Forest Carbon and Climate Program
Department of Forestry
MICHIGAN STATE UNIVERSITY

State and Tribal Capacity Building on Forest Carbon

Forest Carbon and Climate Change in Pennsylvania

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

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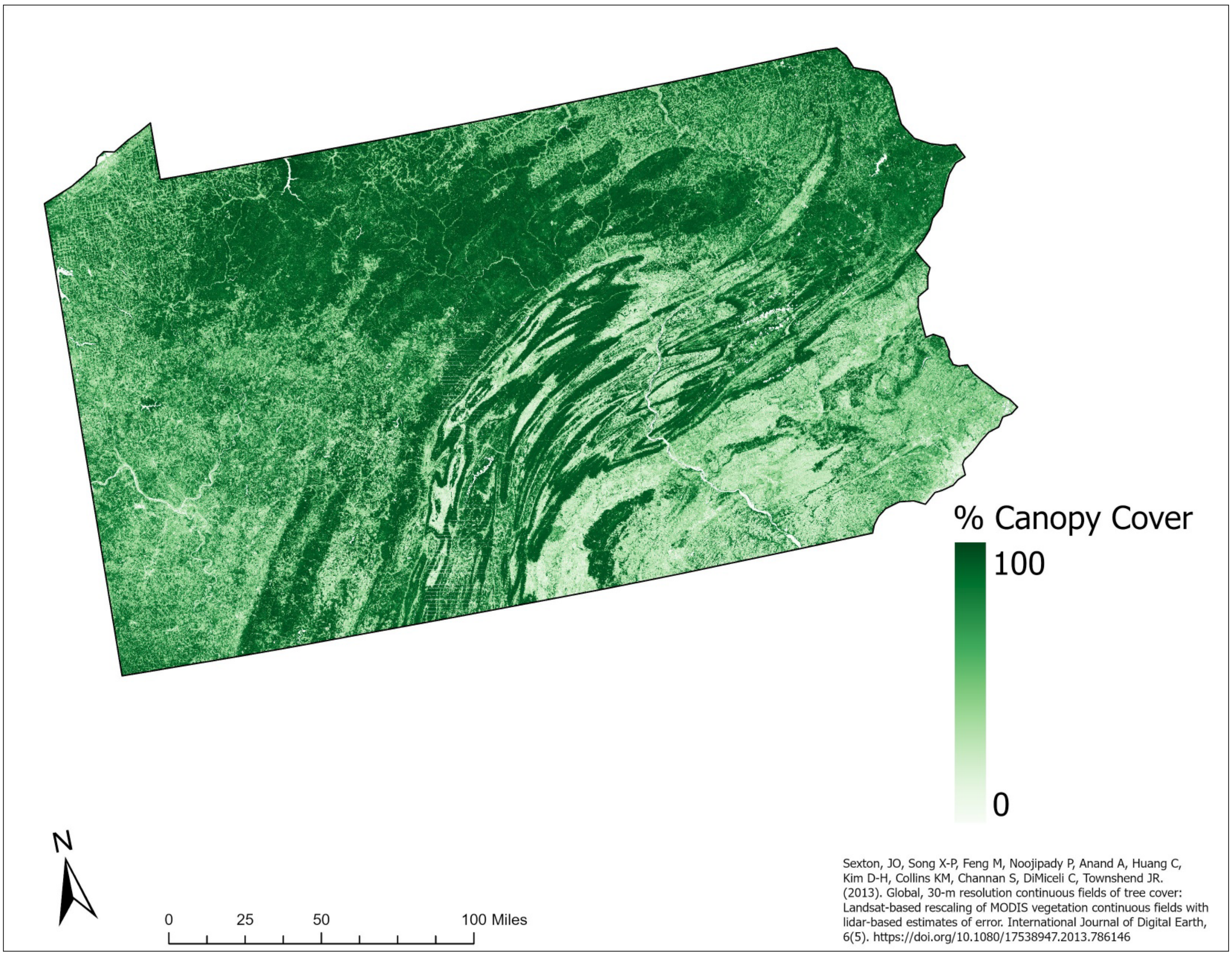
Pennsylvania Forest Overview

Pennsylvania is situated in the Mid-Atlantic region of the United States and lies within the US Forest Service's Eastern Region (USFS Region 9). Bordering states include Ohio to the west, West Virginia, Maryland, and Delaware to the south, New Jersey to the east, and New York to the north, with Lake Erie marking Pennsylvania's northwestern boundary.

