Assessing Vegetation Shifts in Boreal Alaska by Integrating Landsat Imagery with Spatial Modeling

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Background

Boreal forests are one of earth's largest terrestrial biomes, with one-third of terrestrial carbon stored above and below ground. High-latitude ecosystems are undergoing arctic amplification, with climate change altering the fire regime and vegetation. For example, this region is shifting from primarily coniferous to deciduous tree cover, and this is especially pronounced in North America. Analyses which assess how these regions are changing over space and time are important for land management, ecological conservation, and policy.

The objective of this study is to use random forest algorithms with remotely sensed imagery and forest landscape modeling to quantify the spatiotemporal dynamics of carbon storage of four tree species in interior Alaska from 2000-2023.

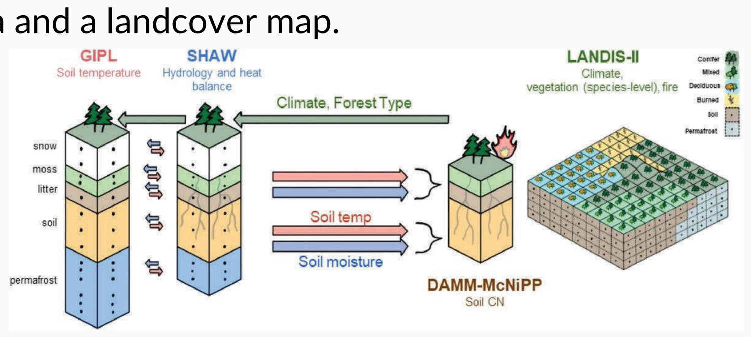
RQ 1: How do species aboveground carbon estimates differ between random forest and LANDIS-II?

RQ 2: How will climate change influence future forest composition and ecosystem carbon cycling within LANDIS-II?

Methods

Using measurements from the Cooperative Alaska Forest Inventory (CAFI), we built random forest models of species aboveground carbon density using the "tidymodels" package in R. Predictor data to use in the model was derived from Landsat, ALOS, and WorldClim using the Google Earth Engine platform. Models were trained for individual species and then run from 2000-2023. To simulate future changes in forest dynamics, we used LANDIS-II, which is a spatially-interactive forest landscape model equipped with modular extensions reflective of different ecosystem processes. In this study we use the Damm-McNiPP-GIPL-SHAW or "Digs" and Social-Climate-Fire extensions to simulate growth, mortality, regeneration, and wildfire from 2000 to 2100. We used three climate streams: historic stream which resamples 1970-1999, and two future (NCAR-CCSM4 and GFDL-CM3)(RCP 8.5). We created a map of initial conditions from FIA data and a landcover map.

