UNIVERSITY OF ALBERTA

Integrating Soil and Climate Drivers to Improve Assisted Reforestation in North America under Climate Change

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Website:

DIVERSE

BACKGROUND

- Tree species and their populations are adapted to specific combinations of climate, soil, and biotic factors, but warming temperatures may result in maladaptation.[1]
- To address these mismatch, foresters assist with reforestation by moving planting stock north and up in elevation to compensate for climate change, but static soil conditions need to be considered. [2,3]
- Historically, managers rely on seed zones or ecosystem delineations (ecozones) to guide seedlot selection. [4,5] These ecozones often represent soil patterns or underlying geology and therefore have the potential to serve as proxies for soil filters within the sequential selection. [6,7]
- This study aims to develop a two-stage approach to guide assisted migration: first, identifying areas that are climatically suitable, then refining these recommendations based on soil conditions.

STUDY OBJECTIVES

- Map soil variables across North American ecozones and assess where ecozones serve as effective soil proxies to be used for regional-scale reforestation and seed transfer guidance.
- Develop a Sequential modelling framework that integrates climate matching with ecozone-level soil predictor filtering.

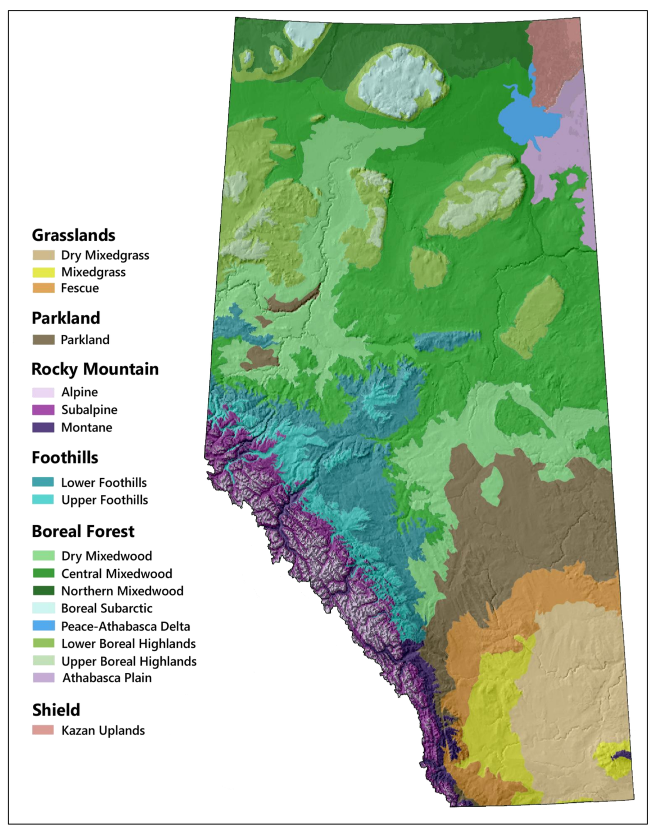


Fig.1. Map of major Alberta Ecozones.

SOIL PROPERTIES VARY MORE BETWEEN ECOZONES THAN WITHIN THEM

Table 3. Percentage of total variance in each soil variable explained by ecozone classification, based on one-way ANOVA results. Soil properties that exhibit percentages above 85% are starred.

Soil Variable	Variation Between Ecozones (%)
Bulk Density (cg/cm³)	92.6*
pH (pHx10)*	92.1*
Cation Exchange Capacity (CEC, mmol/kg)*	90.4*
Nitrogen (kg/kg)*	89.6*
Organic Carbon Density (OCD, hg/dm³)*	88.9*
CEC (Deep, mmol/kg)*	88.5*
SOC (Deep, dg/kg)*	86.1*
Coarse Fragment Volume (CFV, cm³/dm³ vol%)	80.2
Clay (g/kg)	78.3
Silt (g/kg)	77.2
Sand (g/kg)	76.9
Nitrogen (Deep, kg/kg)*	90.1*
OCD (Deep, hg/dm³)	89.0*
Soil Organic Carbon (SOC, dg/kg)	85.7*

* Indicates values for which >85% of the variance was explained by ecozones.

