bbousuite: A set of R packages to facilitate analysis of boreal caribou survival and recruitment data

27 November 2024

# Summary

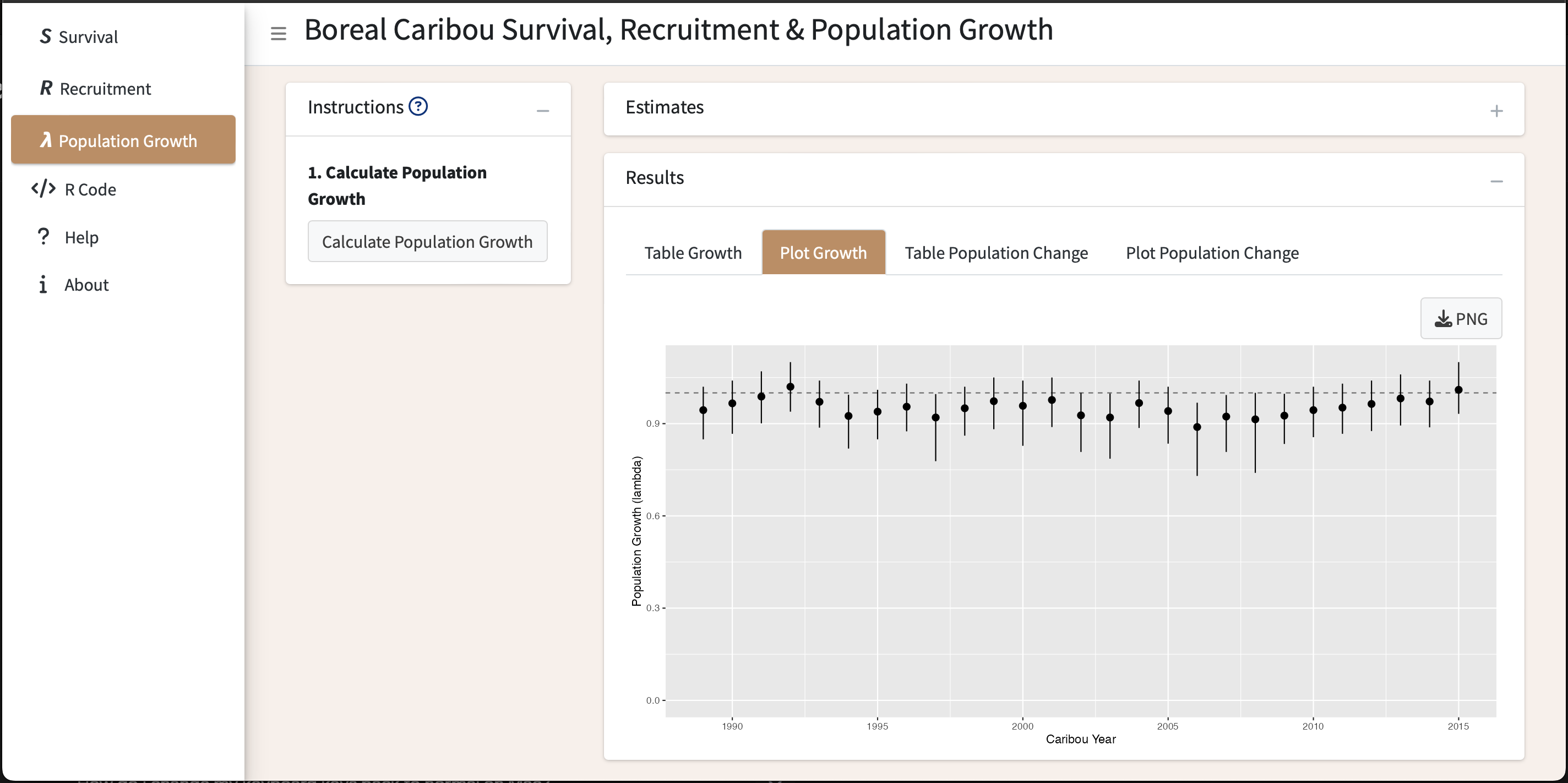
Many animal populations are managed based on their abundance (Williams 2002). However, reliable abundance estimates can be difficult to obtain for mobile low-density populations with large ranges such as boreal caribou (*Rangifer tarandus caribou*). Such populations may be managed based on their population growth rate (), which can be estimated from the female population recruitment () and adult female survival () rates (Hatter and Bergerud 1991; Hatter 2020) using the following equation.

