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 Maryland*

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

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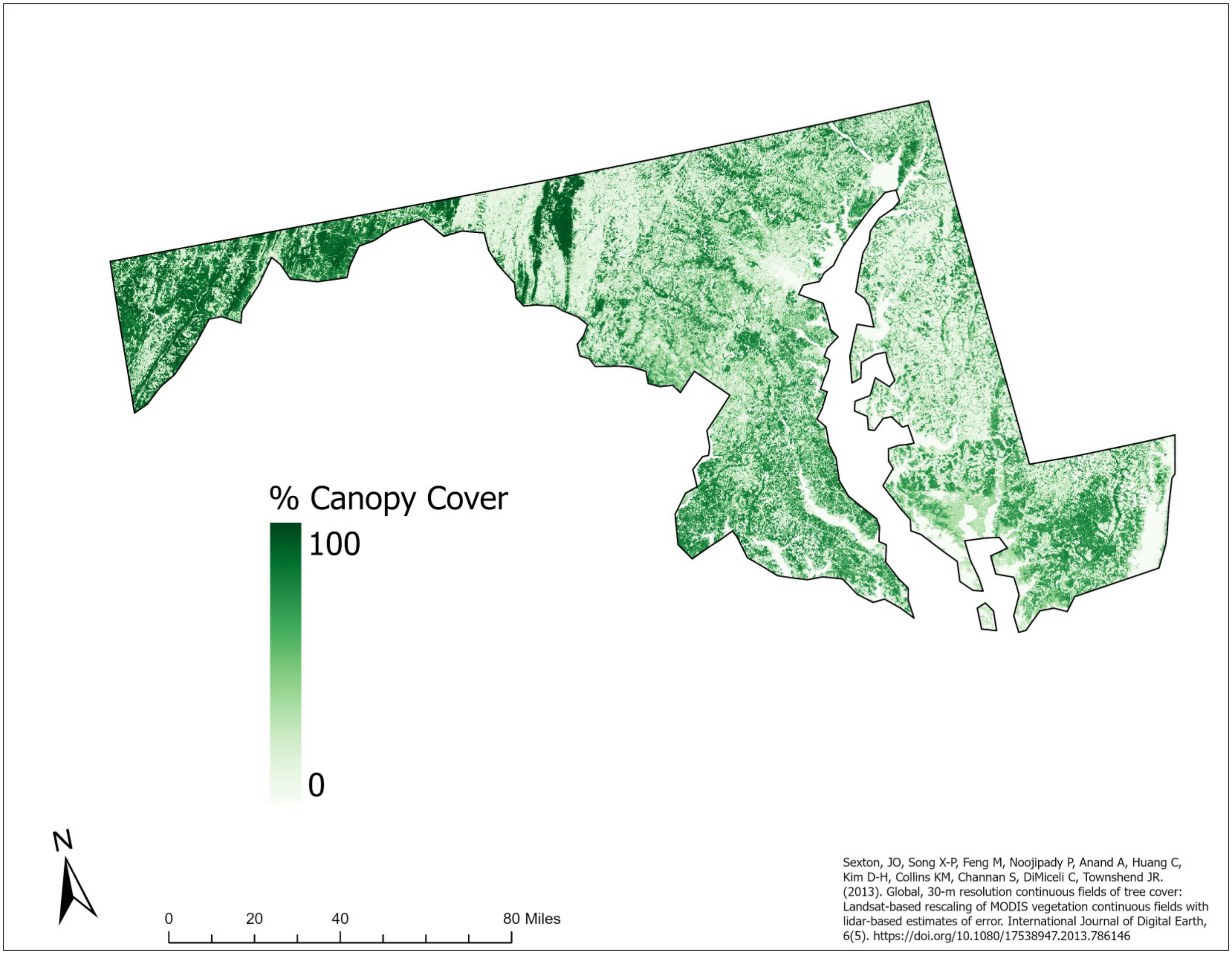
# Maryland Forest Overview

Maryland 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 West Virginia to the west, Pennsylvania to the north, Delaware to the east, and Virginia to the south, with the Atlantic coast marking the remainder of Maryland's southern boundary.

A map of percent tree canopy cover in Maryland is shown in **Figure 1**. This state has variable forest coverage across its extent. The westernmost portions of the state along Maryland's northern border are characterized by mountainous terrain and higher levels of canopy cover. Much of the eastern portion of the state has scattered coverage, with the lowest forest coverage coinciding with coastal and urban areas with higher population densities.