A map of percent tree canopy cover in Pennsylvania is shown in **Figure 1**. This state has variable forest coverage across its extent, with lower levels of coverage in the highly-populated southeastern and southwestern portions of the state, which are characterized by major transportation corridors, urban centers such as Philadelphia and Pittsburgh, and surrounding areas of urban sprawl. The state has an interesting pattern of stratified coverage across the Appalachian Mountains. Dense forest cover characterizes the north-central region of Pennsylvania, which has a high density of protected lands including state parks, state forests, and the Allegheny National Forest.

Figure 1. Percent tree canopy cover in Pennsylvania.



Temperature and Precipitation

Two major factors affecting forest carbon and productivity are temperature and precipitation. **Figure 2** shows normal mean temperatures throughout Pennsylvania between 1991 and 2020. Over this 30-year period, mean annual temperatures varied by about 14 °F across this state. Aside from a southwest-to-northeast strip of high-elevation land in the southwest portion of the state (representing the Allegheny Mountains), temperature trends largely follow latitudinal gradients, with warmer mean temperatures occurring in the southernmost portions of the state and giving way to cooler temperatures to the north. The warmest mean annual temperature is around 57 °F and occurs in the southeast corner of Pennsylvania, while the coolest mean annual temperature is around 43 °F along the state's northern border, particularly in high-elevation zones.

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

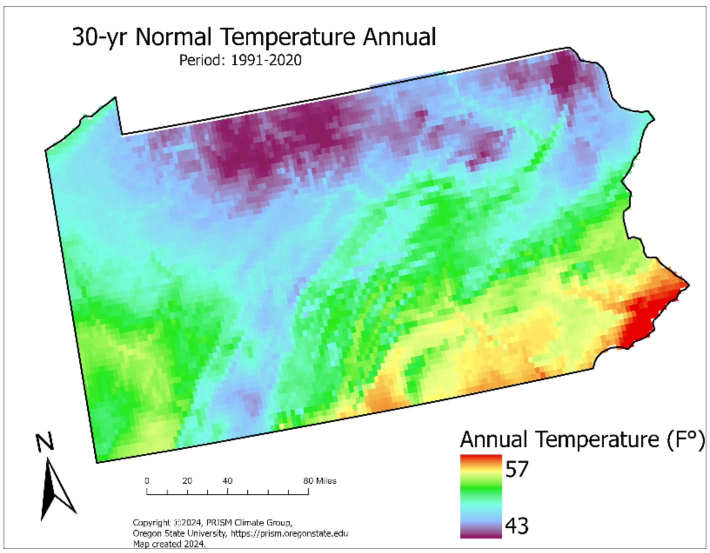


Figure 3. Normal mean precipitation (in.) from 1991-2020 in Pennsylvania.

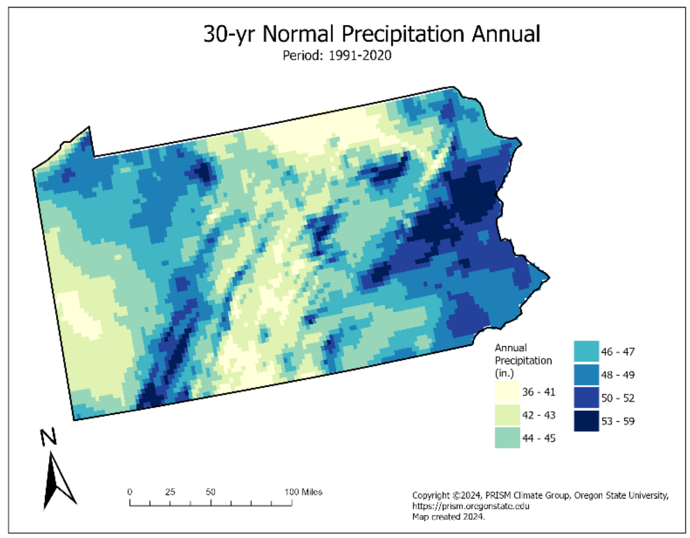


Figure 3 shows normal mean precipitation throughout Pennsylvania between 1991 and 2020 and demonstrates the geographic variation in these trends. Over this 30-year period, mean annual precipitation levels varied by about 23 in. Areas that receive the lowest levels of precipitation (36-41 in.) occur near the state's western border, as well as in the north-central region and stretching southwest along the high-elevation transect of the Appalachian Mountains. Areas receiving the highest amounts of precipitation (53-59 in.) occur in the eastern region of the state, and along the Allegheny front in the southwest.

