Forest Carbon and Climate Program
Department of Forestry
MICHIGAN STATE UNIVERSITY

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State and Tribal Capacity Building on Forest Carbon

Forest Carbon and Climate Change in Maine

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

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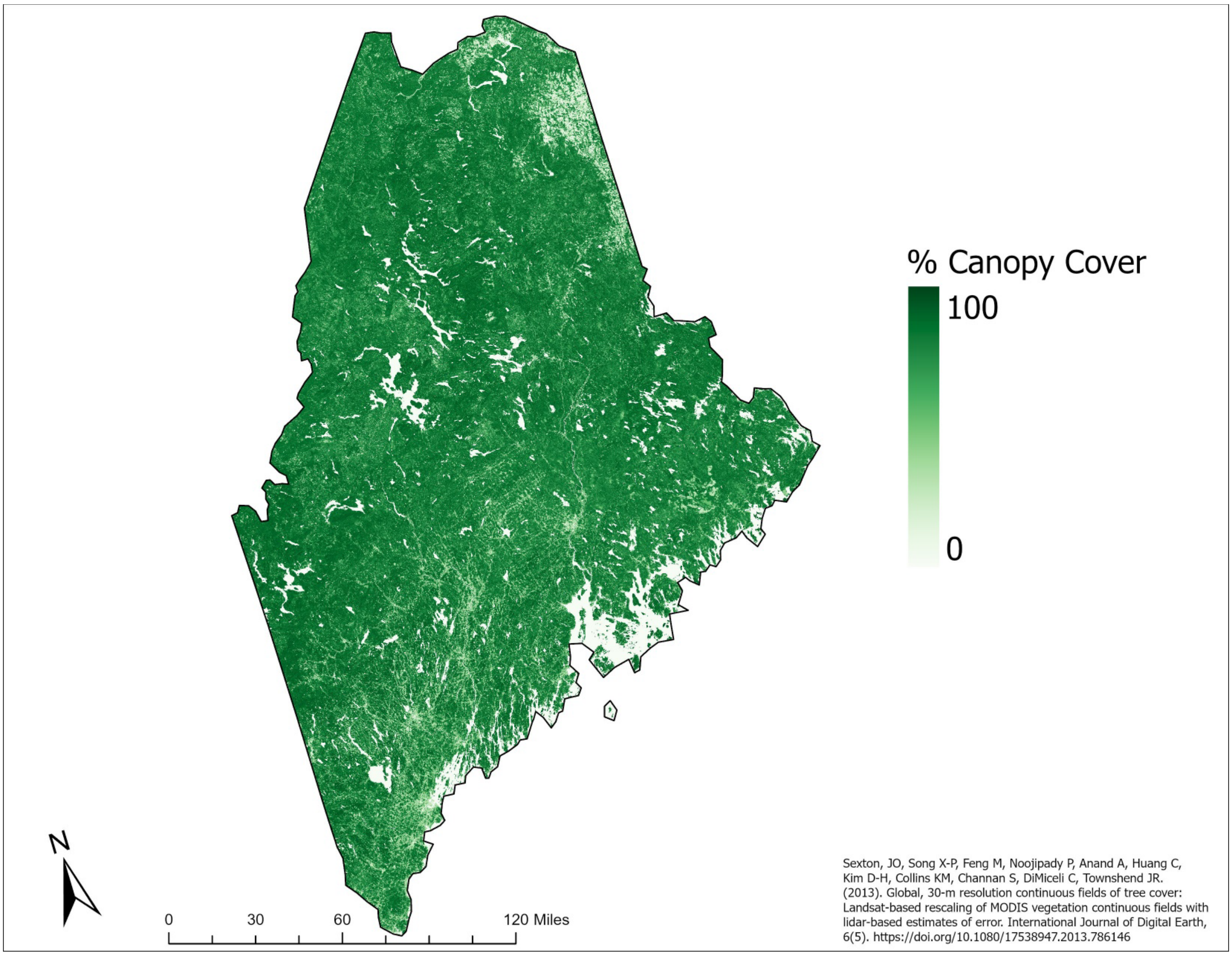
Maine Forest Overview

Maine is situated along the east coast of the United States (U.S.) and lies within the US Forest Service's Eastern Region (USFS Region 9). Marking the northeastern corner of the contiguous U.S., Maine is bordered by New Hampshire to the west, the Canadian province of Québec to the northwest, and the Canadian province of New Brunswick to the northeast, with the Atlantic coast marking Maine's southern boundary. It's the only state in the continental U.S. to share a border with only one other U.S. state.