**Figure 1.** Percent tree canopy cover in Maryland.



## Temperature and Precipitation

Two major factors affecting forest carbon and productivity are temperature and precipitation. **Figure 2** shows normal mean temperatures throughout Maryland between 1991 and 2020. Over this 30-year period, mean annual temperatures varied by about 12 °F across this state. Temperature trends largely follow latitudinal gradients, with warmer mean temperatures occurring in the southernmost portions of the state and giving way to cooler temperatures in the north. The warmest mean annual temperature is around 59 °F and occurs in the southeasternmost portions of Maryland, while the coolest mean annual temperature is around 47 °F in the northwest portion of the state and coincides with higher elevations.

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

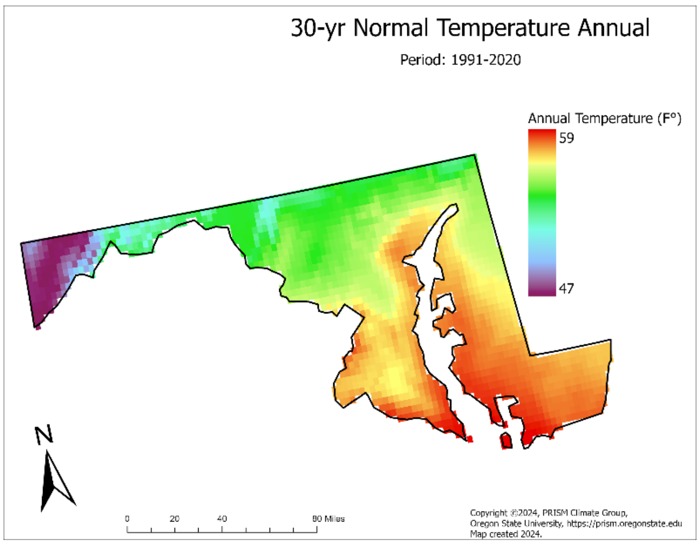



**Figure 3.** Normal mean precipitation (in.) from 1991-2020 in Maryland.

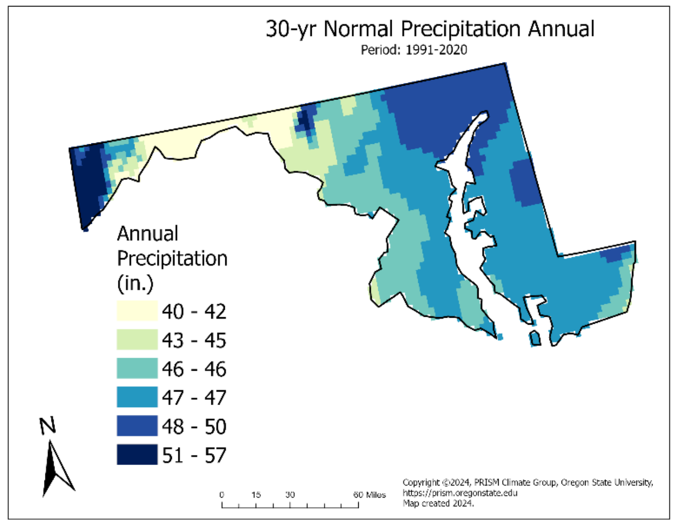



**Figure 3** shows normal mean precipitation throughout Maryland between 1991 and 2020 and demonstrates the geographic variation in these trends. Over this 30-year period, mean annual precipitation levels varied by about 17 in. The area receiving the lowest levels of precipitation (40-42 in.) occurs along the west-central northern border of the state. Notably, this drier area is directly adjacent to the area receiving the greatest levels of precipitation (51-57 in.) in the northwestern corner of the state, which is characterized by higher elevations. The southern half of Maryland generally sees between 43-47 in. of precipitation annually.

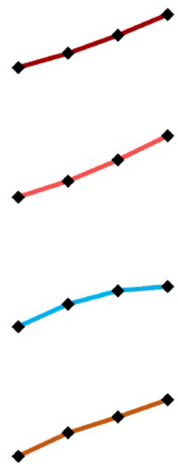
# Projected Future Trends in Temperature / Precipitation

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

## Potential Changes in Climate Variables

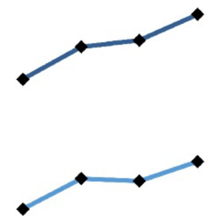
**Temperature (°F)**

| | 2009 | 2039 | 2069 | 2099 |
|---|---|---|---|---|
| Annual Average | 55.0 | 57.6 | 60.9 | 64.6 |
| Growing Season May—Sep | 70.7 | 73.5 | 77.1 | 81.3 |
| Coldest Month Average | 31.6 | 33.9 | 35.2 | 35.7 |
| Warmest Month Average | 76.4 | 79.7 | 81.9 | 84.3 |



**Precipitation (in)**

| | 2009 | 2039 | 2069 | 2099 |
|---|---|---|---|---|
| Annual Total | 43.9 | 48.2 | 49.1 | 52.6 |
| Growing Season May—Sep | 19.7 | 21.7 | 21.5 | 22.7 |



**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 Maryland 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 9.6 °F, with the most drastic increases expected to occur during the growing season (+10.6 °F).

