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State and Tribal Capacity Building on Forest Carbon

Forest Carbon and Climate Change in Minnesota

This technical briefing summarizes topics such as forest densities and cover types, carbon storage, and climate considerations for the state of Minnesota.

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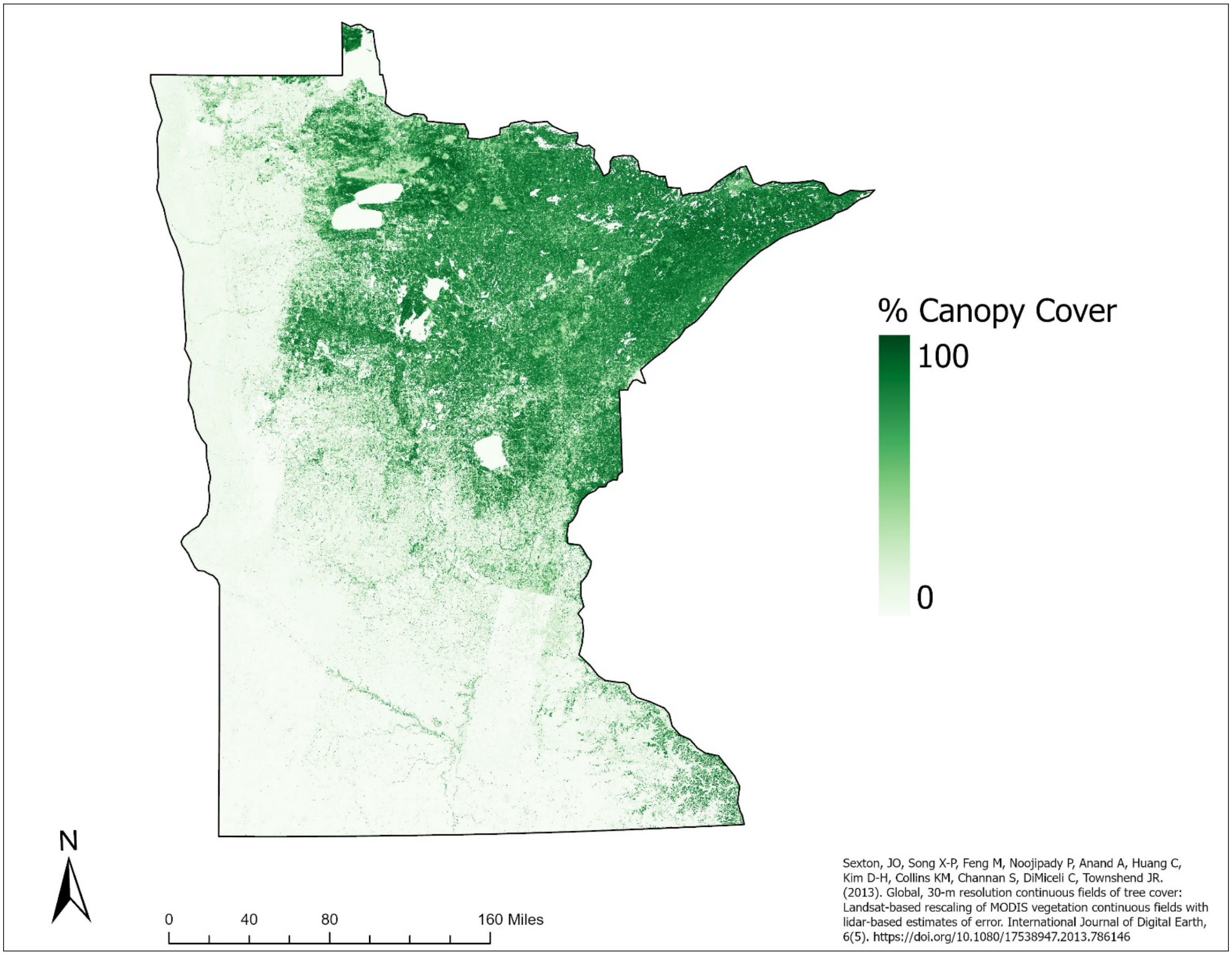
Minnesota Forest Overview

Minnesota is situated in the Midwest region of the United States and lies within the US Forest Service's Eastern Region (USFS Region 9). Bordering states include North Dakota and South Dakota to the west, Iowa to the south, Wisconsin to the east, and the Canadian provinces of Manitoba and Ontario to the north.

A map of percent tree canopy cover in Minnesota is shown in **Figure 1**. This state shows a gradient in forest coverage across its extent, with the highest levels of canopy cover occurring in the northeastern portion of the state, grading into areas of reduced forest coverage to the west and south. These areas of reduced canopy cover coincide with high levels of agricultural land use.

Figure 1. Percent tree canopy cover in Minnesota.

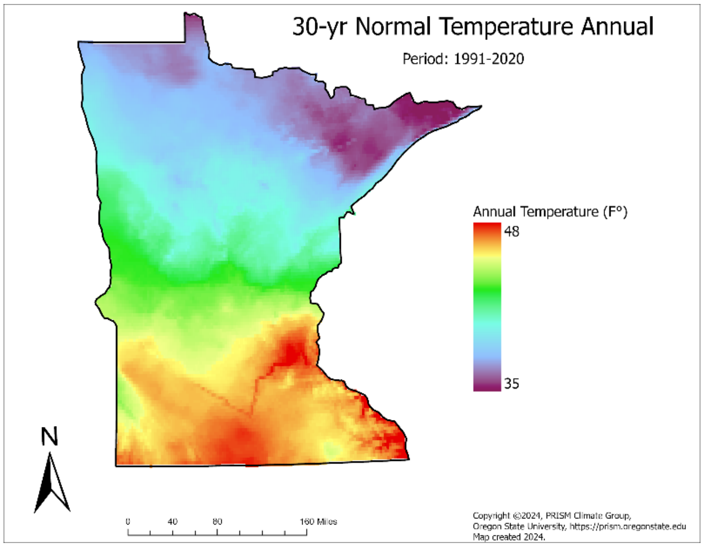


Sexton, JO, Song X-P, Feng M, Noojipady P, Anand A, Huang C, Kim D-H, Collins KM, Channan S, DiMiceli C, Townshend JR. (2013). Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. International Journal of Digital Earth, 6(5). https://doi.org/10.1080/17538947.2013.786146

