Predicted forest structure patterns across the North American taiga-tundra ecotone

Variation in regional changes through 2100 from an individual-based forest growth model

Project
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Summary

Updating and applying a high resolution forest growth model to predict changes at a biome boundary: We updated and applied the individual-based forest growth model SIBBORK-TTE to simulate changes at a variety of sites in and near the taiga-tundra ecotone in Alaska and NW Canada. We developed tools to link a variety of remotely sensed datasets from multiple spatial resolutions and use them to vary simulations of the generation, growth, and mortality of individual trees at 10 m spatial scales across 900 ha. site extents.

We use these new developments in this individual-based modelling approach for examining forest dynamics to study the changes in forest structure and composition across heterogeneous TTE landscapes that are influenced by environmental factors operating across many scales.

Our results capture important regional variations in the magnitude, location, and rates of species-level changes in woody vegetation structure through 2100.

Model development 1: ingesting remote sensing data & updating future climate

Integrating remote sensing data to capture environmental heterogeneity across large modeling extents: To account for current landscape patterns **we built routines to ingest a data cube of topography and land cover maps at a consistent grid to depict site heterogeneity and vary simulation by individual pixels across broad site extents.**

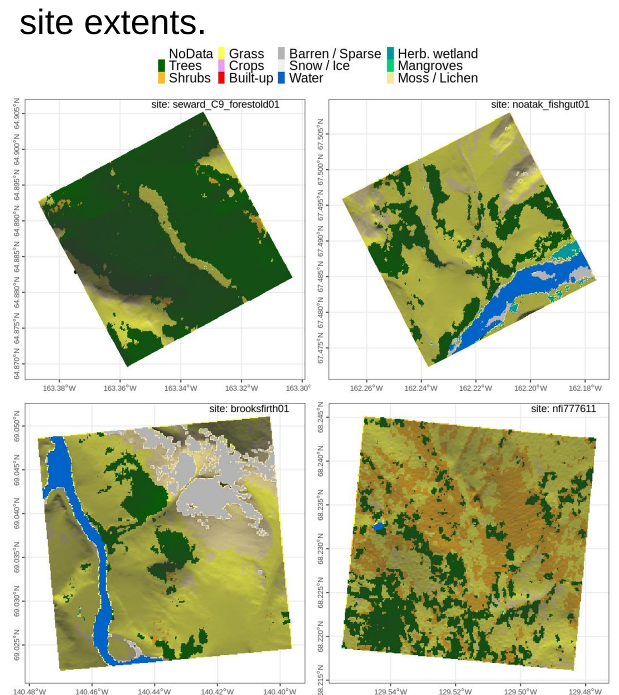

Figure 1. The topography & land cover of 4 sites (left) demonstrate the variation of TTE landscapes examined in this study. Tree-level simulations were driven by spatially variable information that include these datasets. We used this new capability of accounting for detailed current landscape patterns to guide current and future simulations of vegetation growth. The resulted in simulations that are spatially explicit in a way that match real-world vegetation patterns.

Accounting for climate: we built routines to incorporate current and future temperature and precipitation arrays from MERRA2 and CMIP6 gridded climate data. We merge these data to create a climate time series of temperature and precipitation for each site. We incorporate this climate time series into SIBBORK-TTE and use it to simulate individual tree growth across spatial extents initialized with current site conditions based on topography and land cover, and average monthly solar radiation using remotely sensed cloud fraction (Fig. 2).

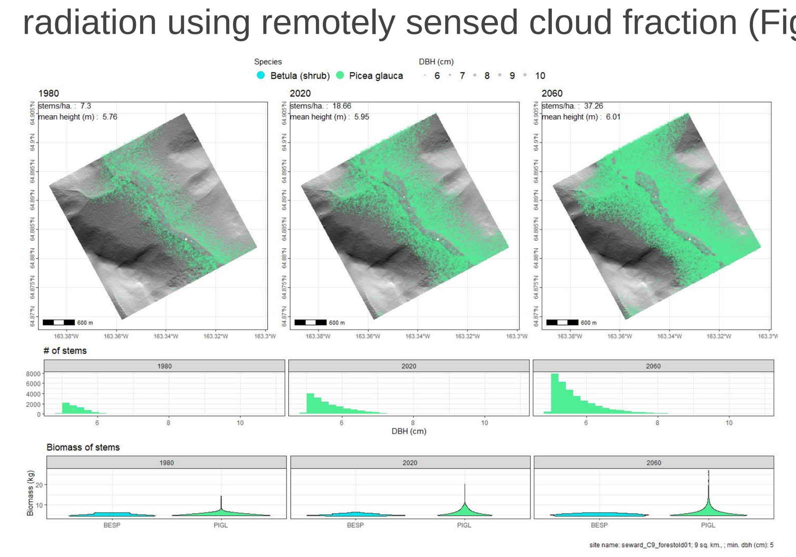

Figure 2. We updated SIBBORK-TTE to incorporate gridded inputs associated with environmental factors at multiple scales. These developments result in individual tree simulations that vary over time and space within a simulation extent in a manner that linked to landscape spatial patterns. Here, the DBH for 3 years of simulations are mapped over the a Seward Peninsula site's hillshade. From 1980 - 2060, the number and pattern of simulated trees change, increasing more on south faces.

