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 Massachusetts

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

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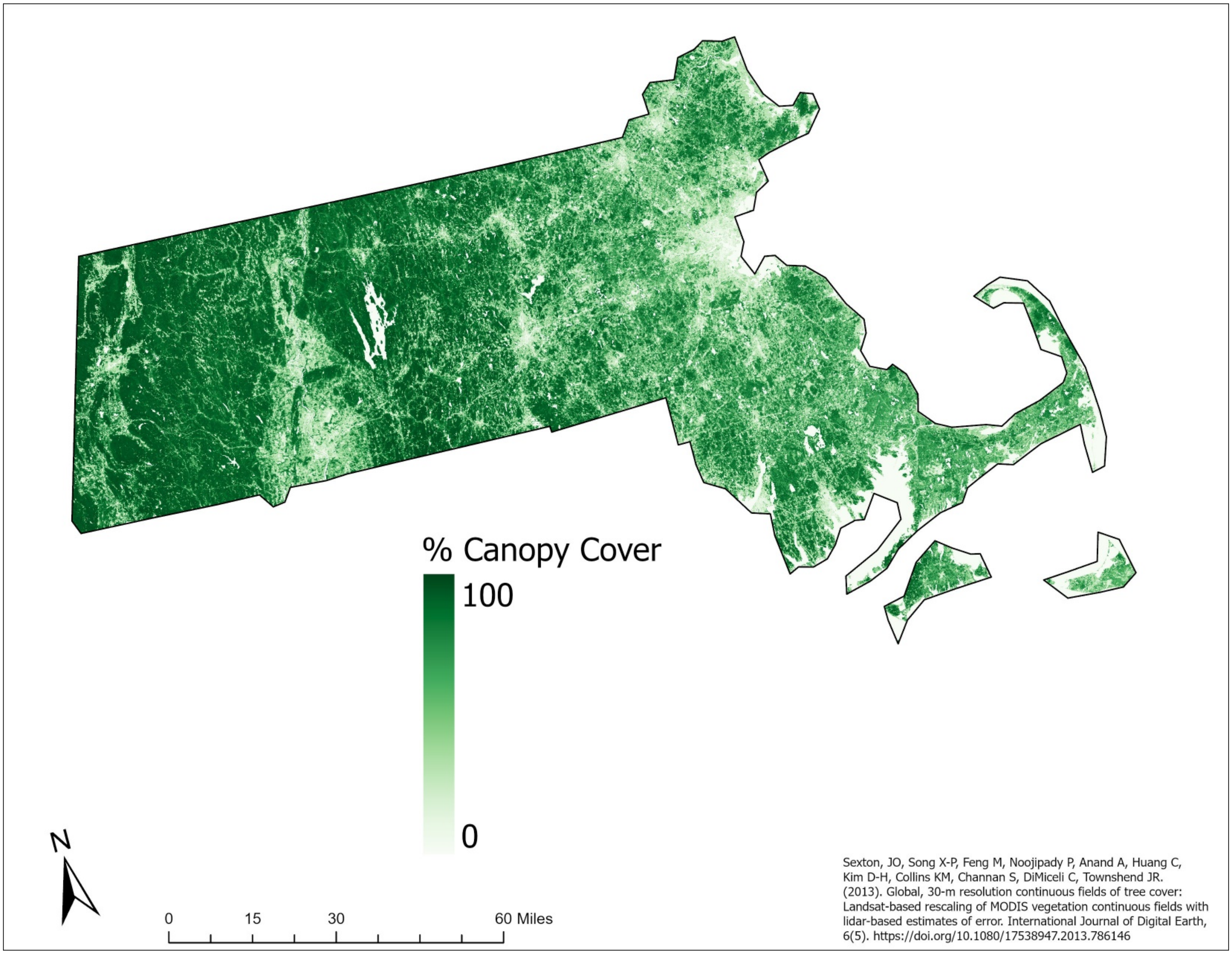
Massachusetts Forest Overview

Massachusetts is situated along the east coast of the United States and lies within the US Forest Service's Eastern Region (USFS Region 9). Bordering states include New York to the west, Vermont and New Hampshire to the north, and Connecticut and Rhode Island to the south, with the Atlantic coast marking Massachusetts's eastern and southeastern boundary.

