Appendix 1

Modeling arctic and red fox demography

Long-term population growth rate ($\lambda_t$) of arctic fox and population size of red fox was predicted by the use of a projection matrix model. The model was formulated based a life-cycle consisting of two age classes, i.e. juveniles and adults ($\geq 2$ years old). Fox may breed as yearlings (arctic fox: Macpherson 1969; red fox: Pech et al. 1997) and all vital rates are made age-specific. The corresponding species-specific age-structured transition matrix ($A_t$) is formulated as:

$$A_t = \begin{bmatrix}
    0.5 \times S_y \times LF_y \times PB_y & 0.5 \times S_y \times LF_y \times PB_y \\
    S_a & S_a
\end{bmatrix} \tag{1}
$$

where $LF =$ litter size, $S =$ survival, $PB =$ proportion breeding, subscript $juv = $ juveniles, $yl = $ yearlings and $ad = $ adults. Thus in Eq. 1, yearling fecundity is the product of juvenile survival, proportion of yearlings breeding and their litter size, multiplied with 0.5 as to consider the female segment of the population only. The same product was used to model adult fecundity, though with the proportion of adults breeding and their litter size instead of that of yearlings. We used the estimate of adult survival as an estimate of yearling survival from 1 year old to 2 year olds, in lack of any estimate for this transition in the literature.

To calculate the stochastic growth rate ($\lambda_t$) for arctic fox and population size of red fox we constructed yearly matrices (Eq. 1) of species-specific demographic parameters (Table 1 in the main text) that were made dependent on the prevailing rodent density (see Henden et al. 2008 for details on, and parameters of, the second order log-linear autoregressive (AR[2]) model of small rodent dynamics). No density dependence (DD) was assumed in the vital rates of arctic fox owing to the current low density of arctic fox in Fennoscandia. However, for red fox we incorporated density dependence in population size (i.e. Beverton-Holt recruitment function; $f(n) = \frac{N}{1 + cN}$ (Caswell 2001), where $N = (A_t \times n)$ and $c = $ strength of DD $= 0.005$) to prevent escalating population numbers. Because of the lack of precise estimates of relations between fox demographic parameters and rodent density in the literature, we assumed logistic functional relationships between prevailing rodent density and vital rates, using the estimated mean maximum vital rates from the literature (Elmhagen 2003, Tannerfeldt and Angerbjörn 1996) as the asymptotic levels. However, as these estimates are based on small samples they are quite uncertain and some vital rates were adjusted to obtain more biologically reasonable values (Table 1 in main text). As no estimates of the parameters of the functional relationship between rodent densities and specific vital rates were found in the literature, we adjusted the intercept and slope to create a reasonable shape of these relationships. For instance, the shape parameters of the demographic functions relating small rodent density to red fox vital rates (Table 1 in main text), were adjusted to fit with what is known about red fox demography from the literature. As a result red fox reproduction and survival is somewhat less sensitive to abundance of rodents (as compared to the arctic fox), in the sense of being a more extensive generalist (Jedrzejewski et al. 1989, Jedrzejewski and Jedrzejewska 1992) capable of some reproduction even at very low densities of small rodents. Additionally, the slope of the logistic functional relationship were assumed to be different for adults and yearlings, with yearlings reaching asymptotic levels at higher rodent densities than adults (parameter values for all logistic functions are given in Table 1 in the main text).

The model was simulated using MATLAB R2007a (The Mathworks Inc. 2007). We censused the model just before the birth pulse (i.e. pre-breeding census), and considered only females, thus assuming a constant/even sex ratio and that males do not limit reproductive output. Each simulation was projected 10,000 years to attain a robust measure of $\lambda_t$, according to Caswell (2001). The populations were censused at discrete times $t, t+1$, and so on according to:

$$n_{t+1} = A \times n_t \tag{2}$$

where the matrix $A_t$ is defined in Eq. 1, and $n_t$ and $n_{t+1}$ are the population vectors at time $t$ and $t+1$, respectively.

References


Table S1. Mean, age specific, demographic parameters as derived from the simulations of the numerical response scenario. Note, however, that estimates for red fox assume density dependence in population size and that red fox vital rates are less sensitive to small rodent fluctuations, especially at low rodent densities.

<table>
<thead>
<tr>
<th>Numerical response scenario</th>
<th>Litter size</th>
<th>Fecundity</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red</td>
<td>Arctic</td>
<td>Red</td>
</tr>
<tr>
<td>&lt;1 year olds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearlings</td>
<td>2.5290</td>
<td>1.7012</td>
<td>0.196</td>
</tr>
<tr>
<td>Adults</td>
<td>4.6944</td>
<td>3.8416</td>
<td>0.871</td>
</tr>
</tbody>
</table>