Temperature and Precipitation

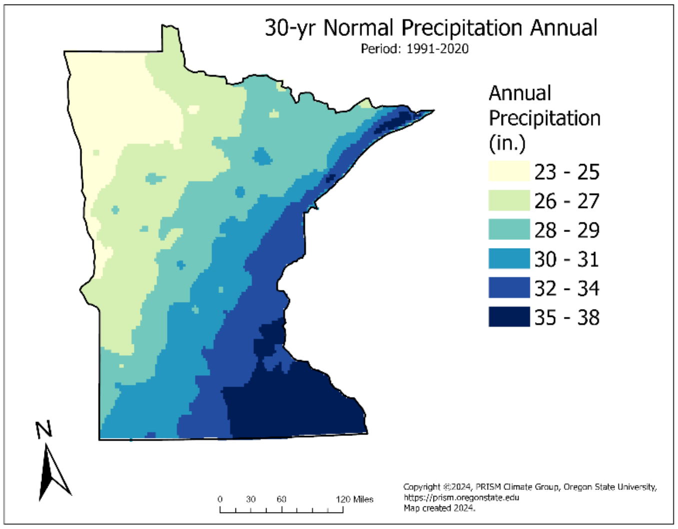
Two major factors affecting forest carbon and productivity are temperature and precipitation. **Figure 2** shows normal mean temperatures throughout Minnesota between 1991 and 2020. Over this 30-year period, mean annual temperatures varied by about 13 °F across this state. Temperature trends largely follow latitudinal gradients, with warmer mean temperatures occurring in the southernmost portions of the state giving way to cooler temperatures to the north. The warmest mean annual temperature is around 48 °F and occurs along Minnesota's south-central and southeastern borders, while the coolest mean annual temperature is around 35 °F in the northeast corner of the state and coincides with higher elevations.

Figure 2. Normal mean temperature (°F) from 1991–2020 in Minnesota.



Copyright ©2024, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu
Map created 2024.

Figure 3. Normal mean precipitation (in.) from 1991-2020 in Minnesota.

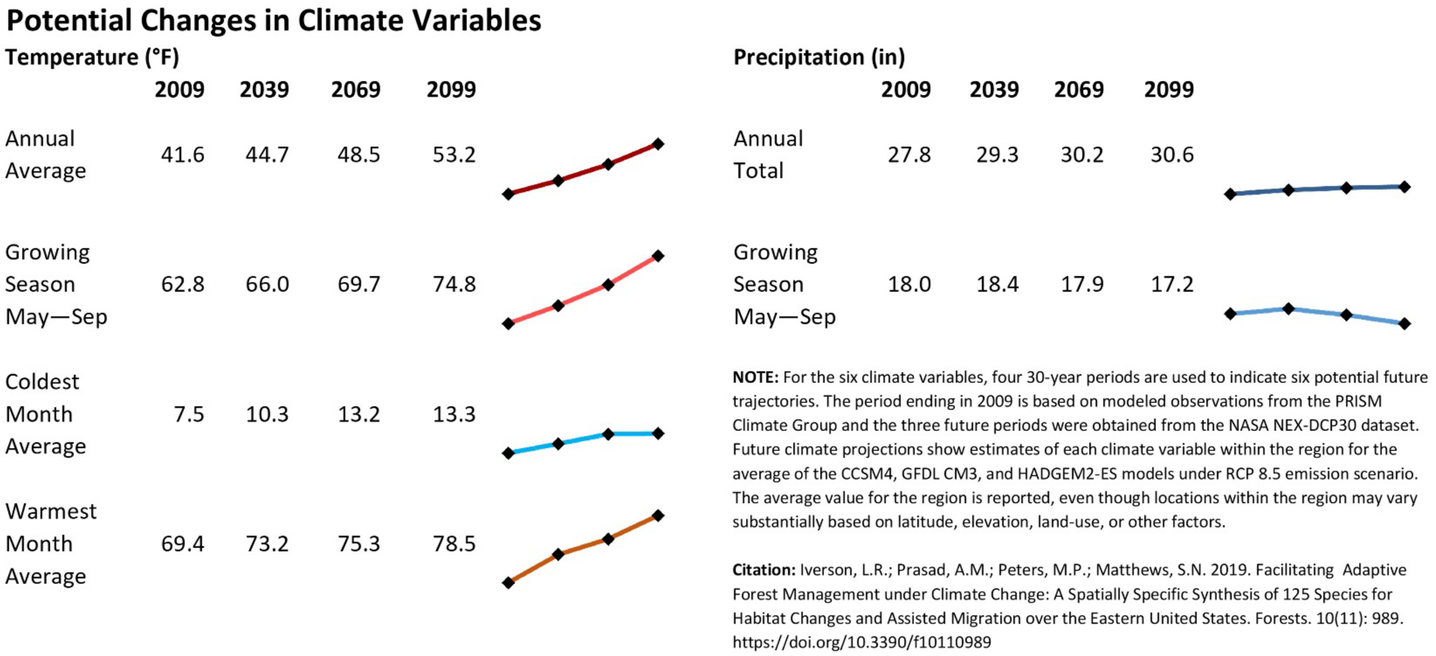


Copyright ©2024, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu
Map created 2024.