RANDOM FOREST MODELS ARE CURRENTLY MORE EFFECTIVE

- Random forest models exhibit lower mean absolute error on average, and consistently higher R^2 values on average.

MODEL EFFICACY IS SPECIES DEPENDENT

- Different species have different ecological niches, range sizes, etc. No single combination of predictors universally optimizes performance across taxa.

MODEL COMPLEXITY ≠ MODEL EFFICACY

- Despite Soils and Land Cover Probability displaying a noticeable effect in the DNN, the more effective Random forest model shows no significance.

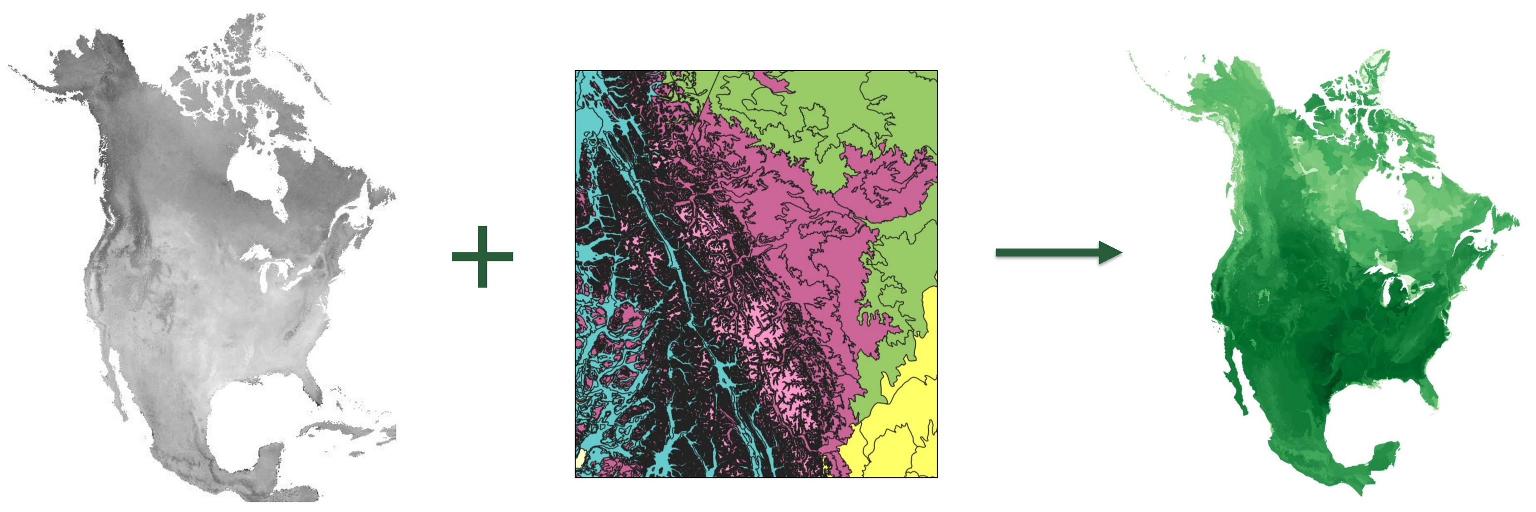
NEXT STEPS

Model performance demonstrated variability across predictor sets and species, indicating substantial opportunity for refinement. The DNN framework is inherently sensitive, and must be fine-tuned. Future efforts will be directed toward increasing spatial resolution and improving the integration of fine-scale environmental predictors to better capture localized ecological processes. The refined modelling framework will ultimately be incorporated into the DIVERSE seed selection tool, enabling evidence-based decision-making for climate-informed reforestation and assisted migration across North America.