A map of percent tree canopy cover in Massachusetts is shown in **Figure 1**. This state has significant forest coverage across much of its extent, with a gradient of increasing canopy cover as you move westward and inland from the coast. Areas within the state that have reduced forest cover coincide with major transportation corridors and areas of higher population densities, such as the cities of Springfield, Worcester, and Boston.

Figure 1. Percent tree canopy cover in Massachusetts.



Temperature and Precipitation

Two major factors affecting forest carbon and productivity are temperature and precipitation. **Figure 2** shows normal mean temperatures throughout Massachusetts between 1991 and 2020. Over this 30-year period, mean annual temperatures varied by about 10 °F across this state. Temperature trends follow latitudinal and elevational gradients, with warmer mean temperatures occurring in the southeasternmost portion of the state giving way to cooler temperatures to the northwest. The warmest mean annual temperature is around 52 °F and occurs in the Mt Hope Bay area in Massachusetts's southeast, while the coolest mean annual temperature is around 42 °F in the northwest portion of the state and coincides with higher elevations.

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

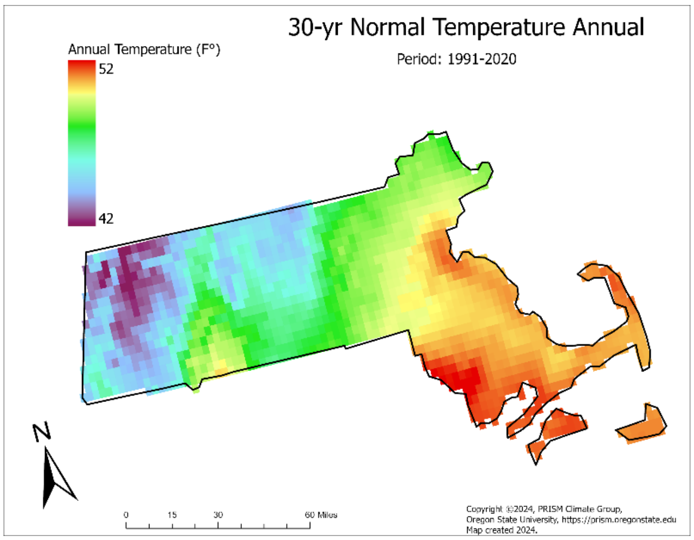


Figure 3. Normal mean precipitation (in.) from 1991-2020 in Massachusetts.

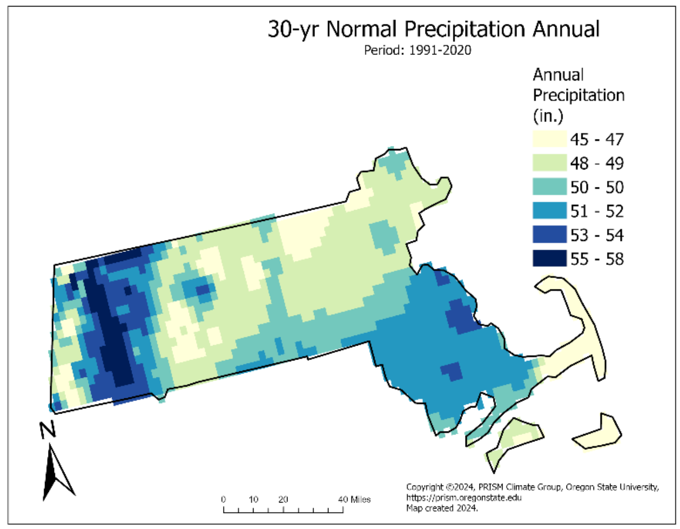


Figure 3 shows normal mean precipitation throughout Massachusetts between 1991 and 2020 and demonstrates the geographic variation in these trends. Over this 30-year period, mean annual precipitation levels varied by about 13 in. Areas that receive the lowest levels of precipitation (45-47 in.) occur in the north and central parts of the state, as well as along Cape Cod and on Nantucket Island. Areas receiving the highest amounts of precipitation (55-58 in.) occur in the western mountainous region of the state.