Figure 3 shows normal mean precipitation throughout Minnesota between 1991 and 2020 and demonstrates the geographic variation in these trends. Over this 30-year period, mean annual precipitation levels varied by about 15 in. and show a gradient of precipitation that follows a northwest-southeast trend. Areas that receive the lowest levels of precipitation (23-25 in.) occur in the northwest portion of the state and grade into areas receiving higher levels of precipitation to the southeast. The southeastern corner of the state receives the highest levels of precipitation, averaging 35-38 in. per year.

Projected Future Trends in Temperature / Precipitation

Figure 4. Model results for potential changes in temperature and precipitation trends in Minnesota through 2099 under a high emission scenario (RCP 8.5).



Potential Changes in Climate Variables

Temperature (°F)

	2009	**2039**	**2069**	**2099**
Annual Average	41.6	44.7	48.5	53.2
Growing Season May—Sep	62.8	66.0	69.7	74.8
Coldest Month Average	7.5	10.3	13.2	13.3
Warmest Month Average	69.4	73.2	75.3	78.5

Precipitation (in)

	2009	**2039**	**2069**	**2099**
Annual Total	27.8	29.3	30.2	30.6
Growing Season May—Sep	18.0	18.4	17.9	17.2

NOTE: For the six climate variables, four 30-year periods are used to indicate six potential future trajectories. The period ending in 2009 is based on modeled observations from the PRISM Climate Group and the three future periods were obtained from the NASA NEX-DCP30 dataset. Future climate projections show estimates of each climate variable within the region for the average of the CCSM4, GFDL CM3, and HADGEM2-ES models under RCP 8.5 emission scenario. The average value for the region is reported, even though locations within the region may vary substantially based on latitude, elevation, land-use, or other factors.

Citation: Iverson, L.R.; Prasad, A.M.; Peters, M.P.; Matthews, S.N. 2019. Facilitating Adaptive Forest Management under Climate Change: A Spatially Specific Synthesis of 125 Species for Habitat Changes and Assisted Migration over the Eastern United States. Forests. 10(11): 989. https://doi.org/10.3390/f10110989

Projected future trends in temperature and precipitation for Minnesota between 2009 and 2099 are shown in **Figure 4**. Model results suggest average temperatures will continue to increase through the end of the century, a trend which is also projected for the coldest and warmest month averages, as well as throughout the growing season (May – Sep.). Over this 90-year period, average annual temperatures are expected to increase by an estimated 11.6 °F, with the most drastic increases expected to occur during the growing season (+12 °F).

Model results of future precipitation in Minnesota show variable trends, with totals projected to steadily increase through 2099 (**Figure 4**). Over a 90-year period, annual precipitation is expected to increase by an estimated 2.8 in., however, precipitation levels are projected to *decrease* during the growing season by an estimated 0.8 in. This suggests that precipitation in Minnesota may increase substantially during the winter months (Oct. – Apr.), while drought events may become more frequent and severe during the growing season.

Forest Density

Figure 5. Forest density as live tree density (No. ha^{-1}) in Minnesota.

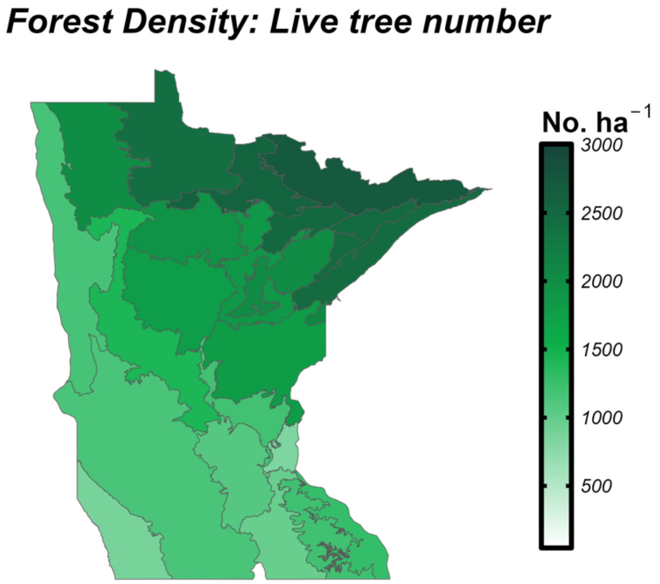
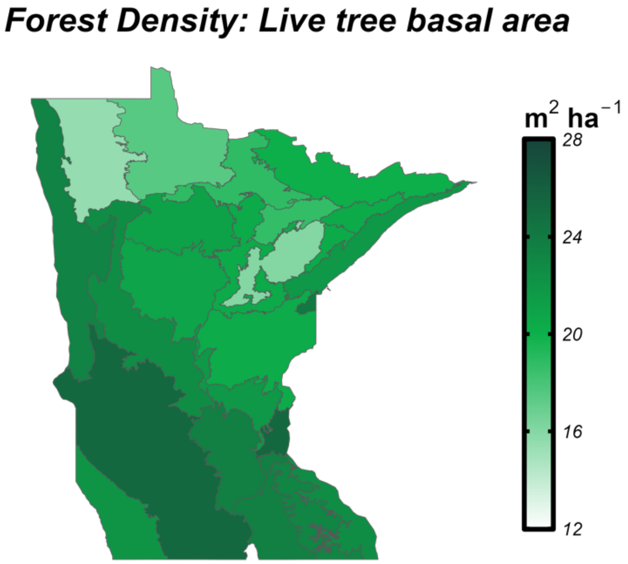


Figure 6. Forest density as live tree basal area (m^2 ha^{-1}) in Minnesota.



Forest density[1] is both a structural characteristic of forests and a reflection of forest dynamics. It can be measured as the number of trees per unit area, or it can be measured in terms of live tree area per unit area, known as "basal area". Live tree basal area represents the amount of ground covered by living trees in two-dimensional space. **Figure 5** shows average forest density in terms of live trees per hectare by ecosection[2] across the state of Minnesota, while **Figure 6** represents forest density by ecosection in terms of basal area (m^2 ha^{-1}).