[1] Stahl, U., Reu, B., & Wirth, C. (2014). Predicting species' range limits from functional traits for the tree flora of North America. Proceedings of the National Academy of Sciences, 111(38), 13739–13744. https://doi.org/10.1073/pnas.1300673111
[2] Franklin, J., Davis, F. W., Ikegami, M., Syphard, A. D., Flint, L. E., Flint, A. L., & Hannah, L. (2013).Modeling plant species distributions under future climates: How fine-scale do climate projections need to be? Global Change Biology, 19(2), 473–483. https://doi.org/10.1111/gcb.12051
[3] Illés, G., & Móricz, N. (2022). Climate envelope analyses suggests significant rearrangements in the distribution ranges of Central European tree species. Annals of Forest Science, 79(1), 35. https://doi.org/10.1186/s13595-022-01154-8
[4] Etterson, J. R., Cornett, M. W., White, M. A., & Kavajecz, L. C. (2020). Assisted migration across fixed seed zones detects adaptation lags in two major North American tree species. Ecological Applications, 30(5), e02092. https://doi.org/10.1002/eap.2092
[5] Hamann, A., Gylander, T., & Chen, P. (2011). Developing seed zones and transfer guidelines with multivariate regression trees. Tree Genetics & Genomes, 7(2), 399–408. https://doi.org/10.1007/s11295-010-0341-7
[6] Bradley, O., Keßler, D., Gadermaier, J., Mayer, M., & Leitgeb, E. (2025). Soil: The Foundation for Ecological Connectivity of Forest Ecosystems. In K. Lapin, J. Oettel, M. Braun, & H. Konrad (Eds.), Ecological Connectivity of Forest Ecosystems (pp. 123–139). Springer Nature Switzerland. https://doi.org/10.1007/978-3 031-82206-3_7
[7] Diamond, J. S., McLaughlin, D. L., Slesak, R. A., & Stovall, A. (2020). Microtopography is a fundamental organizing structure of vegetation and soil chemistry in black ash wetlands. Biogeosciences, 17(4), 901–915. https://doi.org/10.5194/bg-17-901-2020
[8] Poggio, L., De Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E., & Rossiter, D. (2021). SoilGrids 2.0: Producing soil information for the globe with quantified spatial uncertainty. SOIL, 7(1), 217–240. https://doi.org/10.5194/soil-7-217-2021

METHODS

1. WITHIN/BETWEEN ECOZONE VARIANCE



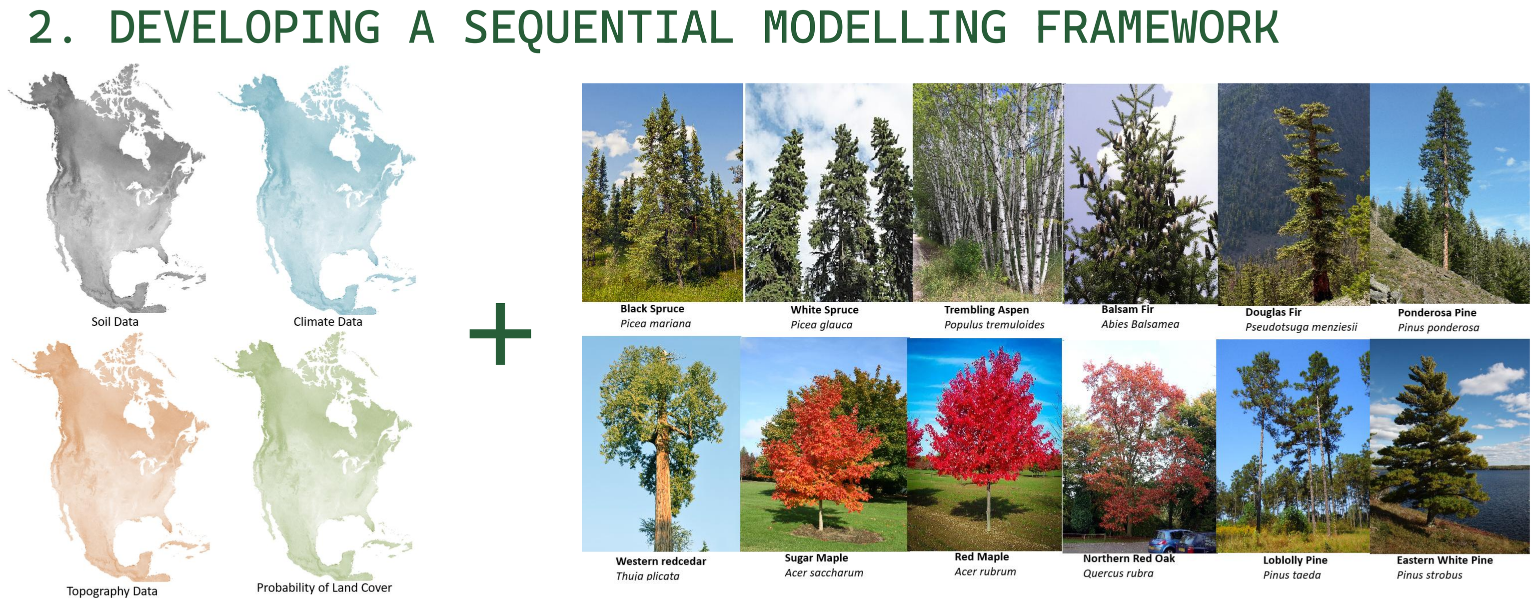
Soil Data (SoilGrids 2021)

