Norfolk Vanguard Offshore Wind Farm

Lesser Black-backed Gull Alde Ore Estuary Population Viability Analysis

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Lesser Black-backed Gull

Alde Ore Estuary

Population Viability Analysis

Prepared by:	Mark Trinder
Authorised by:	Bob Furness
Date:	30/03/2019
Tel:	0141 342 5404
Email:	mark.trinder@macarthurgreen.com
Web:	www.macarthurgreen.com
Address:	93 South Woodside Road | Glasgow | G20 6NT

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1 INTRODUCTION

This report provides details of population viability analysis (PVA) for the Alde-Ore Estuary SPA lesser black-backed gull population. The population model was developed using demographic rates taken from a review conducted by the British Trust for Ornithology (BTO; Horswill and Robinson 2015). Full details of the methods are provided below. The predicted changes ('counterfactuals') in population growth rate and population size are presented across a range of impact levels. The discussion reviews the results and provides a guide for their interpretation.

2 METHODS

The population models included the following aspects:

- Environmental stochasticity;
- Demographic stochasticity; and,
- Density independent and density dependent formulations.

The model has a matrix formulation and simulates an annual post-breeding census over a period of 30 annual time steps with the population made up of single year age classes up to adults, which is a multi-age class for all individuals from age of first breeding and older. The initial population size was derived from the estimated average population of 2,000 pairs (derived from census data for 2010-2016 in the JNCC Seabird Colony Monitoring (SCM) database). The initial population in each age class is calculated from this value using the stable age distribution outputted as the right eigenvector from the population matrix.

Table 1. Demographic rates used in the population model (from Horswill and Robinson 2015).

	Survival						Reproduction	
	0-1	**1-2**	**2-3**	**3-4**	**4-5**	**Adult**	**Fledged young per pair (allowing for nonbreeding rate of 0.34)**	**Age first breeding**
Mean	0.82	0.885					0.351	5
SD	0.022	0.022					0.105	-

During population simulations, survival rates were drawn from beta distributions and the number of fledged young from stretched beta distributions (Morris and Doak 2002). Use of these probability distributions ensures that randomly selected values for each demographic rate are constrained to lie within biologically reasonable bounds. Demographic stochasticity on survival was modelled using a binomial process, whereby the number of individuals which survive from one year to the next is obtained using a binomial function (Akçakaya 1991). Combining environmental and demographic stochasticity in this manner permits both large scale effects (environmental) and chance population effects (demographic) to be simulated.

Both density independent (DI) and density dependent (DD) versions of the models were developed. The density independent versions simulate the populations with no feedback between population size and demographic rates. Population projections produced by such models will either increase to infinity or decrease to extinction.

Density-dependence has been demonstrated to affect lesser black-backed gull and herring gull breeding ecology (Coulson 1991; Camphuysen 2013). Horswill and Robinson (2015), and Horswill et al. (2016), reviewed the evidence for density dependent regulation in seabird populations and found that regulation can operate via a range of mechanisms. At the scale of the populations being modelled for this report it is therefore likely that regulation may be operating on different components of the populations by different means. Ecological theory suggests that long-lived slow breeding species, such as seabirds, buffer themselves against variations in their environment through varying reproductive success rather than survival. Thus the demographic rate most likely to reflect density dependent effects will be reproduction, with breeding success declining as population approaches the ceiling set by food resources. Thus, it was considered more appropriate to model regulation through reproduction rather than survival across multiple rates. This is also more precautionary for assessing mortality impacts, since seabird population growth is more sensitive to variation in survival (particularly of adults). Thus, the modelled population's ability to recover is lower when density dependence operates through reproduction than through survival.

Relating the reproductive rate to the population size also corresponds with studies which indicate that foraging ranges are negatively related to food availability which in turn affects variations in reproductive success between colonies. A wide range of values of density dependence could be explored, but the aim of the work was to indicate the possible difference in output between a biologically unrealistic density independent (worst case) scenario, and a plausible density dependent model (more realistic but with a precautionary density dependent formulation in the absence of empirical evidence on density dependent mechanisms in this population).

A Weibull function was used for the density dependent modelling. This function relates reproduction (F) to population size (N) using the following equation:

$F = maxF * \exp(-a * (Nb))$

Where maxF = the estimated biological maximum reproductive rate for the species being modelled and *a* and *b* are scale and shape parameters (respectively) for the Weibull function.