A map of percent tree canopy cover in Maine is shown in **Figure 1**. This state has significant forest coverage across much of its extent, with only a small area of reduced coverage in the northeast, along the border with New Brunswick. Areas that show no forest cover represent major water bodies such as inland lakes and bays along the southern coast.

Figure 1. Percent tree canopy cover in Maine.



Temperature and Precipitation

Two major factors affecting forest carbon and productivity are temperature and precipitation. **Figure 2** shows normal mean temperatures throughout Maine between 1991 and 2020. Over this 30-year period, mean annual temperatures varied by about 15 °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 49 °F and occurs in the southwest corner of the state, while the coolest mean annual temperature is around 34 °F occurring along Maine's northwestern border, as well as further inland in high-elevation areas.

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

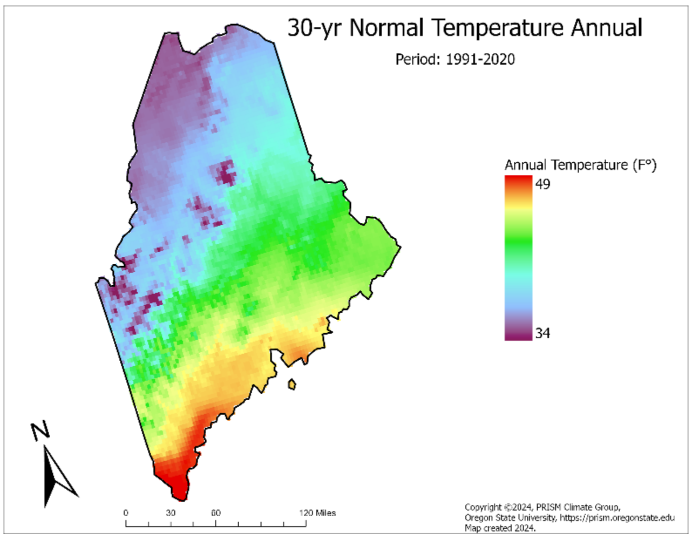


Figure 3. Normal mean precipitation (in.) from 1991-2020 in Maine.

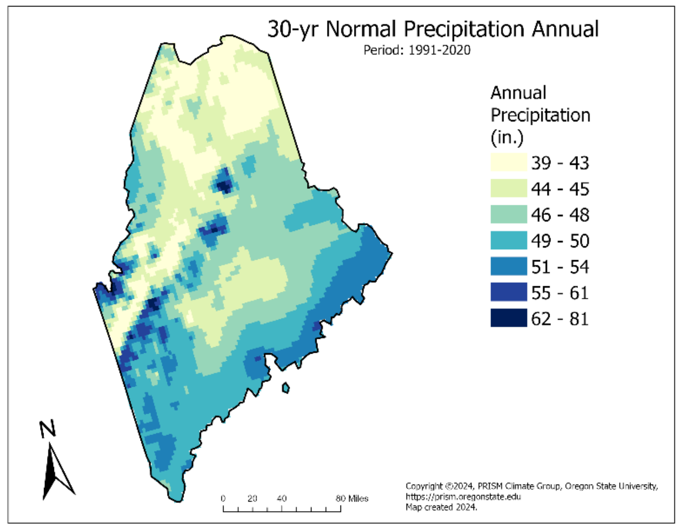


Figure 3 shows normal mean precipitation throughout Maine between 1991 and 2020 and demonstrates the geographic variation in these trends. Over this 30-year period, mean annual precipitation levels varied by about 42 in. Areas that receive the lowest levels of precipitation (39-43 in.) occur in the northernmost reaches of the state, as well as along a narrow southwest-northeast transect within the inland northwest. Areas receiving the highest amounts of precipitation (62-81 in.) occur in high elevation zones of the inland northwest, along high-elevation areas of the Appalachian Mountain range. These high-precipitation areas notably correspond with the state's coldest inland areas (**Figure 2**).

