Extended analyses for Northwest Territories caribou range planning

Alex M. Chubaty (achubaty@for-cast.ca) *FOR-CAST Research & Analytics*
Tati Micheletti (tati.micheletti@gmail.com) *University of British Columbia*

Overview

We simulated vegetation, wildfire, and caribou in the NT1 study area for the years 2011-2100 following the modelling approaches of Micheletti et al. (2021) and Stewart et al. (in review), developed for an initial pilot study in the Northwest Territories. All models have been developed using the PERFICT approach (McIntire et al. 2022), which enables them to be part of update cycles as needed going forward.

Here, we used the most recent CIMP6 climate projections for four climate change scenarios (CanESM5 under each of SSP 370 and 585, as well as CNRM-ESM2-1 under each of SSP 370 and 585). We generated wildfire predictions such that historical fire data from 2011-2020 are used instead of simulating fire in those years. We ran 10 replicates for each scenario (instead of 5) to better capture stochastic variation for each scenario. Caribou results were summarized over 10-year periods from 2011 to 2091, across each of the new or updated caribou planning polygons (provided by GNWT) within NT1 study area:

a. Range planning areas (includes Wek'eezhii, Gwich'in, Inuvialuit, Sahtu, Southern NWT);
b. Herd study areas;
c. Geographic-barriers-to-caribou-movement areas;

We also summarized vegetation and wildfire model projections for the NT1 study area and for each of these new reporting areas over the entire simulation timescale (2011-2100). Additional details are provided below.

Code availability

Model code for this project is available from https://github.com/FOR-CAST/NT_caribou (public repository).

Model outputs

A subset of data inputs and model outputs are available from https://drive.google.com/drive/u/0/folders/0AAAMKzVjPKt5Uk9PVA (restricted access) and are described in further detail below.

Filetypes Please note that many of these output files are quite large due to the extent of the study area, and one might face software limitations when converting these objects to *e.g.*, an Excel-compatible format.

- `.tif` files can be opened using the `raster` package in `R` or imported to GIS software (*e.g.*, ArcGIS, QGIS);
- `.qs` files can be opened in `R` using the `qs` package (`qs::qread()`) and these tables may be subsequently saved in an alternate format (*e.g.*, `.csv` for use with Microsoft Excel).

Landscape simulations

Simulations followed the approach described in Micheletti et al. (2021), but used the latest versions of the climate-sensitive vegetation model (*LandR.CS*), together with a climate-sensitive wildfire model (*fireSense*). Additionally, we generated wildfire predictions such that historical fire data from 2011-2020 are used instead of simulating fire in those years.

Each simulation run produced the following files, where `YYYY` corresponds to the simulation year:

Filename pattern	Description
ANPPMap_YYYY_yearYYYY.tif	yearly aboveground net primary productivity (ANPP) maps
burnMap_YYYY_yearYYYY.tif	yearly wildfire burn maps
burnSummary_year2100.qs	wildfire burn summary for year 2100, containing information on all simulated fires with total area burned for all years
cohortData_YYYY_yearYYYY.qs	yearly vegetation (tree only) cohort data objects, from which cohort age, aboveground biomass, and species composition can be extracted using the accompanying 'pixelGroupMap'
fireSense_EscapePredicted_YYYY_yearYYYY.tif	wildfire escape model predictions for all years
fireSense_IgnitionPredicted_YYYY_yearYYYY.tif	wildfire ignition model predictions for all years
fireSense_SpreadPredicted_YYYY_yearYYYY.tif	wildfire spread model predictions for all years
mortalityMap_YYYY_yearYYYY.tif	yearly vegetation (tree) mortality maps
pixelGroupMap_YYYY_yearYYYY.tif	yearly map of vegetation pixel groups
rstCurrentBurn_YYYY_yearYYYY.tif	yearly wildfire of simulated burned pixels for all years
simulatedBiomassMap_YYYY_yearYYYY.tif	yearly simulated vegetation biomass maps

All landscape simulation summary products can be found at https://drive.google.com/drive/u/0/folders/1t6032ggUC__jzaJs5H39LW6iFfrqlK_T (restricted access).