LANDIS-II



Study Area

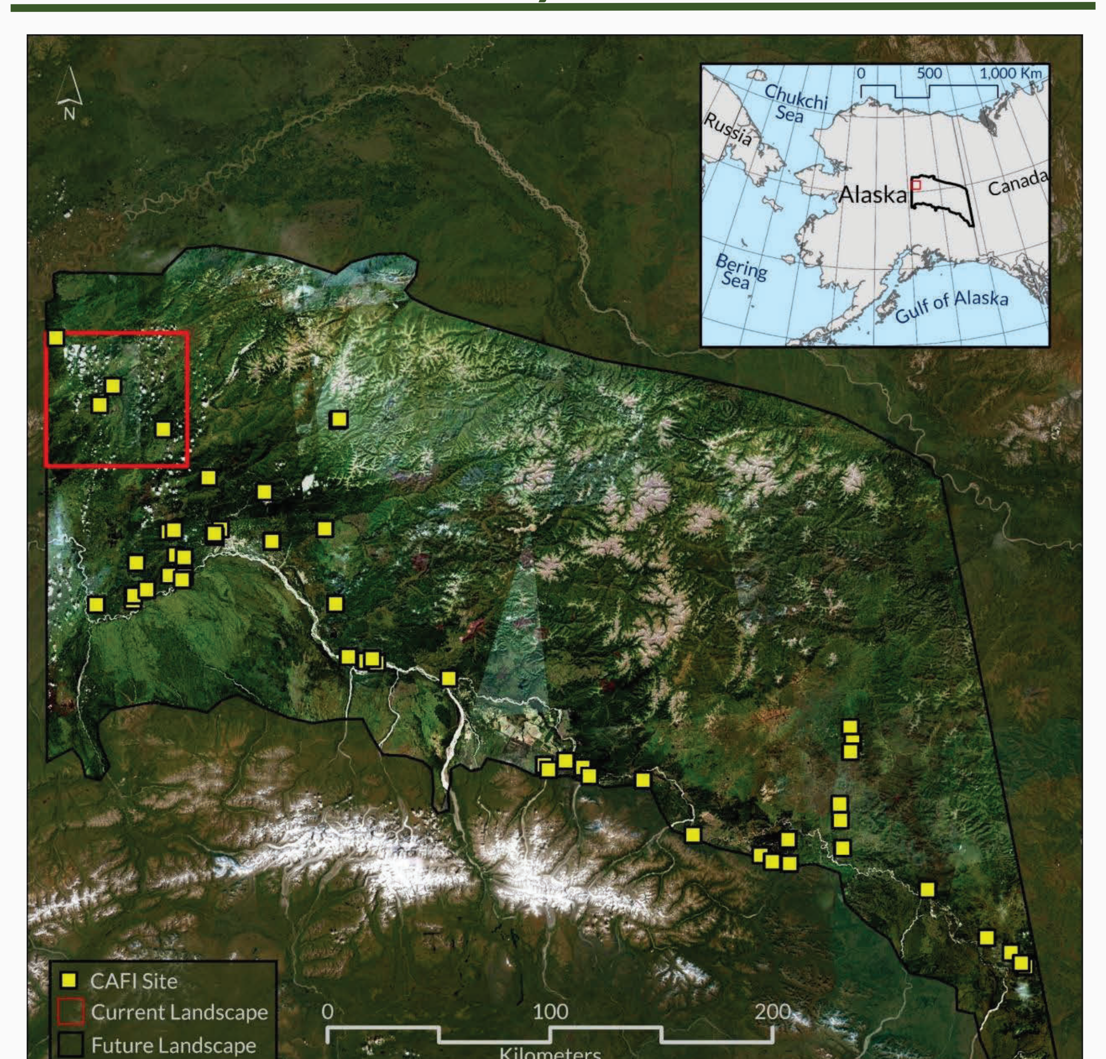


Figure 1: Study landscape in interior Alaska bounded by the Brooks Range to the North and the Alaska Range to the south. This region is topographically complex with vast boreal tree cover with conifer and deciduous species. The primary disturbance is wildfire and tends to be infrequent and stand-replacing in behavior. We limit our analyses in this study to the red bounding box, however, remote sensing information was acquired across all CAFI Sites (yellow).