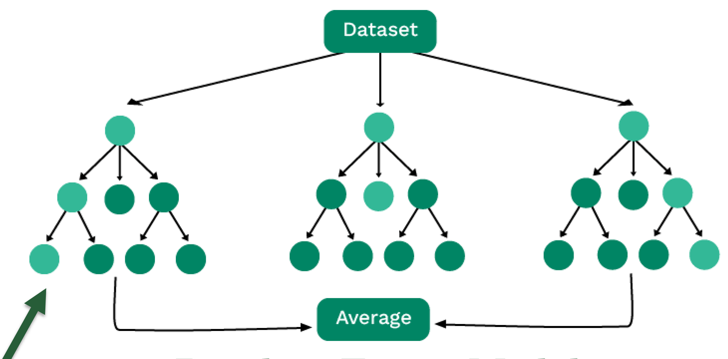
Ecozone Delineations (Various sources)

Average Soil Parameters by Ecozone

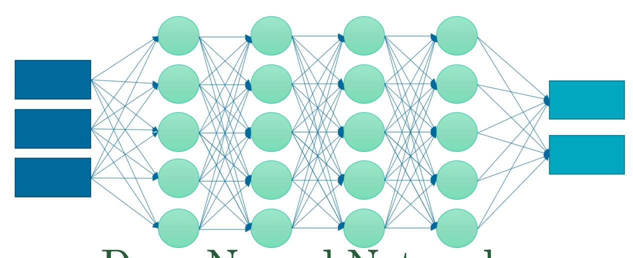
ANOVA Analysis to assess Between/Within Ecozone Variance

2. DEVELOPING A SEQUENTIAL MODELLING FRAMEWORK





Random Forest Model



Deep Neural Network (DNN)

