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 Michigan

These technical briefings summarize topics such as forest densities and cover types, carbon storage, and climate considerations for states in the Eastern United States.

EASTERN REGION

The content of this technical briefing is the product of the State and Tribal Capacity Building on Forest Carbon webinar and workshop series that occurred from December 2023 – July 2024. The series sought to support state and tribal forestry agencies in various stages of working on forest carbon management and stewardship efforts through webinars, interactive in-person learning, and print materials. The project developed four webinars focusing on numerous aspects of forest and carbon in the Eastern US helping participants develop the tools to assess potential trade-offs and opportunities in forest management and planning. In addition to the four webinars, participants were invited to participate in two in-person workshops to delve deeper into technical topics of forest carbon including forest inventorying, forest carbon models, stakeholder perceptions, and communication tactics for both internal and external audiences. For more information please visit:
https://www.canr.msu.edu/socioeconomics/Workshops/Carbon-Capacity

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Michigan Forest Overview

Michigan is situated in the Midwest region of the United States and lies within the US Forest Service's Eastern Region (USFS Region 9). The state is unique in that it's characterized by two distinct land masses: the Upper Peninsula to the north, and the Lower Peninsula to the south. The shape of these peninsulas is primarily defined by a series of large freshwater lakes, known as the Great Lakes. Michigan's Upper Peninsula is bordered by Wisconsin to the southwest, Lake Superior to the north, Lake Michigan to its south (central area), and Lake Huron marks its southeastern boundary. The Lower Peninsula is bordered by Indiana to the southwest, Ohio to the southeast, Lake Michigan to the west, Lake Huron to the east, and Lake Erie marks its southeastern boundary. Both peninsulas also share a small stretch of their eastern borders with the Canadian province of Ontario.

A map of percent tree canopy cover in Michigan is shown in **Figure 1**. This state shows a gradient in forest coverage across its extent, with lower levels of canopy cover in the southern portion of the Lower Peninsula, grading into higher coverage levels in the northern portion of that peninsula, and very high levels of canopy cover across the entire extent of the Upper Peninsula. Lower forest cover in the southern portions of the state coincide with the existence of widespread agricultural lands and urban sprawl throughout that region. Whereas the northern Lower Peninsula and the Upper Peninsula are characterized by much lower population densities and significantly fewer agricultural lands.

Figure 1. Percent tree canopy cover in Michigan.

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
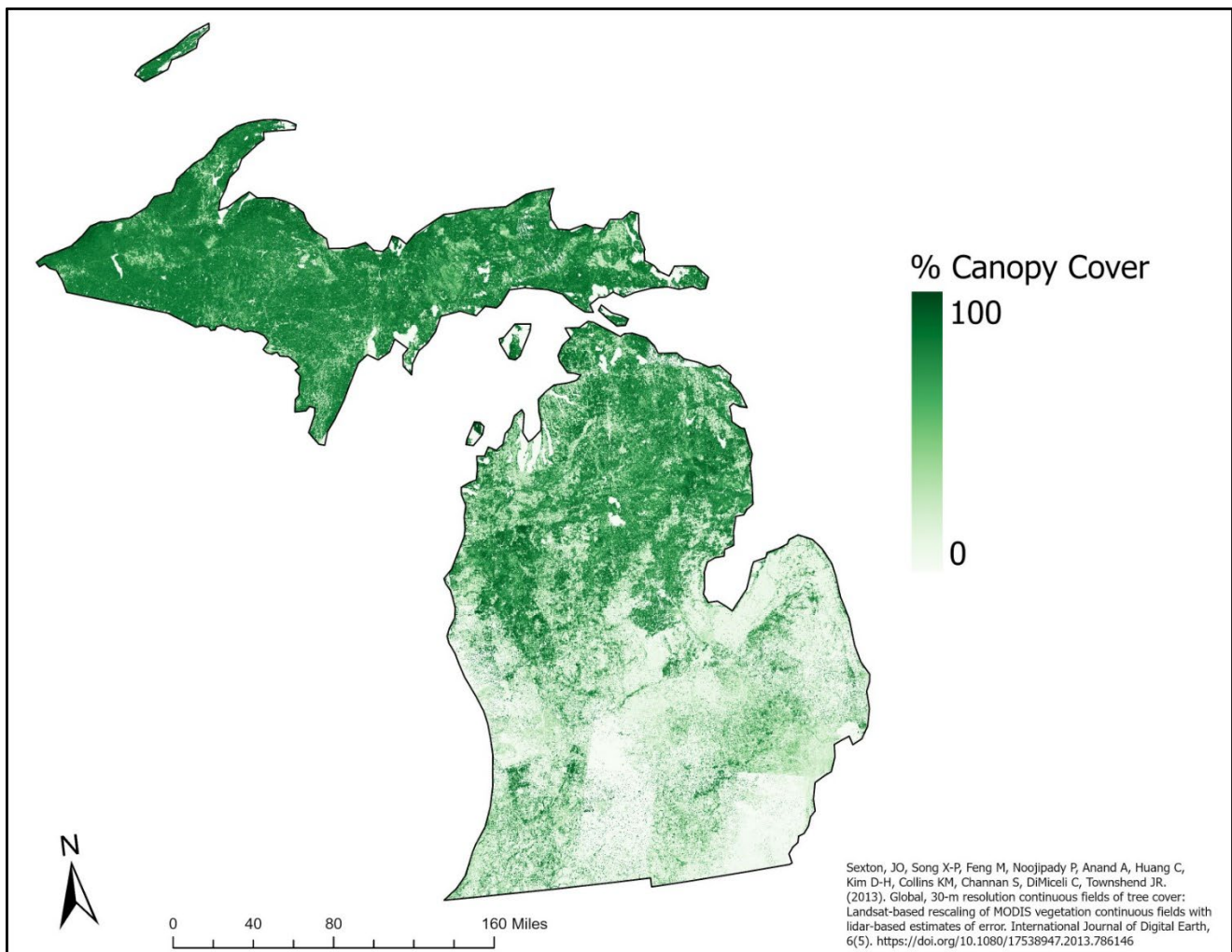
Temperature and Precipitation