Methods Continued

Remote Sensing

1. Calculate response variable and build model dataset

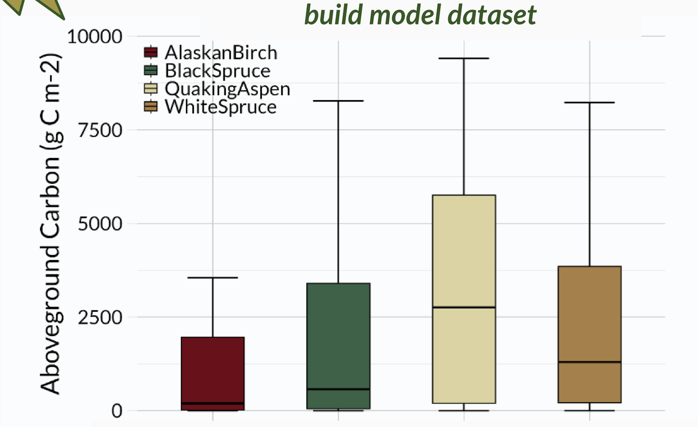
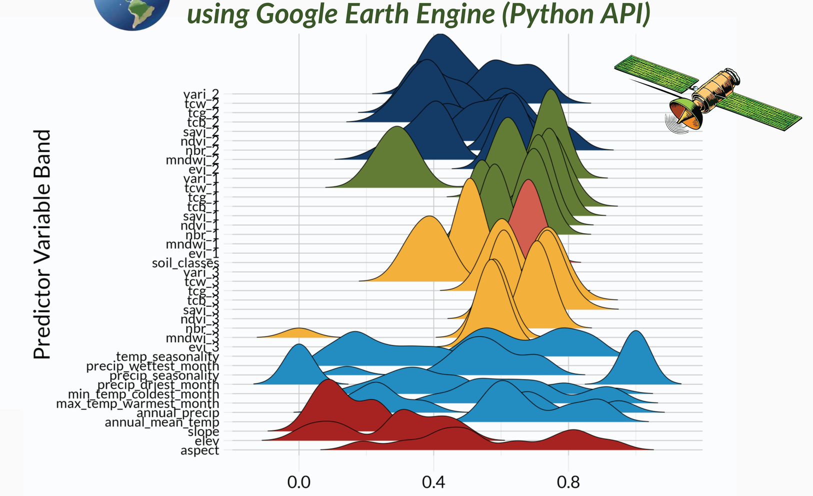
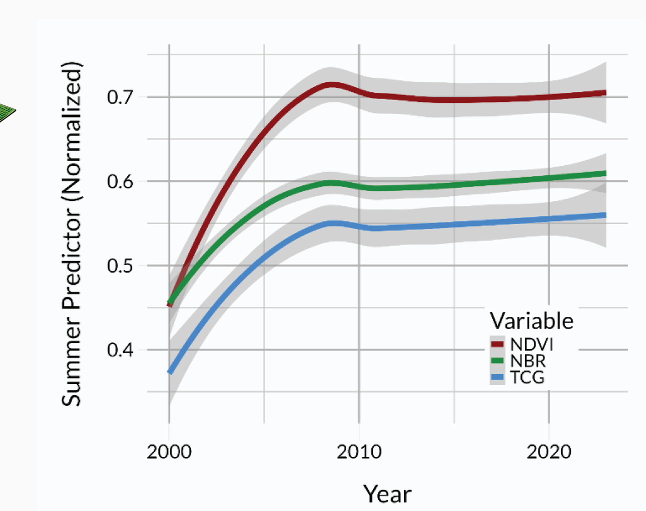


Figure 2: Measured carbon across species in situ from 2015 as calculated using Jenkins equations. Quaking Aspen had the highest carbon in this sampling year.