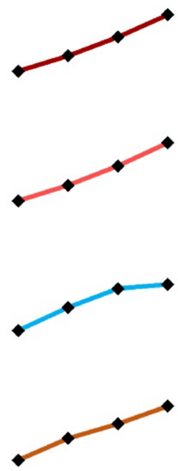
Projected Future Trends in Temperature / Precipitation

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

Potential Changes in Climate Variables

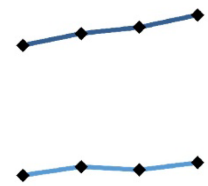
Temperature (°F)

	2009	**2039**	**2069**	**2099**
Annual Average	48.7	51.6	55.2	59.3
Growing Season May—Sep	65.0	68.2	72.2	76.9
Coldest Month Average	23.8	26.1	28.0	28.4
Warmest Month Average	70.8	74.6	77.0	80.1



Precipitation (in)

	2009	**2039**	**2069**	**2099**
Annual Total	43.3	45.8	47.0	49.5
Growing Season May—Sep	20.4	20.8	20.6	21.0



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 Pennsylvania 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 10.6 °F, with the most drastic increases expected to occur during the growing season (+11.9 °F).

Model results of future precipitation in Pennsylvania follow 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 6.2 in., which is a higher rate of change than projections for the growing season (+0.6 in.). This suggests that the most significant changes to precipitation in Pennsylvania may occur during the winter months (Oct. – Apr.).

Forest Density

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

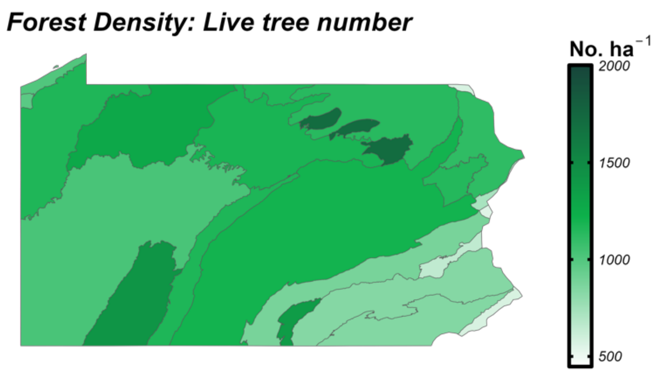
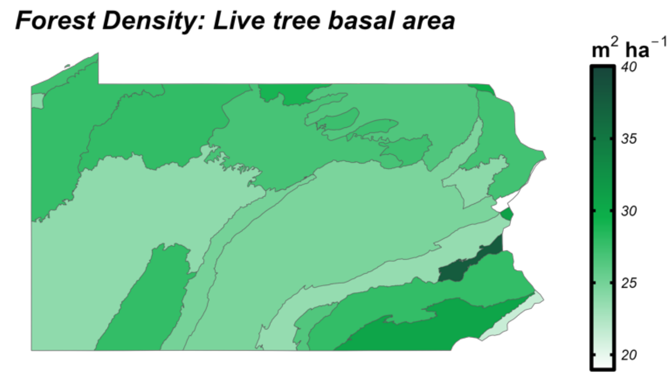


Figure 6. Forest density as live tree basal area (m^2 ha^{-1}) in Pennsylvania.



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 total tree volume 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 Pennsylvania, 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 larger ecosection in the southeast corner of the state has a relatively low forest density in terms of number of trees per hectare (**Figure 5**), but its density in terms of volume (**Figure 6**) is relatively high. This suggests that forests in this zone may be characterized by fewer total trees per unit area, but on average, these trees tend to be relatively large. By contrast, a narrow ecosection along the eastern border of Pennsylvania (circa the northern portion of Bucks County) has the state's highest forest density in terms of basal area, but represents one of the state's lowest forest densities in terms of live trees, suggesting the prevalence of few, relatively large in this zone.

[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 Pennsylvania.