By comparing these figures we can see that the large ecosection in the southwestern portion of Minnesota has a relatively low forest density in terms of number of trees per hectare (**Figure 5**), but its density in terms of basal area (**Figure 6**) is among the highest in the state. This suggests that there may be fewer total trees per unit area in this zone, but on average, these trees tend to be relatively large. By contrast, the northeastern ecosection of Minnesota has the highest forest density in terms of number of trees, but an average forest density in terms of basal area. This suggests that forests in this zone are characterized by many, smaller-stemmed trees.

[1] All forest inventory and carbon data were estimated using data from the Forest Inventory and Analysis (FIA) Program which can be accessed through the FIA DataMart (USDA Forest Service, 2024. *Forest inventory and analysis program.* Available at: https://www.fia.fs.usda.gov/) using the rFIA package (Stanke et al, 2020. rFIA: an R package for estimation of forest attributes with the US Forest Inventory and analysis database. *Environ Model Softw.* **127**:104664. https://doi.org/10.1016/j.envsoft.2020.104664) in the R programming environment (R Core Team, 2020. *R: A language and environment for statistical computing*, Vienna, Austria: R Foundation for Statistical Computing.

[2] Ecosection definition can be found at Cleland et al, 2007. Ecological Subregions: Sections and Subsections for the conterminous United States. *General Technical Report WO-76D*, Washington Office, USDA Forest Service. https://doi.org/10.2737/WO-GTR-76D

Forest Cover Types and Carbon

Figure 7. Total forest area (thousand ha) by forest type[3] in Minnesota.

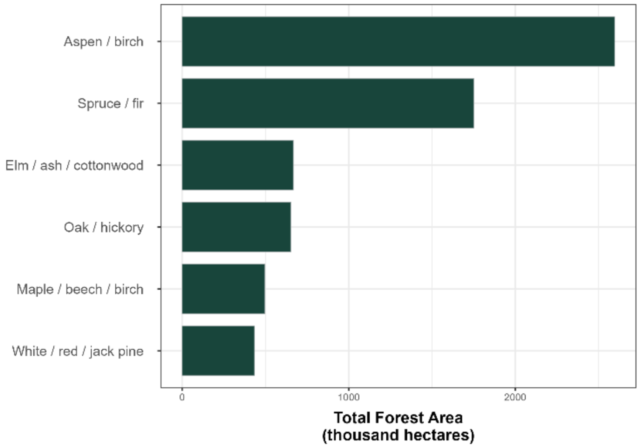
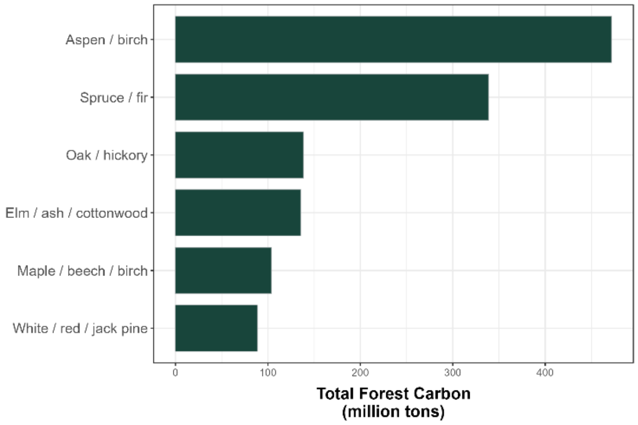


Figure 8. Total forest carbon (million tons) by forest type in Minnesota. Total forest carbon is the sum of carbon stored across all aboveground and belowground pools (includes Soil Organic carbon + Live Belowground carbon + Live Aboveground carbon + Litter carbon + Dead wood carbon).



Minnesota is dominated by 6 key forest cover types: Aspen / birch, Spruce / fir, Elm / ash / cottonwood, Oak / hickory, Maple / beech / birch, and White / red / jack pine. **Figure 7** and **Figure 8** show state-level data of total forested area and total forest carbon, respectively, for each of these cover type groups. As these figures show, Aspen / birch is the dominant forest type of Minnesota, spanning an area upwards of 2.5 million hectares and storing over 450 million tons of carbon statewide. With coverage levels ranging from <0.5-1.75 million hectares, other forest types in this state are less abundant, yet play an important role contributing to enhanced biodiversity and landscape heterogeneity. Comparing trends from **Figure 7** with those in **Figure 8** demonstrates how carbon storage levels vary by forest cover type. For example, Elm / ash / cottonwood forests cover slightly more land area than Oak / hickory stands in Minnesota (**Figure 7**), yet when it comes to carbon, Oak / hickory stands store slightly more carbon than their Elm / ash / cottonwood counterparts (**Figure 8**).