2. Image acquisition and preprocessing using Google Earth Engine (Python API)



3. Assess dynamics of input data



Forest Modeling

LANDIS-II Input Maps and Climate Streams

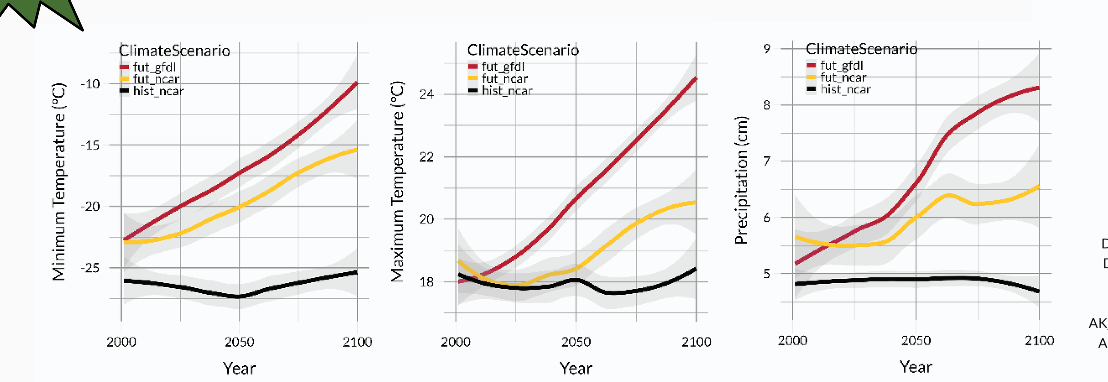
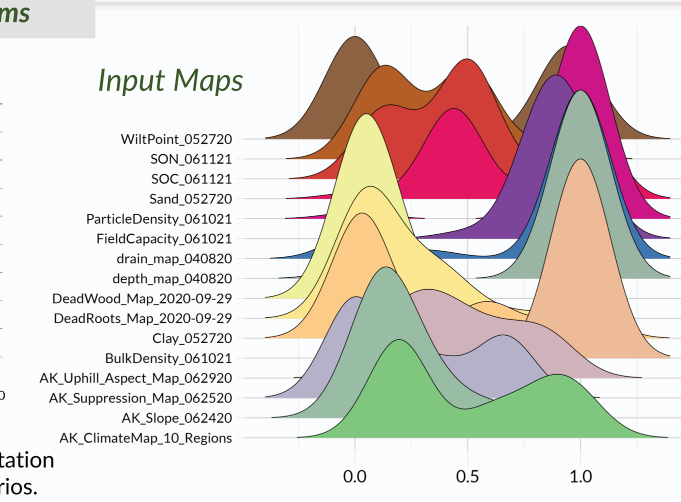
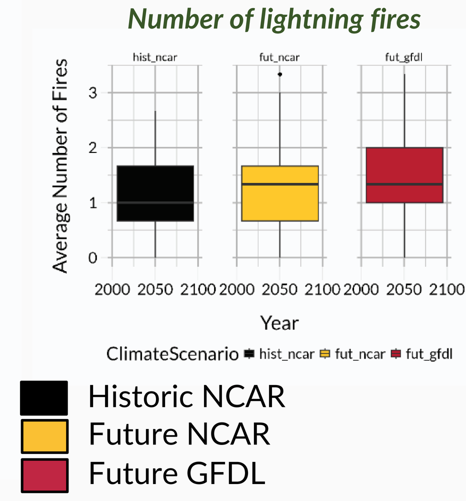


