Table 10). The probability of a 10% decline in the population size was 16.7% with no additional mortality (yellow line Figure 17).

Kintyre population, demographic parameter set: 3
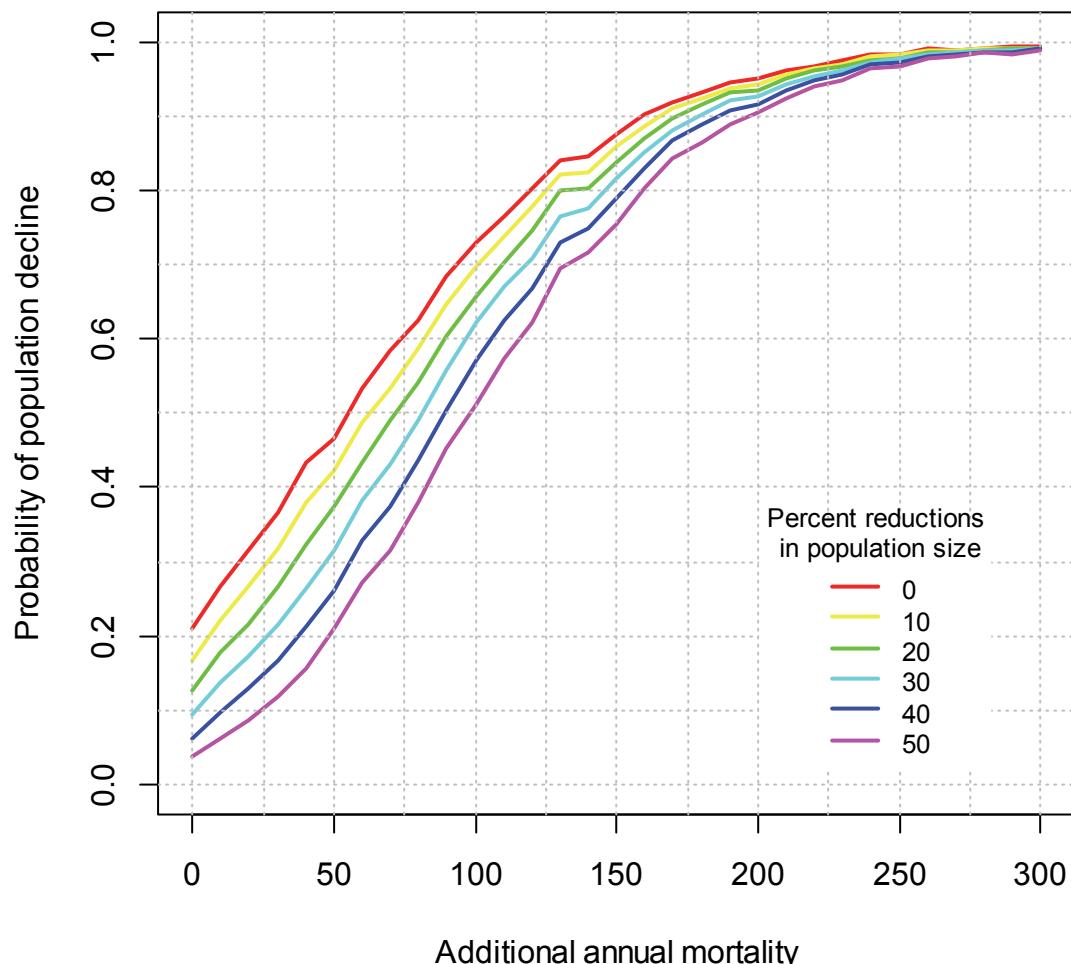
Figure 17. The probability of population decline in relation to increasing annual mortality in the Kintyre population of Greenland white-fronted geese using parameter set 3. The red line shows the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

In terms of the increase in risk of population decline, the increase in the risk of a 10% population decline exceeded 10% when additional mortality was around 20 individuals per year (yellow line Figure 18). The increase in the risk of a 20% decline also exceeded 10% when additional mortality was around 20 individuals per year. (green line Figure 18)