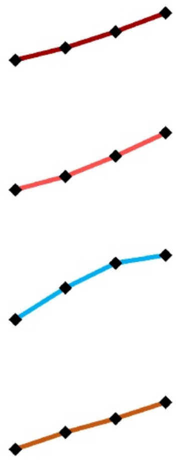
Projected Future Trends in Temperature / Precipitation

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

Potential Changes in Climate Variables

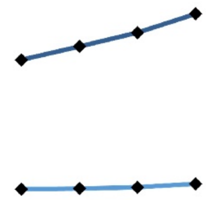
Temperature (°F)

	2009	2039	2069	2099
Annual Average	48.0	50.7	54.2	58.3
Growing Season May—Sep	64.4	67.0	70.8	75.2
Coldest Month Average	23.0	25.7	27.8	28.4
Warmest Month Average	70.8	73.5	75.7	78.3



Precipitation (in)

	2009	2039	2069	2099
Annual Total	48.8	50.6	52.5	55.1
Growing Season May—Sep	20.1	20.1	20.2	20.4



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 Massachusetts 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 10.3 °F, with the most drastic increases expected to occur during the growing season (+10.8 °F).

Model results of future precipitation in Massachusetts follow similar 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 6.3 in., which is a higher rate of change than projections for the growing season (+0.3 in.). This suggests that the most significant changes to precipitation in Massachusetts may occur during the winter months (Oct. – Apr.).

Forest Density

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

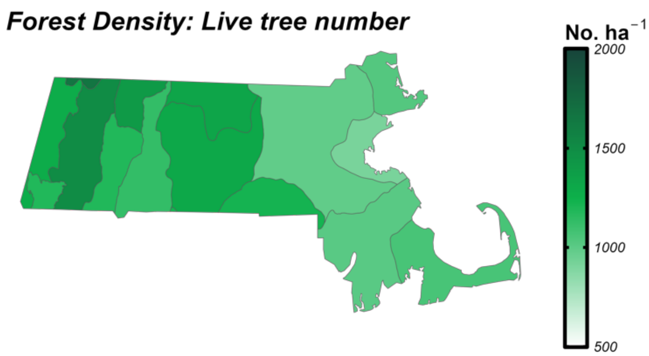
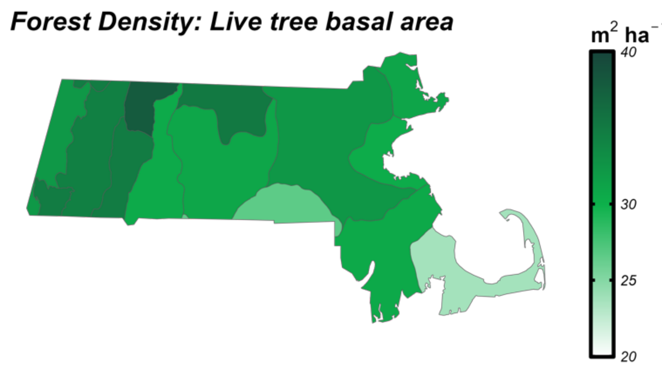


Figure 6. Forest density as live tree basal area (m^2 ha^{-1}) in Massachusetts.



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 Massachusetts, 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 largest ecosection on the eastern side of the state (near Middlesex County) 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 about average for Massachusetts. This suggests that in this ecosection, there may be fewer total trees per unit area, but on average, these trees tend to be relatively large. Meanwhile, the easternmost ecosection of Massachusetts, which stretches into the Atlantic Ocean, has a comparable forest density to nearby ecosections in terms of number of trees, but a lower forest density in terms of basal area, suggesting it contains a similar number of trees to neighboring ecosections, but on average, trees in this zone tend to be relatively small.

[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 Massachusetts.