Model results of future precipitation in Maryland follow similar trends, with totals projected to increase through 2099 (**Figure 4**). Over a 90-year period, annual precipitation is expected to increase by an estimated 8.7 in., which is a higher rate of change than projections for the growing season (+3 in.). This suggests that the most significant changes to precipitation in Maryland may occur during the winter months (Oct. – Apr.).

# Forest Density

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

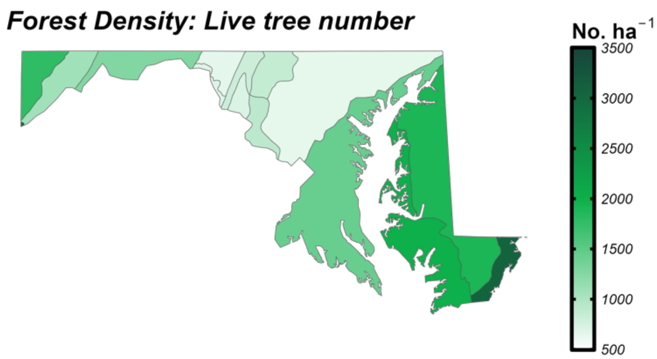
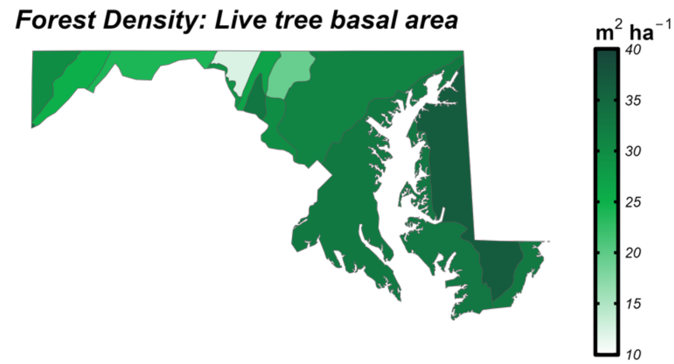



**Figure 6.** Forest density as live tree basal area (m$^2$ ha$^{-1}$) in Maryland.




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 Maryland, 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 eastern ecosection along Maryland's northern border 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 relatively high. This suggests that in this zone, there may be fewer total trees per unit area, but on average, these trees tend to be relatively large. Meanwhile, the southeasternmost ecosection of Maryland, which borders the Atlantic coast, has the state's highest forest density in terms of number of trees, and a high forest density in terms of basal area suggesting a high overall forest density 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 Maryland.

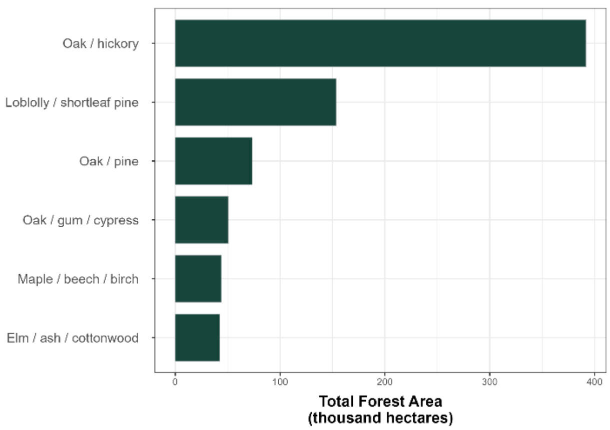
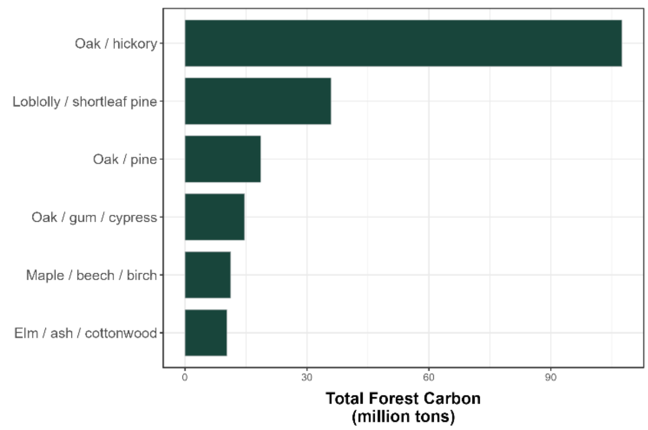



**Figure 8.** Total forest carbon (million tons) by forest type in Maryland. Total forest carbon is the sum of carbon stored across all aboveground and belowground pools (includes Soil Organic carbon + Live Belowground carbon + Live Aboveground carbon + Litter carbon + Dead wood carbon).