Two major factors affecting forest carbon and productivity are temperature and precipitation. **Figure 2** shows normal mean temperatures throughout Michigan between 1991 and 2020. Over this 30-year period, mean annual temperatures varied by about 14 °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 to the north. The warmest mean annual temperature is around 51 °F and occurs in the southeastern and southwestern corners of Michigan's Lower Peninsula, while the coolest mean annual temperature is around 37 °F and occurs in the western portion of the Upper Peninsula and coincides with higher elevations.

Figure 2. Normal mean temperature (°F) from 1991–2020 in Michigan.
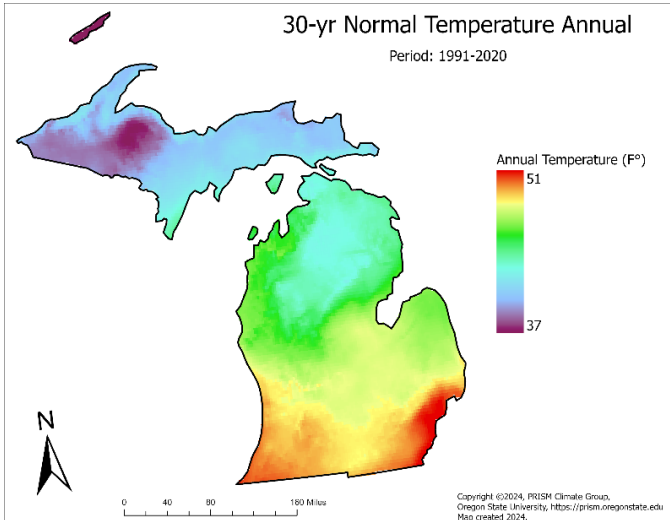
Figure 3. Normal mean precipitation (in.) from 1991-2020 in Michigan.
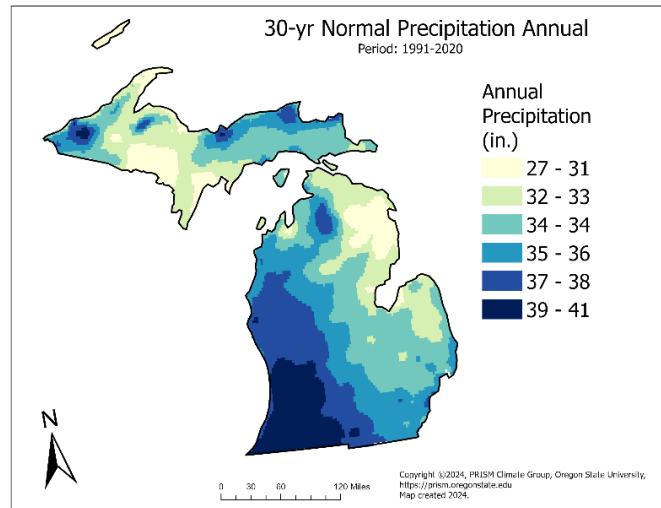
Figure 3 shows normal mean precipitation throughout Michigan between 1991 and 2020 and demonstrates the geographic variation in these trends. Over this 30-year period, mean annual precipitation levels varied by about 14 in. Areas that receive the lowest levels of precipitation (27-31 in.) occur in the southwest portion of the Upper Peninsula and in the northeast portion of the Lower Peninsula. Areas receiving the highest amounts of precipitation (39-41 in.) occur in the southwestern portion of the Lower Peninsula as well as in a few scattered locations along the northern shore of Michigan's Upper Peninsula (**Figure 3**).