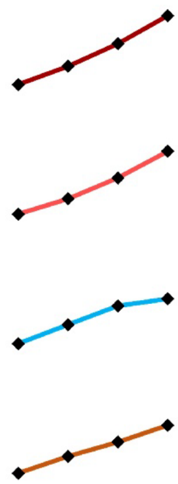
Projected Future Trends in Temperature / Precipitation

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

Potential Changes in Climate Variables

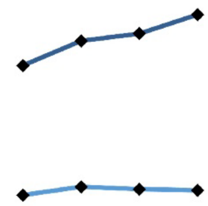
Temperature (°F)

	2009	2039	2069	2099
Annual Average	41.2	44.3	48.0	52.7
Growing Season May—Sep	59.7	62.6	66.4	71.3
Coldest Month Average	12.0	14.7	17.5	18.5
Warmest Month Average	66.2	69.0	71.4	74.2



Precipitation (in)

	2009	2039	2069	2099
Annual Total	45.1	48.1	48.9	51.2
Growing Season May—Sep	19.6	20.2	20.0	19.9



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 Maine 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 11.5 °F, with the most drastic increases expected to occur during the growing season (+11.6 °F).

Model results of future precipitation in Maine 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 6.1 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 Maine may occur during the winter months (Oct. – Apr.).

Forest Density

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

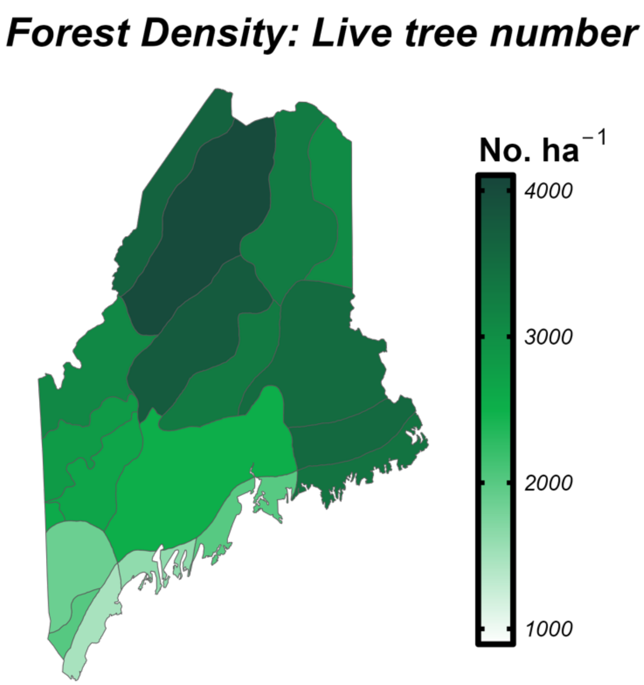
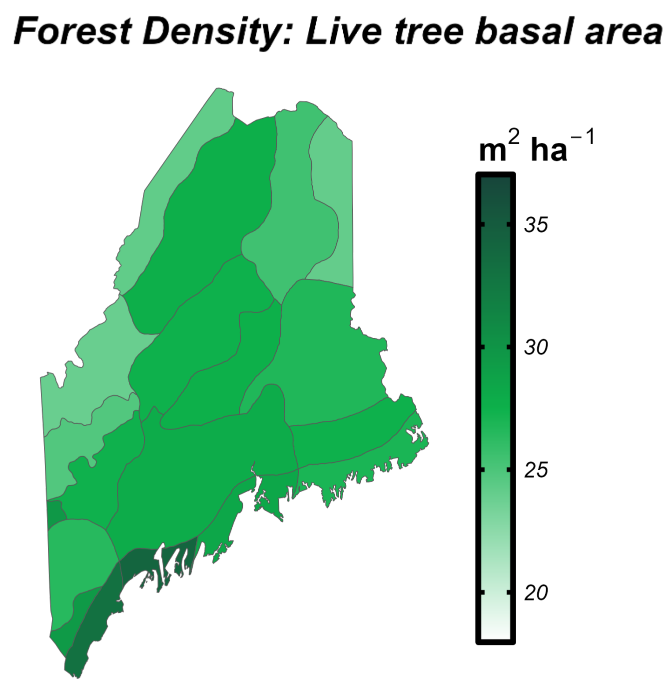


Figure 6. Forest density as live tree basal area (m^2 ha^{-1}) in Maine.