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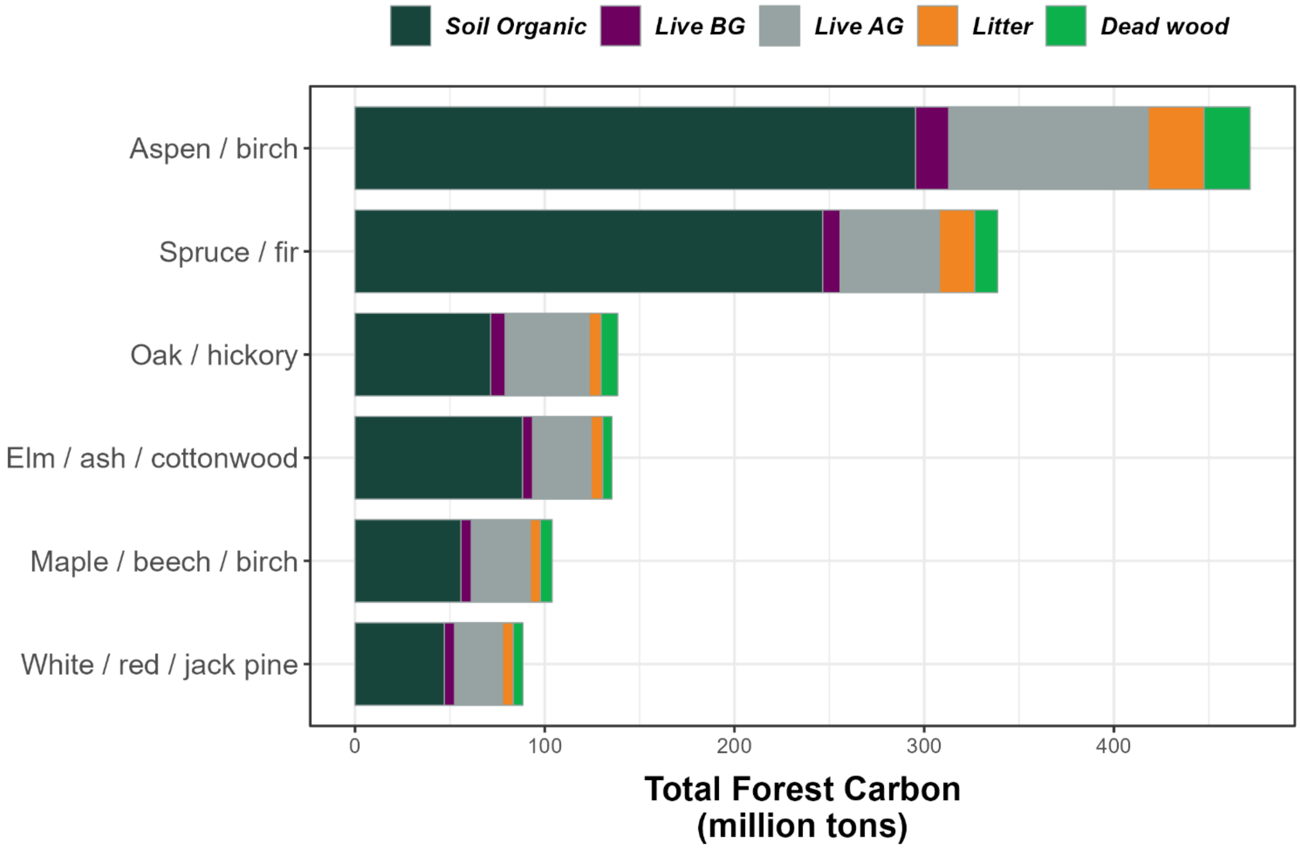
[3] Forest Types are a classification of forest land based upon and named for the tree species that forms the plurality of live-tree stocking. These forest types used in the briefing align with FIA's definition of Forest type group which are a combination of forest types that share closely associated species and site requirements. Longer definitions of both forest types and forest type groups are found in Appendix D of the Forest Inventory and Analysis Database: Database Description and User Guide for Phase 2 (version 9.1) which can be accessed here: https://research.fs.usda.gov/sites/default/files/2023-11/wo-fiadb_user_guide_p2_9-1_final.pdf

Forest Carbon Pools

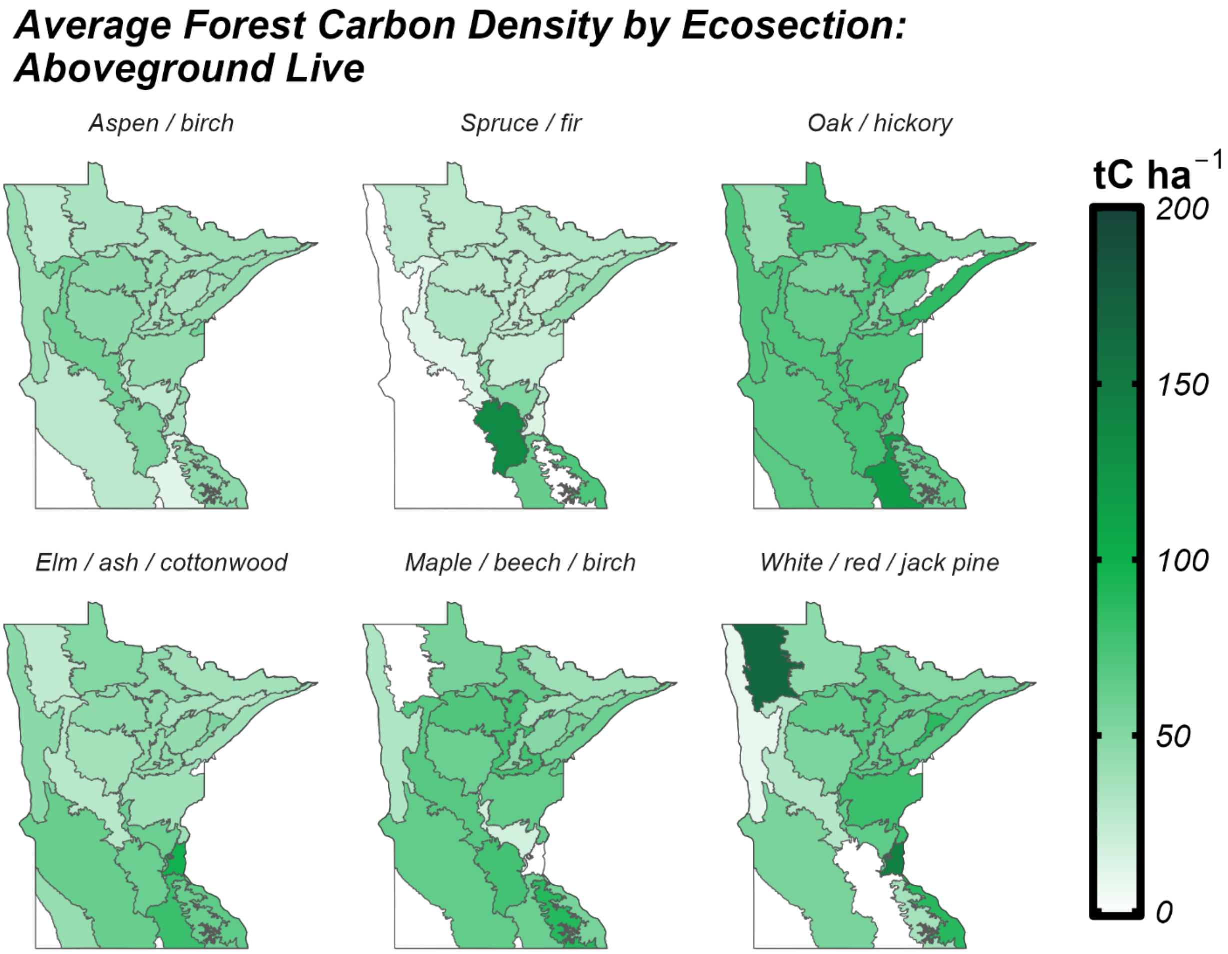
Figure 9. Total forest carbon (million tons) by pool and forest type in Minnesota.



