Appendix 2: Simulating nest success effects on finite growth rate (λ)

Sandercock et al. (2005) produced the most comprehensive study on southern white-tailed ptarmigan (*Lagopus leucures altipetens*) demographic rates from data collected at four study sites at and near Mount Blue Sky in Colorado, including estimates of multiple subcomponents of fecundity specific to separate age classes (1, 2, and 3+) and nesting attempts (1–3). Data were limited to nests first observed early in the nesting process, so biases in vital rate estimates associated with nests found after nest initiation were likely minimal.

We parameterized the pre-breeding census model described by Sandercock et al. (2005) using a combination of vital rate estimates presented from three separate sources. We used the estimates of total clutch laid, renest probability, chicks per egg laid, probability of fledgling success, and fledglings per chick based on information provided in Table 1 of Sandercock et al. (2005) to parameterize the transition (Leslie) matrix. Further, we used the same fecundity formulas to calculate the fecundity terms (F_{1-3+}) of the transition matrix, but we replaced the estimates of nest success with our estimates derived from daily nest survival. We made the assumption that this rate was constant across age class and nest attempts given that (a) we found no evidence for a hen age effect from our daily nest survival model, and (b) nest success did not vary significantly by nest attempt or age class in Sandercock et al. (2005). We used the survival estimates obtained from telemetry tracking of breeding-age birds presented in Seglund et al. (2018) to represent the survival terms (S_{0-3+}) in the transition matrix, and we set $S_0 = S_1$ (following Sandercock et al. 2005) and all other rates as equal because age classes 2 and 3+ were pooled in that study.

We were interested in the effect of variation in nest success on growth rate (λ). In the simplest form this evaluation can be done by varying nest success across some range of plausible values while holding other vital rates in the transition matrix at their fixed mean values, followed by calculating the eigen vector of the transition matrix and using the dominant eigenvalue to represent λ. However, including variation in all vital rates provides a better understanding of the relationships. We examined the influence of variation in the other vital rates on λ using a simple simulation that repeatedly generated λ from the transition matrix based on the associated means and variances of vital rates and using distribution functions that matched the support of their possible values. Conceptually, this is similar to a life stage simulation analysis (Wisdom et al. 2000). Therefore, our process was iterative, and within each of 10,000 iterations we did the following:

1. Simulate a transition matrix by varying the parameter values using random draws from lognormal (rates with values ≥ 0) or beta (rates with values between 0–1) distributions. The shape parameters of the beta distribution were calculated using the parameters corresponding to the mean and variance and moment matching (formulas provided in Hobbs and Hooten 2015).
2. Calculate the dominate eigen value (λ) of the transition matrix using the *lambda* function from the popbio (v2.7) R package (Stubben and Milligan 2007).
3. Save λ and the associated nest success rate.

After simulating 10,000 λ's, we used a linear model to regress λ values against their corresponding nest success values. We calculated the percent change in λ across the range of observed nest success estimates, and we plotted the resulting regression line and identified the nest success rate at which growth was predicted to stabilize ($\lambda = 1$), conditional on the rates used to parameterize the simulation (Figure A2-1). We present this as a simple heuristic to understand the slope of the relationship. There are important caveats to this simulation. First, we lacked the necessary annual estimates to consider correlations between vital rates, which could modify the relationships. Second, the identified thresholds for λ ≥ 1 are expected to change with different underlying vital rates (e.g., if vital rates vary by site). For example, Sandercock et al. (2005) found that the internal demographics of the white-tailed ptarmigan population at Mount Blue Sky and surrounding areas were insufficient to sustain the population (λ = 0.73), which indicates that using vital rates from this population to simulate λ will result in a high identified threshold for nest success to stabilize the population. We therefore suggest that the percent change across the range of nest success values is the most informative piece of information to come from this simulation. Nonetheless, the vital rates in this simulation were estimated from field data and represent a realistic scenario for some white-tailed ptarmigan populations in Colorado.

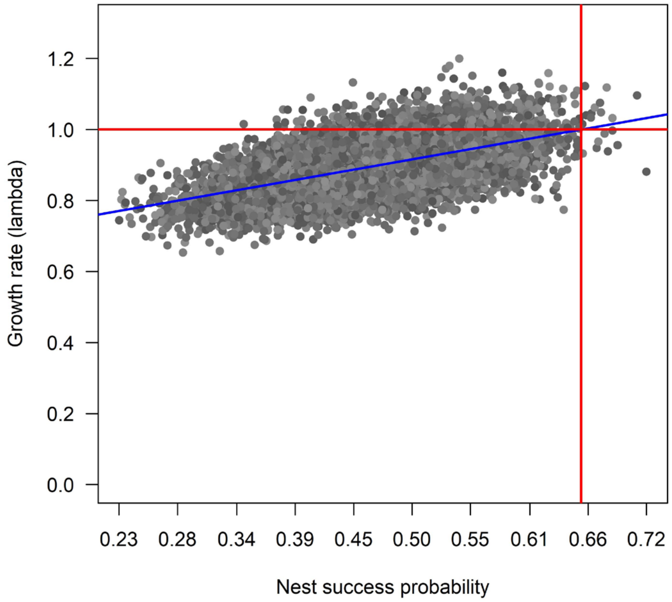

Figure A2-1. Change in finite growth rate (λ) as a function of nest success probability. Nest success probability was derived from daily nest survival estimated for southern white-tailed ptarmigan (*Lagopus leucura altipetens*) nests monitored across 6 study sites in Colorado. Each point represents a simulated growth rate from a transition (Leslie) matrix with randomly generated vital rate values. The blue line represents the predicted relationship from a linear regression, and horizontal and vertical red lines indicate the intersection of stable λ (1) and nest success probability (0.657).

References

Hobbs, N. T., and M. B. Hooten. 2015. Bayesian models. Bayesian Models. Princeton University Press.

Sandercock, B. K., K. Martin, and S. J. Hannon. 2005. Demographic consequences of age-structure in extreme environments: population models for arctic and alpine ptarmigan. Oecologia **146**:13-24.

Seglund, A., P. A. Street, K. Aagaard, J. Runge, and M. Flenner. 2018. Southern white-tailed ptarmigan (Lagopus leucura altipetens) population assessment and conservation considerations in Colorado. Final Report. Colorado Parks and Wildlife.

Stubben, C., and B. Milligan. 2007. Estimating and analyzing demographic models using the popbio package in R. Journal of Statistical Software **22**:1-23.

Wisdom, M. J., L. S. Mills, and D. F. Doak. 2000. Life stage simulation analysis: estimating vital-rate effects on population growth for conservation. Ecology **81**:628-641.