MAJOR FINDINGS

ECOZONE AVERAGES ACCURATELY REPRESENT RAW SOIL DATA

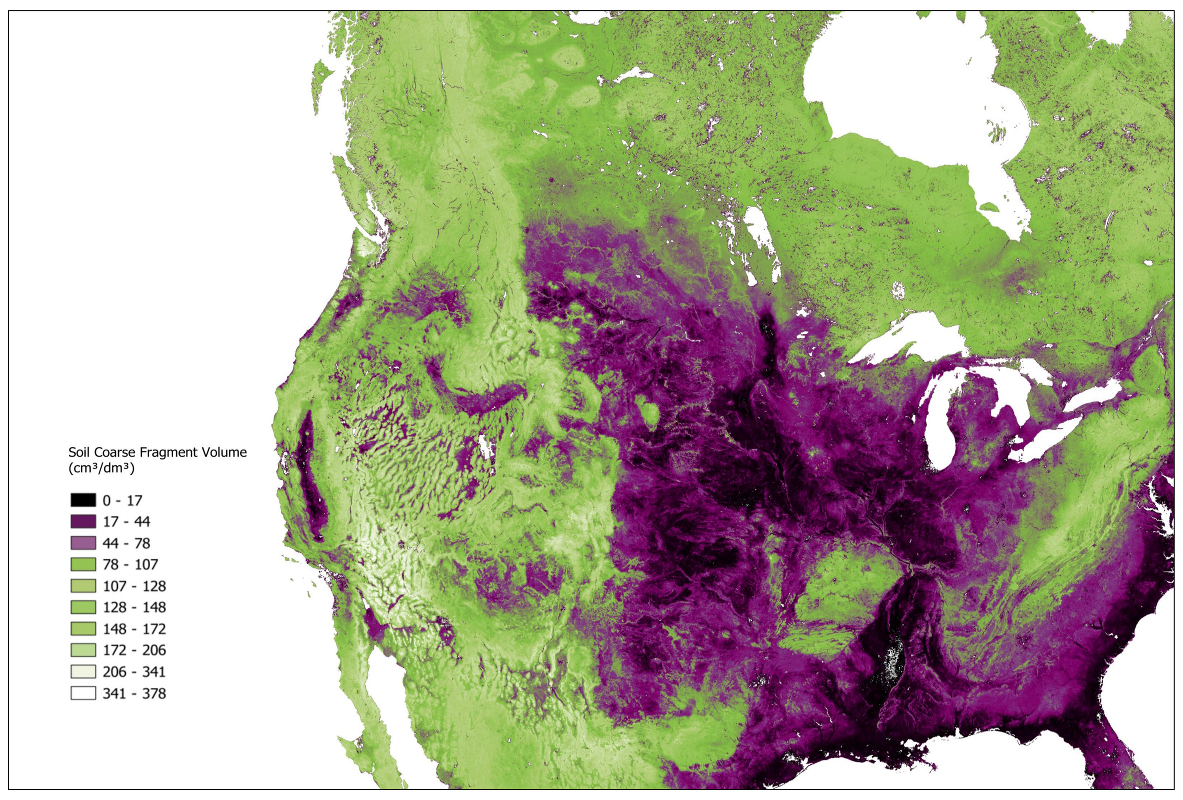


Fig. 2. Map of North America, depicting raw coarse fragment volume (CFV) data within the 15-30cm layer.