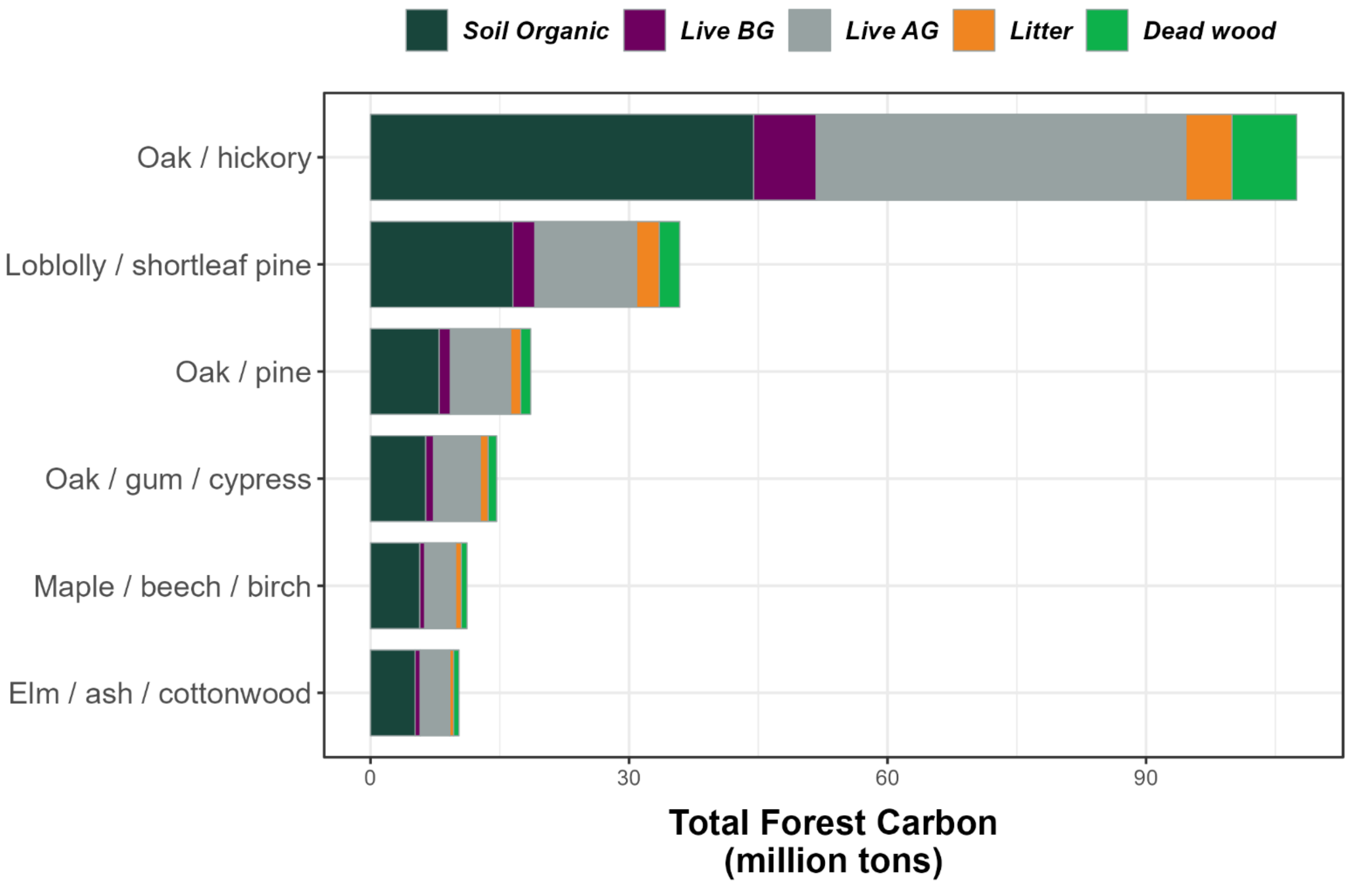



Maryland is dominated by 6 key forest cover types: Oak / hickory, Loblolly / shortleaf pine, Oak / pine, Oak / gum / cypress, Maple / beech / birch, and Elm / ash / cottonwood. **Figure 7** and **Figure 8** show state-level data of total forested area and total forest carbon, respectively, for each of these cover type groups. As these figures show, Oak / hickory is the dominant forest type of Maryland, spanning an area upwards of 375,000 hectares and storing over 100 million tons of carbon statewide. With coverage levels ranging from <50,000-150,000 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 / gum / cypress forests cover only slightly more land area than Maple / beech / birch and Elm / ash / cottonwood stands in Maryland (**Figure 7**), yet when it comes to carbon, the difference is greater, with Maple / beech / birch and Elm / ash / cottonwood stands storing about two thirds the carbon of their Oak / gum / cypress 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

