Ecosystem-level climate matching with soil constraints for assisted migration in Canadian forests

Genevieve Dorrell[1], Andreas Hamann[1]*, Andy Y. Yu[1], Nicholas Boyce[1], Zach Zimmerman[1], Kevin A. Solarik[2, 3] and Christian Messier[3,4]

(Extended abstact with figures and tables of a manuscipt in submission. Please contact the corresponding author for more details)

[1] University of Alberta, Renewable Resources Department, Edmonton, Alberta, Canada

[2] National Council for Air and Stream Improvement, Montréal, Québec, Canada

[3] Université du Québec à Montréal, Département des sciences biologiques, Centre d'Étude de la Forêt (CEF), Montréal, Québec, Canada

[4] Université du Québec en Outaouais, Département des sciences naturelles, Institut des Sciences de la Forêt Tempérée (ISFORT), Ripon, Québec, Canada

* Corresponding author's contact information: andreas.hamann@ualberta.ca

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Extended Abstract

Forest regeneration decisions have traditionally relied on the assumption that locally sourced planting stock is adapted to the climatic conditions of the target site. Under ongoing climate change, this assumption no longer holds consistently, and both species choice and seed sourcing need to account for shifting climate conditions. The challenge is to provide guidance that reflects these changes while remaining compatible with operational forest management practices.

This study applies an ecosystem-level climate matching approach to evaluate how species suitability and seed sourcing are expected to change across Canada. Future climate conditions for target ecosystems are compared with historical climates across North America to identify the closest climate analogues. Species recommendations are then derived from the composition of these climate-matched ecosystems. Climate similarity is evaluated first, and ecosystem-level soil similarity is applied as a secondary constraint to refine candidate matches.

At the continental scale, climate matching indicates a general northward shift in suitable climate conditions (Fig. 1). Forested climate analogues persist across much of Canada but with a notable change along the south-western boreal boundary with pronounced shift toward grassland-associated climates. Long-distance climate matches occur in he Rocky Mountain foothills, with limited nearby analogues.

When results are summarized for the 22 forest management areas of DIVERSE project partners (Fig. 2a), forest cover is largely maintained across most regions under projected climates (Fig. 2b). Declines are concentrated in a small number of southern boreal areas, including Peace River East and Pasquia–Porcupine. In contrast, the diversity of potentially suitable tree species generally increases over time in many regions, particularly in central and eastern Canada (Fig. 2c), reflecting the emergence of suitable conditions for species currently found further south.

Changes in species composition are illustrated in Table 1 for the Haliburton forest management area. Most currently dominant species remain suitable under future climates, but their relative importance shifts over time. For example, species such as red maple increase in importance, while species associated with cooler climates, such as paper birch and balsam fir, decline. At the same time, several species currently present at low abundance increase in importance, representing potential candidates for assisted migration. These results indicate that adaptation is achieved primarily through changes in seed sourcing and relative species composition, rather than wholesale replacement of species.

Ecosystem delineations capture a large proportion of variation in soil properties (Table 2), supporting their use as a practical basis for incorporating edaphic constraints. Applying soil similarity as a secondary filter refines climate matches without substantially altering overall patterns, allowing ecologically implausible matches to be excluded while maintaining the climate signal.

Overall, the results show that climate change leads to gradual but meaningful shifts in species suitability and seed sourcing across most regions. For forest management, this implies that adaptation can often be achieved through incremental adjustments, particularly in seed sourcing, while maintaining familiar species assemblages. However, some regions, especially in western Canada, show weaker climate analogues and may require broader changes in species selection.

The ecosystem-level approach presented here provides a practical framework for interpreting these changes at management-relevant scales. It is implemented in a web-based seed selection tool (http://tinyurl.com/DIVERSE-SST), which allows users to explore climate- and soil-matched species and seed source options for specific forest management areas.

Table 1. Species selection table for the Halliburton forest management area. The values are the average of the 5 closest climate matches for each climate period, and values are the expected percent of the landbase. Non-forested area is rescaled to remove human disturbance. This is an abbreviated table for illustration. Full tables for all ecosystems and forest management areas are available via the web tool *http://tinyurl.com/DIVERSE-SST*.