Kintyre population, demographic parameter set: 3
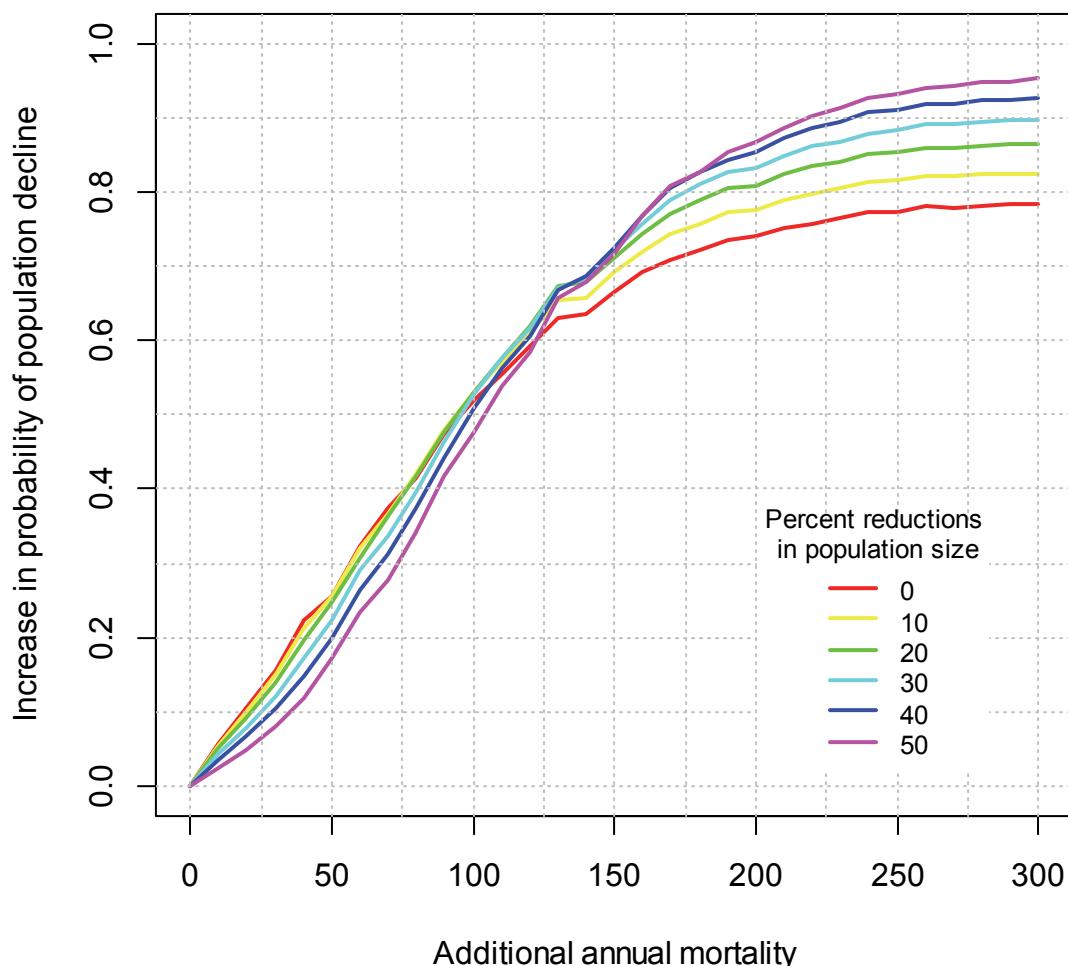
Figure 18. The increase in the probability of population decline in relation to increasing annual mortality in the Kintyre population of Greenland white-fronted Geese using parameter set 3. The red line shows the increase in the probability of any decline in the population size (i.e. of a reduction below the starting population size) and the remaining lines show the increase in the probability that the population will decline by 10, 20, 30, 40 and 50% from the starting population size.