The bbousuite is a set of R packages (R Core Team 2024) to facilitate simulation and analysis of boreal caribou survival and recruitment data to estimate population growth.

It consists of:

* [bboudata](https://poissonconsulting.github.io/bboudata/), a collection of simulated and anonymized empirical survival and recruitment datasets.
* [bboutools](https://poissonconsulting.github.io/bboutools/), a set of functions to estimate population growth in a Bayesian or Maximum Likelihood (ML) framework, implemented under the hood using the Nimble R package (De Valpine et al. 2017).
* [bboushiny](https://poissonconsulting.github.io/bboushiny/), a Graphical User Interface (GUI) to bboutools ().
* [bbouretro](https://poissonconsulting.github.io/bbouretro/), a set of functions to estimate population growth using traditional frequentist methods.
* [bbousims](https://poissonconsulting.github.io/bbousims/), a set of functions to simulate survival and recruitment data from hypothetical radio-collaring and composition surveys.

Each R package has a website with function documentation, a ‘Get Started’ guide and vignettes.



A screenshot of the bboushiny GUI.

# Statement of need

Boreal caribou occur in most provinces and territories in Canada, and are listed as threatened under Canada’s Species at Risk Act (Environment & Climate Change Canada 2023). Each jurisdiction is responsible for monitoring their respective boreal caribou populations. Numerous methods have been used to estimate population growth, which can complicate cross-jurisdictional comparisons on the status of the various populations.

The set of R packages in bbousuite aims to address this challenge. bboutools provides a standardized methodology with simple, general models and reasonable defaults for estimating survival, recruitment, and population growth that can be compared across jurisdictions. In addition, bboushiny provides access to bboutools functionality in a GUI; bbouretro facilitates comparison with traditional methods; and bbousims facilitates comparison of various methods’ ability to recover known parameter values from simulated data.

There is an existing web-based application for estimating boreal caribou population growth rate (Eacker et al. 2019). We consider bbousuite to be an evolution of this application. The methods used are similar, but the bboushiny GUI is more stream-lined while the bboutools, bbouretro, and bbousims R packages provide more fine-grained control of analyses and the ability to compare methods.

The caribouMetrics R package and [associated shiny application](https://github.com/LandSciTech/BayesianCaribouDemographicProjection) also have overlapping functionality. However, the primary goal of these tools is to forecast boreal caribou populations under different monitoring and disturbance scenarios (Dyson et al. 2022).

# Overview of methods

Survival is estimated from the monthly fate of radio-collared adult females, with an option to include uncertain mortalites in the total monthly mortalities prior to model fitting. bbouretro uses the staggered entry Kaplan-Meier method (Pollock et al. 1989), as outlined in the [bbouretro methods article](https://poissonconsulting.github.io/bbouretro/articles/retro-methods.html#survival-s). bboutools uses a generalized linear mixed-effects model (GLMM) approach. A full model description can be found in the [bboutools methods article](https://poissonconsulting.github.io/bboutools/articles/methods.html#survival-model).

Recruitment is estimated from annual aerial composition surveys. bbouretro follows methods in DeCesare et al. (2012), as outlined in the [bbouretro methods article](https://poissonconsulting.github.io/bbouretro/articles/retro-methods.html#recruitment-r). bboutools uses a GLMM approach. A full model description can be found in the [bboutools methods article](https://poissonconsulting.github.io/bboutools/articles/methods.html#recruitment-model). The model includes demographic stochasticity through the binomial distributions. Groups are aggregated by year prior to model fitting. The calf sex ratio is fixed and can be adjusted by the user, with default of 0.5. The female proportion of the adult population can be estimated from counts of cows and bulls or fixed, with a default of 0.65, which accounts for higher mortality of males (Smith 2004). In bbouretro and bboutools, estimated recruitment is the female calf recruitment, adjusted following DeCesare et al. (2012), which accounts for recruitment of calves into the yearling/adult age class at the end of the caribou year.

Population growth () is estimated using the Hatter-Bergerud equation (Hatter and Bergerud 1991) presented above. More details can be found in the [bbouretro methods article](https://poissonconsulting.github.io/bbouretro/articles/retro-methods.html#population-growth-lambda).