Scientific name	Common name	1960s	1990s	2020s	2050s	2080s
	non-Forested	39.07	34.29	38.29	32.35	36.52
Acer saccharum	sugar maple	10.75	7.72	6.76	6.38	3.09
Pinus strobus	eastern white pine	5.07	7.8	7.05	5.18	1.72
Acer rubrum	red maple	4.54	6.84	8.94	9.35	5.21
Quercus rubra	northern red oak	2.43	3.14	2.89	3.63	3.27
Betula papyrifera	paper birch	4.59	4.05	1.39	0.48	0.16
Abies balsamea	balsam fir	4.25	4.14	1.79	0.3	0.03
Prunus serotina	black cherry	0.43	1.02	2.21	3.13	4.43
Ulmus americana	American elm	0.11	0.15	0.7	1.38	2.73
Quercus alba	white oak	0.08	0.11	0.36	2.56	3.52
Fraxinus pennsylvanica	green ash	0.06	0.04	0.21	1.43	3.75

Table 2. Percentage of total variance in each soil variable explained by ecozone classification, based on an analysis of variance.

Soil Variable	R^2
Bulk Density (cg/cm^3)	0.92
pH (pH)	0.92
Cation Exchange Capacity (mmol/kg)	0.90
Nitrogen (g/kg)	0.89
Organic Carbon Density (hg/dm^3)	0.88
Coarse Fragment Volume (cm^3/dm^3 vol%)	0.80
Clay (g/kg)	0.78
Silt (g/kg)	0.77
Sand (g/kg)	0.76
Soil Organic Carbon (SOC, dg/kg)	0.85

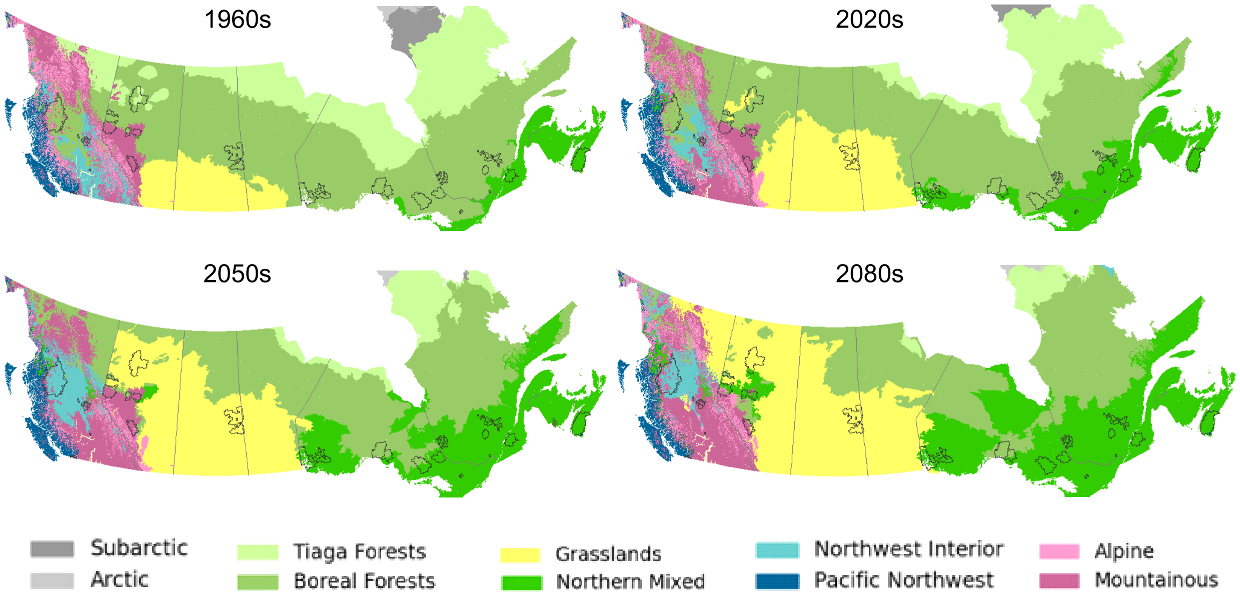

Figure 1. Shifts of suitable climate habitat based on CMIP6 SSP2-45 (middle-of-the-road) multi-model climate projections. Colors represent a majority biome classification, according to the 5 closest source-target ecosystem climate matches. Forest management areas used in subsequent analysis (Fig. 2) are shown as black outlines