Previous population modelling of seabirds (MacArthur Green 2014) reviewed available evidence and determined that a precautionary, but realistic value for *b* for seabirds was 1.2 as this generates population trends similar to those observed for a range of seabird species and populations (Cury et al. 2011). Following this, the value for *a* was calculated using the equation above with *b* = 1.2, F equal to the mean reproductive rate (Table 1), maxF equal to the estimated biological maximum (1.5 fledglings per individual) and N set to the initial population estimate (2,000 pairs).

Estimating the value for *a* in this manner makes the assumption that the populations are currently at their carrying capacity, and ensured that baseline simulations (i.e. with no additional mortality) were tuned to remain around this size (although with variations due to stochastic variation in the parameters). In practice, at the beginning of each simulation the model was run with incremental adjustment to parameter *a* until the end population size (after 30 years) under baseline conditions was close (within 0.5%) to the initial size. The value of *a* thus obtained was then used for predictive simulations with increasing levels of additional mortality.

The density independent models were not tuned in this manner, with population predictions generated on the basis of the rates in Table 1 with no adjustment.

A closed population was assumed. This was a necessary simplification since rates of exchange between colonies are unknown. While this is unrealistic (for example at least two lesser black-backed gulls ringed as chicks at Walney Island were early colonists breeding at the Alde-Ore Estuary SPA; Brown and Grice 2005), it was considered to be a pragmatic and precautionary approach, since immigration from other colonies will tend to buffer any additional mortality impact on the focal population. However, Wanless et al. (1996) reported high and variable rates of immigration and emigration of lesser black-backed gulls, with net immigration being an important influence on population dynamics.

A range of additional mortality values was modelled, from zero to an upper value in excess of the highest in-combination value under consideration, at increments appropriate to the range modelled. The additional mortality was modelled as a per capita rate. The rate was calculated at the beginning of each simulation as the absolute mortality for that simulation divided by the initial total population size. In this manner the estimated mortality in the starting year (e.g. 100 individuals per year) remains in proportion with changes in the population size, such that if the population doubles in size then the additional mortality also doubles (and vice versa). Furthermore, the additional mortality was applied to all age classes in proportion to their presence (i.e. wind farm mortality was not considered to target specific age classes).

Following a request from Natural England, the model incorporated a ‘matched run’ approach (Cook and Robinson 2017). In this formulation, at each level of additional mortality in each iteration of the model (e.g. each one of the 1,000 simulations) two parallel population projections were generated: baseline and impact. These two projections utilise an identical sequence of demographic rate values (survival and reproduction), differing only because the impact population is subject to additional mortality at each time step and the baseline one is not. By using the same random seed value for the impact and baseline runs at each time of each simulation it was also possible to ensure that the sequences also included identical sequences of demographic stochasticity. In the density dependent simulations the productivity values will also diverge, since these are a function of the population size which will differ between impact and baseline runs. However, by calculating the productivity (using the density dependent function) and then applying a common error value the impact and baseline runs shared the same sequence of inter-annual variations.

Although additional mortality was applied to all age classes, the outputs are presented in relation to the adult component of the total. This keeps the outputs consistent with the units which breeding colonies are counted in (i.e. breeding pairs). Thus, if a figure or table presents an additional mortality of 100 adults this actually represents a total additional mortality (for all age classes) which will be approximately double this, since adults typically represent 50-60% of the population (as estimated from the stable age distribution).

At each level of additional mortality, 1,000 simulations were conducted and summary outputs calculated. Most outputs used data from all years of each simulation, however the population growth rate was calculated as the average rate between the fifth and the final (30th) year to avoid initial conditions exerting a bias on the value obtained. Note that since all the predictions use past data on demographic parameters they therefore take no account of likely future impacts of continuing climate change on seabird demography.

Graphical and tabulated outputs for each simulated scenario are provided:

- Counterfactual of the population growth rate (CPGR), presented across the full range of additional mortality, calculated at the following percentiles: 2.5%, 50% (median) and 97.5% (note that the confidence intervals are two-sided, with 95% of simulated outputs lying between the 2.5% and 97.5% lines); and,
- Counterfactual of population size (CPS), the ratio of impacted to baseline population size across the full range of additional mortality, calculated at 5 year intervals up to 30 years.

3 RESULTS

The stable age distributions for each population and parameter set are provided in Table 2**Error! Reference source not found.** for density independent and density dependent model runs. Note that these represent the average age distributions for each model as they were calculated using the average demographic rates. During stochastic simulations the ratios will vary around these mean values. As density dependence operates in the models through reproduction, differences in the age ratios between the density independent and density dependent versions reflects modification to the rate of reproduction (e.g. reduced reproduction will reduce the proportion of all sub-adult age classes and increase the proportion of adults).