Figure 3: LANDIS-II climate scenarios through the study period. Overall, a steady increase in precipitation and temperature across the landscape (averaged over 3 replicates) for the two climate change scenarios.

Input Maps



Number of lightning fires



Results

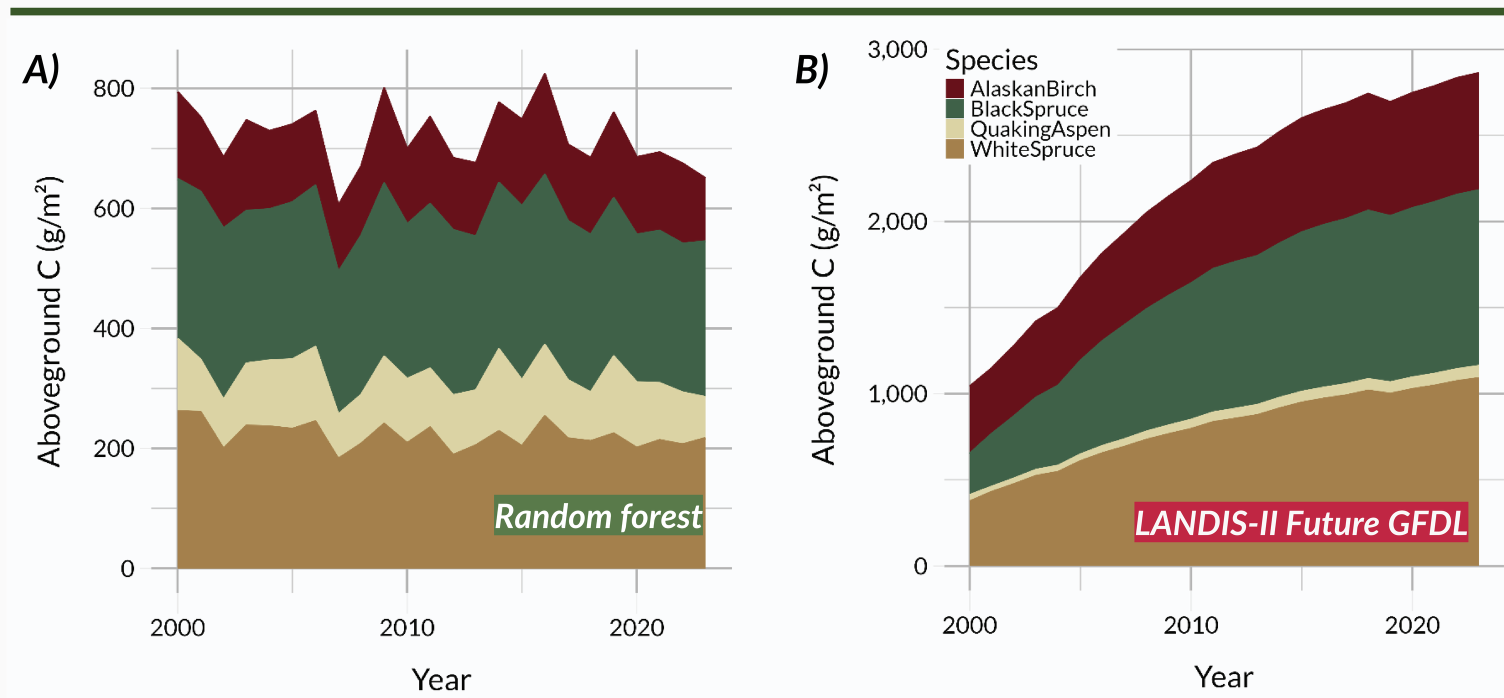
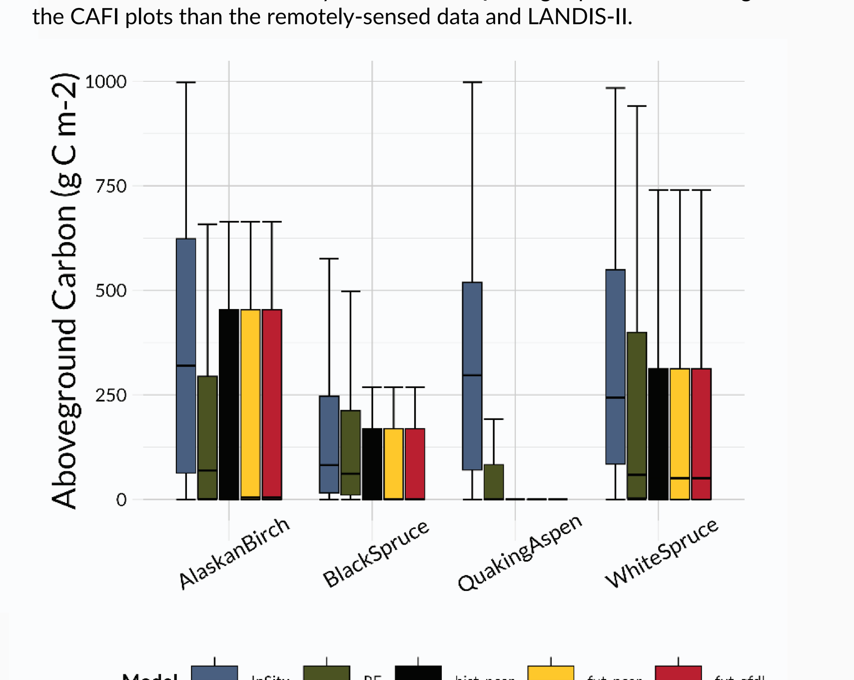