Forest carbon storage can be further assessed by examining how it's distributed across different ecosystem carbon pools. **Figure 9** shows the amount of carbon stored in different carbon pools of key forest cover types in Minnesota. These values show how different forest types allocate distinct proportions of forest carbon into soil organic matter, live belowground (BG) biomass, live aboveground (AG) biomass, litter, and dead wood pools. Minnesota forests generally allocate more ecosystem carbon to belowground pools (soil organic matter + live BG biomass) than aboveground pools (live AG biomass + litter + dead wood), yet the proportions in which they do so varies significantly across forest cover types. For instance, Spruce / fir forests allocate more than 3x the amount of carbon to belowground pools than aboveground pools, whereas forest types like Oak / hickory and White / red / jack pine distribute carbon more evenly between belowground and aboveground pools. Another noteworthy trait shown in **Figure 9** is the magnitude of carbon storage levels across different pools and cover types. Aspen / birch's dominating presence on this landscape means its statewide carbon pools are outsized compared to other groups. For example, leaf litter and dead wood pools of Minnesota's Aspen / birch forests on their own contain more than half the total ecosystem carbon (sum of carbon stored across all pools) contained by the White / red / jack pine group.

Forest Carbon Density

Figure 9. Aboveground live forest carbon density (tC ha-1) by forest type in Minnesota.



Forest carbon density can be influenced by many ecosystem traits, such as tree density, stand age, species mix/ cover type, soil fertility, elevation, and a site's management and disturbance history. In **Figure 9**, the carbon density of aboveground living forest biomass is shown for 6 key cover types in Minnesota. Of these, White / red / jack pine stands hold the highest levels of aboveground live carbon per unit area, represented by the deep shade of green shown for an ecosection in the northwestern portion of the state. By contrast, Aspen / birch stands have a much lower carbon density per unit area in this ecosection. Across much of their extent, Aspen / birch and Maple / beech / birch stands exhibit relatively even carbon densities, while cover types like Spruce / fir and White / red / jack pine show higher levels of variability across ecosections. In these instances, variable carbon densities can be driven by the relative prevalence or absence of each forest type from a given ecosection.

Species-Specific Considerations for Climate Adaptation

Climate change is expected impact the distribution of species into the future. Predictive modeling of potential future changes that incorporate species interactions, dispersal mechanisms, demography, physiology, and evolution is needed to assist in adaptive forest planning. The USDA Forest Service **Climate Change Tree Atlas, Version 4**, provides modeled potential suitable habitat for 125 species in the eastern US, with an additional 23 species. https://www.fs.usda.gov/nrs/atlas/tree/

Core Climate Change Atlas components:

- DISTRIB-II: Species habitat suitability model
- SHIFT: Migration model (when combined with DISTRIB-II, estimates colonization potential (HQCL) of future suitable habitats
- Adaptability Ratings: Species adaptability ratings (species traits not included in DISTRIB-II and SHIFT models)

In addition to the modeled potential suitable habitat for individual tree species, the Climate Change Atlas includes Current and potential future habitat, capability and migration for individual tree species and potential changes in climate variables summarized by the following spatial extents:

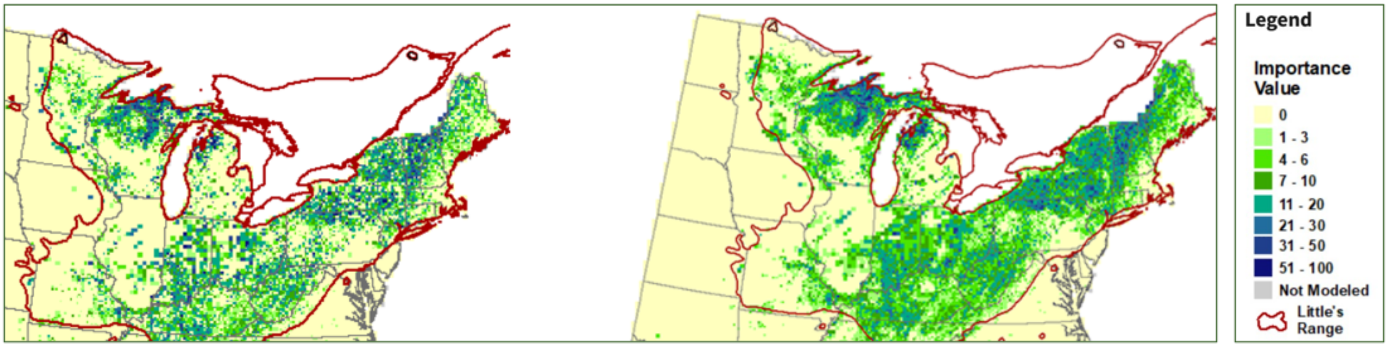
Geographic Area	Description
National Forest Summaries	Results summarized for 55 national forests
National Park Summaries	Results summarized for 78 national parks
HUC6 Watershed	Results summarized by hydrologic unit codes level 3 (HUC 6) which are hierarchical classifications based on surface hydrologic features in which level 3 maps watershed basins (Seaber et al, 1987) https://pubs.usgs.gov/wsp/wsp2294/
Ecoregional Vulnerability Assessments (EVAS)	Results summarized by ecoregions used in the USDA Climate Hub Regional Vulnerability Assessments https://www.climatehubs.usda.gov/assessments
USDA Forest Service EcoMap 2007 Sections	Results summarized by ecological sections that delineate ecosystems with distinctive vegetation and other unique ecological characteristics (Cleland et al, 2007, McNab et al, 2007)
National Climate Assessment (NCA) 2015 Regional Summaries	Results summarized by National Climate Assessment Region which include the Midwest, Northeast, Northern Plains, Southeast, and Southern Plains
1 x 1° Grid Summaries	Results summarized by 1x1° latitude and longitude
State Summaries	Results summarized for 38 states
Urban areas	Results summarized for 185 urban areas across the eastern US

