The Journal of Open Source Software

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

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DOI: 10.21105/joss.07997

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Editor: Ethan White

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Submitted: 28 December 2024
Published: 30 May 2025

Summary

Many animal populations are managed based on their abundance (Williams et al., 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 (λ), which can be estimated from the female population recruitment (R) and adult female survival (S) rates (Hatter, 2020; Hatter & Bergerud, 1991) using the following equation.

$$\lambda = \frac{S}{1 - R}$$

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`, a collection of simulated and anonymized empirical survival and recruitment datasets.
- `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`, a Graphical User Interface (GUI) to `bboutools` (Figure 1).
- `bbouretro`, a set of functions to estimate population growth using traditional frequentist methods.
- `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.

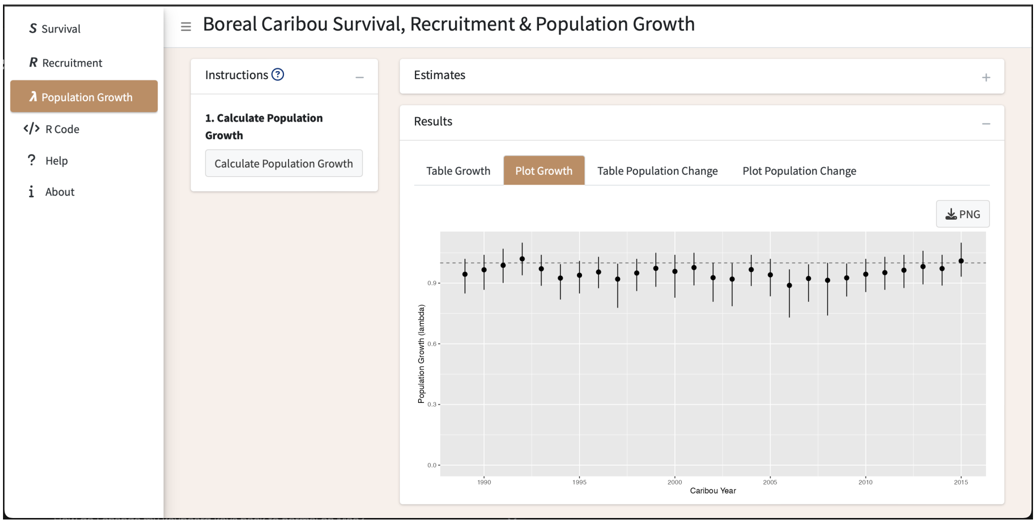

Figure 1: A screenshot of the bboushiny GUI.

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 and 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 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. `bboutools` uses a generalized linear mixed-effects model (GLMM) approach. A full model description can be found in the `bboutools` methods article.

Recruitment is estimated from annual aerial composition surveys. `bbouretro` follows methods in DeCesare et al. (2012), as outlined in the `bbouretro` methods article. `bboutools` uses a GLMM approach. A full model description can be found in the `bboutools` methods article.

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 (λ) is estimated using the Hatter-Bergerud equation (Hatter & Bergerud, 1991) presented above. More details can be found in the `bbouretro` methods article.

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 and simulations analysis article, respectively. Based on our findings (e.g., Figure 2), 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 & Schaub, 2011). More discussion on the benefits of random effects models can be found in the simulations analysis article.