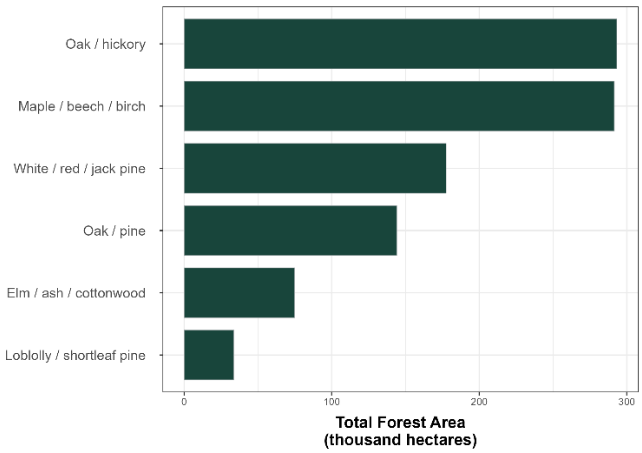
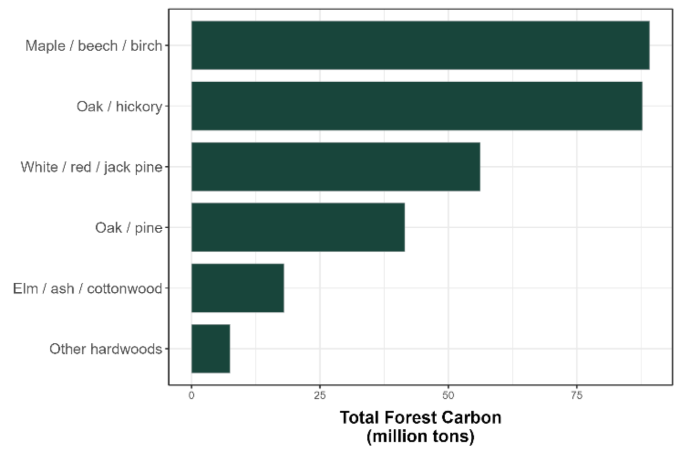


Figure 8. Total forest carbon (million tons) by forest type in Massachusetts. Total forest carbon is the sum of carbon stored across all aboveground and belowground pools (includes Soil Organic carbon + Live Belowground carbon + Live Aboveground carbon + Litter carbon + Dead wood carbon).