Table 10. The probabilities of population decline relative to the initial population size in the Kintyre population of Greenland white-fronted geese using parameter set 3. The numbers in the individual cells show the probability that, with a given additional mortality, the population will decline to a figure reaching or exceeding the stated percentage reduction in population size. For example, there is a probability of 0.4228 that increased mortality of 50 birds per annum will give rise to a population reduction of 10% or greater.

Additional annual mortality	Percentage reduction in population size					
	0%	10%	20%	30%	40%	50%
0	0.2104	0.1668	0.1264	0.0934	0.0626	0.0370
10	0.2660	0.2202	0.1778	0.1358	0.0966	0.0610
20	0.3154	0.2664	0.2164	0.1720	0.1286	0.0850
30	0.3656	0.3176	0.2660	0.2148	0.1664	0.1180
40	0.4338	0.3798	0.3218	0.2642	0.2116	0.1550
50	0.4658	0.4228	0.3730	0.3154	0.2614	0.2086
60	0.5334	0.4874	0.4330	0.3828	0.3274	0.2708
70	0.5842	0.5338	0.4910	0.4308	0.3744	0.3148
80	0.6264	0.5882	0.5428	0.4904	0.4368	0.3796
90	0.6852	0.6468	0.6044	0.5576	0.5040	0.4532
100	0.7310	0.6968	0.6566	0.6222	0.5724	0.5126
110	0.7664	0.7384	0.7036	0.6698	0.6252	0.5750
120	0.8036	0.7776	0.7462	0.7098	0.6676	0.6224
130	0.8422	0.8218	0.7994	0.7648	0.7310	0.6950
140	0.8454	0.8246	0.8042	0.7770	0.7490	0.7172
150	0.8764	0.8590	0.8384	0.8164	0.7884	0.7536
160	0.9034	0.8866	0.8712	0.8506	0.8300	0.8042
170	0.9196	0.9104	0.8978	0.8826	0.8678	0.8446
180	0.9326	0.9248	0.9160	0.9038	0.8890	0.8658
190	0.9474	0.9394	0.9316	0.9208	0.9074	0.8906
200	0.9518	0.9442	0.9360	0.9264	0.9170	0.9062
210	0.9614	0.9560	0.9506	0.9426	0.9352	0.9248
220	0.9684	0.9654	0.9612	0.9556	0.9490	0.9404
230	0.9750	0.9714	0.9672	0.9626	0.9566	0.9500
240	0.9836	0.9812	0.9772	0.9730	0.9702	0.9638
250	0.9844	0.9828	0.9798	0.9776	0.9736	0.9688
260	0.9910	0.9888	0.9868	0.9844	0.9816	0.9784
270	0.9902	0.9888	0.9868	0.9856	0.9828	0.9808
280	0.9926	0.9918	0.9898	0.9886	0.9872	0.9860
290	0.9934	0.9926	0.9916	0.9900	0.9878	0.9850
300	0.9944	0.9928	0.9924	0.9918	0.9912	0.9902

3.4 Generation of further estimates of risk of population decline

It is also useful to consider the increase in the probability of a population decline below certain levels (e.g. 100, 90, and 80%) of the starting population size in relation to the proportion of the population killed per year. The following tables (11-19) illustrate this for each population (Scottish, Caithness and Kintyre) and parameter set (1, 2, and 3).

In each table, additional mortality is shown as an absolute value in column one and as a proportion of the starting population size in column 2. This proportion was calculated by dividing the additional absolute mortality value by the starting population size (e.g. for the Scottish population the first non-zero mortality value simulated (25) was divided by the starting population size (10,091) to obtain 0.0025).

The values in the remaining columns (the increases in the risk of decline) were calculated from values presented in the relevant tables for each population and parameter set given previously (Tables 2-10). For example, for the Scottish population under parameter set 1, Table 2 relates to Table 11. The values in the first row of Table 2 (for the percentage reduction in population size of 0, 10 and 20%) were subtracted from all subsequent rows in the table, thereby setting the starting point (row 1) to zero and generating values relative to this starting point in the rows below.