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 Maine, 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 southernmost ecosection of Maine has the state's lowest forest density in terms of number of trees per hectare (**Figure 5**), but its density in terms of basal area (**Figure 6**) is much higher than most other ecosections. 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 northwestern ecosections of Maine, near the border with Québec, have the state's highest forest densities in terms of number of trees, but average forest densities in terms of basal area, suggesting forests in this region are characterized by more, relatively smaller, stems than in the southern portion of the state.

[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 Maine.

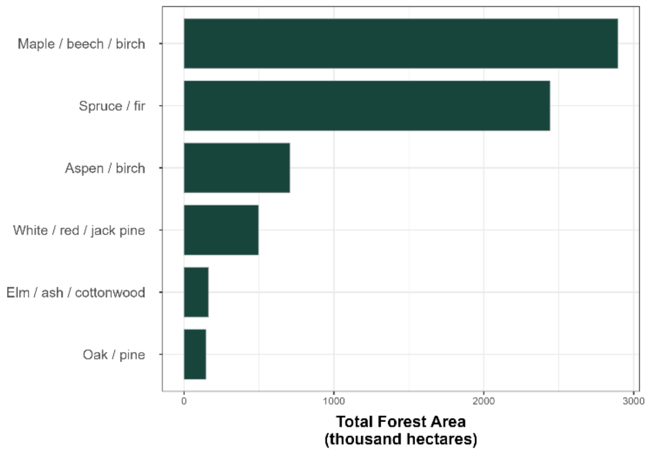
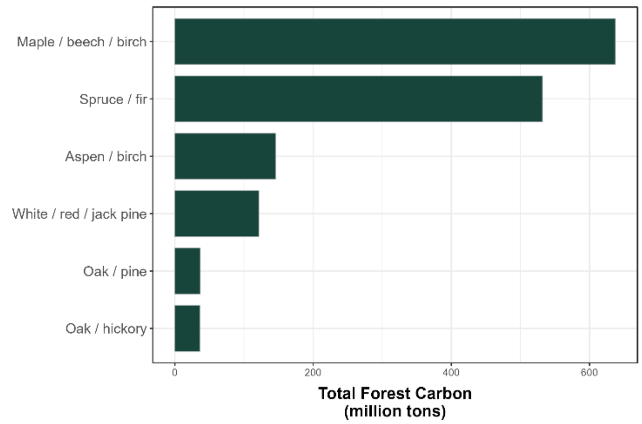


Figure 8. Total forest carbon (million tons) by forest type in Maine. Total forest carbon is the sum of carbon stored across all aboveground and belowground pools (includes Soil Organic carbon + Live Belowground carbon + Live Aboveground carbon + Litter carbon + Dead wood carbon).