Table 2. Density independent stable age distribution

Age class	Proportion	
	Density independent	Density dependent
0-1	0.134	0.123
1-2	0.108	0.101
2-3	0.095	0.089
3-4	0.083	0.079
Adult	0.579	0.608

Figures A.1 to A.4 provide the CPS and CPGR for the density independent and density dependent versions of the model. These results are also tabulated (Tables A.1 to A.4).

4 DISCUSSION

While the demographic data for this species received low scores for quality (Horswill and Robinson 2015), due in large part to a relative paucity of studies, counterfactual metrics are somewhat less sensitive to mis-specification of rates than other measures, such as absolute trends, and therefore the results are considered to be robust. Similarly, the inclusion of density dependence in seabird population models is often considered unjustified on the grounds of limited knowledge. However, the methods used to parameterise this regulation, combined with the initial ‘tuning’ phase which ensures that the baseline density dependent simulations are precautionary (by adjusting the strength of density dependence until the model produces a stable population at the starting size) are intended to ensure the results are appropriate and precautionary.

Although the trend in the Alde-Ore Estuary population is not well known, and allowing for the potential limitations in the data as noted above, the demographic rates indicate that under baseline conditions the population growth rate would be in excess of 10%. While this estimate must be treated with caution, it does indicate that smaller reductions in the growth rate, such as up to 3% for example, are unlikely to trigger a population decline. Thus, using the more precautionary density independent model, the results suggest that an adult mortality of up to 120, which corresponds to a 3% reduction in growth rate, is unlikely to trigger a population decline.

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APPENDIX

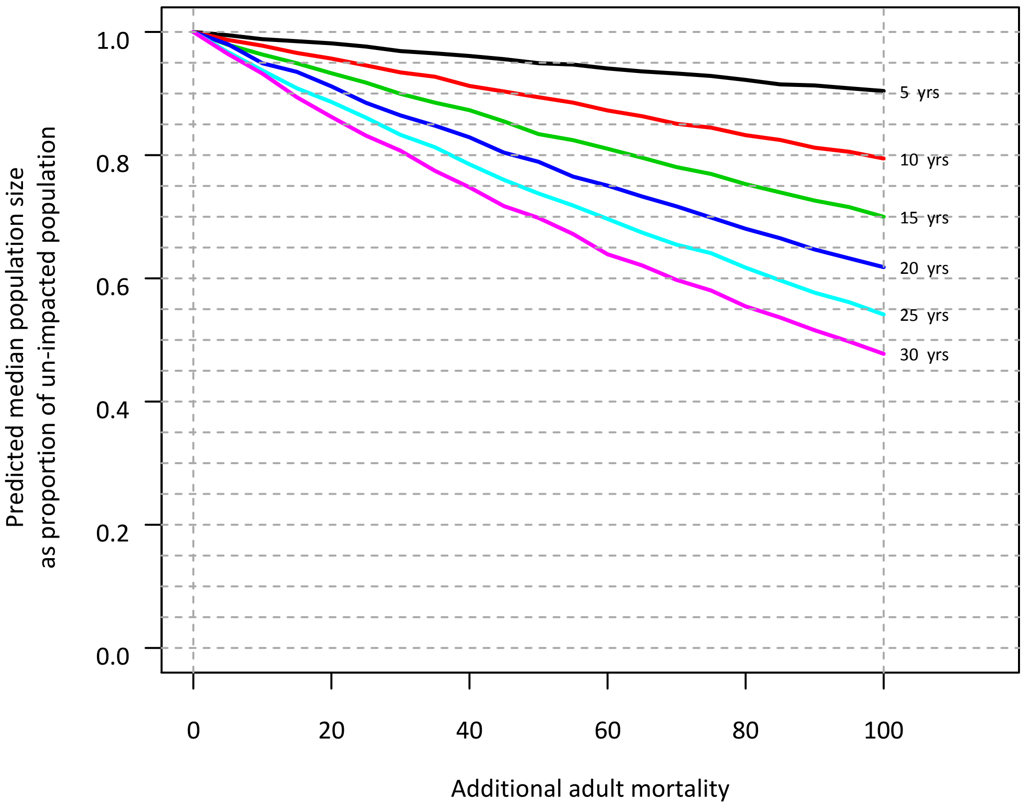

Figure A.1. Lesser black-backed gull, demographic rate set 1, counterfactuals of population size after 5 to 30 years, estimated using a matched runs method, from 1000 density independent simulations