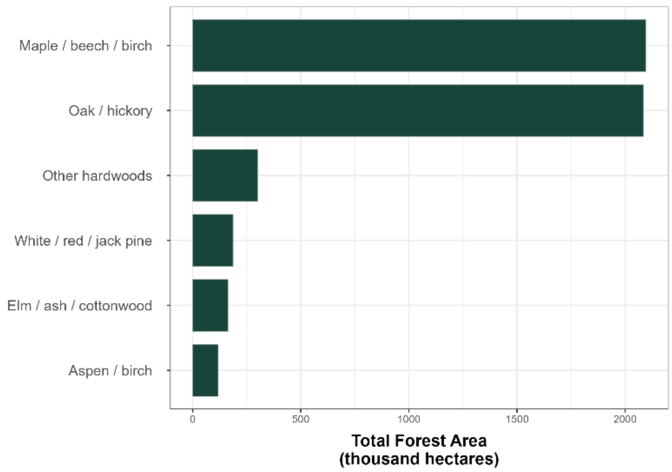
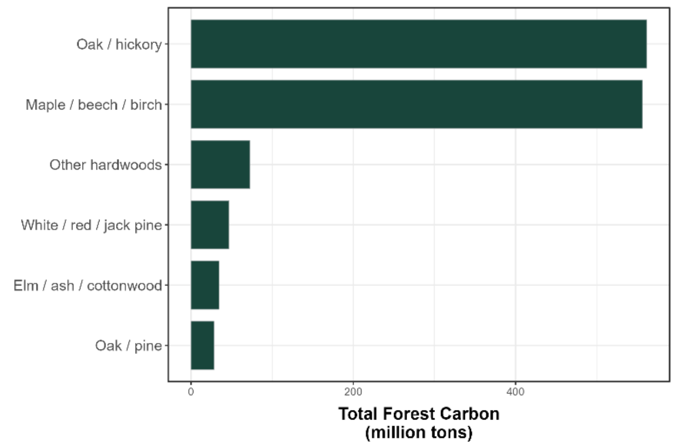


Figure 8. Total forest carbon (million tons) by forest type in Pennsylvania. Total forest carbon is the sum of carbon stored across all aboveground and belowground pools (includes Soil Organic carbon + Live Belowground carbon + Live Aboveground carbon + Litter carbon + Dead wood carbon).