Figure 4: Aboveground C estimates (gC/m²) across the landscape from the two methods (LANDIS-II– left, Random forest - right), for two conifer and two deciduous tree species. Estimates derived from random forests indicate annual variability as shown by the jagged lines. LANDIS-II estimates are initially comparable to random forest estimates in year 2000, however substantially increase throughout the study period, almost doubling for some species by 2023.

Figure 5: Aboveground carbon estimates in 2015. The overall trend is such that the median aboveground carbon is highest in situ (CAFI plots), followed by the random forest estimates with remotely-sensed data. Quaking aspen had much higher C in the CAFI plots than the remotely-sensed data and LANDIS-II.



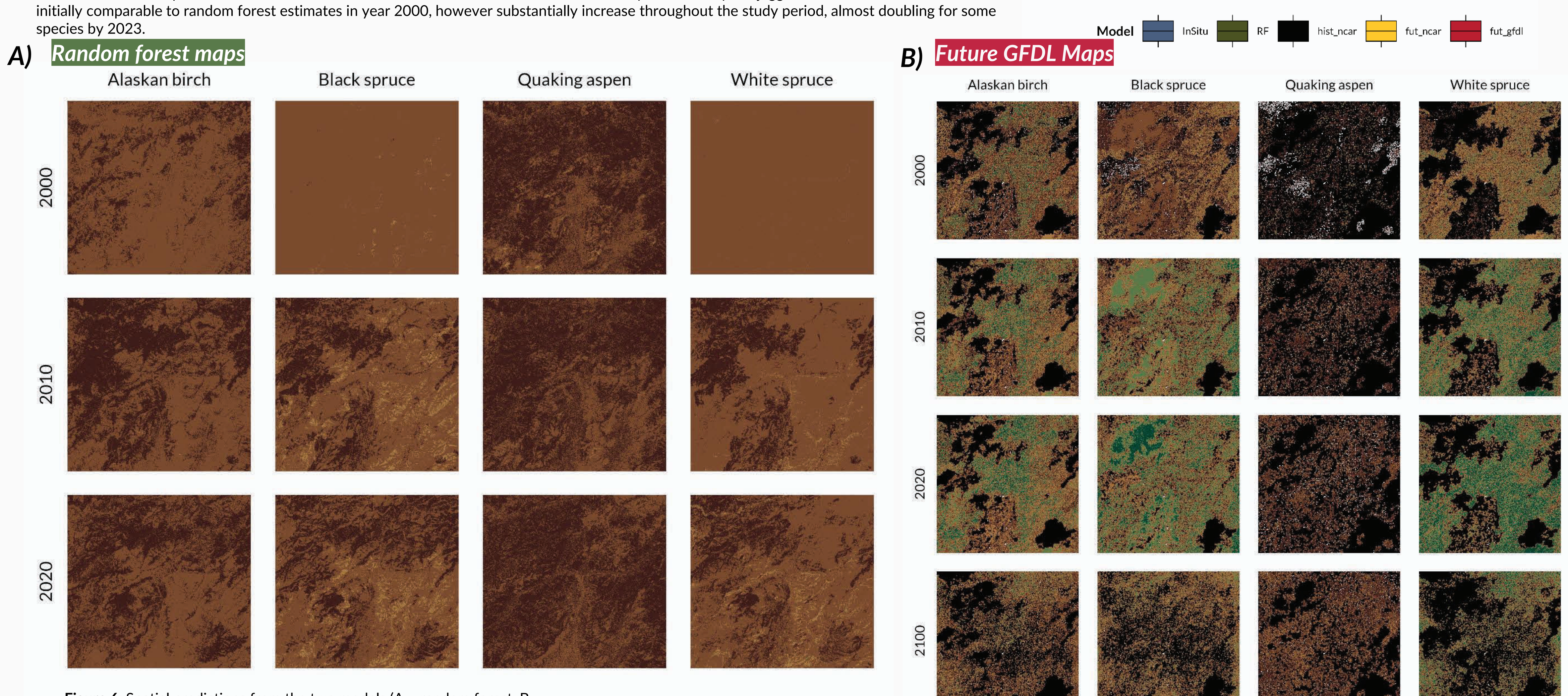


Figure 6: Spatial predictions from the two models (A – random forest, B – LANDIS-II). Panel A suggests that the distribution of carbon has a wider range in 2010 and 2020 compared to 2000 for all species. In comparison, Panel B shows more aboveground carbon at same simulation years as the random forest for the four species. Moreover, there is an increasing trend in aboveground carbon from 2000-2023 B which is not obvious in A, however, by 2100 there is substantial loss in aboveground carbon for the four species.

g C m-2

Inactive	500 – 1,200	1,200 – 2,350
1 – 100	100 – 500	2,350 – 7,050

Conclusion

We assessed dynamics of aboveground carbon density for four tree species in interior Alaska across 380,400 hectares from 2000-2023 and found differences in the estimated carbon in the year 2015 derived from the two models when compared to in situ measurements from the same year. Both models underrepresented aboveground carbon of quaking aspen. The random forest results suggest more year-to-year variability in aboveground carbon than LANDIS-II (Figure 4A). Figure 4A also shows that by 2023 the average amount of aboveground carbon for the four species across the landscape did not deviate substantially from estimates in 2000.

Despite more area burned, high aboveground carbon estimates from LANDIS-II suggest that warmer climate and precipitation lend favorable conditions for tree establishment and reproduction through DGS processes (Figures 3 & 4B). However, by the year 2100 there is substantial loss in aboveground carbon density for all species (Figure 6B).This research shows the challenges involved in model integration and obtaining accurate estimates of aboveground carbon at a landscape scale.