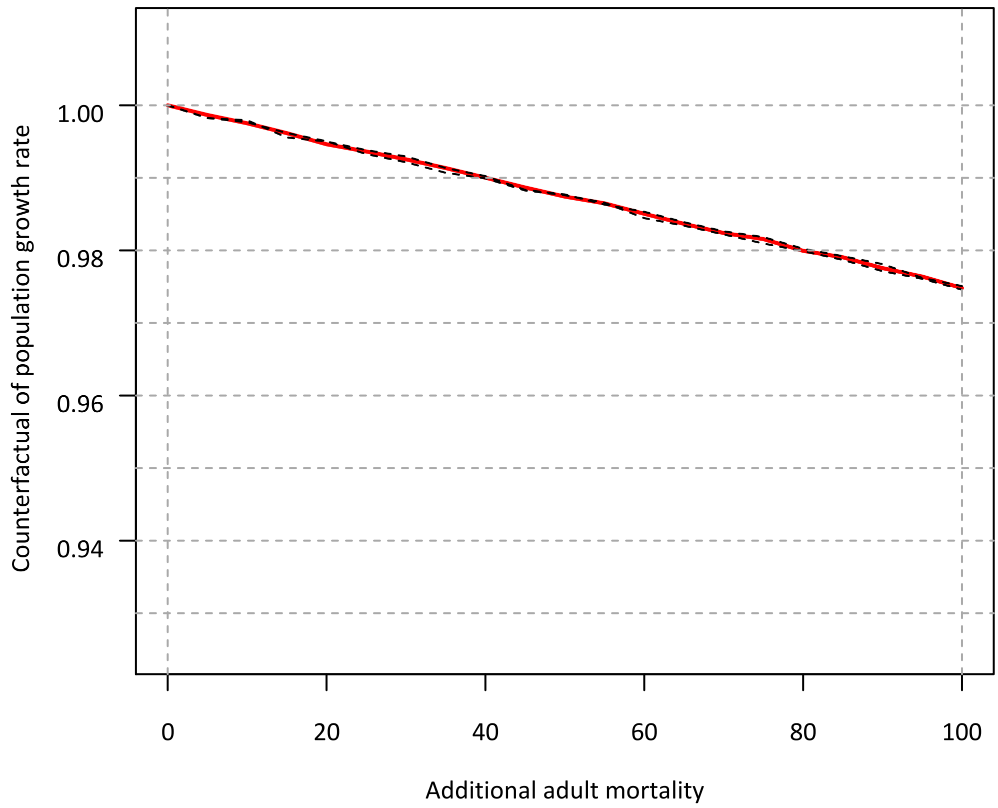

Figure A.2. Lesser black-backed gull, demographic rate set 1, counterfactuals of population growth rate calculated between year 5 and year 30, using a matched runs method, from 1000 density independent simulations.