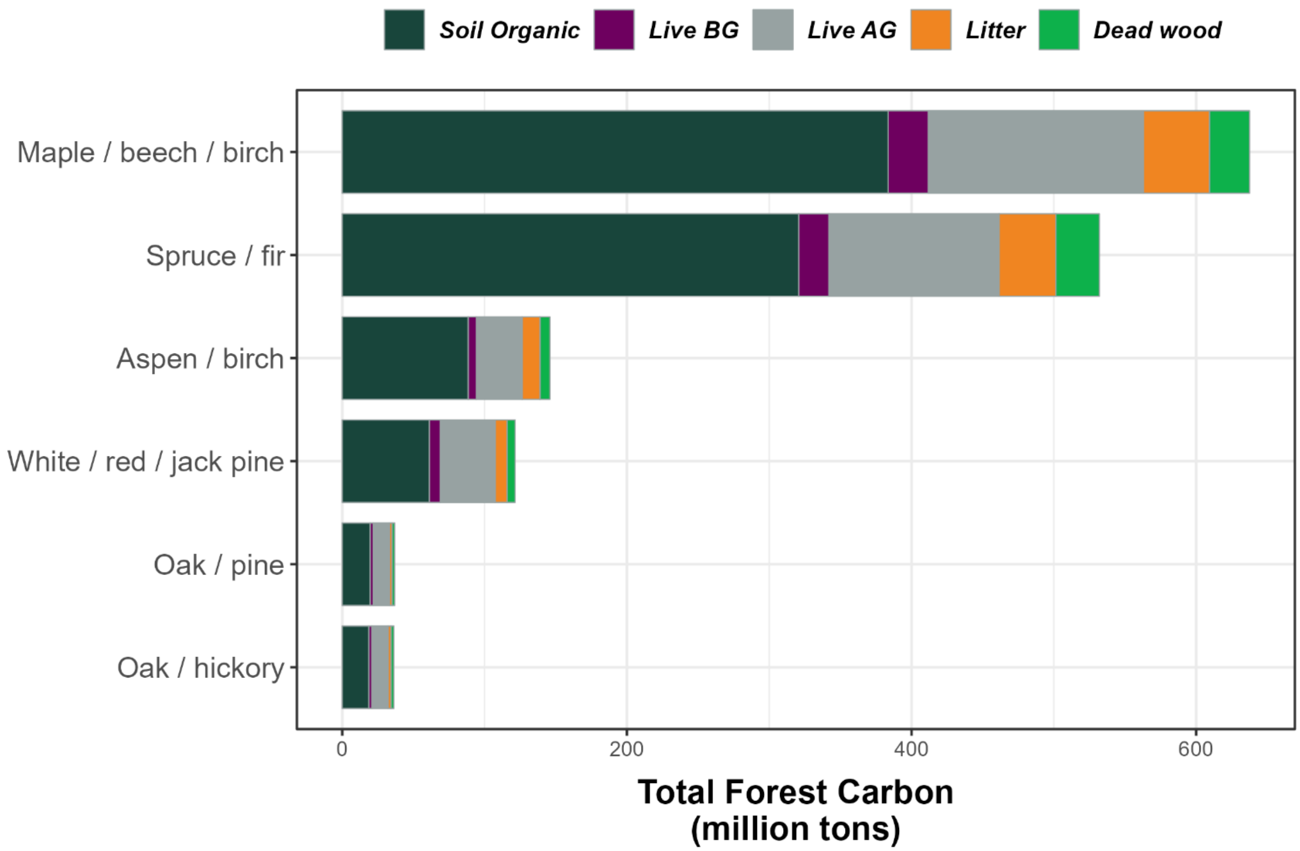


Maine is dominated by 2 key forest cover types: Maple / beech / birch and Spruce / fir. However, Aspen / birch, White / red / jack pine, Elm / ash / cottonwood, Oak / pine, and Oak / hickory still cover substantial areas and store a significant amount of carbon but to a lesser degree. **Figure 7** and **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 Spruce / fir are the dominant forest types of Maine, collectively spanning an area of ~5.2 million hectares and storing roughly 1.15 billion tons of carbon statewide. With coverage levels ranging from ~250,000-700,000 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, Elm / ash / cottonwood forests cover slightly more land area than Oak / pine stands in Maine (**Figure 7**), yet when it comes to carbon, Oak / pine stands store more carbon than their Elm / ash / cottonwood counterparts, ranking as the 5th most important forest type for carbon storage, while Elm / ash / cottonwood doesn't even rank within the top six cover types for carbon storage in the state (**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

