

Extended analyses for Northwest Territories caribou range planning

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Overview

This document summarizes the data product deliverables quoted for ENR-GNWT as described in the tasks below:

1. Landscape simulations (5 replicates for each of the 3 CMIP6 climate scenarios) for the period between 2011 and 2100, followed by summarizing wildfire results using 3 different sets of polygons contained within the NT1 caribou management area.
2. Simulated caribou population growth using landscape simulations described in 1, followed by summarizing results per polygon (table of raw results).
3. Simulated caribou resource selection using landscape simulations described in 1, followed by summarizing results per polygon (table of raw results, maps of change from 2021 to 2100, and average and deviance across replicates and climate scenarios as uncertainty).

All data products and modules have been developed using the PERFICT approach as outlined in McIntire et al. (2022), which enables them to be part of update cycles as needed going forward.

Changes from the expected deliverables

To reduce uncertainty, we have increased the number of replicates from 5 to 10, and the climate scenarios from 3 to 4 (two GMC's – CanESM5 and CNRM-ESM2-1 – and 2 SSPs – 370 and 585), which represent the most likely climate scenarios to be realized. Moreover, to ensure compatibility with the time steps proposed for caribou (10 year period), the last simulation performed for both RSF and population growth was 2091, not 2100 (as we start the simulations in 2011).

Opening files

Please note that `tif` files can be opened using the `raster` package in R or imported to a GIS software (i.e., ArcGIS, QGIS). On the other hand, `qs` files need to be opened in R using the `qs` library (`qs::qread()`), but can be saved in R as a `.csv` file and opened in Excel. We caution, however, that most of these files are very large due to the extent of the study area and one might face software limitations when converting these objects to an Excel compatible format.

Landscape simulations

Our simulation experiments were designed to contrast climate-sensitive and non-climate sensitive models for tree growth and mortality, in addition to wildfire from 2011-2100 (Table 2, Micheletti et al. 2021). Simulations used a climate-sensitive vegetation model (LandR.CS), together with a climate-sensitive wildfire model (fireSense).

Each simulation run produced the following files, where YYYY is the year in question:

- yearly aboveground net primary productivity (ANPP) maps:
-> ANPPMap_YYYY_yearYYYY.tif

- yearly wildfire burn maps: -> `burnMap_YYYY_yearYYYY.tif`
- wildfire burn summary for year 2100, containing information on all simulated fires with total area burned for all years:
-> `burnSummary_year2100.qs`
- yearly wildfire of simulated burned pixels for all years:
-> `rstCurrentBurn_YYYY_yearYYYY.tif`
- yearly vegetation (tree only) cohort data objects, -> `cohortData_YYYY_yearYYYY.qs` from which cohort age, aboveground biomass, and species composition can be extracted using the accompanying map:
-> `pixelGroupMap_YYYY_yearYYYY.tif` (matched by pixelGroup)
- wildfire ignition, escape, and spread model predictions for all years:
-> `fireSense_IgnitionPredicted_YYYY_yearYYYY.tif` -> `fireSense_EscapePredicted_YYYY_yearYYYY.tif`
-> `fireSense_SpreadPredicted_YYYY_yearYYYY.tif`
- yearly vegetation (tree) mortality maps:
-> `mortalityMap_YYYY_yearYYYY.tif`
- yearly simulated vegetation biomass maps:
-> `simulatedBiomassMap_YYYY_yearYYYY.tif`

Raw outputs: Total archive size: 57.2GB.

Summarized layers: Total archive size: 57.2GB.

All landscape simulation summary products can be find at https://drive.google.com/drive/u/0/folders/1t6032ggUC__jzaJs5H39LW6iFfrqIK_T

Boreal Caribou simulations

For both models below (RSF and Population Growth), we simulated changes across 90 years of climate-driven landscape change [as described in Stewart et al. (in review); available here].

Boreal Population Resource Selection (RSF)

We forecast suitable habitat for Boreal woodland caribou (*Rangifer tarandus caribou*) across the union of the three sets of polygons containing Northwest Territories' caribou ranges. We generated the following products, where SHP stands for the shapefile used for the maps (RangePlanRegions, GNWT_NT1_range, Revised_Study_Areas), YYYY stands for the year (2011, 2031, 2051, 2071 or 2091), RR stands for the replicate number (01 to 10), CLIMMOD stands for the climate model (CanESM5 or CNRM-ESM2-1) and XXX stands for the SSP (370 or 585) :

- bi-decadal relative selection (RSF) forecast for each climate model and replicate:
-> `NT1_BCR6_CLIMMOD_SSPXXX_runRR_relativeSelectioncaribouRSF_NT_YearYYYY.tif`
- bi-decadal relative selection (RSF) forecast uncertainty (in the form of standard error) for each climate model and replicate:
-> `NT1_BCR6_CLIMMOD_SSPXXX_runRR_relativeSelectionUncertaincaribouRSF_NT_YearYYYY.tif`
- For each shapefile:
 - map of the average difference between first and last year across:
 - * all climate models and SSP:
-> `averageDifference_SHP_allScenarios.png`
 - * each climate models and SSP:
-> `averageDifference_SHP_NT1_BCR6_CLIMMOD_SSPXXX.png`
 - map of the SD difference first and last year across:
 - * all climate models and SSP:
-> `sdDifference_SHP_allScenarios.png`

- * each climate models and SSP:
 - > `sdDifference_SHP_NT1_BCR6_CLIMMOD_SSPXXX.png`
- Table of mean, standard deviation (SD) and confidence interval (CI) of binned RSF values for each polygon within the shapefile, climate model and replicate within the shapefile: -> `meanRSFperPolygon_SHP.qs`
- Summarized table with mean, standard deviation (SD) and confidence interval (CI) of binned RSF values for each polygon within the shapefile, both for all and across climate model, across replicates:
 - > `meanRSFperPolySummary_SHP.qs`