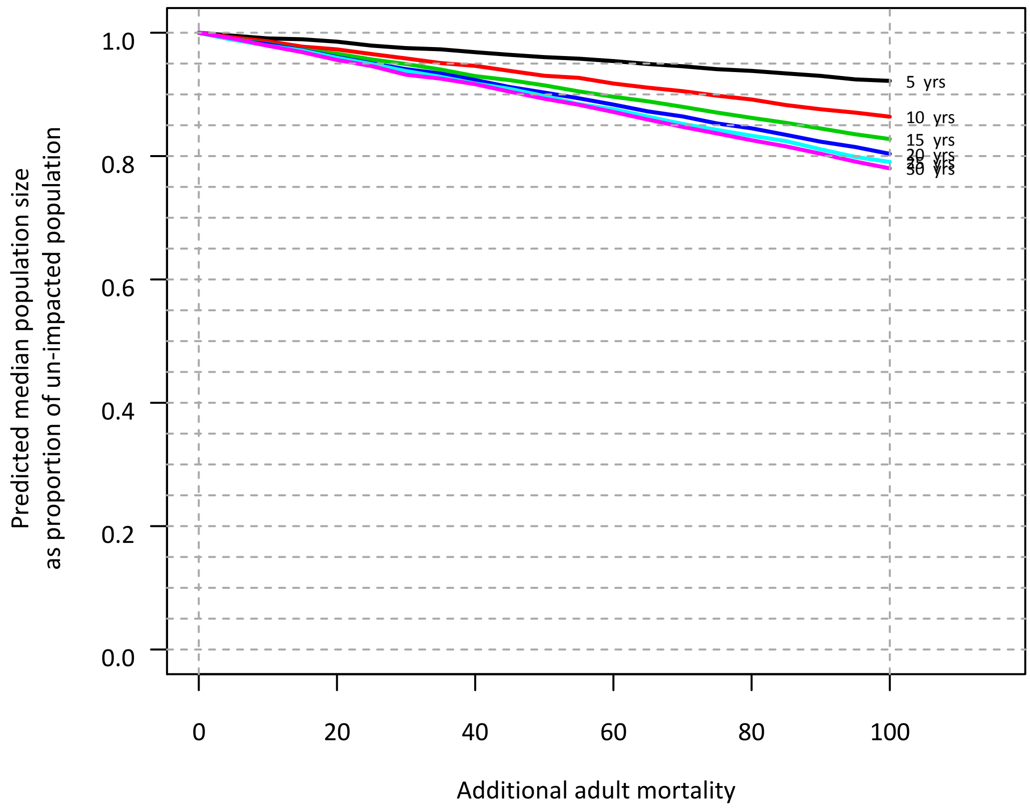

Figure A.3. Lesser black-backed gull, demographic rate set 1, counterfactuals of population size after 5 to 30 years, estimated using a matched runs method, from 1000 density dependent simulations.

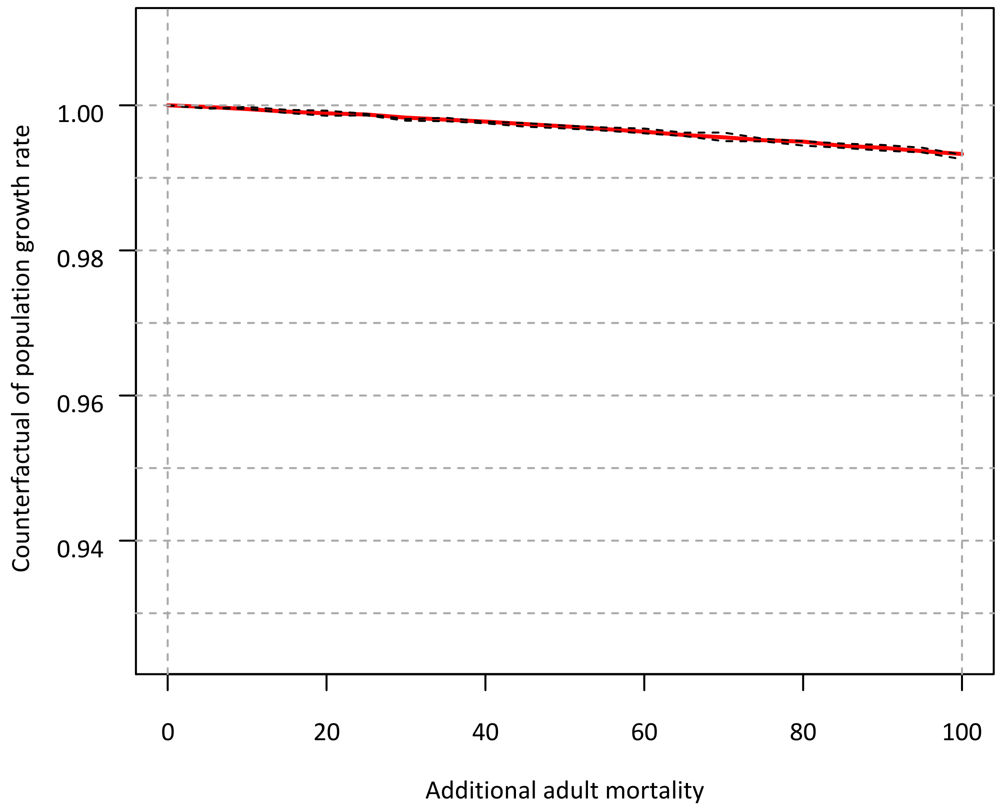

Figure A.4. Lesser black-backed gull, demographic rate set 1, counterfactuals of population growth rate calculated between year 5 and year 30, using a matched runs method, from 1000 density dependent simulations.

Table A.1. Lesser black-backed gull, demographic rate set 1, counterfactuals of population size after 5 to 30 years, estimated using a matched runs method, from 1000 density independent simulations.