Table 11. Scottish Greenland white-fronted goose population simulated using parameter set 1: increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
25	0.0025	0.0186	0.0202	0.0162
50	0.0050	0.0370	0.0318	0.0260
75	0.0074	0.0430	0.0376	0.0296
100	0.0099	0.0732	0.0646	0.0540
125	0.0124	0.0868	0.0780	0.0668
150	0.0149	0.1170	0.1040	0.0876
175	0.0173	0.1330	0.1208	0.1062
200	0.0198	0.1582	0.1428	0.1280
225	0.0223	0.1826	0.1628	0.1446
250	0.0248	0.2148	0.1998	0.1778
275	0.0273	0.2308	0.2160	0.1924
300	0.0297	0.2708	0.2508	0.2298
325	0.0322	0.2666	0.2512	0.2294
350	0.0347	0.3036	0.2888	0.2658
375	0.0372	0.3318	0.3130	0.2940
400	0.0396	0.3632	0.3460	0.3274
425	0.0421	0.3830	0.3646	0.3414
450	0.0446	0.4184	0.4036	0.3810
475	0.0471	0.4564	0.4350	0.4114
500	0.0495	0.4664	0.4550	0.4356
525	0.0520	0.5076	0.4962	0.4746
550	0.0545	0.5066	0.4996	0.4860
575	0.0570	0.5428	0.5292	0.5154
600	0.0595	0.5804	0.5694	0.5566
625	0.0619	0.6062	0.5954	0.5732
650	0.0644	0.6228	0.6202	0.6058
675	0.0669	0.6374	0.6322	0.6230
700	0.0694	0.6688	0.6646	0.6556
725	0.0718	0.6806	0.6814	0.6722
750	0.0743	0.7044	0.7024	0.6996
775	0.0768	0.7252	0.7286	0.7252
800	0.0793	0.7286	0.7294	0.7280
825	0.0818	0.7464	0.7518	0.7460
850	0.0842	0.7592	0.7622	0.7574
875	0.0867	0.7830	0.7898	0.7890
900	0.0892	0.7882	0.7950	0.8008
925	0.0917	0.8034	0.8108	0.8152
950	0.0941	0.8172	0.8278	0.8340
975	0.0966	0.8164	0.8258	0.8308
1000	0.0991	0.8376	0.8472	0.8538

Table 12. Caithness Greenland white-fronted goose population simulated using parameter set 1; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
5	0.0148	0.1242	0.1074	0.0920
10	0.0296	0.2406	0.2250	0.2074
15	0.0444	0.3896	0.3706	0.3498
20	0.0592	0.5732	0.5644	0.5518
25	0.0740	0.7016	0.7020	0.6966
30	0.0888	0.7828	0.7886	0.7900
35	0.1036	0.8370	0.8508	0.8576
40	0.1183	0.8826	0.8976	0.9106
45	0.1331	0.8946	0.9122	0.9262
50	0.1479	0.9058	0.9238	0.9394

Table 13. Kintyre Greenland white-fronted goose population simulated using parameter set 1; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
10	0.0042	0.0304	0.0304	0.0214
20	0.0083	0.0608	0.0540	0.0468
30	0.0125	0.0892	0.0766	0.0624
40	0.0166	0.1264	0.1112	0.0970
50	0.0208	0.1742	0.1542	0.1376
60	0.0249	0.2006	0.1818	0.1654
70	0.0291	0.2524	0.2356	0.2114
80	0.0333	0.2948	0.2778	0.2542
90	0.0374	0.3366	0.3174	0.2950
100	0.0416	0.3762	0.3606	0.3422
110	0.0457	0.4254	0.4102	0.3832
120	0.0499	0.4762	0.4576	0.4376
130	0.0540	0.5234	0.5098	0.4886
140	0.0582	0.5618	0.5512	0.5382
150	0.0623	0.6112	0.6078	0.5918
160	0.0665	0.6390	0.6336	0.6198
170	0.0707	0.6678	0.6602	0.6512
180	0.0748	0.6926	0.6928	0.6858
190	0.0790	0.7246	0.7256	0.7206
200	0.0831	0.7536	0.7564	0.7566
210	0.0873	0.7798	0.7884	0.7898
220	0.0914	0.8012	0.8082	0.8124
230	0.0956	0.8154	0.8256	0.8302
240	0.0998	0.8318	0.8432	0.8496
250	0.1039	0.8436	0.8580	0.8672
260	0.1081	0.8594	0.8720	0.8798
270	0.1122	0.8606	0.8762	0.8860
280	0.1164	0.8766	0.8918	0.9042
290	0.1205	0.8774	0.8938	0.9056
300	0.1247	0.8914	0.9072	0.9196