Boreal Population Growth

We also simulated demographic parameters for all polygons within all three shapefiles. We generated the following products, where SHP stands for the shapefile used for the maps (RangePlanRegions, GNWT_NT1_range, Revised_Study_Areas), YYYY stands for the year (2011, 2031, 2051, 2071 or 2091), RR stands for the replicate number (01 to 10), CLIMMOD stands for the climate model (CanESM5 or CNRM-ESM2-1) and XXX stands for the SSP (370 or 585) :

- layers used for population growth calculation per climate model and replicate:
 - > `caribouLayers_yearYYYY_NT1_BCR6_CLIMMOD_SSPXXX_runRR.tif`
- disturbance summary at year 2091 (which contains all disturbances for all other years), per climate model and replicate:
 - > `disturbances_Year2091_NT1_BCR6_CLIMMOD_SSPXXX_runRR_year2091.rds`
- predicted caribou values (lambda, recruitment and adult female mortality) at year 2091 (which contains values for all other years), per climate model and replicate:
 - > `predictedCaribou_Year2091_NT1_BCR6_CLIMMOD_SSPXXX_runRR_year2091.rds`
- caribou population demographics plots per polygon per shapefile, showing increasing levels of uncertainty (5 to 85 quantiles; colored bands) using climate models and replicates as uncertainty measures:
 - > `caribou_SHP_allCM_Johnson_Johnson.png`
- caribou population demographics table (summary) per polygon per shapefile, replicate and climate model:
 - > `populationGrowthTable.csv`
- disturbance table (summary) per polygon per shapefile, replicate and climate model:
 - > `disturbanceTable.csv`

Raw outputs: Total archive size: 30.1GB.

Summarized layers: Total archive size: 44.6GB.

All caribou summary products can be find at https://drive.google.com/drive/u/0/folders/1IpC_u5c7Mluvqdxzk3pue5NFaBHyY6A6

Code availability

All code used for the current project is publicly available at: https://github.com/FOR-CAST/NT_caribou. Some additional tools used and details of specific scripts are described below.

Additional tools for analyzing simulation results

Biomass_summary module Summarizes the results of multiple LandR Biomass simulations, across multiple study areas, climate scenarios, and replicates. Intended to be used for post-simulation processing of multiple LandR Biomass simulations, following a LandR-fS project structure and workflow described and templated in the SpaDES.project package.

Available from: https://github.com/PredictiveEcology/Biomass_summary

caribouMetrics package Implements caribou resource selection functions, as well as caribou population and demographic models. Incorporates code from Tati's `caribouPopGrowthModel` module and is used in this module to add uncertainty due to beta distribution used to fit the original models proposed by Johnson et al. (n.d.).

Available from: <https://github.com/LandSciTech/caribouMetrics>

fireSense_summary module Summarizes the results of multiple fireSense simulations, across multiple study areas, climate scenarios, and replicates. Creates burn summary figures, historic burn summary plots, and cumulative simulated burn maps.

Available from: https://github.com/PredictiveEcology/fireSense_summary

posthocLandR module Post-processing module for LandR Biomass simulations. Prepares the biomass, leading species, average forest age objects for summary across simulations.

Available from: <https://github.com/tati-micheletti/NWT/blob/development/modules/posthocLandR/posthocLandR.R>

usefulFuns package Various utilities for producing summary plots and objects, including:

- assembling the layers for the caribou RSFs and plotting them;
- various plots for vegetation biomass;
- forest age plots;
- generating and plotting burn summary maps;
- helper functions for working with bird models;
- preparing climate layers.

Available from: <https://github.com/PredictiveEcology/usefulFuns> (forked from <https://github.com/tati-micheletti/usefulFuns>)

Summary R scripts Various utilities to summarize the NWT simulation outputs and create plots for caribou components can be found in the R folder within the repository.

- https://github.com/FOR-CAST/NT_caribou/tree/main/R

More specifically, the script used to create summaries and maps for both RSF and population growth can be found at:

- https://github.com/FOR-CAST/NT_caribou/tree/main/R/summarizeCaribou.R

References

- Johnson, Cheryl A., Glenn D. Sutherland, Erin Neave, Mathieu Leblond, Patrick Kirby, Clara Superbie, and Philip D. McLoughlin. n.d. "Science to Inform Policy: Linking Population Dynamics to Habitat for a Threatened Species in Canada." *Journal of Applied Ecology*. Accessed May 8, 2020. <https://doi.org/10.1111/1365-2664.13637>.
- McIntire, Eliot, Alex Chubaty, Steve Cumming, David Andison, Ceres Barros, Céline Boisvenue, Samuel Hache, Yong Luo, Tatiane Micheletti, and Frances Stewart. 2022. "PERFICT: A Re-Imagined Foundation for Predictive Ecology." *Ecology Letters* In press. <https://doi.org/10.22541/au.163252535.52485317/v1>.
- Micheletti, Tatiane, Frances E. C. Stewart, Steven G. Cumming, Samuel Haché, Diana Stralberg, Junior A. Tremblay, Ceres Barros, et al. 2021. "Assessing Pathways of Climate Change Effects in SpaDES: An Application to Boreal Landbirds of Northwest Territories Canada." *Frontiers in Ecology and Evolution* 9 (October). <https://doi.org/10.3389/fevo.2021.679673>.

Stewart, Frances E C, T Micheletti, Eliot J B McIntire, Samuel Haché, Mathieu Leblond, Junior A Tremblay, Ceres Barros, et al. in review. “Forecasting Caribou Resource Selection and Demography Under Landscape and Climate Change in the Northwest Territories, Canada,” in review.