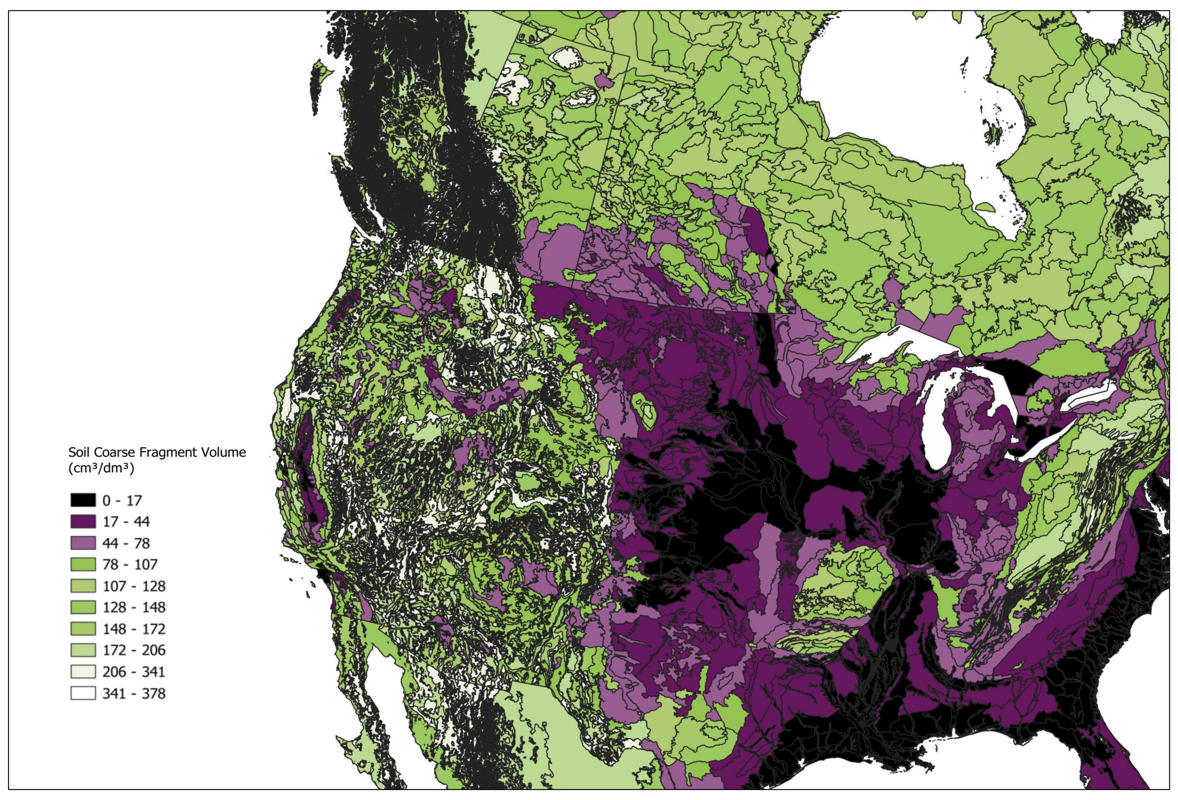


Fig. 3. Major Ecozones of North America, depicting average coarse fragment volume (CFV) across all depth layers