Table 14. Scottish Greenland white-fronted goose population simulated using parameter set 2; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
25	0.0025	0.0576	0.0492	0.0496
50	0.0050	0.0786	0.0680	0.0704
75	0.0074	0.1224	0.1144	0.1138
100	0.0099	0.1656	0.1682	0.1610
125	0.0124	0.2034	0.2010	0.2012
150	0.0149	0.2468	0.2402	0.2398
175	0.0173	0.2780	0.2794	0.2788
200	0.0198	0.3228	0.3240	0.3322
225	0.0223	0.3510	0.3558	0.3660
250	0.0248	0.3794	0.3914	0.4082
275	0.0273	0.4196	0.4340	0.4492
300	0.0297	0.4472	0.4690	0.4948
325	0.0322	0.4784	0.5030	0.5310
350	0.0347	0.5012	0.5320	0.5560
375	0.0372	0.5214	0.5512	0.5856
400	0.0396	0.5356	0.5660	0.6038
425	0.0421	0.5530	0.5920	0.6318
450	0.0446	0.5642	0.6010	0.6462
475	0.0471	0.5890	0.6316	0.6810
500	0.0495	0.5982	0.6428	0.6914
525	0.0520	0.6130	0.6620	0.7170
550	0.0545	0.6178	0.6700	0.7280
575	0.0570	0.6312	0.6836	0.7420
600	0.0595	0.6294	0.6816	0.7398
625	0.0619	0.6392	0.6932	0.7544
650	0.0644	0.6398	0.6944	0.7562
675	0.0669	0.6456	0.7012	0.7644
700	0.0694	0.6496	0.7058	0.7698
725	0.0718	0.6510	0.7078	0.7718
750	0.0743	0.6542	0.7114	0.7748
775	0.0768	0.6566	0.7138	0.7792
800	0.0793	0.6596	0.7164	0.7830
825	0.0818	0.6616	0.7194	0.7864
850	0.0842	0.6594	0.7192	0.7870
875	0.0867	0.6628	0.7216	0.7888
900	0.0892	0.6614	0.7208	0.7874
925	0.0917	0.6630	0.7226	0.7904
950	0.0941	0.6632	0.7230	0.7910
975	0.0966	0.6646	0.7244	0.7926
1000	0.0991	0.6650	0.7244	0.7926

Table 15. Caithness Greenland white-fronted goose population simulated using parameter set 2; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
5	0.0148	0.2558	0.2466	0.2456
10	0.0296	0.4342	0.4500	0.4662
15	0.0444	0.5610	0.5956	0.6328
20	0.0592	0.6240	0.6766	0.7306
25	0.0740	0.6512	0.7074	0.7692
30	0.0888	0.6588	0.7172	0.7818
35	0.1036	0.6606	0.7194	0.7842
40	0.1183	0.6608	0.7200	0.7846
45	0.1331	0.6620	0.7212	0.7860
50	0.1479	0.6620	0.7212	0.7860