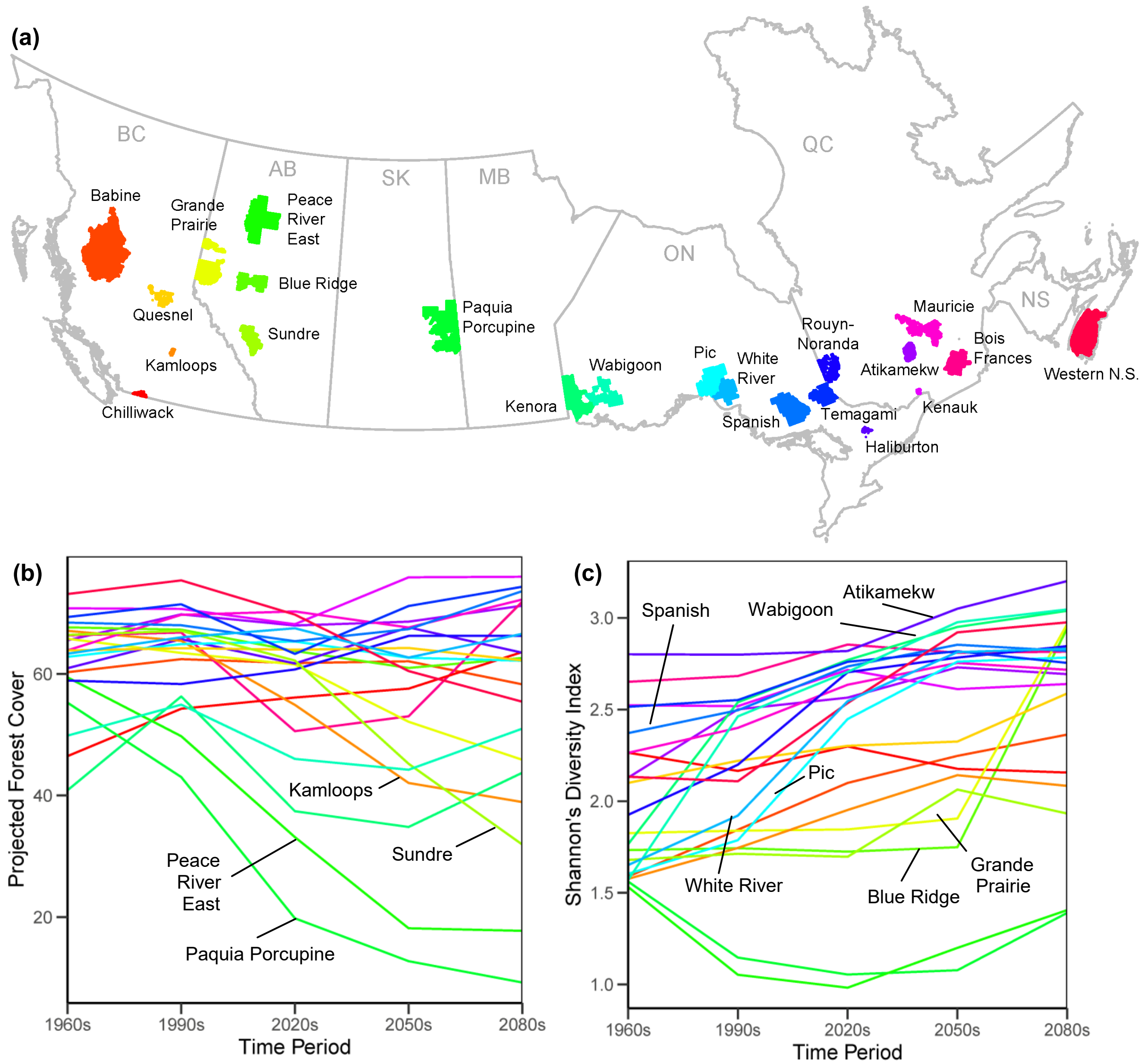

Figure 2. Maintenance of climatic habitat for forest tree species, summarized for 22 forest management areas of DIVERSE project participants **(a)**. The line plots show the sum of historic and future climate habitat **(b)**, and the diversity of potential tree species habitat **(c)**.