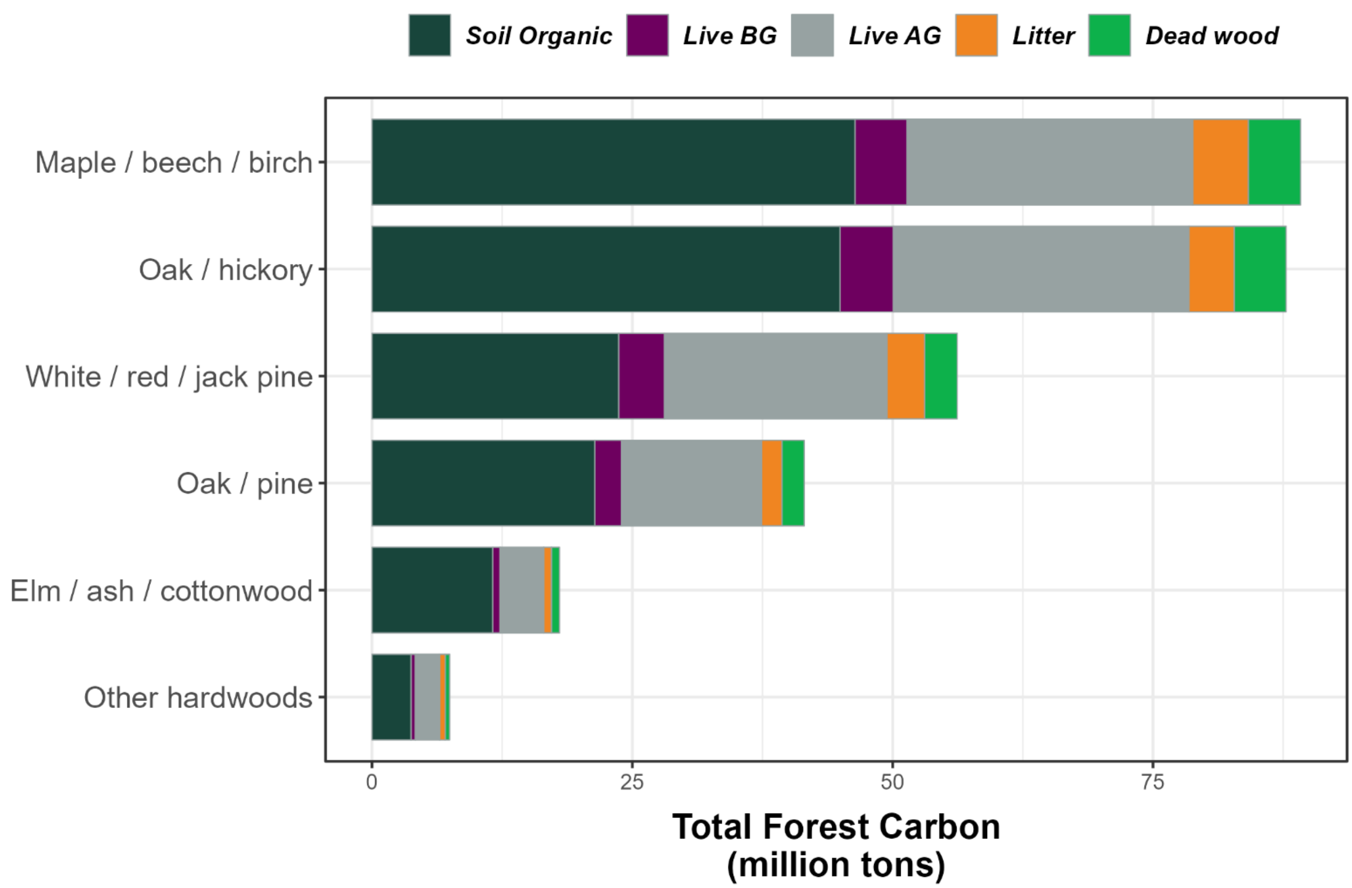


Massachusetts is dominated by 7 key forest cover types: Oak / hickory, Maple / beech / birch, White / red / jack pine, Oak / pine, Elm / ash / cottonwood, Loblolly / shortleaf pine, and other hardwoods. **Figure 7** and **Figure 8** show state-level data of total forested area and total forest carbon, respectively, for these cover type groups. As these figures show, Oak / hickory and Maple / beech / birch are the dominant forest types of Massachusetts, spanning a collective area upwards of 550,000 hectares and storing roughly 180 million tons of carbon statewide. With coverage levels ranging from ~30,000-175,000 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, Oak / hickory forests cover slightly more land area than Maple / beech / birch stands in Massachusetts (**Figure 7**), yet when it comes to carbon, Maple / beech / birch stands store slightly more carbon than their Oak / hickory 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

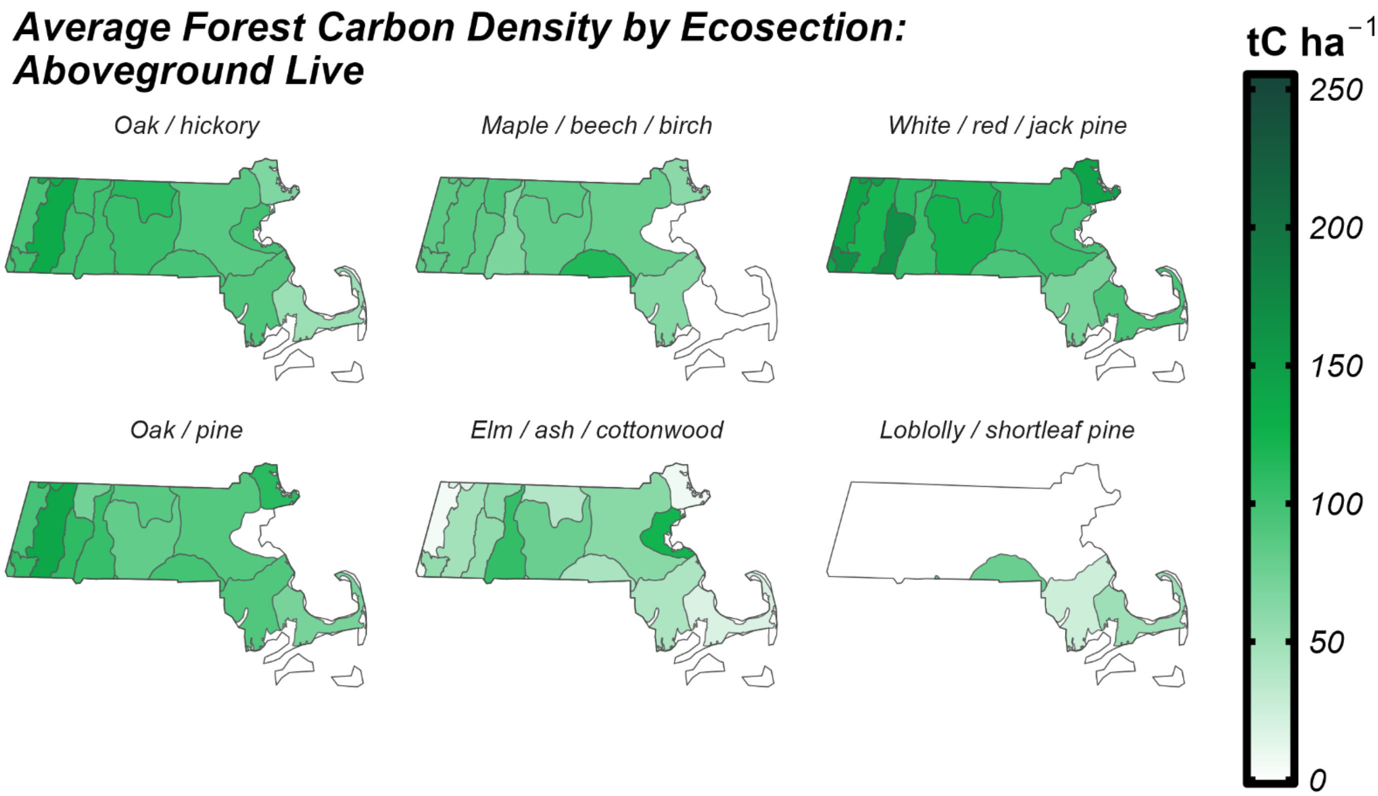
Figure 9. Total forest carbon (million tons) by pool and forest type in Massachusetts.