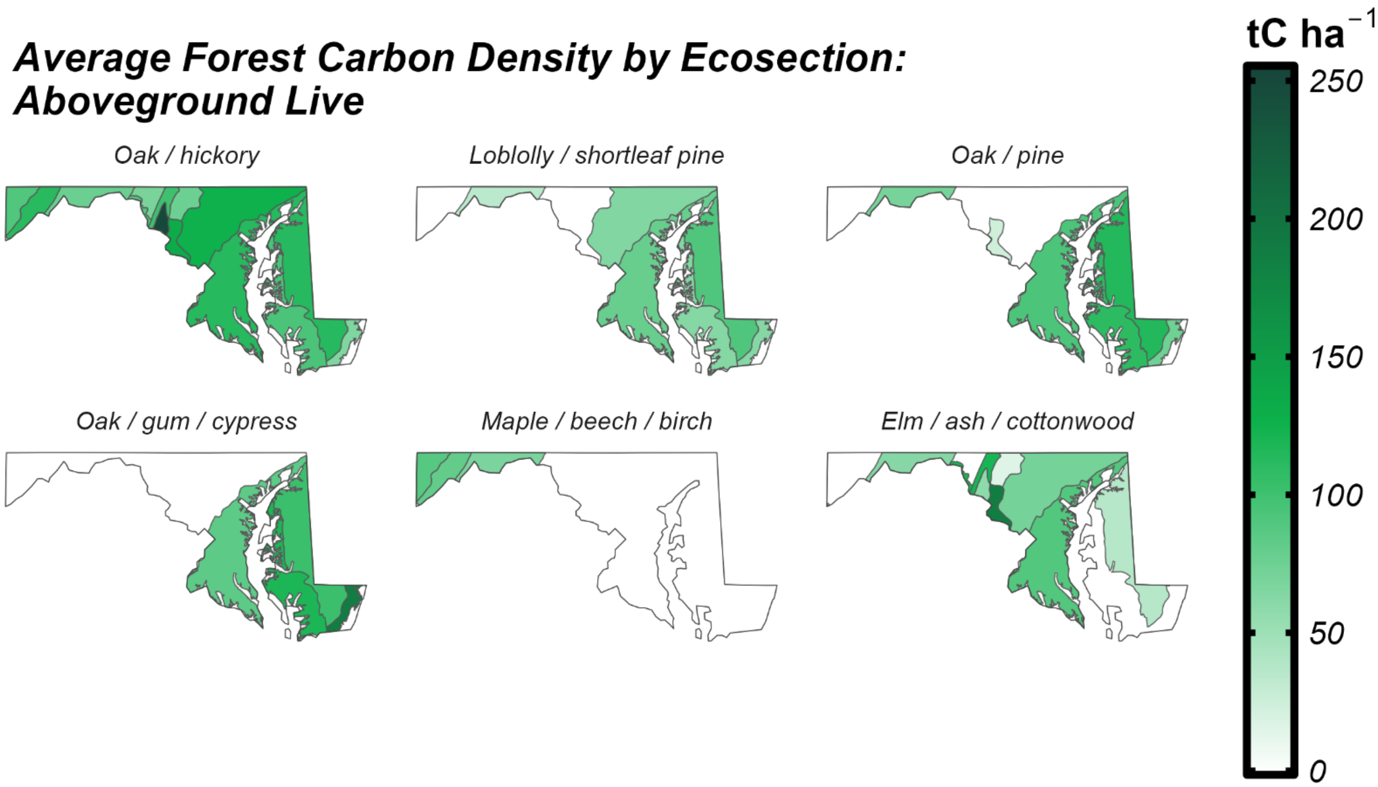
**Figure 9.** Total forest carbon (million tons) by pool and forest type in Maryland.




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 Maryland. 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 Loblolly / shortleaf pine, Maple / beech / birch, and Elm / ash / cottonwood allocate more ecosystem carbon to belowground pools (soil organic matter + live BG biomass), whereas Oak / hickory stands allocate more carbon to aboveground pools (live AG biomass + litter + deadwood) and forest types like Oak / pine and Oak / gum / cypress tend 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. Oak / hickory'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 Maryland's 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 Maple / beech / birch or Elm / ash / cottonwood groups.