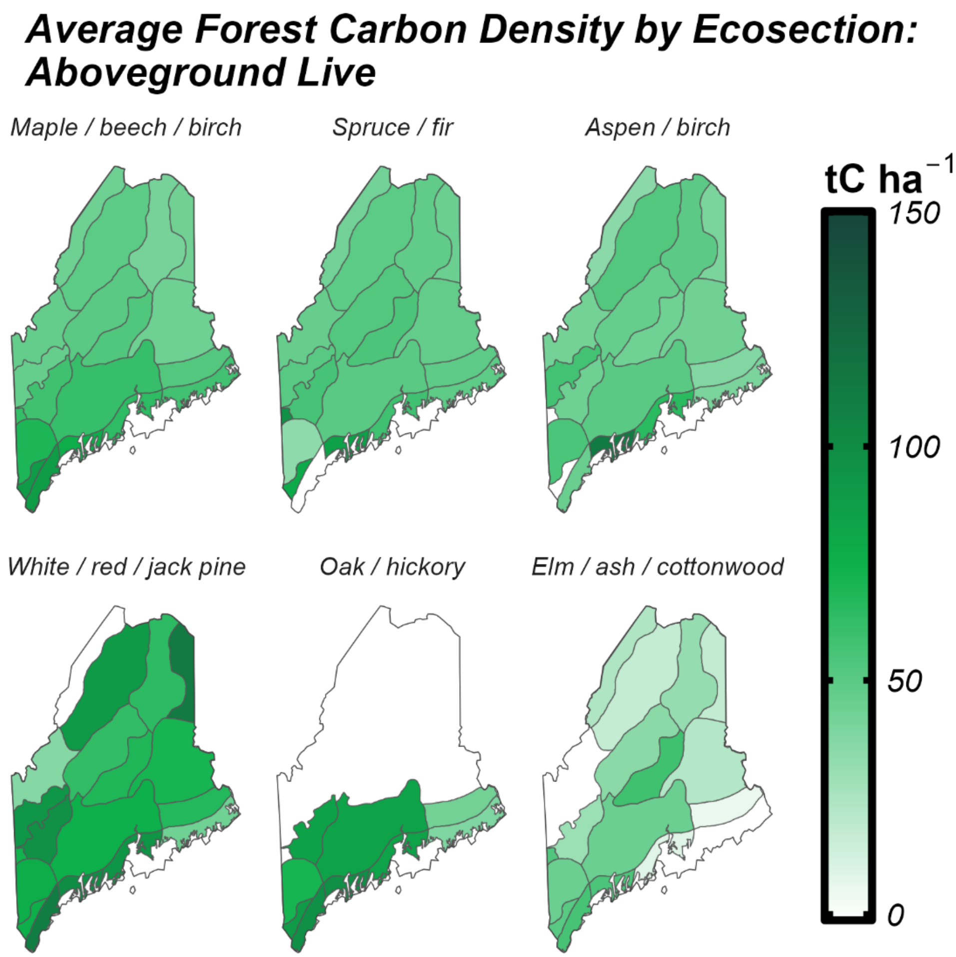
Figure 9. Total forest carbon (million tons) by pool and forest type in Maine.



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 Maine. 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, Spruce / fir, and Aspen / birch allocate significantly more ecosystem carbon to belowground pools (soil organic matter + live BG biomass), whereas forest types like Oak / pine and Oak / hickory 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. Maple / beech / 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 Maine's Maple / beech / birch forests on their own contain roughly double the amount of stored carbon than the total ecosystem carbon (sum of carbon stored across all pools) contained by the Oak /pine or Oak / hickory groups.

Forest Carbon Density

Figure 10. Aboveground live forest carbon density (tC ha^{-1}) by forest type in Maine.



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 10**, the carbon density of aboveground living forest biomass is shown for 6 key cover types in Maine. Of these, Aspen / birch and White / red / jack pine stands hold the highest levels of aboveground live carbon per unit area, represented by the deep shade of green in a southern ecosection (Aspen / birch) and northeastern ecosection (White / red / jack pine). Across much of their extent, Maple / beech / birch and Spruce / fir 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 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.

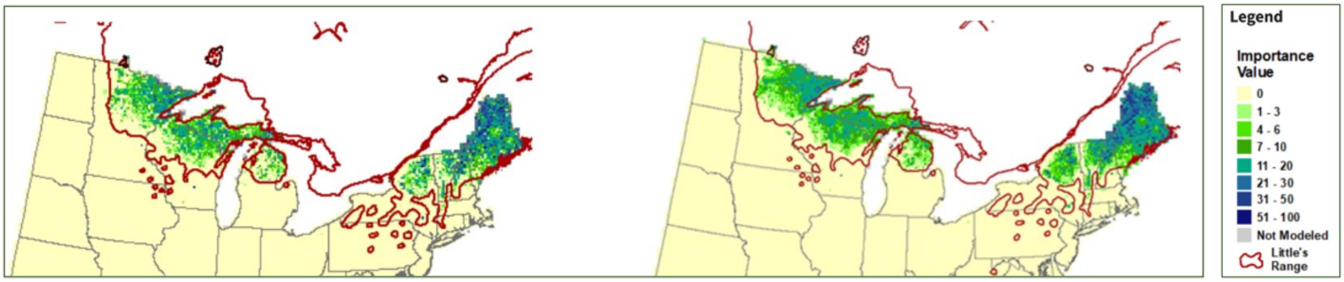
Habitat Suitability and Migration Models