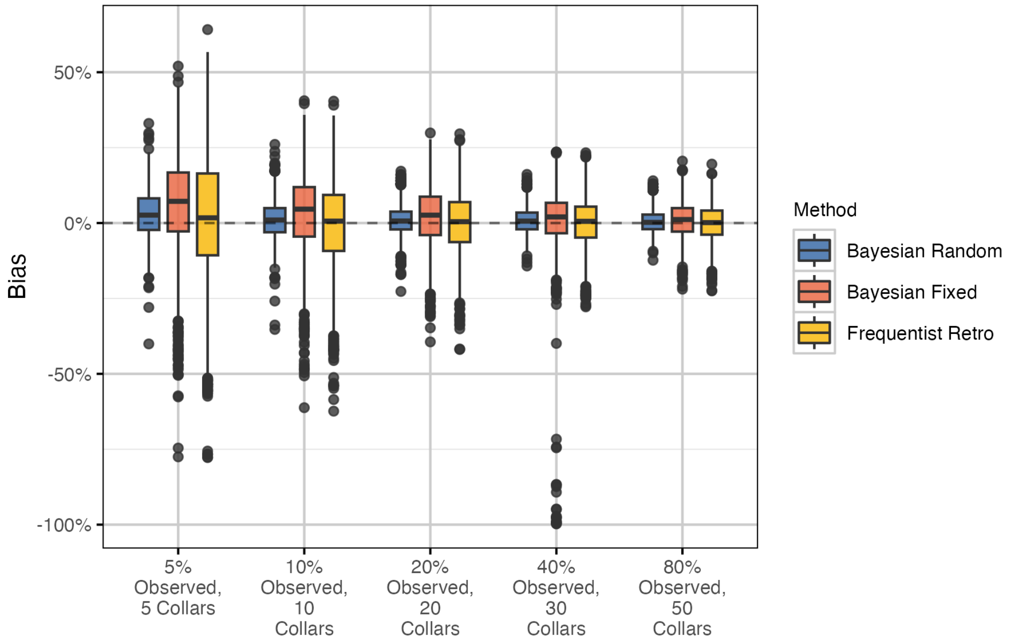

Figure 2: Bias (% difference) in annual population growth point estimates and known population growth for 100 simulations and 20 years, by sample size and statistical method.

Acknowledgements

We acknowledge contributions from Alan Constant, Sarah Lyons, Colton Stephens and Nicole Hill. Development of `bbousuite` was funded by the Province of Alberta and Environment and Climate Change Canada.

References

De Valpine, P., Turek, D., Paciorek, C. J., Anderson-Bergman, C., Lang, D. T., & Bodik, R. (2017). Programming with models: Writing statistical algorithms for general model structures with NIMBLE. *Journal of Computational and Graphical Statistics*, *26*(2), 403–413. https://doi.org/10.1080/10618600.2016.1172487

DeCesare, N. J., Hebblewhite, M., Bradley, M., Smith, K. G., Hervieux, D., & Neufeld, L. (2012). Estimating ungulate recruitment and growth rates using age ratios. *The Journal of Wildlife Management*, *76*(1), 144–153. https://doi.org/10.1002/jwmg.244

Dyson, M., Endicott, S., Simpkins, C., Turner, J. W., Avery-Gomm, S., Johnson, C. A., Leblond, M., Neilson, E. W., Rempel, R., Wiebe, P. A., Baltzer, J. L., Stewart, F. E. C., & Hughes, J. (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, D. R., Hebblewhite, M., Steenweg, R., Russell, M., Flasko, A., & Hervieux, D. (2019). Web-based application for threatened woodland caribou population modeling. *Wildlife Society Bulletin*, *43*(1), 167–177. https://doi.org/10.1002/wsb.950

Environment and Climate Change Canada. (2023). Caribou in Canada. In *Government of Canada*. https://www.canada.ca/en/environment-climate-change/services/species-risk-education-centre/caribou.html

Hatter, I. (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, I., & Bergerud, W. (1991). Moose recruitment, adult mortality and rate of change. *Alces*, *27*, 65–73.

Kery, M., & Schaub, M. (2011). *Bayesian population analysis using WinBUGS: A hierarchical perspective*. Academic Press. ISBN: 0-12-387020-8

Pollock, K. H., Winterstein, S. R., Bunck, C. M., & Curtis, P. D. (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*. R Foundation for Statistical Computing. https://www.R-project.org/

Smith, K. G. (2004). *Woodland caribou demography and persistence relative to landscape change in west-central Alberta* [M.Sc. Thesis]. University of Alberta.

Williams, B. K., Nichols, J. D., & Conroy, M. J. (2002). *Analysis and management of animal populations: Modeling, estimation, and decision making*. Academic Press.