## Forest Carbon Density

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




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 Maryland. Of these, Oak / hickory stands hold the highest levels of aboveground live carbon per unit area, represented by the deep shade of green in a small central ecosection along Maryland's southern border. By contrast, Elm / ash / cottonwood stands have a much lower carbon density per unit area in this ecosection. Across much of their extent, Loblolly / shortleaf pine stands exhibit relatively even carbon densities, while cover types like Oak / hickory 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 |

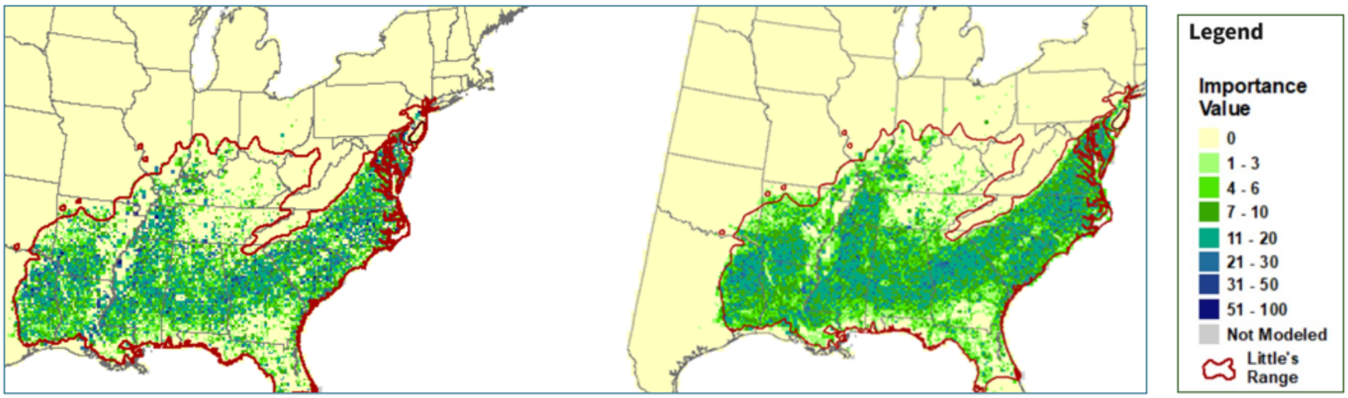
Additional background on this tool can be found at: https://research.fs.usda.gov/centers/ccrc along with short video tutorials on the Climate Change Atlas website.

# Habitat Suitability and Migration Models

## Model Reliability: High

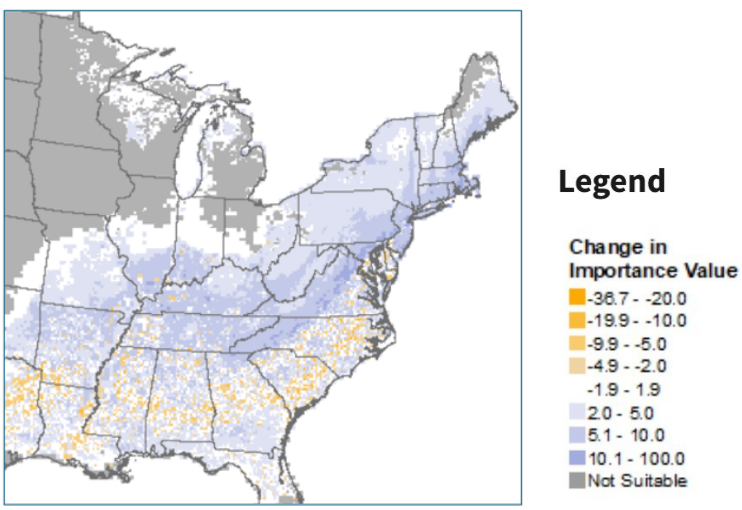
Key Species Example: Modeled potential suitable habitat for Sweetgum (*Liquidambar styraciflua*) through 2100