Model development 2: simulation of permafrost seasonality

Building and validating permafrost seasonality: we built a permafrost module to simulate the active layer thickness (ALT) of permafrost. Simulations produce monthly estimates of across all years of the simulations for each site grid's 10 m pixel (Fig. 3). The grid-cell variation in ALT across sites allows for representation of permafrost variability across heterogenous extents of continuous and discontinuous permafrost - an important driver of vegetation patterns in the TTE.

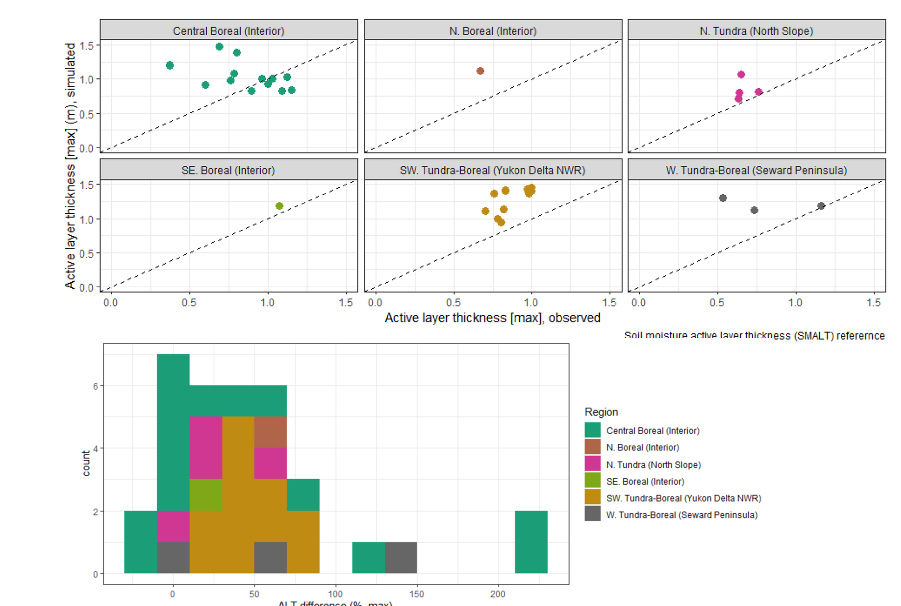

Figure 3. Results from the validation of simulated permafrost maximum active layer thickness (ALT) at model validation sites across 6 regions in Alaska. Reference observations were derived from from the SMALT (Schaefer et al. 2021) and CALM (Brown et al. 2000) datsets. These observations were matched to simulations at the pixel level, using the centroid of each observation at the simulation corresponding to the same month and year of the reference observation. Uncertainties in the geolocation at the pixel-level contribute to these conservative (worst-case) correspondences.

Study design:

Targeting ecotone study sites: We used a Landsat tree cover based map of forest structure pattern and field-derived forest composition & structure (using existing field plots and published accounts) to build a database of 900 ha. target sites for simulation in and near the TTE across Alaska and NW Canada. These sites were grouped into 8 regions subject to a range of vegetation, topography, and climate gradients across forests in and near the TTE. Simulations of woody vegetation (trees & shrubs) track composition and structure across landscape initialized to current patterns of vegetation structure (Fig. 4).