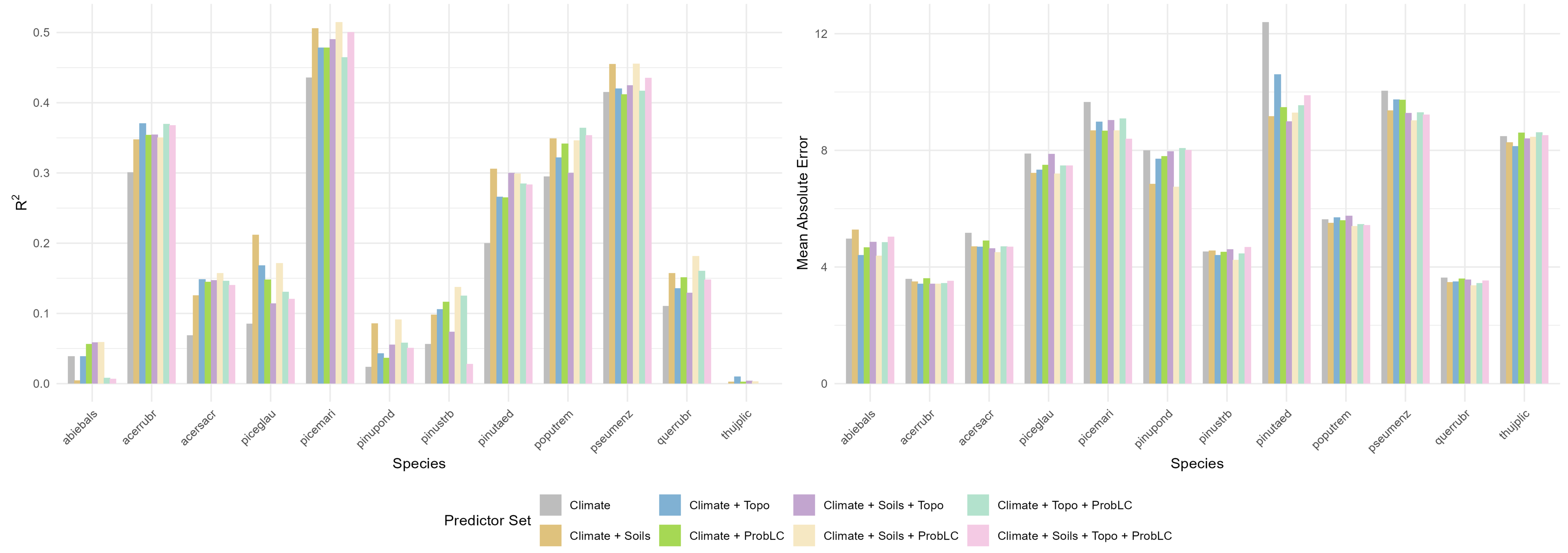


Fig. 3. R^2 and mean absolute error for a deep neural network model, of the twelve study species. comprised of different predictor combinations. Model trained on Aggregated forest plot data.

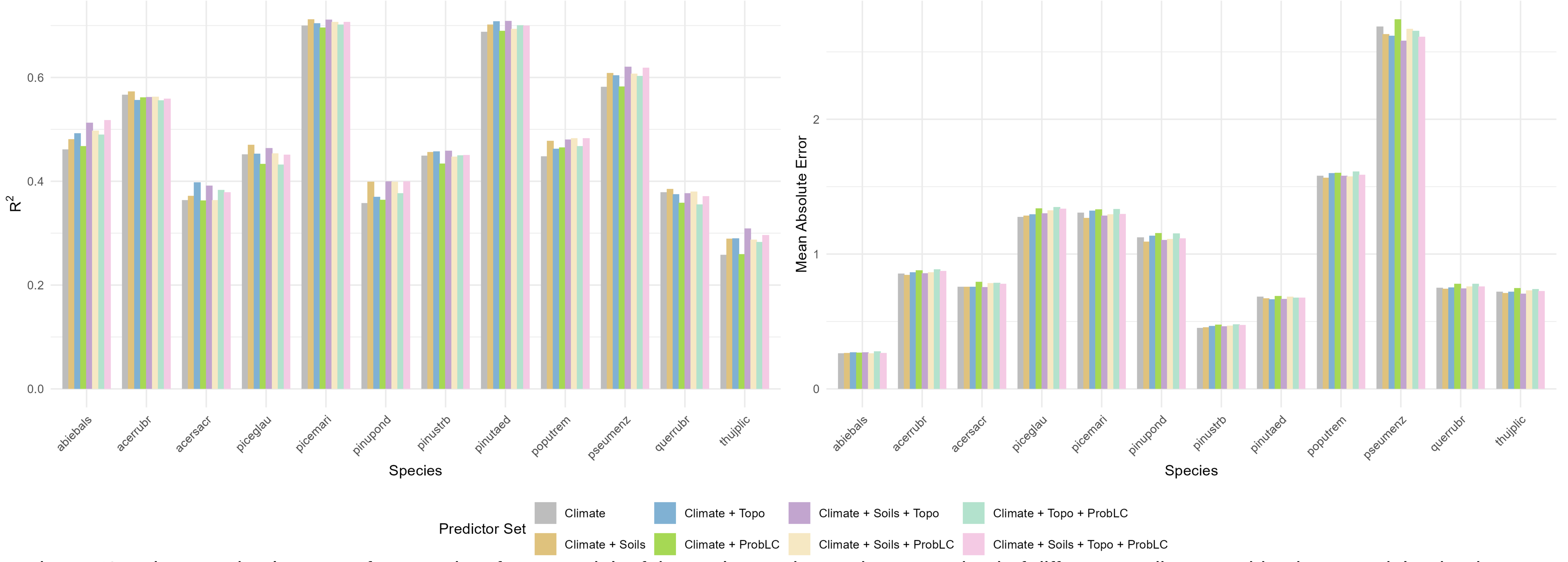


Fig. 4. R^2 and mean absolute error for a random forest model, of the twelve study species. comprised of different predictor combinations. Model trained on Aggregated forest plot data.