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



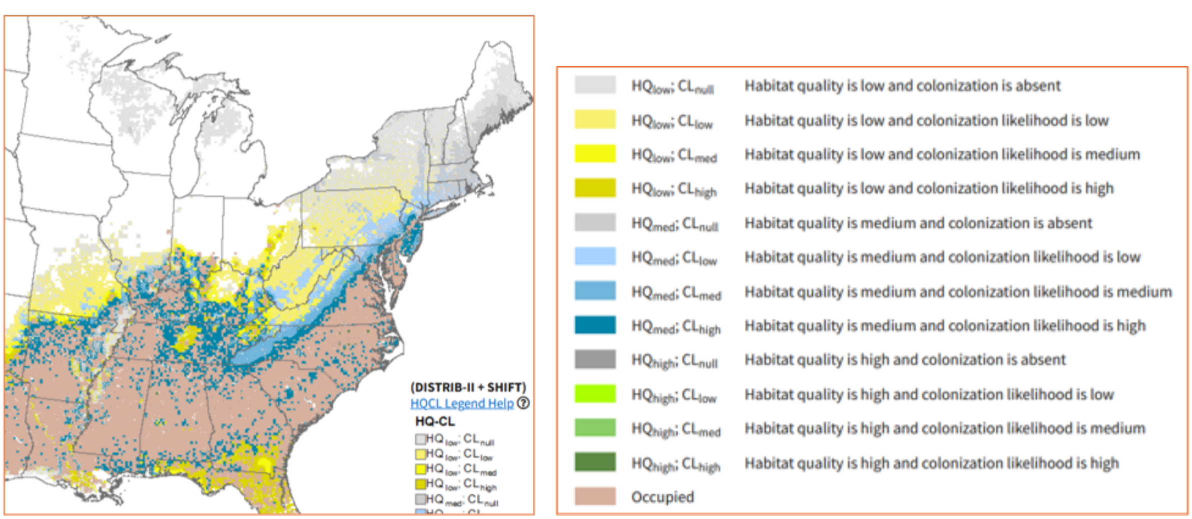

Importance value is a measure of abundance that accounts for both tree basal area and number of stems, ranging from 0-100

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



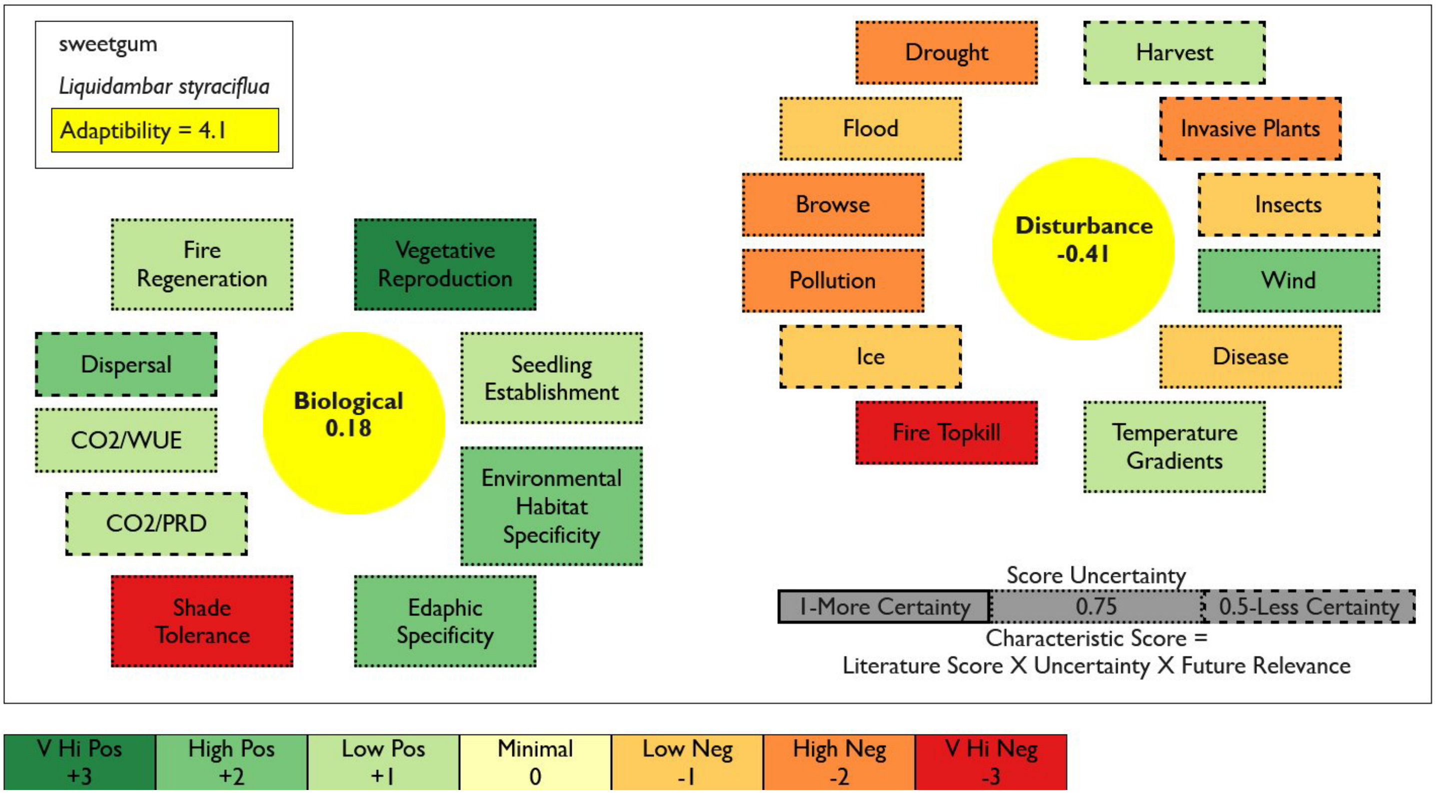

Colonization is limited to range margins and infill (Blue) which is derived from habitat quality (DISTRIB) and migration model (SHIFT) utilizing the colonization likelihood model (CL). Orange shading represents current species' distributions where abundance is predicted to decrease due to loss of habitat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