Projected Future Trends in Temperature/Precipitation

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

Potential Changes in Climate Variables

Temperature (°F)

	2009	2039	2069	2099	
Annual Average	44.9	48.1	51.8	56.4	
Growing Season May—Sep	62.8	66.1	69.9	75.0	
Coldest Month Average	17.8	19.9	22.7	23.0	
Warmest Month Average	68.9	72.9	75.1	78.1	

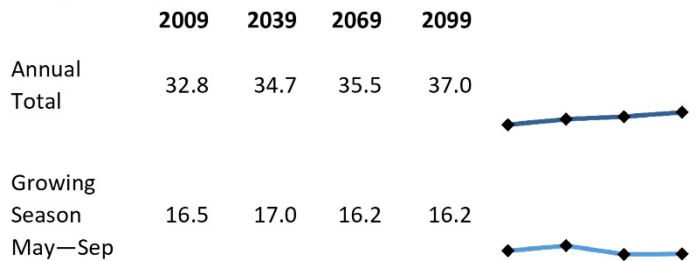**Precipitation (in)**

	2009	2039	2069	2099	
Annual Total	32.8	34.7	35.5	37.0	
Growing Season May—Sep	16.5	17.0	16.2	16.2	
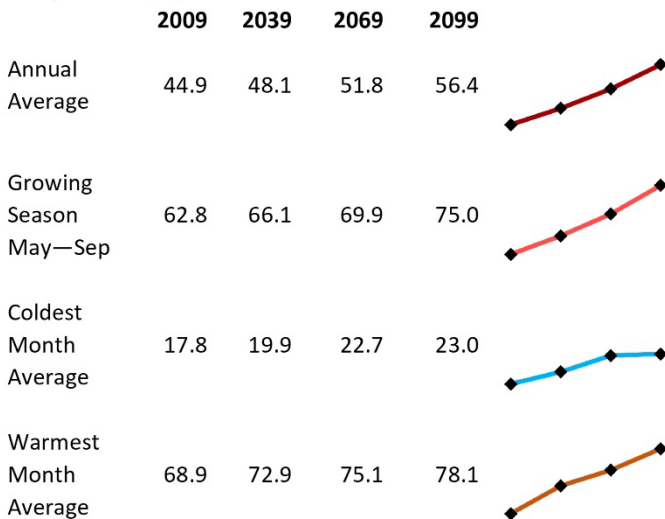
NOTE: For the six climate variables, four 30-year periods are used to indicate six potential future trajectories. The period ending in 2009 is based on modeled observations from the PRISM Climate Group and the three future periods were obtained from the NASA NEX-DCP30 dataset. Future climate projections 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
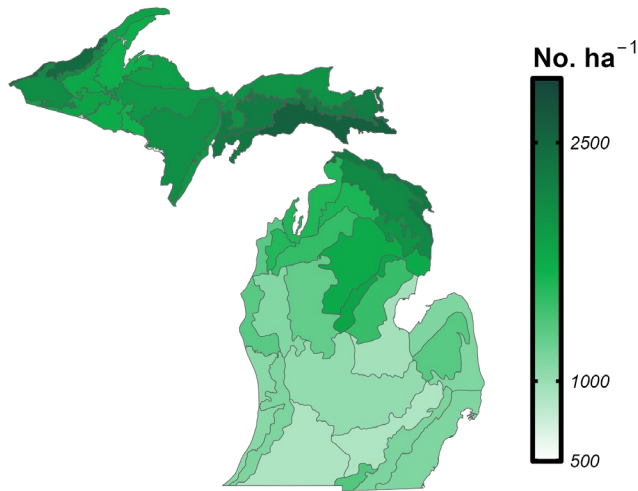
Projected future trends in temperature and precipitation for Michigan between 4 time periods (timeframes in graphic span from 1980-2009, 2010-2039, 2040-2069, and 2070-2099) are shown in **Figure 4**. Model results suggest average temperatures will continue to increase through the end of the century, a trend which is also projected for the coldest and warmest month averages, as well as throughout the growing season (May – Sep.). During this 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 (+12.2 °F).