Table 16. Kintyre Greenland white-fronted goose population simulated using parameter set 2; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
10	0.0042	0.0616	0.0538	0.0544
20	0.0083	0.1292	0.1214	0.1228
30	0.0125	0.2048	0.2024	0.2078
40	0.0166	0.2574	0.2596	0.2614
50	0.0208	0.3244	0.3316	0.3374
60	0.0249	0.3820	0.4016	0.4136
70	0.0291	0.4314	0.4518	0.4730
80	0.0333	0.4808	0.5104	0.5342
90	0.0374	0.5220	0.5538	0.5878
100	0.0416	0.5582	0.5980	0.6414
110	0.0457	0.5776	0.6222	0.6670
120	0.0499	0.5944	0.6426	0.6948
130	0.0540	0.6158	0.6674	0.7214
140	0.0582	0.6240	0.6804	0.7394
150	0.0623	0.6366	0.6934	0.7560
160	0.0665	0.6414	0.7006	0.7638
170	0.0707	0.6426	0.7048	0.7698
180	0.0748	0.6488	0.7098	0.7760
190	0.0790	0.6552	0.7168	0.7842
200	0.0831	0.6578	0.7206	0.7892
210	0.0873	0.6582	0.7208	0.7896
220	0.0914	0.6608	0.7236	0.7920
230	0.0956	0.6608	0.7240	0.7926
240	0.0998	0.6608	0.7246	0.7936
250	0.1039	0.6608	0.7240	0.7934
260	0.1081	0.6620	0.7256	0.7948
270	0.1122	0.6616	0.7254	0.7942
280	0.1164	0.6618	0.7254	0.7948
290	0.1205	0.6622	0.7260	0.7954
300	0.1247	0.6618	0.7254	0.7948

Table 17. Scottish Greenland white-fronted goose population simulated using parameter set 3; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
25	0.0025	0.0388	0.0318	0.0316
50	0.0050	0.0748	0.0624	0.0598
75	0.0074	0.0852	0.0784	0.0730
100	0.0099	0.1344	0.1202	0.1150
125	0.0124	0.1584	0.1492	0.1388
150	0.0149	0.1770	0.1710	0.1656
175	0.0173	0.2178	0.2112	0.2026
200	0.0198	0.2574	0.2480	0.2398
225	0.0223	0.2942	0.2858	0.2768
250	0.0248	0.3250	0.3240	0.3138
275	0.0273	0.3446	0.3408	0.3346
300	0.0297	0.3736	0.3640	0.3618
325	0.0322	0.4048	0.4068	0.4050
350	0.0347	0.4390	0.4422	0.4392
375	0.0372	0.4682	0.4750	0.4738
400	0.0396	0.4834	0.4876	0.4956
425	0.0421	0.5134	0.5212	0.5282
450	0.0446	0.5522	0.5626	0.5658
475	0.0471	0.5630	0.5736	0.5886
500	0.0495	0.5788	0.5918	0.6024
525	0.0520	0.6052	0.6204	0.6360
550	0.0545	0.6356	0.6492	0.6638
575	0.0570	0.6356	0.6550	0.6748
600	0.0595	0.6566	0.6786	0.6998
625	0.0619	0.6718	0.6936	0.7186
650	0.0644	0.6808	0.7074	0.7338
675	0.0669	0.6970	0.7228	0.7454
700	0.0694	0.7086	0.7360	0.7662
725	0.0718	0.7108	0.7388	0.7664
750	0.0743	0.7192	0.7518	0.7854
775	0.0768	0.7280	0.7612	0.7950
800	0.0793	0.7366	0.7704	0.8068
825	0.0818	0.7424	0.7750	0.8106
850	0.0842	0.7442	0.7754	0.8090
875	0.0867	0.7538	0.7886	0.8260
900	0.0892	0.7550	0.7910	0.8294
925	0.0917	0.7606	0.7976	0.8366
950	0.0941	0.7614	0.7994	0.8380
975	0.0966	0.7696	0.8080	0.8478
1000	0.0991	0.7708	0.8080	0.8472

Table 18. Caithness Greenland white-fronted goose population simulated using parameter set 3; increase in the probability of population decline below 100 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
5	0.0148	0.1844	0.1780	0.1656
10	0.0296	0.3874	0.3872	0.3858
15	0.0444	0.5144	0.5248	0.5250
20	0.0592	0.6438	0.6690	0.6906
25	0.0740	0.7140	0.7460	0.7760
30	0.0888	0.7512	0.7876	0.8244
35	0.1036	0.7698	0.8100	0.8490
40	0.1183	0.7784	0.8190	0.8596
45	0.1331	0.7822	0.8238	0.8648
50	0.1479	0.7830	0.8252	0.8666

Table 19. Kintyre Greenland white-fronted goose population simulated using parameter set 3; increase in the probability of population decline below 100, 90 and 80% of the starting size in relation to the proportion of the population killed per year.