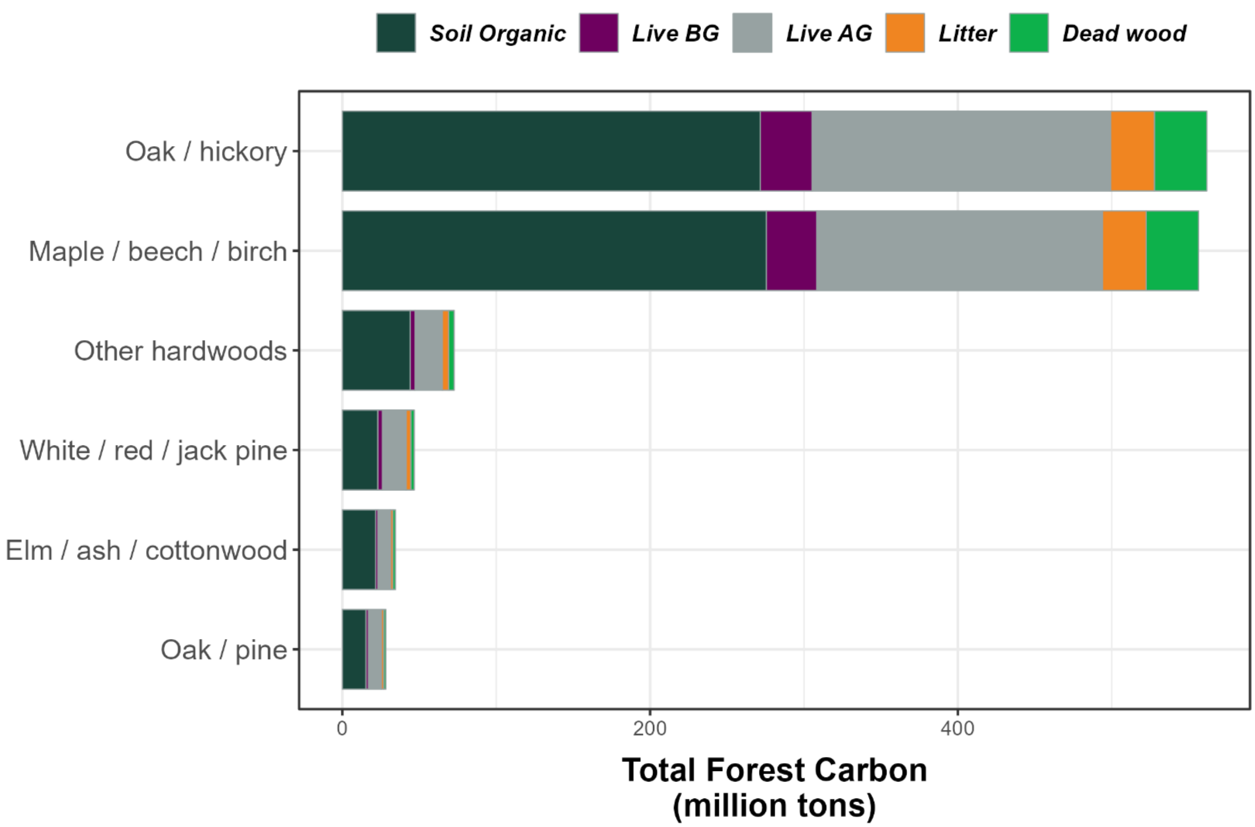


Pennsylvania is dominated by 2 key forest cover types: Maple / beech / birch and Oak / hickory. However, Other hardwoods, White / red / jack pine, Elm / ash / cottonwood, Aspen / birch, and Oak / pine either cover substantial area or store large amounts of carbon but to significantly lesser degree. **Figure 7** and **Figure 8** show state-level data of total forested area and total forest carbon, respectively, for these cover type groups. As these figures show, Maple / beech / birch and Oak / hickory are the dominant forest types of Pennsylvania, spanning an area exceeding 4 million hectares and collectively storing roughly 1.1 billion tons of carbon statewide. With coverage levels ranging from ~125,000-300,000 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, Maple / beech / birch forests cover slightly more land area than Oak / hickory stands in Pennsylvania (**Figure 7**), yet when it comes to carbon, Oak / hickory stands store slightly more carbon than their Maple / beech / birch counterparts (**Figure 8**).

[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

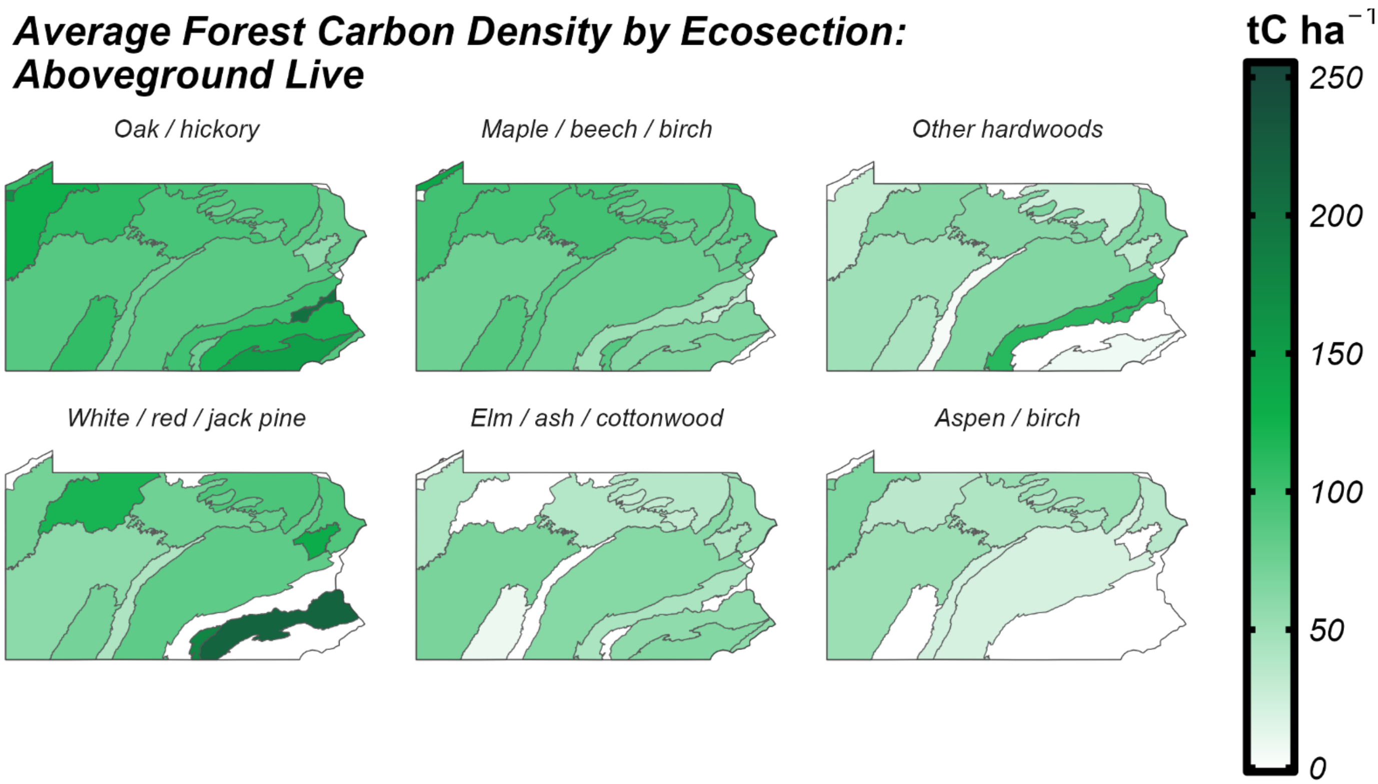
Figure 9. Total forest carbon (million tons) by pool and forest type in Pennsylvania.