Model Reliability: High

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

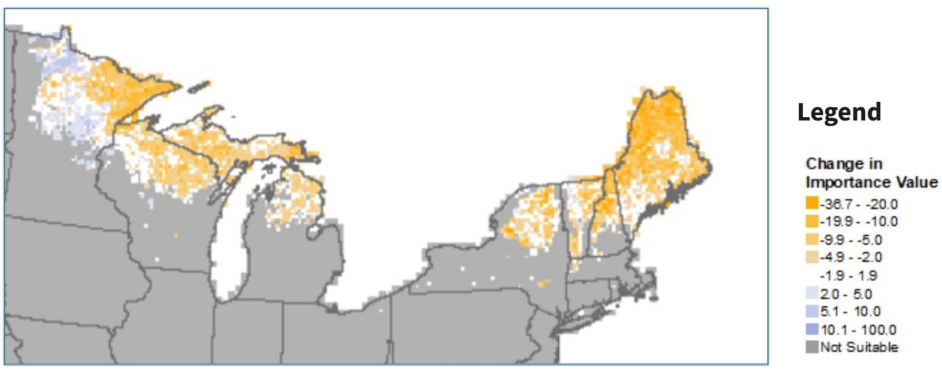
Current habitat quality and distribution (DISTRIB-II)

Potential migration (SHIFT) and colonization likelihood (CL)



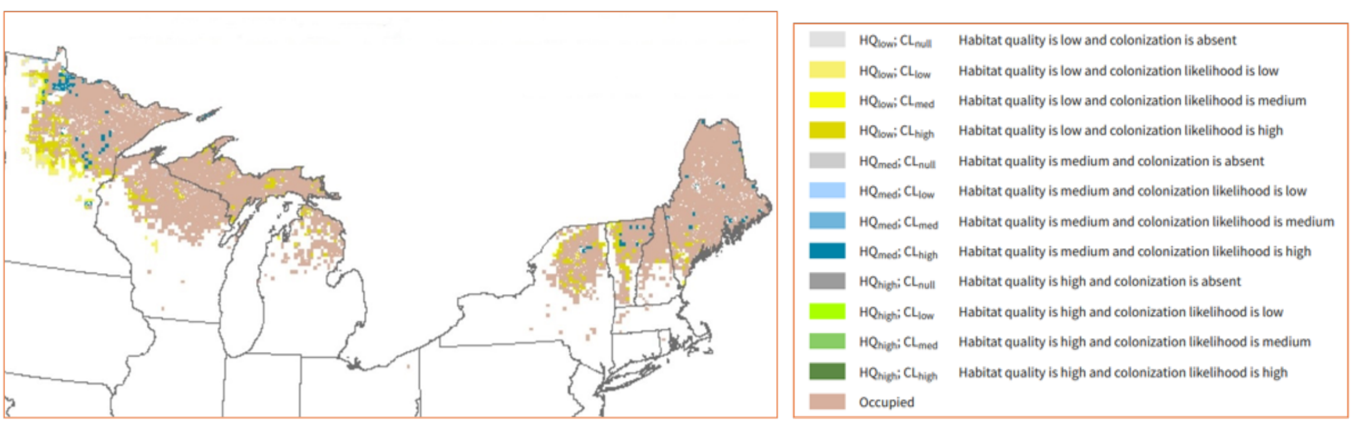
Importance value is a measure of abundance that accounts for both tree basal area and number of stems, ranging from 0-100.