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



## Adaptability Ratings

Key Species Example: Sweetgum (*Liquidambar styraciflua*)




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 Sweetgum

Sweetgum is distributed widely (22.5% of area), very abundant (third only to loblolly pine and red maple), densely occurring, and with high IV across the southern half of the eastern US. It occupies 23% of the eastern US territory and ranks highest in importance for some of the region (though loblolly pine beats it out much of the time). Its highly reliable model suggests an increase of habitat, including to the north all the way into Maine (under RCP 8.5), by 2100. However, the SHIFT model largely limits those northern locations from being naturally colonized within 100 years, though a fairly large northward expansion has some possibility. The species is also moderate in its adaptability, yielding a very good capacity to cope with a changing climate. The SHIFT model also indicates it a very good species for infilling.

# Citations:


## Habitat suitability models on trees:

Peters et al. (2020). Climate change tree atlas, Version 4. U.S. Forest Service, Northern Research Station and Northern Institute of Applied Climate Science, Delaware, OH. https://www.nrs.fs.fed.us/atlas;

Iverson, L.R, Peters, M.P., Prasad, A.M., & Matthews, S.N. (2019). Analysis of Climate Change Impacts on Tree Species of the Eastern US: Results of DISTRIB-II Modeling. Forests, 10(4), 302. doi: 10.3390/f10040302 https://www.fs.usda.gov/treesearch/pubs/57857

Peters, M. P., Iverson, L. R., Prasad, A. M., & Matthews, S. N. (2019). Utilizing the density of inventory samples to define a hybrid lattice for species distribution models: DISTRIB-II for 135 eastern U.S. trees. Ecology and Evolution. doi: 10.1002/ece3.5445 https://www.fs.usda.gov/treesearch/pubs/58353

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. doi: 10.3390/f10110989 https://www.fs.usda.gov/treesearch/pubs/59105

Prasad, A. M., Iverson, L. R., Matthews, S. N., & Peters, M. P. (2016). A multistage decision support framework to guide tree species management under climate change via habitat suitability and colonization models, and a knowledge-based scoring system. Landscape Ecology, 31(9), 2187–2204. doi: 10.1007/s10980-016-0369-7 https://www.fs.usda.gov/treesearch/pubs/50748

Prasad, A. M., Gardiner, J. D., Iverson, L. R., Matthews, S. N., & Peters, M. (2013). Exploring tree species colonization potentials using a spatially explicit simulation model: implications for four oaks under climate change. Global Change Biology, 19(7), 2196–2208. doi: 10.1111/gcb.12204 https://www.fs.usda.gov/treesearch/pubs/43705

Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management 254:390-406. http://www.treesearch.fs.fed.us/pubs/13412

## Adaptability of tree species:

Iverson, L. R., S. N. Matthews, A. M. Prasad, M. P. Peters, et al. (2012). Development of risk matrices for evaluating climatic change responses of forested habitats. Climatic Change 114(2): 231-243. doi: 10.1007/s10584-012-0412-x. https://www.fs.usda.gov/treesearch/pubs/41221

Matthews, S. N., L. R. Iverson, A. M. Prasad, M. P. Peters, and P. G. Rodewald. 2011. Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history factors. Forest Ecology and Management 262:1460-1472. http://www.fs.usda.gov/treesearch/pubs/38643

## Climate summary definitions:

McNab, W.H.; Cleland, D.T.; Freeouf, J.A.; Keys, Jr., J.E.; Nowacki, G.J.; Carpenter, C.A., comps. 2007. Description of ecological subregions: sections of the conterminous United States [CD-ROM]. Gen. Tech. Report WO-76B. Washington, DC: U.S. Department of Agriculture, Forest Service. 80 p. https://research.fs.usda.gov/treesearch/48669

Cleland, D.T.; Freeouf, J.A.; Keys, J.E.; Nowacki, G.J.; Carpenter, C.A.; and McNab, W.H. 2007. Ecological Subregions: Sections and Subsections for the conterminous United States. Gen. Tech. Report WO-76D [Map on CD-ROM] (A.M. Sloan, cartographer). Washington, DC: U.S. Department of Agriculture, Forest Service, presentation scale 1:3,500,000; colored. https://research.fs.usda.gov/treesearch/48672

Seaber, Paul R., F. Paul Kapanos, and George L. Knapp (1987). Hydrologic Unit Maps. United States Geological Survey Water-Supply Paper 2294: i–iii, 1–63.