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 Massachusetts. 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. For instance, forests composed of Maple / beech / birch, Oak / hickory, Oak / pine, Elm / ash / cottonwood and other hardwoods allocate more ecosystem carbon to belowground pools (soil organic matter + live BG biomass), whereas the White / red / jack pine forest type tends to distribute stored carbon more evenly between aboveground and belowground 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 Maple / beech / birch and Oak / hickory stands on this landscape means their statewide carbon pools are outsized compared to other groups. For example, leaf litter and dead wood pools of Massachusetts's Maple / beech / birch or Oak / hickory forests on their own contain more stored carbon than the total ecosystem carbon (sum of carbon stored across all pools) contained by the other hardwoods group.

Forest Carbon Density

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



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 Massachusetts. Of these, White / red / jack pine stands hold the highest levels of aboveground live carbon per unit area, represented by the deeper shades of green in several western ecosections. By contrast, Elm / ash / cottonwood stands have a much lower carbon density per unit area for ecosections in this region. Across much of their extent, Oak / hickory and Maple / beech / birch stands exhibit relatively even carbon densities, while cover types like White / red / jack pine and Elm / ash / cottonwood 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 Tree 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

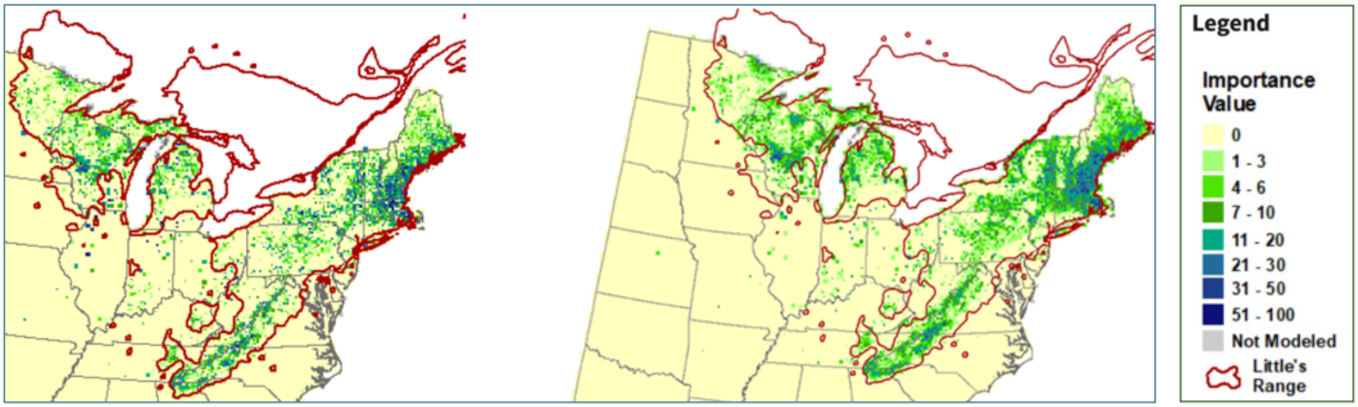
Additional background on this tool can be found at: https://research.fs.usda.gov/centers/ccrc along with short video tutorials on the Climate Change Atlas website.