Future Work

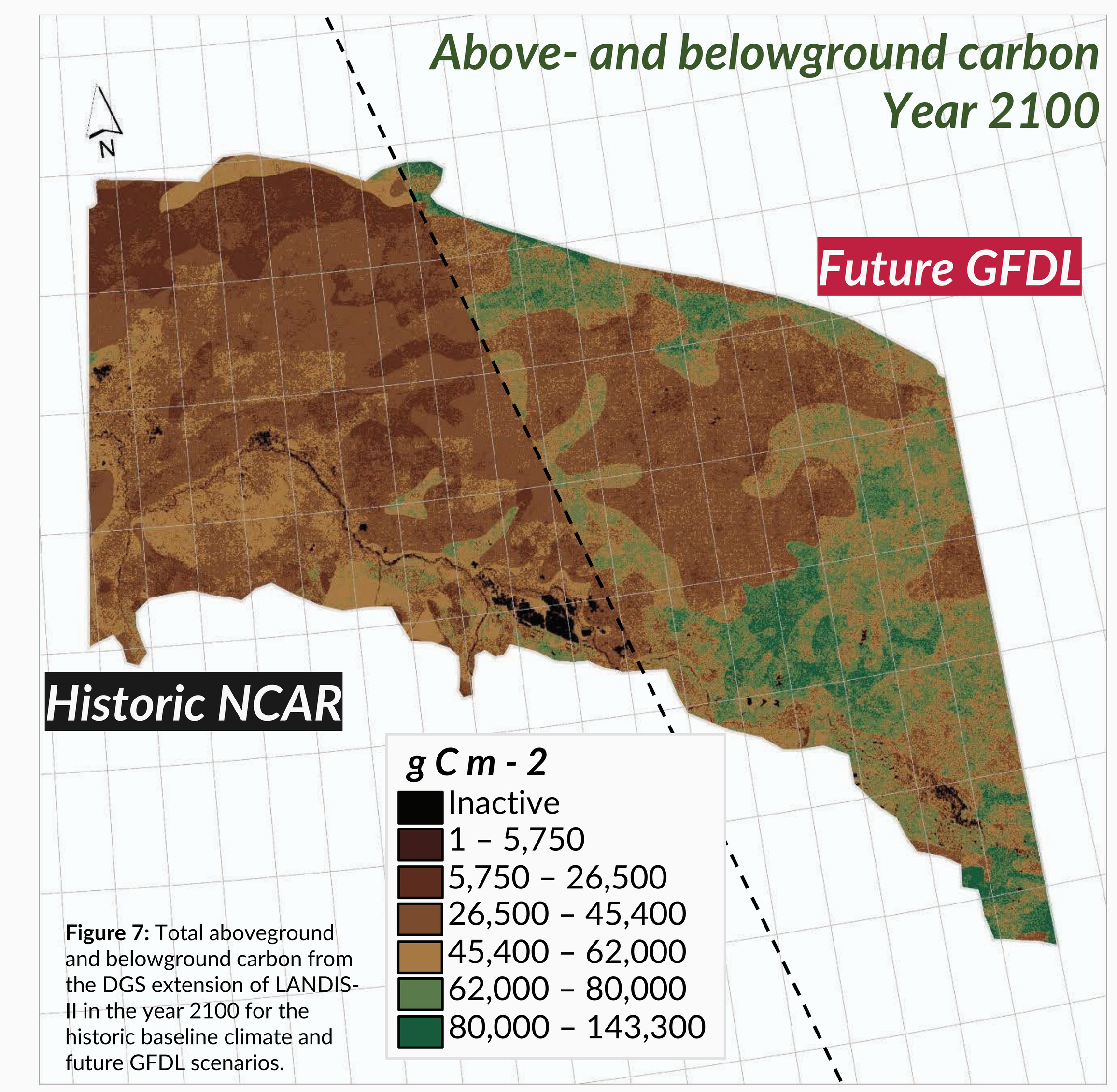


Figure 7: Total aboveground and belowground carbon from the DGS extension of LANDIS-II in the year 2100 for the historic baseline climate and future GFDL scenarios.

Future work will include re-parameterizing random forests with plot data that has more locations and adding additional species not included here. Model simulations for both random forests and LANDIS-II will be scaled up to the larger landscape (Figure 7), which is approximately 8.7 million hectares.

Given that much of the terrestrial carbon is stored in the permafrost-rich soils of boreal ecosystems, efforts at comparing estimates of both above and belowground carbon across models are critical as aboveground carbon is only tells one side of the story.

Acknowledgements

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