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). We used the `caribouMetrics` package (https://github.com/LandSciTech/caribouMetrics) which implements caribou resource selection functions, as well as caribou population and demographic models (which extend the original models proposed by Johnson et al. (2020)).

All caribou summary products can be found at https://drive.google.com/drive/u/0/folders/1IpC_u5c7Mluvqdxzk3pue5NFaBHyY6A6 (restricted access).

Boreal caribou simulation: 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):

Filename pattern	Description
averageDifference_SHP_allScenarios.png	map of the average difference between first and last year across all climate scenarios, per shapefile
averageDifference_SHP_NT1_BCR6_-CLIMMOD_SSPXXX.png	map of the average difference between first and last year across, per climate scenario, per 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	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
NT1_BCR6_CLIMMOD_SSPXXX_runRR_-relativeSelectioncaribouRSF_NT_YearYYYY.tif	bi-decadal relative selection (RSF) forecast for each climate model and replicate
NT1_BCR6_CLIMMOD_SSPXXX_runRR_-relativeSelectionUncertaincaribouRSF_NT_-YearYYYY.tif	bi-decadal relative selection (RSF) forecast uncertainty (in the form of standard error) for each climate model and replicate
sdDifference_SHP_allScenarios.png	map of the SD difference first and last year across all climate scenarios, per shapefile
sdDifference_SHP_NT1_BCR6_CLIMMOD_-SSPXXX.png	map of the SD difference first and last year, per climate scenario, per shapefile

Boreal caribou simulations: 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):

Filename pattern	Description
caribouLayers_yearYYYY_NT1_BCR6_-CLIMMOD_SSPXXX_runRR.tif	layers used for population growth calculation per climate model and replicate
disturbances_Year2091_NT1_BCR6_CLIMMOD_-SSPXXX_runRR_year2091.rds	disturbance summary at year 2091 (which contains all disturbances for all other years), per climate model and replicate
predictedCaribou_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
caribou_SHP_allCM_Johnson_Johnson.png	caribou population demographics plots per polygon per shapefile, showing increasing levels of uncertainty (5 to 85 quantiles; coloured bands) using climate models and replicates as uncertainty measures
populationGrowthTable.csv	caribou population demographics table (summary) per polygon per shapefile, replicate and climate model
disturbanceTable.csv	disturbance table (summary) per polygon per shapefile, replicate and climate model

References

C. A. Johnson, G. D. Sutherland, E. Neave, M. Leblond, P. Kirby, C. Superbie, and P. D. McLoughlin. Science to inform policy: Linking population dynamics to habitat for a threatened species in Canada. *Journal of Applied Ecology*, 2020. ISSN 1365-2664. doi:10.1111/1365-2664.13637.

E. J. B. McIntire, A. M. Chubaty, S. G. Cumming, D. Andison, C. Barros, C. Boisvenue, S. Hache, Y. Luo, T. Micheletti, and F. E. C. Stewart. Predictive Ecology: a re-imagined foundation and the tools for ecological models. *Ecology Letters*, 2022. doi:10.1111/ele.13994.

T. Micheletti, F. E. C. Stewart, S. G. Cumming, S. Haché, D. Stralberg, J. A. Tremblay, C. Barros, I. M. S. Eddy, A. M. Chubaty, M. Leblond, R. F. Pankratz, C. L. Mahon, S. L. Van Wilgenburg, E. M. Bayne, F. Schmiegelow, and E. J. B. McIntire. Assessing pathways of climate change effects in spades: An application to boreal landbirds of northwest territories canada. *Frontiers in Ecology and Evolution*, 9, 10 2021. doi:10.3389/fevo.2021.679673.

F. E. C. Stewart, T. Micheletti, E. J. B. McIntire, S. Haché, M. Leblond, J. A. Tremblay, C. Barros, I. Eddy, J. Marchal, M. van Telgen, J. Hodson, F. K. A. Schmiegelow, A. M. Chubaty, and S. G. Cumming. Forecasting caribou resource selection and demography under landscape and climate change in the Northwest Territories, Canada. in review. URL https://drive.google.com/file/d/1NHzLDCbfEr2x5J3eD59r7uojrE-VN1y9/.