Habitat Suitability and Migration Models

Model Reliability: High

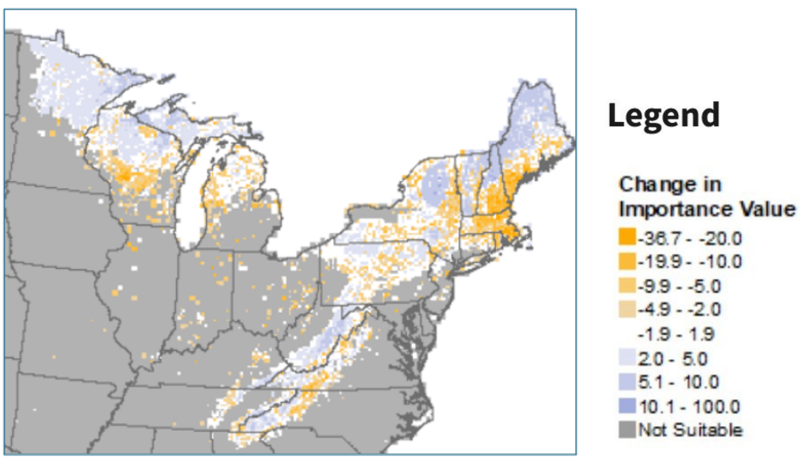
Key Species Example: Modeled potential suitable habitat for Eastern White Pine (*Pinus strobus*) through 2100

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



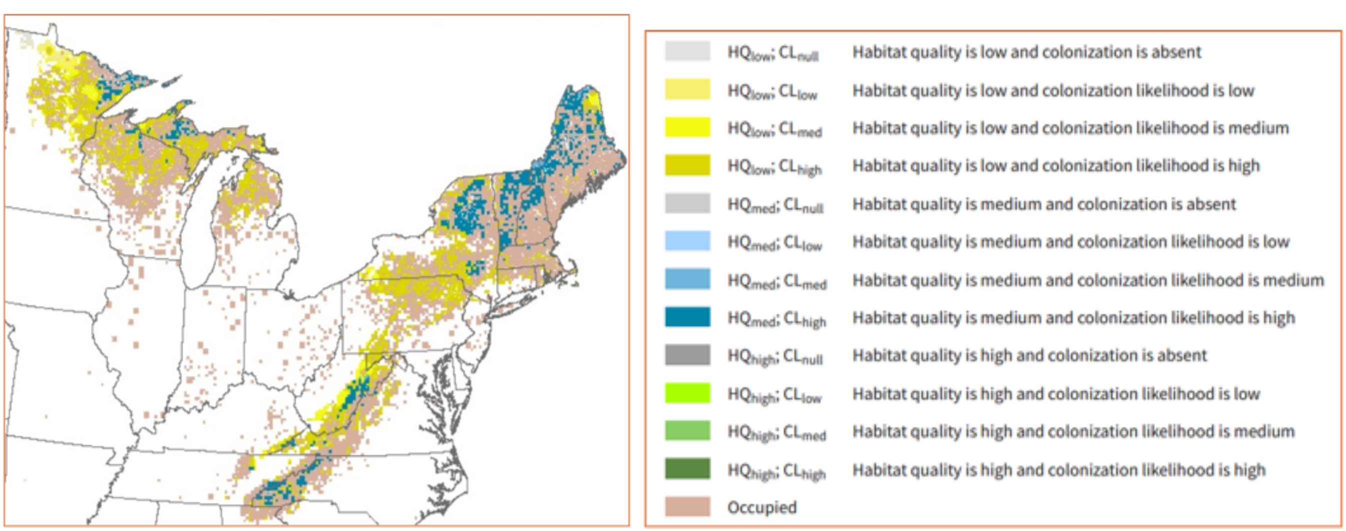
Importance value is a measure of abundance that accounts for both tree basal area and number of stems, ranging from 0-100.

