Supplementary Materials

Estimation Models and Procedures

Though immigration of red deer started between 1914–1918 [13], population size estimates were not available on a regular annual until 1948. Hunting was started in 1971. This study therefore utilizes population estimates, numbers of harvests and roadkill data as available in the period after 1948. The following two data sets were prepared.

When including road kill data:

$$M(t) = N(t) + H(t) + R(t) \tag{1}$$

When without roadkill data:

$$W(t) = N(t) + H(t) \tag{2}$$

Here, $N(t)$, $H(t)$, and $R(t)$ are estimated/realized numbers of red deer, hunting bags and road kills in year t. These data were used for the following two state-space models.

Exponential growth case (Ew and Ew/o):

$$\mu(t) = \mu(t-1) + r\mu(t-1) + \alpha(t),\ \alpha(t) \sim N(0, \sigma_\alpha^2) \tag{3}$$

$$x(t) = \mu(t) + \beta(t),\ \beta(t) \sim N\left(0, \sigma_\beta^2\right) \tag{4}$$

Logistic growth case (Lw and Lw/o):

$$\mu(t) = \mu(t-1) + r\mu(t-1)\left[1 - \frac{\mu(t-1)}{K}\right] + \alpha(t),\ \alpha(t) \sim N(0, \sigma_\alpha^2) \tag{5}$$

$$x(t) = \mu(t) + \beta(t),\ \beta(t) \sim N\left(0, \sigma_\beta^2\right) \tag{6}$$

Here, eqs. (3) and (5) are state equations and eqs. (4) and (6) are measurement equations, respectively. $\mu(\cdot)$s are unobserved state variables used for describing state transitions. r and K are the intrinsic growth rate and the carrying capacity, and $\alpha(t)$ is the process error with mean zero and variance σ_α^2 that follows the normal distribution. It is assumed that $\mu(t=1) \sim N(\mu(0), \sigma_\alpha^2)$. $x(t)$s are the observed values of the red deer population at the year t, and $\beta(t)$ is the observation error with mean zero and variance σ_β^2 that follows normal distribution.

Estimation Results

Exponential and logistic growth were assumed as state equations. The latter incorporates the density effect, while the former does not consider the same. As indicated in the body text, the population growth of Lithuanian *C. elaphus* so far exhibits exponential growth. In the estimation of the state-space model, both non-informative and weak priors can be applied (Table S1). The weak prior for r and K are set to be $r \sim N(0.09, 0.1^2)$, and $K \sim N(k, 400^2)$, where k takes 150,000, 200,000, 250,000, 300,000, 350,000 or 400,000 in the case of logistic growth. When setting only $r \sim N(0.09, 0.1^2)$ in logistic growth, the estimated mean value of K is 9.33E+307 for Lw and 8.98E+30 for Lw/o as shown in Table S1, suggesting the current population growth is virtually an exponential growth. When setting$K \sim N(k, 400^2)$, the mean K is almost the same as the weak prior K (Table S1), which may suggest that there is no global solution of K near k.

Table S1. Estimation results of the state-space model: exponential and logistic growth with roadkill (Ew and Lw, upper part) and exponential and logistic growth without road kill (Ew/o and Lw/o, lower part).

Weak prior (K)	exponential	logistic						
		(without K)	**150,000**	**200,000**	**250,000**	**300,000**	**350,000**	**400,000**
r with road kill								
mean	0.09763	0.02278	0.11693	0.11206	0.10900	0.10779	0.10595	0.10523
2.5%	0.07895	0.00057	0.09038	0.08921	0.08788	0.08659	0.08502	0.08192
50%	0.09758	0.01673	0.11754	0.11194	0.10906	0.10774	0.10573	0.10572
97.5%	0.11592	0.08046	0.14244	0.13617	0.13209	0.13033	0.12721	0.12460
Rhat	1.00023	1.01571	1.00031	1.00016	1.02029	1.00175	1.00280	1.02425
K with road kill								
mean	-	9.33E+307	149,999	200,001	249,976	300,000	350,004	400,023
Rhat	-	NaN	1.00073	1.00381	1.01528	0.99912	0.99977	1.02022
r w/o road kill								
mean	0.10520	0.02278	0.11693	0.11206	0.10900	0.10779	0.10595	0.10523
2.5%	0.08192	0.00069	0.09138	0.08891	0.08756	0.08606	0.08502	0.08369
50%	0.10572	0.01889	0.11729	0.11227	0.10904	0.10818	0.10578	0.10497
97.5%	0.12460	8.34100	0.14360	0.13600	0.13146	0.12916	0.12693	0.12548
Rhat	1.02420	1.02748	1.00047	0.99996	0.99955	1.01547	1.00322	1.00046
K w/o road kill								
mean	-	8.98E+30	150,009	200,010	250,017	300,020	349,962	399,995
Rhat	-	NaN	1.00019	1.00067	0.99984	0.99924	1.03694	1.00060

The estimated results of exponential and logistic growth with and without roadkill are presented in Figure S1. The values of Rhat are less than 1.1 in all cases, suggesting parameters converge. The estimated values of r in the case of logistic growth are almost the same for Lw and Lw/o (green and brown lines in Figure S1), while the value of r without road kill is obviously higher than that without road kill in exponential growth (black dash lines). As the value of weak prior K increases, the estimated 50% values of r appear to approach r of Ew.

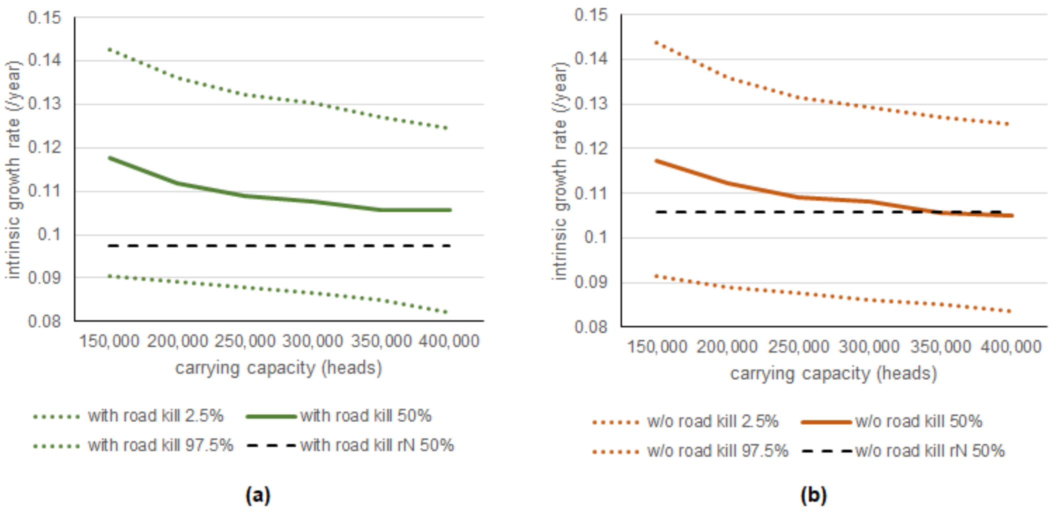

Figure S1. Estimates of the intrinsic growth rate with a 95% confidence interval, **(a)** including and **(b)** excluding roadkill data. Thick solid lines are the values at 50%, dash lines in lower and upper are the values at 2.5% and 97.5% when applying logistic growth. The carrying capacity values are on the horizon axes. Black dash lines indicate the values at 50% when applying exponential growth.