	Counterfactual of population size at 5 year intervals						
Additional adult mortality	**Estimate**	**yr.5**	**yr.10**	**yr.15**	**yr.20**	**yr.25**	**yr.30**
0	Lower 95%	1.000	1.000	1.000	1.000	1.000	1.000
	Median	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
	Upper 95%	1.000	1.000	1.000	1.000	1.000	1.000
5	Lower 95%	0.976	0.955	0.938	0.920	0.909	0.892
	Median	**0.994**	**0.988**	**0.982**	**0.976**	**0.970**	**0.965**
	Upper 95%	1.013	1.021	1.025	1.030	1.034	1.039
10	Lower 95%	0.968	0.943	0.922	0.901	0.875	0.859
	Median	**0.990**	**0.977**	**0.964**	**0.952**	**0.940**	**0.927**
	Upper 95%	1.012	1.012	1.010	1.004	1.006	1.000
15	Lower 95%	0.967	0.936	0.906	0.881	0.852	0.830
	Median	**0.985**	**0.966**	**0.948**	**0.930**	**0.913**	**0.896**
	Upper 95%	1.003	0.998	0.992	0.987	0.977	0.965
20	Lower 95%	0.960	0.922	0.885	0.857	0.827	0.798
	Median	**0.980**	**0.956**	**0.932**	**0.909**	**0.886**	**0.863**
	Upper 95%	1.003	0.992	0.981	0.965	0.952	0.939
25	Lower 95%	0.956	0.911	0.872	0.837	0.801	0.767
	Median	**0.975**	**0.946**	**0.916**	**0.887**	**0.860**	**0.835**
	Upper 95%	0.996	0.980	0.962	0.944	0.927	0.903
30	Lower 95%	0.951	0.900	0.859	0.817	0.783	0.743
	Median	**0.970**	**0.935**	**0.899**	**0.866**	**0.833**	**0.803**
	Upper 95%	0.990	0.967	0.942	0.918	0.894	0.867
35	Lower 95%	0.946	0.890	0.845	0.799	0.755	0.720
	Median	**0.965**	**0.924**	**0.884**	**0.845**	**0.809**	**0.773**
	Upper 95%	0.986	0.956	0.927	0.898	0.868	0.838
40	Lower 95%	0.940	0.881	0.829	0.780	0.735	0.688
	Median	**0.961**	**0.914**	**0.869**	**0.826**	**0.785**	**0.747**
	Upper 95%	0.982	0.947	0.911	0.876	0.840	0.809
45	Lower 95%	0.935	0.870	0.811	0.759	0.710	0.666
	Median	**0.956**	**0.904**	**0.854**	**0.808**	**0.762**	**0.720**
	Upper 95%	0.977	0.937	0.896	0.861	0.818	0.786
50	Lower 95%	0.930	0.858	0.798	0.741	0.688	0.636
	Median	**0.951**	**0.893**	**0.839**	**0.788**	**0.738**	**0.695**
	Upper 95%	0.972	0.927	0.882	0.834	0.795	0.757
55	Lower 95%	0.928	0.852	0.786	0.720	0.669	0.617
	Median	**0.946**	**0.883**	**0.824**	**0.769**	**0.717**	**0.669**
	Upper 95%	0.966	0.918	0.864	0.814	0.768	0.727
60	Lower 95%	0.921	0.839	0.769	0.703	0.646	0.591
	Median	**0.941**	**0.873**	**0.808**	**0.750**	**0.696**	**0.645**
	Upper 95%	0.961	0.907	0.853	0.801	0.751	0.702

	Counterfactual of population size at 5 year intervals						
Additional adult mortality	**Estimate**	**yr.5**	**yr.10**	**yr.15**	**yr.20**	**yr.25**	**yr.30**
65	Lower 95%	0.915	0.832	0.756	0.688	0.627	0.568
	Median	**0.936**	**0.862**	**0.794**	**0.731**	**0.674**	**0.620**
	Upper 95%	0.957	0.894	0.832	0.778	0.726	0.682
70	Lower 95%	0.911	0.822	0.738	0.670	0.606	0.546
	Median	**0.931**	**0.853**	**0.781**	**0.715**	**0.654**	**0.599**
	Upper 95%	0.953	0.888	0.824	0.764	0.709	0.655
75	Lower 95%	0.907	0.812	0.729	0.658	0.589	0.527
	Median	**0.928**	**0.845**	**0.768**	**0.699**	**0.637**	**0.578**
	Upper 95%	0.948	0.875	0.808	0.741	0.686	0.631
80	Lower 95%	0.901	0.800	0.716	0.639	0.570	0.510
	Median	**0.922**	**0.833**	**0.754**	**0.680**	**0.616**	**0.556**
	Upper 95%	0.943	0.867	0.794	0.724	0.665	0.611
85	Lower 95%	0.899	0.793	0.704	0.625	0.552	0.491
	Median	**0.918**	**0.824**	**0.740**	**0.664**	**0.598**	**0.536**
	Upper 95%	0.936	0.857	0.777	0.712	0.649	0.589
90	Lower 95%	0.892	0.783	0.689	0.608	0.538	0.472
	Median	**0.914**	**0.815**	**0.728**	**0.649**	**0.580**	**0.518**
	Upper 95%	0.936	0.847	0.762	0.691	0.625	0.569
95	Lower 95%	0.889	0.775	0.676	0.591	0.518	0.455
	Median	**0.908**	**0.805**	**0.715**	**0.634**	**0.562**	**0.498**
	Upper 95%	0.927	0.838	0.750	0.677	0.611	0.547
100	Lower 95%	0.883	0.764	0.666	0.578	0.505	0.437
	Median	**0.903**	**0.796**	**0.701**	**0.618**	**0.545**	**0.480**
	Upper 95%	0.923	0.830	0.740	0.660	0.585	0.522