Additional mortality	Proportion of population killed per year	Increase in risk of population decline below thresholds of starting population size		
		100%	90%	80%
0	0.0000	0.0000	0.0000	0.0000
10	0.0042	0.0556	0.0534	0.0514
20	0.0083	0.1050	0.0996	0.0900
30	0.0125	0.1552	0.1508	0.1396
40	0.0166	0.2234	0.2130	0.1954
50	0.0208	0.2554	0.2560	0.2466
60	0.0249	0.3230	0.3206	0.3066
70	0.0291	0.3738	0.3670	0.3646
80	0.0333	0.4160	0.4214	0.4164
90	0.0374	0.4748	0.4800	0.4780
100	0.0416	0.5206	0.5300	0.5302
110	0.0457	0.5560	0.5716	0.5772
120	0.0499	0.5932	0.6108	0.6198
130	0.0540	0.6318	0.6550	0.6730
140	0.0582	0.6350	0.6578	0.6778
150	0.0623	0.6660	0.6922	0.7120
160	0.0665	0.6930	0.7198	0.7448
170	0.0707	0.7092	0.7436	0.7714
180	0.0748	0.7222	0.7580	0.7896
190	0.0790	0.7370	0.7726	0.8052
200	0.0831	0.7414	0.7774	0.8096
210	0.0873	0.7510	0.7892	0.8242
220	0.0914	0.7580	0.7986	0.8348
230	0.0956	0.7646	0.8046	0.8408
240	0.0998	0.7732	0.8144	0.8508
250	0.1039	0.7740	0.8160	0.8534
260	0.1081	0.7806	0.8220	0.8604
270	0.1122	0.7798	0.8220	0.8604
280	0.1164	0.7822	0.8250	0.8634
290	0.1205	0.7830	0.8258	0.8652
300	0.1247	0.7840	0.8260	0.8660

4. DISCUSSION

The probability of observing population declines in Greenland white-fronted geese of up to 50% has been modelled at the level of the Scottish, Caithness and Kintyre populations with the three sets of demographic parameters providing a span of potential outcomes.

For each population the trends observed in relation to increasing additional mortality were similar. This is not surprising given that the only difference in each case was the starting population size and the increments of additional mortality applied.

Comparing across the populations reveals that the increase in the risk of *any* population decline exceeds 10% for parameter set 1 when around 1.3% of the population is killed per year, for parameter set 2 when around 0.6% of the population is killed per year and for parameter set 3 when around 0.8% of the population is killed per year.

The increase in the risk of a 10% population decline exceeds 10% for parameter set 1 when around 1.5% of the population is killed per year, for set 2 when around 0.6% of the population is killed per year and for set 3 when around 0.8% of the population is killed per year.

The increase in the risk of a 20% population decline exceeds 10% for parameter set 1 when around 1.6% of the population is killed per year, for set 2 when around 0.6% of the population is killed per year and for set 3 when around 0.9% of the population is killed per year.

Detailed estimates of the increase in risk of population decline as a function of the proportion of the population killed are provided in section 3.4. From these tables it can be seen that, for example, if the management goal is to keep the increase in the risk of triggering a 10% population decline below 20%, the model using parameter set 1 indicates that the additional annual absolute mortality threshold should be less than 0.0247 of the population size. For the Scottish population this would set a limit of 250, for Caithness it would be 8 and for Kintyre it would be 59.

It is important to stress that the thresholds for population decline and additional mortality discussed here have only been provided as an illustration of how to interpret the model outputs and do not imply that these are the most suitable or appropriate ones to use. This decision is for the statutory authorities, in that it is their role to advise on whether any changes in mortality will have a significant effect on the population size of protected populations, or on the integrity of sites designated for their protection.

5. REFERENCES

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