Population viability analyses

Supplement to the article "Persistent organic pollution in a high-Arctic top predator: sex-dependent thresholds in adult survival"

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In order to get a quantitative estimate of the vulnerability of the population and the effect of pollution, we used the monitoring data and a “count based” approach to estimate the quasi-extinction risk using the diffusion technique described by Lande and Orzack [1] and following the procedure given by Morris and Doak [2].

We estimated the mean population growth rate (μ) and the mean variance in growth rate (σ^2) according to:

$$\hat{\mu} = \tfrac{1}{q} \sum_{i=1}^{q-1} \log\left(N_{i+1} / N_i\right), \tag{S1}$$

$$\sigma^2 = \tfrac{1}{q-1} \sum_{i=1}^{q-1} \left[\log\left(N_{i+1}/N_i\right) - \hat{\mu}\right]^2 . \tag{S2}$$

Lower and upper 95% confidence limits of μ and σ^2 were estimated according to Dennis et al. [3]. For μ this equals:

$$[\,\hat{\mu} - t_{\alpha,q-1}\,\mathrm{SE}(\hat{\mu})\,;\ \hat{\mu} + t_{\alpha,q-1}\,\mathrm{SE}(\hat{\mu})], \tag{S3}$$

where $t_{\alpha,q-1}$ is the critical value of the two-tailed Student’s *t* distribution with a significance level α of 0.05 and *q* is the number of years of monitoring.

For σ^2 the confidence limits are:

$$[(q-1)\,\sigma^2\,\chi^{-2}_{0.05,q-1}\ ;\ (q-1)\,\sigma^2\,\chi^{-2}_{0.95,q-1}], \tag{S4}$$

using the χ^2 distribution based on q–1 degrees of freedom.

For the Bjørnøya population of the glaucous gull (Table S1, Fig. 1), the estimated growth rate $\hat{\mu}$ with 95% confidence limits is –0.082 [–0.173; +0.009], and the estimated variance σ^2 is 0.065 [0.042; 0.115]. The effect of contamination on population dynamics via adult survival was modelled by adding to the observed annual growth rate the term $q^{\mathrm{hi}}\left(\phi^{\mathrm{lo}} - \phi^{\mathrm{hi}}\right)$ derived in Equation 3, and re-estimating the population parameters from this modified time series. The corresponding figures were –0.050 [–0.138; +0.038] for $\hat{\mu}$ and 0.060 [0.039; 0.108] for σ^2.

There was no first order positive or negative autocorrelation in growth rates (DW = 2.2, positive $p < 0.59$, negative $p < 0.41$), nor any density effect of annual growth rates ($R^2 = 0.06$, $p = 0.28$) which both are important key assumptions for using the diffusion approximation. The total population size of glaucous gulls was estimated to approximately 400 pairs in 2010 (Table S1), which was used as a starting point for the calculations. The quasi-extinction level was set at 20 individuals.

The analysis was run in MATLAB and adjusted Morris and Doak's [2] code (ExtProb) using the cumulative distribution function (CDF [1]) to estimate the time and probability that the population reaches 20 breeding pairs in the future (Fig. S1). Confidence limits were estimated by bootstrapping 1500 times.

The analysis shows that the population is at high risk of extinction given that the environmental conditions are the same in the future. The estimate for a 50% probability of quasi-extinction is 19 years. The corresponding upper 95% confidence limit is only 16 years (Fig. S1). When the highly contaminated individuals are excluded from the model, the corresponding figures are 50 and 32 years for the median and 95% confidence limit, respectively (Fig. S1).

References

1. Lande R, Orzack SH. 1988 Extinction dynamics of age-structured populations in a fluctuating environment. *Proc. Natl. Acad. Sci. USA* **85**, 7418–7421.
2. Morris WF, Doak DF. 2002 *Quantitative conservation biology*. Sunderland: Sinauer.
3. Dennis B, Munholland PL, Scott JM. 1991 Estimation of growth and extinction parameters for endangered species. *Ecol. Monogr.* **61**, 115–143.

Table S1. Population counts and growth rates of glaucous gulls at Bjørnøya. A total population count was performed in 2006. The other years are based on counts in a study plot and extrapolated using the value of 2006. Italics indicate missing values that have been interpolated using the PROC EXPAND procedure in SAS.

Year	Population count	Population growth rate
1987	2565	
1988	2257	–0.1279
1989	*2118*	–0.0636
1990	*2074*	–0.0209
1991	2052	–0.0107
1992	1950	–0.0510
1993	1642	–0.1719
1994	*1318*	–0.2200
1995	1231	–0.0681
1996	*1512*	+0.2058
1997	*1824*	+0.1872
1998	1710	–0.0643
1999	1180	–0.3710
2000	1266	+0.0703
2001	1026	–0.2102
2002	1214	+0.1683
2003	650	–0.6247
2004	735	+0.1229
2005	393	–0.6261
2005	650	+0.5032
2006	650	±0.0000
2007	479	–0.3053
2009	410	–0.1555
2010	393	–0.0423

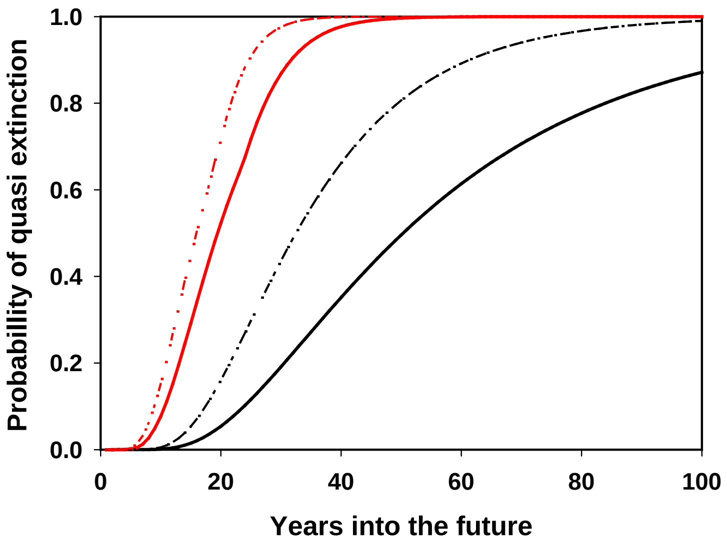

Figure S1. The extinction time cumulative distribution function (and 95% upper confidence limits) for glaucous gulls at Bjørnøya. The *x* axis shows the time required for the population to decline from 400 pairs (the population estimate in 2010) to the quasi-extinction threshold of 20 breeding pairs. Bold lines show the estimate for the best model and dotted lines the upper 95% confidence limits. Red is the current situation for the population, and black corresponds to estimates with no effect of organochlorines on adult survival.