## Comparison of methods

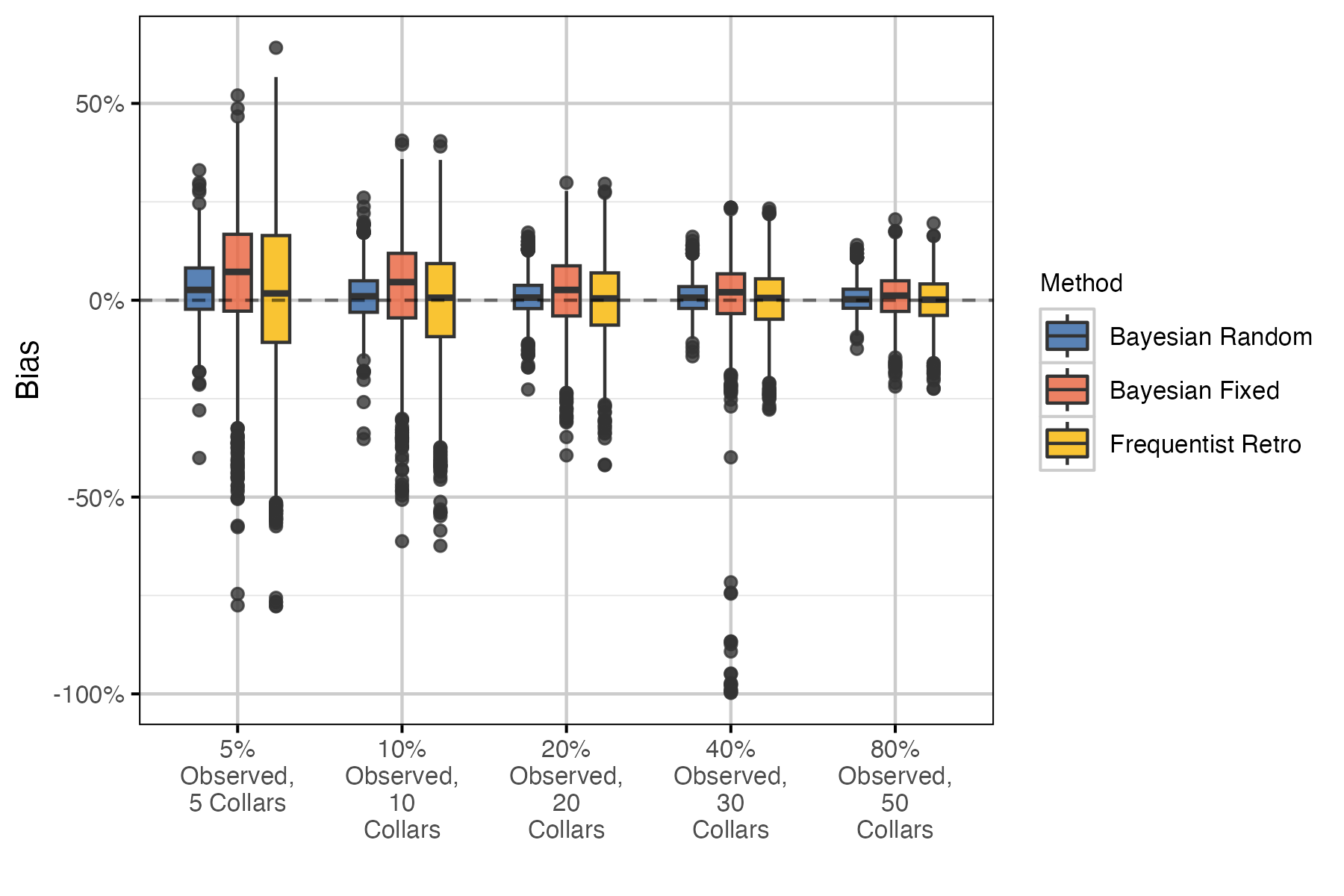
Some key differences between bbouretro and bboutools include:

* bbouretro variances are estimated using approximation formulas (survival) or bootstrap resampling methods. Uncertainty estimates are less precise and reliable than bboutools.
* bboutools models can estimate uncertainty in survival for cases with 0 mortalities in a year.
* bboutools models can include year as a random effect, where individual year effects are assumed to be drawn from a common underlying distribution and information is shared among years.
* bboutools models can include an underlying trend.