Additional background on this tool can be found at: https://research.fs.usda.gov/centers/ccrc along with short video tutorials on the Climate Change Atlas website.

Habitat Suitability and Migration Models

Model Reliability: **High**

Key Species Example: Modeled potential suitable habitat for Sugar Maple (*Acer saccharum)* through 2100

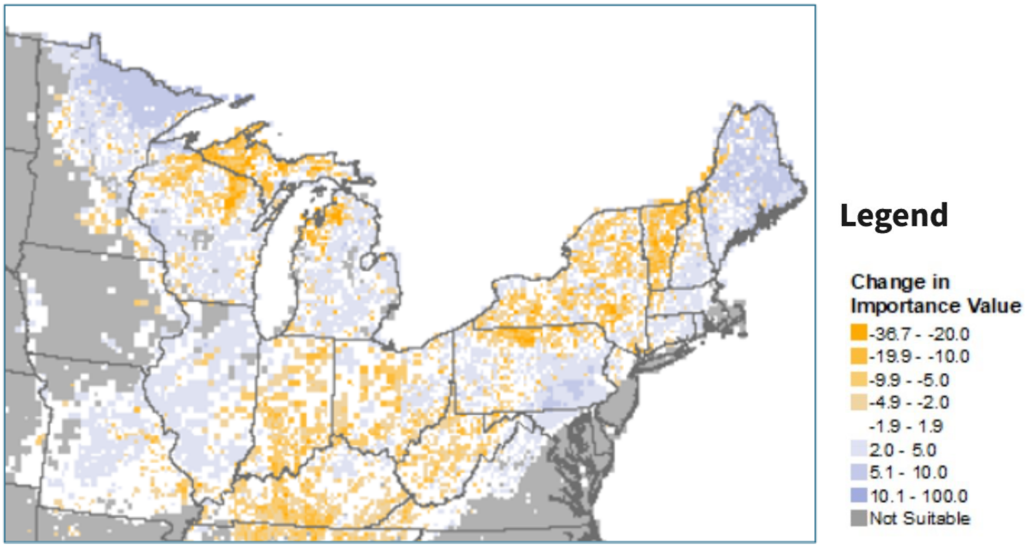


Current habitat quality and distribution (DISTRIB-II)

Potential migration (SHIFT) and colonization likelihood (CL)

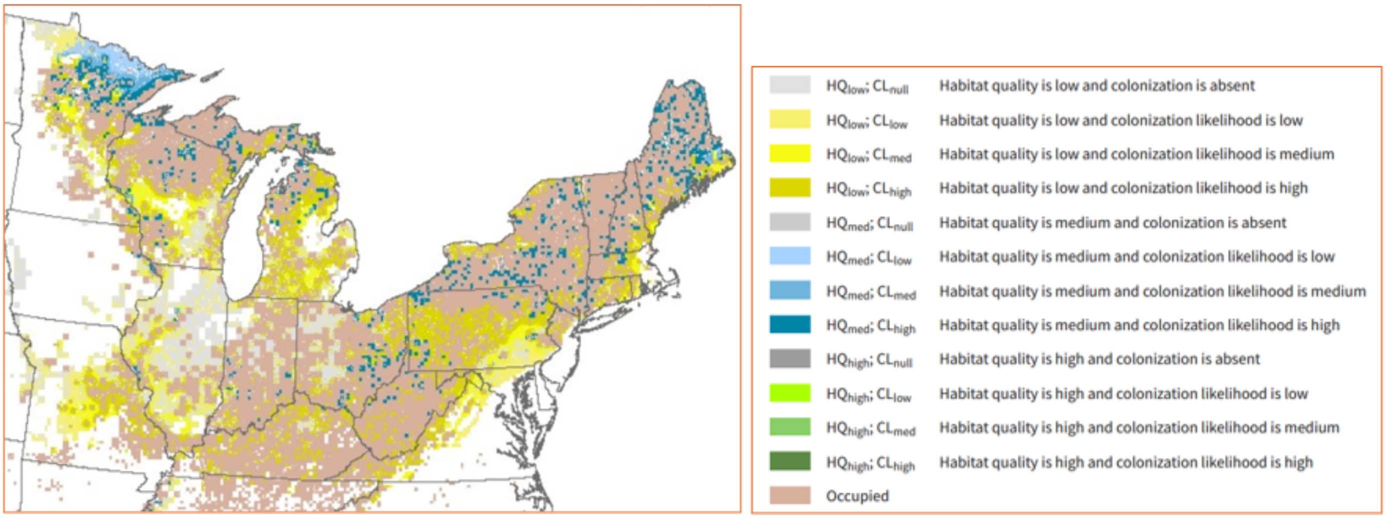
Importance value is a measure of abundance that accounts for both tree basal area and number of stems, ranging from 0-100.