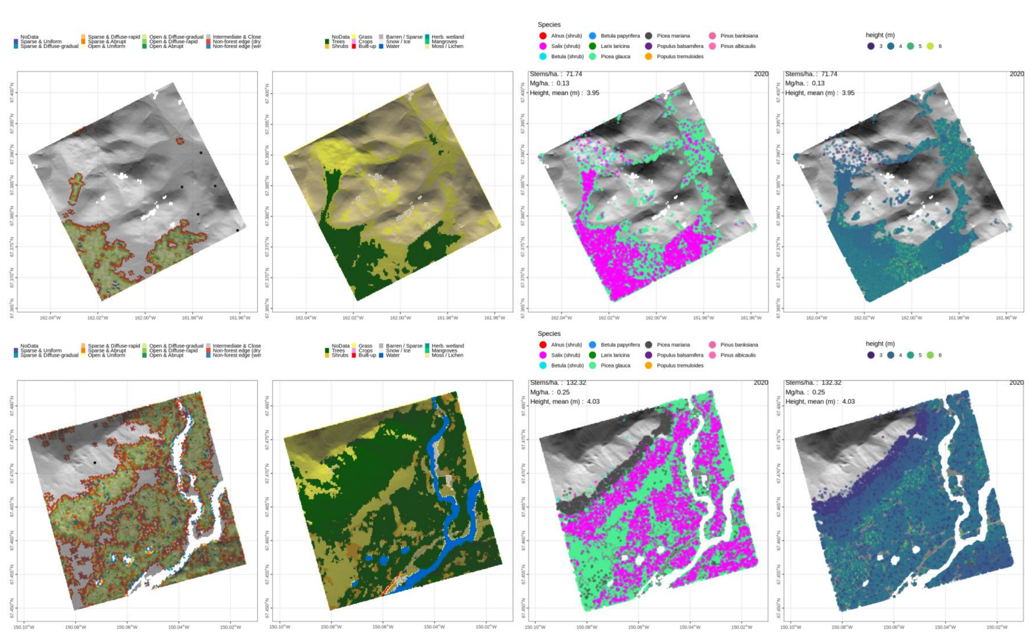

Figure 4. We targeted ecotone sites using a map of the current TTE (Montesano et al. 2020). Simulations overlaid on current datasets reproduce patterns of heterogeneous vegetation common across arctic-boreal landscapes. Here, 2 sites in the Brooks Range (Gwahzal) show how composition and density according to topography and land cover. Maps show (left to right): *TTE pattern, land cover, species, height (m)*.

Model application:

Calibrating the model for the TTE: At a subset of study sites, we calibrated SIBBORK-TTE with forest composition and structure from field-derived stem density, height, and biomass to establish robust simulation of TTE vegetation.

Running the model: We ran SIBBORK-TTE across tree, shrub, and grass land covers from 1800-2100 using a CMIP6 SSP585 scenario for 47 individual 900 ha. sites at 10 m resolution. These runs produced a database of simulated tree growth time series across 8 regions in and near the TTE (Fig. 5).

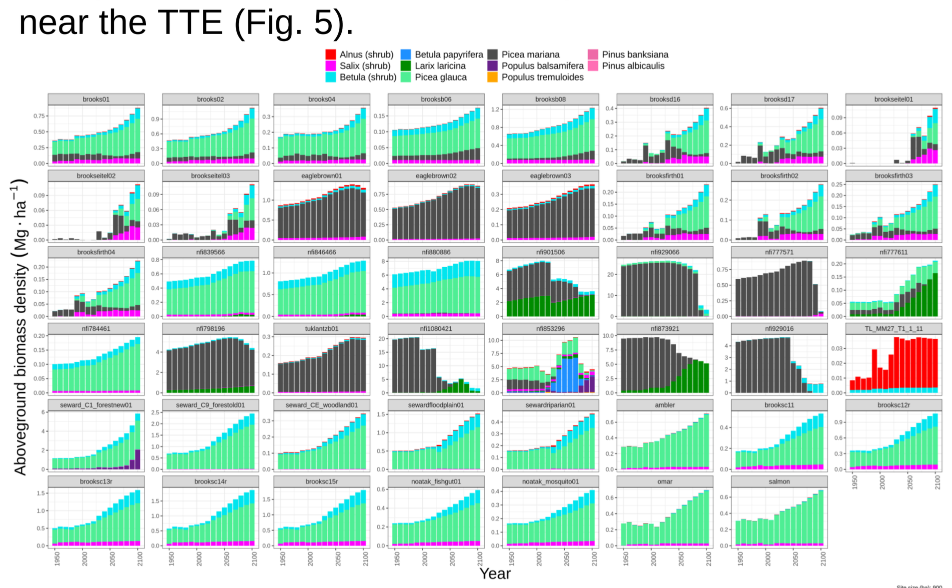

Figure 5. The database of simulations at 47 TTE sites shown as AGB time series from 1950-2100.

Results: predictions of regional variation in structure & composition change through 2100

Simulations suggest forest structure changes through 2100 will be significant, but regionally variable (Fig. 6). *P. glauca* and *P. mariana* (the most prominent species in the simulations) show regional variation in abundance and change trajectories. Simulations in the Brooks Range (Gwazhal) show faster rates of positive change in *P. glauca* from east to west. They fail to reproduce a decoupling of increasing temperature and growth (the divergence problem). Predictions of negative changes are most prominent in *P. mariana* for sites in the eastern regions of the TTE study domain. These predictions of negative changes in biomass among conifer species accompany positive biomass change in deciduous species after 2050.On the Seward Peninsula, where deciduous trees are present on the landscape, their share of the woody biomass increases markedly after 2050 .

Figure 6. Regional aggregations of the simulated change in the composition of aboveground biomass of woody vegetation at 10-year intervals from 1950 - 2100.