In addition, with bboutools models that are fit in a Bayesian framework:

* models can incorporate prior knowledge, which is especially useful when data are sparse.
* posterior distributions of parameters can be combined to produce derived parameters (e.g., population growth) with full information about uncertainty retained.

We compared estimates from bbouretro and bboutools on anonymized empirical and simulated data. Comprehensive results and discussion can be found in the [empirical comparisons article](https://poissonconsulting.github.io/bbousuite/articles/empirical-comparisons.html) and [simulations analysis article](https://poissonconsulting.github.io/bbousuite/articles/simulations.html), respectively. Based on our findings (e.g., ), we propose bboutools as a standardized method for comparing estimates across jurisdictions. In particular, random effects models are recommended by default when there are 5 years of data (Kery and Schaub 2011). More discussion on the benefits of random effects models can be found [in the simulations analysis article](https://poissonconsulting.github.io/bbousuite/articles/simulations.html#discussion).



Bias (% difference) in annual population growth point estimates and known population growth for 100 simulations and 20 years, by sample size and statistical method.

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# References

De Valpine, Perry, Daniel Turek, Christopher J. Paciorek, Clifford Anderson-Bergman, Duncan Temple Lang, and Rastislav Bodik. 2017. “Programming With Models: Writing Statistical Algorithms for General Model Structures With NIMBLE.” *Journal of Computational and Graphical Statistics* 26 (2): 403–13. <https://doi.org/10.1080/10618600.2016.1172487>.

DeCesare, Nicholas J., Mark Hebblewhite, Mark Bradley, Kirby G. Smith, David Hervieux, and Lalenia Neufeld. 2012. “Estimating Ungulate Recruitment and Growth Rates Using Age Ratios.” *The Journal of Wildlife Management* 76 (1): 144–53. <https://doi.org/10.1002/jwmg.244>.

Dyson, Matt, Sarah Endicott, Craig Simpkins, Julie W. Turner, Stephanie Avery-Gomm, Cheryl A. Johnson, Mathieu Leblond, et al. 2022. “Existing Caribou Habitat and Demographic Models Need Improvement for Ring of Fire Impact Assessment: A Roadmap for Improving the Usefulness, Transparency, and Availability of Models for Conservation.” *bioRxiv*. <https://doi.org/10.1101/2022.06.01.494350>.

Eacker, Daniel R., Mark Hebblewhite, Robin Steenweg, Mike Russell, Amy Flasko, and Dave Hervieux. 2019. “Web‐based Application for Threatened Woodland Caribou Population Modeling.” *Wildlife Society Bulletin* 43 (1): 167–77. <https://doi.org/10.1002/wsb.950>.

Environment & Climate Change Canada, I. 2023. “Caribou in Canada.” *Government of Canada*. <https://www.canada.ca/en/environment-climate-change/services/species-risk-education-centre/caribou.html>.

Hatter, Ian. 2020. “Revisiting the Recruitment-Mortality Equation to Assess Moose Growth Rates.” *Alces: A Journal Devoted to the Biology and Management of Moose* 56: 39–47. <https://alcesjournal.org/index.php/alces/article/view/263>.

Hatter, Ian, and Wendy Bergerud. 1991. “Moose Recuriment Adult Mortality and Rate of Change” 27: 65–73.

Kery, Marc, and Michael Schaub. 2011. *Bayesian Population Analysis Using WinBUGS : A Hierarchical Perspective*. Boston: Academic Press. <http://www.vogelwarte.ch/bpa.html>.

Pollock, Kenneth H., Scott R. Winterstein, Christine M. Bunck, and Paul D. Curtis. 1989. “Survival Analysis in Telemetry Studies: The Staggered Entry Design.” *The Journal of Wildlife Management* 53 (1): 7. <https://doi.org/10.2307/3801296>.

R Core Team. 2024. “R: A Language and Environment for Statistical Computing.” Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org/>.

Smith, Kirby Gordon. 2004. “Woodland Caribou Demography and Persistence Relative to Landscape Change in West-Central Alberta.” 125.

Williams, Byron K. 2002. *Analysis and Management of Animal Populations: Modeling, Estimation, and Decision Making*. San Diego: Academic Press.