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



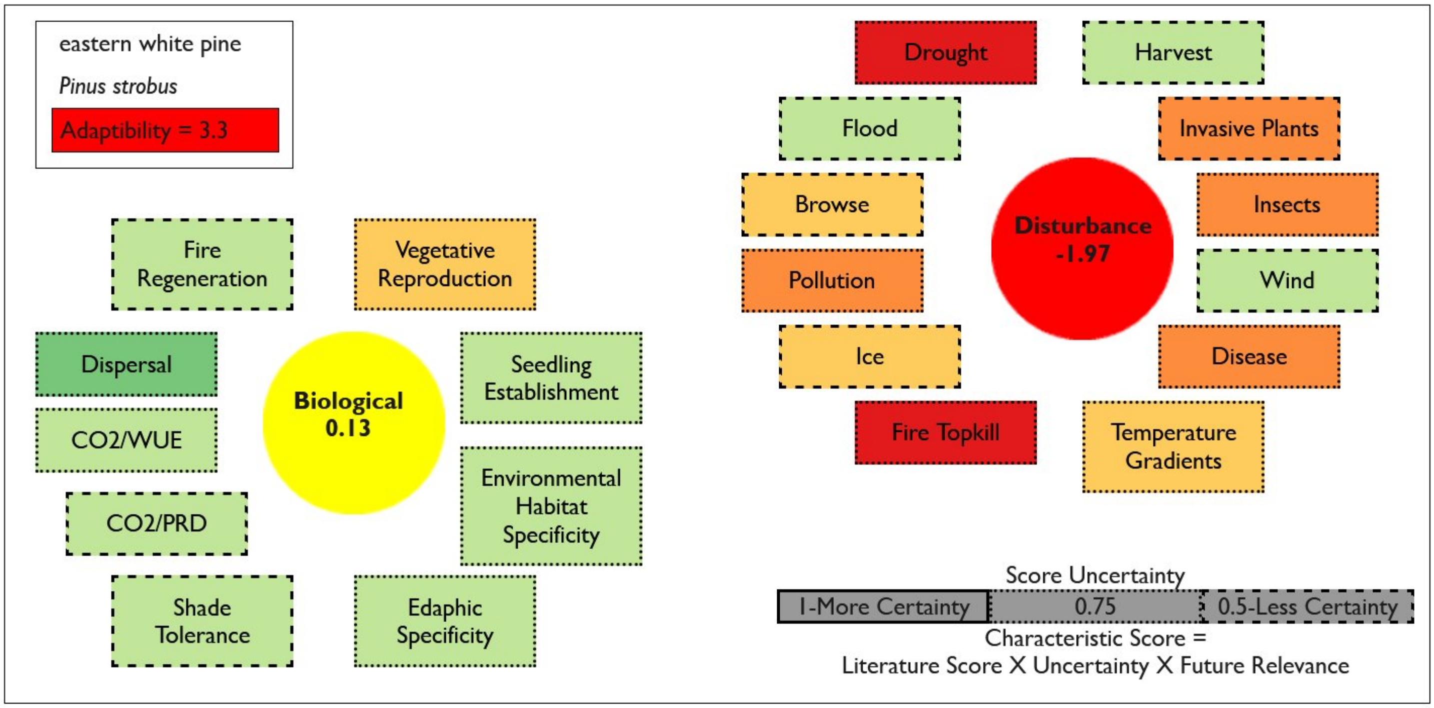
Colonization is limited to range margins and infill (Blue) which is derived from habitat quality (DISTRIB) and migration model (SHIFT) utilizing the colonization likelihood model (CL). Orange shading represents current species' distributions where abundance is predicted to decrease due to loss of habitat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

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



Adaptability Ratings

Key Species Example: Eastern White Pine *(Pinus Strobus)*



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 Red Oak

Eastern white pine is a widely distributed (10.6% of area), dense, and high importance northern pine with little modeled change in suitable habitat by 2100. It does, however, suffer from some negative traits (e.g., susceptibility to drought, fire, and insects) which drops it to low adaptability. Because of its high current abundance, we upgrade its capacity to cope to fair. SHIFT shows good infill.

Citations:

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