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 Pennsylvania. 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. Pennsylvania 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 across forest cover types. For instance, other hardwoods and Elm / ash / cottonwood forests allocate roughly double the amount of carbon to belowground pools than aboveground pools, whereas forest types like White / red / jack pine and Oak / 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. The dominating presence of Oak / hickory and Maple / beech / birch on this landscape means their statewide carbon pools are outsized compared to other groups. For example, the summed leaf litter and dead wood pools of Pennsylvania's Oak / hickory and Maple / beech / birch forests contain more stored carbon than the total ecosystem carbon (sum of carbon stored across all pools) contained by any other forest cover type in the state.

Forest Carbon Density

Figure 9. Aboveground live forest carbon density (tC ha^{-1}) by forest type in Pennsylvania.



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 Pennsylvania. 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 southeastern portion of the state. By contrast, Maple / beech / birch and Elm / ash / cottonwood stands have a much lower carbon density per unit area in this ecosection. Across much of their extent, Maple / beech / birch and Aspen / birch stands exhibit relatively even carbon densities, while cover types like Oak / hickory 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 1x1° latitude and longitude
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

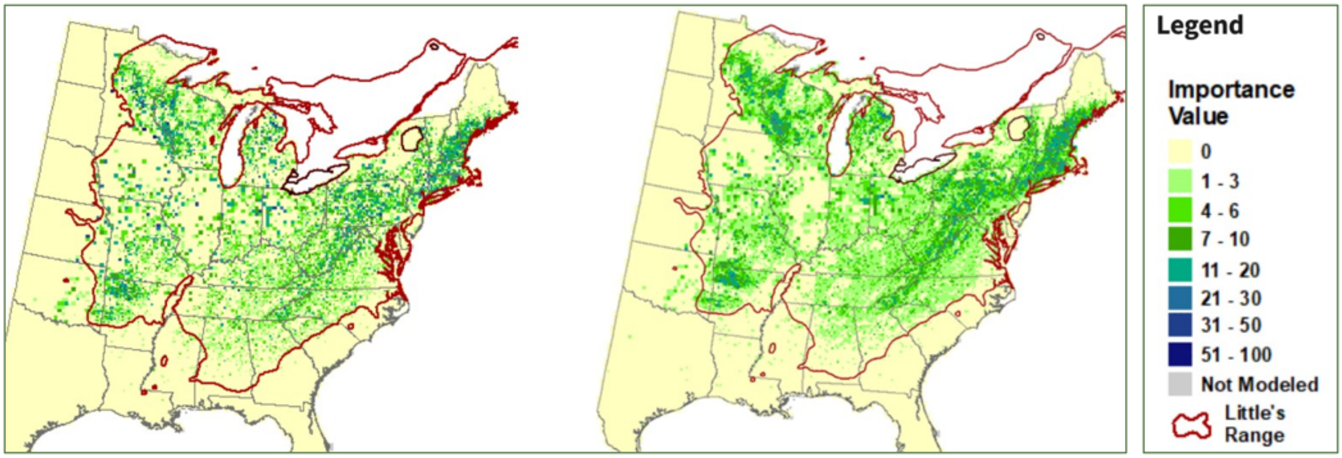
Additional background on this tool can be found at: https://research.fs.usda.gov/centers/ccrc along with short video tutorials on the Climate Change Atlas website.