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



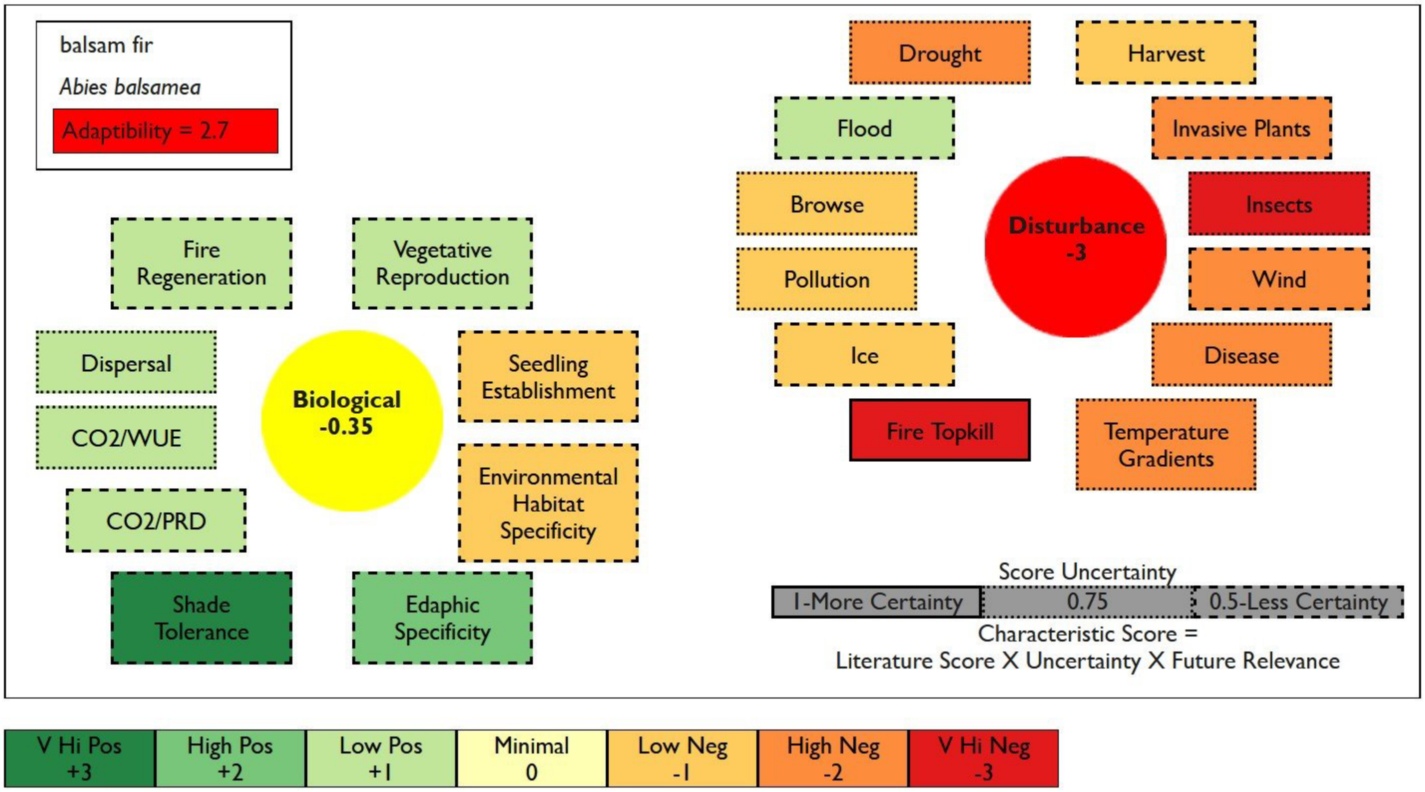
Colonization is limited to range margins and infill (Blue) which is derived from habitat quality (DISTRIB-II) and migration model (SHIFT) utilizing the colonization likelihood model (CL). Orange shading represents current species' distributions where abundance is predicted to decrease due to loss of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

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



Adaptability Ratings

Key Species Example: Balsam fir (*Abies balsamea*)



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 Balsam fir

Balsam fir is a narrow range, densely populated, and of high importance where it occurs. It has a reliable model that consistently showed no real change in overall habitat area but a substantial reduction in overall suitable habitat. Even though precipitation increases slightly, the 3.8-6.4C increase in heat by 2100 may be critical. It is also poorly adapted (Adapt=2.7) and is very susceptible to insects, fire, and drought, all boding poorly for this species in the long run. The fact that it is abundant in its range (7.3% of eastern US) provides a fair capability to cope with the changing climate. SHIFT outputs are not significant for this species as most of the habitat is occupied except for some infill and migration West in Minnesota.

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