Table A.2. Lesser black-backed gull, demographic rate set 1, counterfactuals of population growth rate calculated between year 5 and year 30 using a matched runs method, from 1000 density independent simulations.

Additional adult mortality	**Lower 95%**	**Median**	**Upper 95%**
0	1.000	1.000	1.000
5	0.996	0.999	1.002
10	0.995	0.997	1.001
15	0.993	0.996	0.999
20	0.992	0.995	0.998
25	0.991	0.994	0.997
30	0.990	0.992	0.996
35	0.988	0.991	0.994
40	0.987	0.990	0.993
45	0.986	0.989	0.992

Additional adult mortality	Lower 95%	Median	Upper 95%
50	0.984	0.987	0.991
55	0.983	0.986	0.990
60	0.982	0.985	0.988
65	0.981	0.984	0.987
70	0.979	0.982	0.986
75	0.978	0.981	0.985
80	0.977	0.980	0.984
85	0.975	0.979	0.982
90	0.974	0.977	0.981
95	0.973	0.976	0.980
100	0.971	0.975	0.978

Table A.3. Lesser black-backed gull, demographic rate set 1, counterfactuals of population size after 5 to 30 years, estimated using a matched runs method, from 1000 density dependent simulations.

	Counterfactual of population size at 5 year intervals						
Additional adult mortality	**Estimate**	**yr.5**	**yr.10**	**yr.15**	**yr.20**	**yr.25**	**yr.30**
	Lower 95%	1.000	1.000	1.000	1.000	1.000	1.000
0	**Median**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
	Upper 95%	1.000	1.000	1.000	1.000	1.000	1.000
	Lower 95%	0.980	0.971	0.969	0.968	0.968	0.965
5	**Median**	**0.995**	**0.992**	**0.990**	**0.990**	**0.989**	**0.989**
	Upper 95%	1.011	1.015	1.014	1.011	1.011	1.011
	Lower 95%	0.976	0.966	0.961	0.959	0.958	0.956
10	**Median**	**0.992**	**0.987**	**0.983**	**0.981**	**0.979**	**0.978**
	Upper 95%	1.007	1.007	1.005	1.002	1.001	1.001
	Lower 95%	0.973	0.959	0.951	0.949	0.947	0.943
15	**Median**	**0.988**	**0.980**	**0.974**	**0.971**	**0.969**	**0.969**
	Upper 95%	1.005	1.000	0.998	0.994	0.991	0.992
	Lower 95%	0.969	0.952	0.944	0.940	0.936	0.933
20	**Median**	**0.985**	**0.972**	**0.965**	**0.961**	**0.959**	**0.958**
	Upper 95%	1.000	0.993	0.989	0.983	0.981	0.982
	Lower 95%	0.965	0.946	0.934	0.932	0.928	0.924
25	**Median**	**0.980**	**0.965**	**0.957**	**0.951**	**0.948**	**0.947**
	Upper 95%	0.995	0.986	0.980	0.972	0.970	0.970
	Lower 95%	0.962	0.940	0.926	0.919	0.916	0.913
30	**Median**	**0.976**	**0.959**	**0.948**	**0.942**	**0.938**	**0.935**
	Upper 95%	0.990	0.978	0.969	0.963	0.960	0.958
	Lower 95%	0.957	0.931	0.918	0.909	0.905	0.902
35	**Median**	**0.972**	**0.952**	**0.939**	**0.932**	**0.928**	**0.925**
	Upper 95%	0.988	0.972	0.961	0.956	0.952	0.948
	Lower 95%	0.952	0.925	0.910	0.900	0.895	0.892
40	**Median**	**0.969**	**0.946**	**0.931**	**0.922**	**0.918**	**0.915**
	Upper 95%	0.984	0.965	0.953	0.946	0.942	0.937
	Lower 95%	0.949	0.917	0.900	0.889	0.883	0.878
45	**Median**	**0.965**	**0.938**	**0.922**	**0.913**	**0.907**	**0.904**
	Upper 95%	0.979	0.959	0.944	0.935	0.930	0.927
	Lower 95%	0.944	0.909	0.890	0.880	0.873	0.868
50	**Median**	**0.961**	**0.931**	**0.914**	**0.903**	**0.896**	**0.892**
	Upper 95%	0.977	0.952	0.936	0.925	0.920	0.919
	Lower 95%	0.940	0.902	0.881	0.869	0.862	0.855
55	**Median**	**0.956**	**0.924**	**0.905**	**0.893**	**0.886**	**0.881**
	Upper 95%	0.972	0.945	0.929	0.916	0.909	0.906
	Lower 95%	0.938	0.896	0.875	0.860	0.851	0.845
60	**Median**	**0.953**	**0.917**	**0.896**	**0.883**	**0.875**	**0.870**
	Upper 95%	0.970	0.940	0.916	0.908	0.899	0.896