Habitat Suitability and Migration Models

Model Reliability: Medium

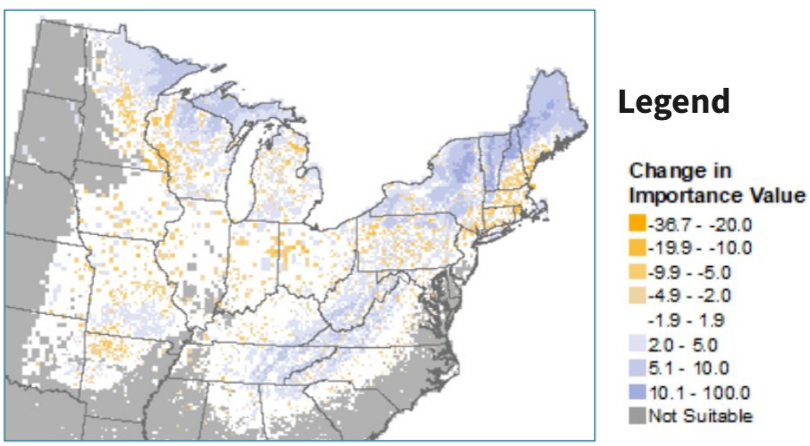
Key Species Example: Modeled potential suitable habitat for Northern Red Oak (*Quercus rubra*) through 2100

Current habitat quality and distribution (DISTRIB) Potential migration (SHIFT) and colonization likelihood (CL)

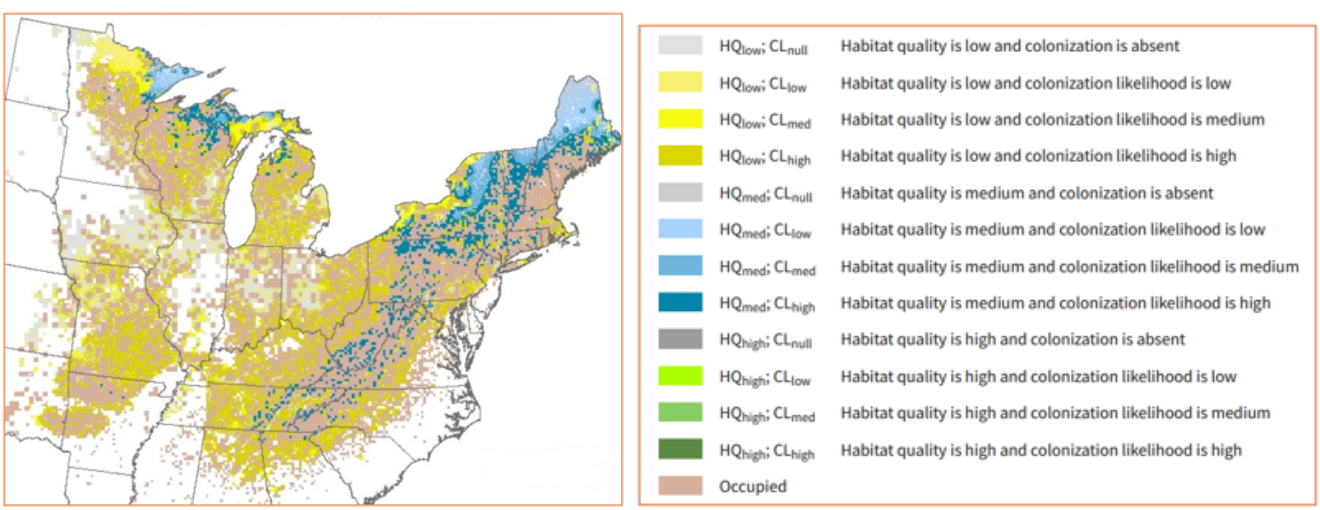


Importance value is a measure of abundance that accounts for both tree basal area and number of stems, ranging from 0-100