Colonization potential of future habitats under a high emission scenario (RCP 8.5)



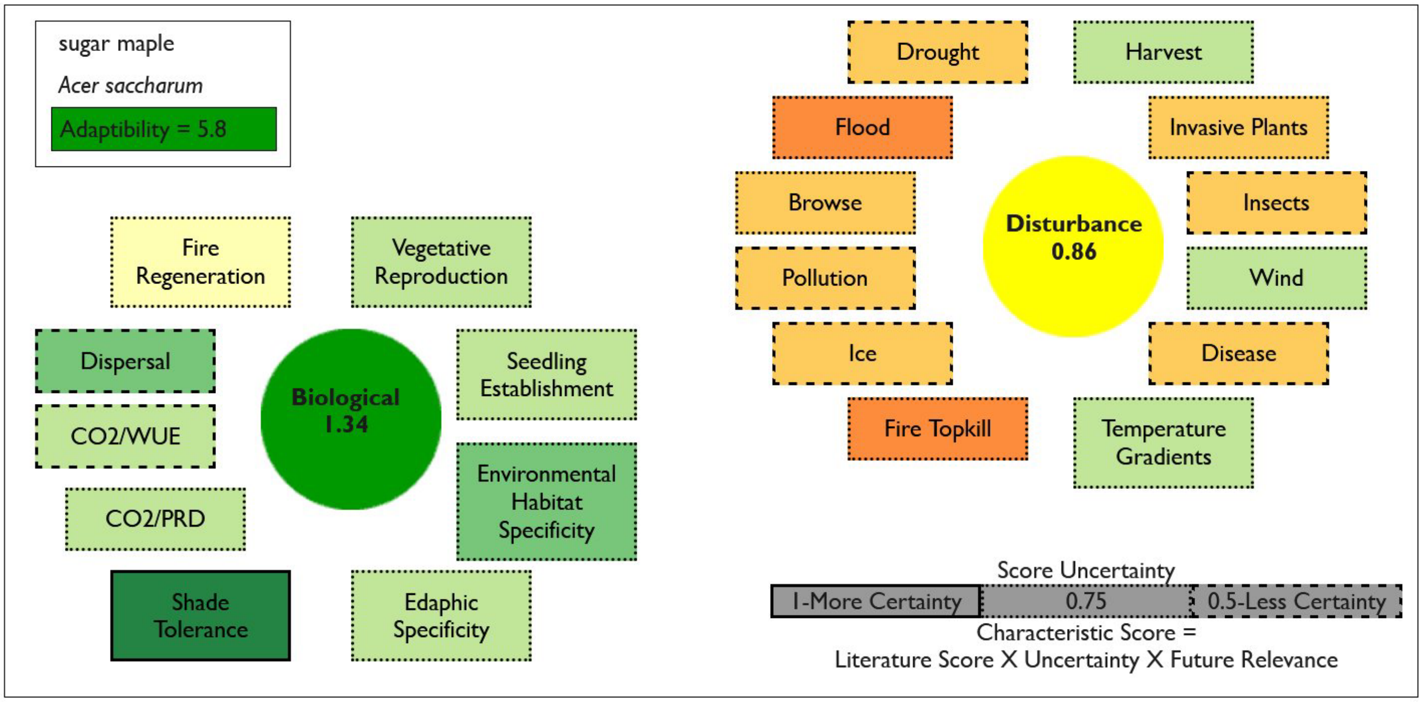
Colonization is limited to range margins and infill (Blue) which is derived from habitat quality (DISTRIB) and migration model (SHIFT) utilizing the colonization likelihood model (CL). Orange shading represents current species' distributions where abundance is predicted to decrease due to loss of habitat suitability.

DISTRIB-II + SHIFT: Habitat quality and colonization likelihood (RCP 8.5)



Adaptability Ratings

Key Species Example: Sugar Maple (*Acer saccharum*)



V Hi Pos	High Pos	Low Pos	Minimal	Low Neg	High Neg	V Hi Neg
+3	+2	+1	0	-1	-2	-3

The Adaptability score, which assesses 21 variables to assign adaptability ratings to tree species in the eastern US, reflects a species' potential adaptability to climate change-driven stressors and disturbances at range wide scale. Adaptability ratings provide broad insights into factors that cannot be directly included in the Climate Change Tree Atlas species migration models. Two types of species traits are evaluated: 1) biological and 2) disturbance, each with their own set of factors to help characterize species' traits and responses to disturbance. Uncertainty is also included for each trait or factor assessed. When coupled with other modeled projections, adaptability ratings can support future planning under a changing climate.

The Adaptability variable is single score derived from the Modification Factors which encompass scores for the 12 disturbance and 9 biological factors. The Adaptability results can be considered relative to other tree species. For example, a species with a low Adaptability variable likely does not have life history characteristics to allow it to thrive under most conditions whereas a high Adaptability variable will likely do better under the climate change outputs from the DISTRIB-II and SHIFT Models.

Climate Change Atlas Summary for Sugar Maple

Sugar maple is widely distributed (21.3% of area), dense, and with high IV across much of the northern 2/3 of the Eastern US. It ranks fourth in overall abundance across the eastern US, behind loblolly pine, red maple and sweetgum. It rates as highly adaptable although under persistent drought or other stresses, it would likely decline. In contrast to our earlier models which showed substantial habitat decline in the south under harsh climate change, the species is modeled to decline only modestly, so we rate it with a very good capacity to cope, and to be a good infill species (according to SHIFT).

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Habitat suitability models on trees:

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