	Counterfactual of population size at 5 year intervals						
Additional adult mortality	**Estimate**	**yr.5**	**yr.10**	**yr.15**	**yr.20**	**yr.25**	**yr.30**
65	Lower 95%	0.932	0.890	0.864	0.849	0.838	0.833
	Median	**0.949**	**0.912**	**0.888**	**0.873**	**0.865**	**0.859**
	Upper 95%	0.966	0.931	0.909	0.897	0.888	0.883
70	Lower 95%	0.928	0.881	0.857	0.839	0.830	0.822
	Median	**0.945**	**0.904**	**0.880**	**0.864**	**0.854**	**0.848**
	Upper 95%	0.962	0.925	0.902	0.886	0.878	0.873
75	Lower 95%	0.924	0.875	0.848	0.828	0.817	0.809
	Median	**0.941**	**0.897**	**0.870**	**0.854**	**0.843**	**0.835**
	Upper 95%	0.957	0.917	0.892	0.876	0.866	0.860
80	Lower 95%	0.920	0.868	0.837	0.819	0.807	0.799
	Median	**0.938**	**0.890**	**0.863**	**0.844**	**0.832**	**0.826**
	Upper 95%	0.954	0.911	0.884	0.868	0.858	0.853
85	Lower 95%	0.918	0.861	0.829	0.806	0.795	0.786
	Median	**0.933**	**0.884**	**0.853**	**0.834**	**0.822**	**0.814**
	Upper 95%	0.951	0.905	0.876	0.858	0.848	0.840
90	Lower 95%	0.915	0.854	0.819	0.798	0.780	0.774
	Median	**0.929**	**0.876**	**0.844**	**0.824**	**0.810**	**0.802**
	Upper 95%	0.945	0.898	0.867	0.849	0.836	0.829
95	Lower 95%	0.908	0.847	0.812	0.790	0.772	0.765
	Median	**0.925**	**0.869**	**0.836**	**0.814**	**0.799**	**0.790**
	Upper 95%	0.942	0.890	0.858	0.839	0.825	0.816
100	Lower 95%	0.904	0.840	0.802	0.779	0.762	0.750
	Median	**0.922**	**0.863**	**0.827**	**0.803**	**0.789**	**0.780**
	Upper 95%	0.939	0.886	0.852	0.830	0.814	0.803

Table A.4. Lesser black-backed gull, demographic rate set 1, counterfactuals of population growth rate calculated between year 5 and year 30 using a matched runs method, from 1000 density dependent simulations.

Additional adult mortality	**Lower 95%**	**Median**	**Upper 95%**
0	1.000	1.000	1.000
5	0.999	1.000	1.001
10	0.998	0.999	1.001
15	0.998	0.999	1.000
20	0.998	0.999	1.000
25	0.997	0.999	1.000
30	0.997	0.998	0.999
35	0.997	0.998	0.999
40	0.996	0.998	0.999
45	0.996	0.997	0.999

Additional adult mortality	Lower 95%	Median	Upper 95%
50	0.996	0.997	0.998
55	0.995	0.997	0.998
60	0.995	0.996	0.998
65	0.995	0.996	0.997
70	0.994	0.996	0.997
75	0.994	0.995	0.997
80	0.993	0.995	0.996
85	0.993	0.995	0.996
90	0.993	0.994	0.996
95	0.992	0.994	0.995
100	0.992	0.993	0.995