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

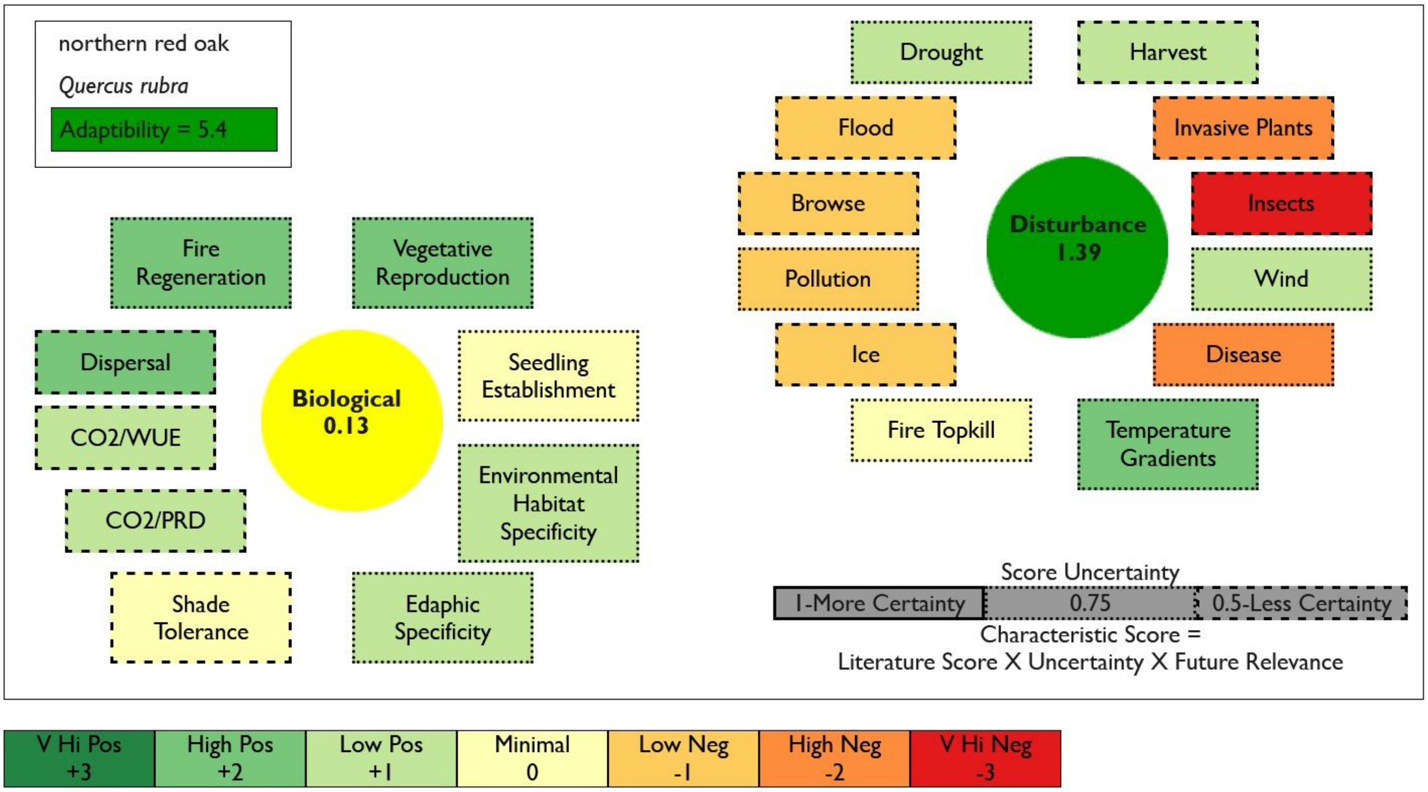


DISTRIB-II + SHIFT: Habitat quality and colonization likelihood (RCP 8.5)



Adaptability Ratings

Key Species Example: Red Oak (*Quercus rubra*)



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 Red Oak

Northern red oak is a widely distributed species (24.4% of area, more than any other oak except white oak and sixth overall), dense, high IV, and abundant throughout most of the northern 2/3 of the eastern US. Its medium reliable model predicts a small increase in habitat all the way to the northern border of the country. The SHIFT model allows some potential for natural migration into those new habitats within 100 years. It is rated as highly adaptable to a changing climate and thus its overall capability is very good.

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