Model results of future precipitation in Michigan follow variable trends, with totals projected to steadily increase through 2099 (**Figure 4**). Over this period, annual precipitation is expected to increase by an estimated 4.2 in., however, precipitation levels are projected to *decrease* during the growing season by an estimated 0.3 in. This suggests that precipitation in Michigan may increase substantially during the winter months (Oct. – Apr.), while drought events may become more frequent and severe during the growing season.

Forest Density

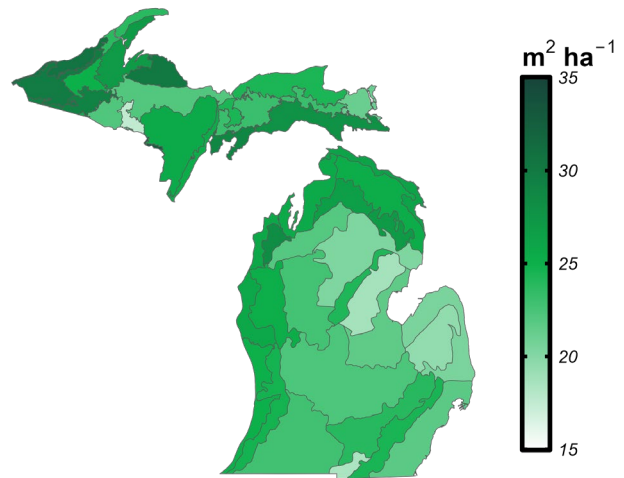**Figure 5.** Forest density as live tree density (No. ha^{-1}) in Michigan.

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

Forest Density: Live tree number

Data: USDA Forest Service, 2024

Forest Density: Live tree basal area

Data: USDA Forest Service, 2024

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 Michigan, 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 ecosections in the southwest portion of the Lower Peninsula generally have lower forest densities than ecosections in the northeastern Lower Peninsula terms of number of trees per hectare (**Figure 5**), but their densities in terms of basal area (**Figure 6**) are relatively similar. This suggests that in the southwest portion of the state, there may be fewer total trees per unit area, but on average, these trees tend to be larger. Meanwhile, the southeasternmost ecosection of Michigan's Upper Peninsula, which borders the coasts of Lake Michigan and Lake Huron, has the state's highest forest density in terms of number of trees, but an average forest density in terms of basal area, suggesting the prevalence of many, smaller-stemmed trees 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

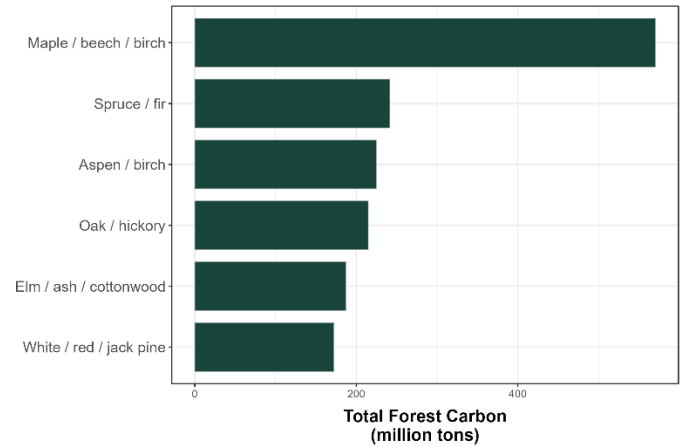# Forest Cover Types and Carbon

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

Data: USDA Forest Service, 2024
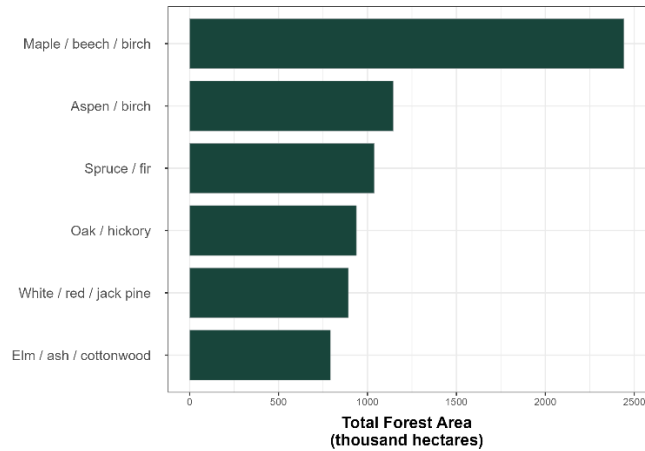
Figure 8. Total forest carbon (million tons) by forest type in Michigan. Total forest carbon is the sum of carbon stored across all aboveground and belowground pools (includes Soil Organic carbon + Live Belowground carbon + Live Aboveground carbon + Litter carbon + Dead wood carbon).
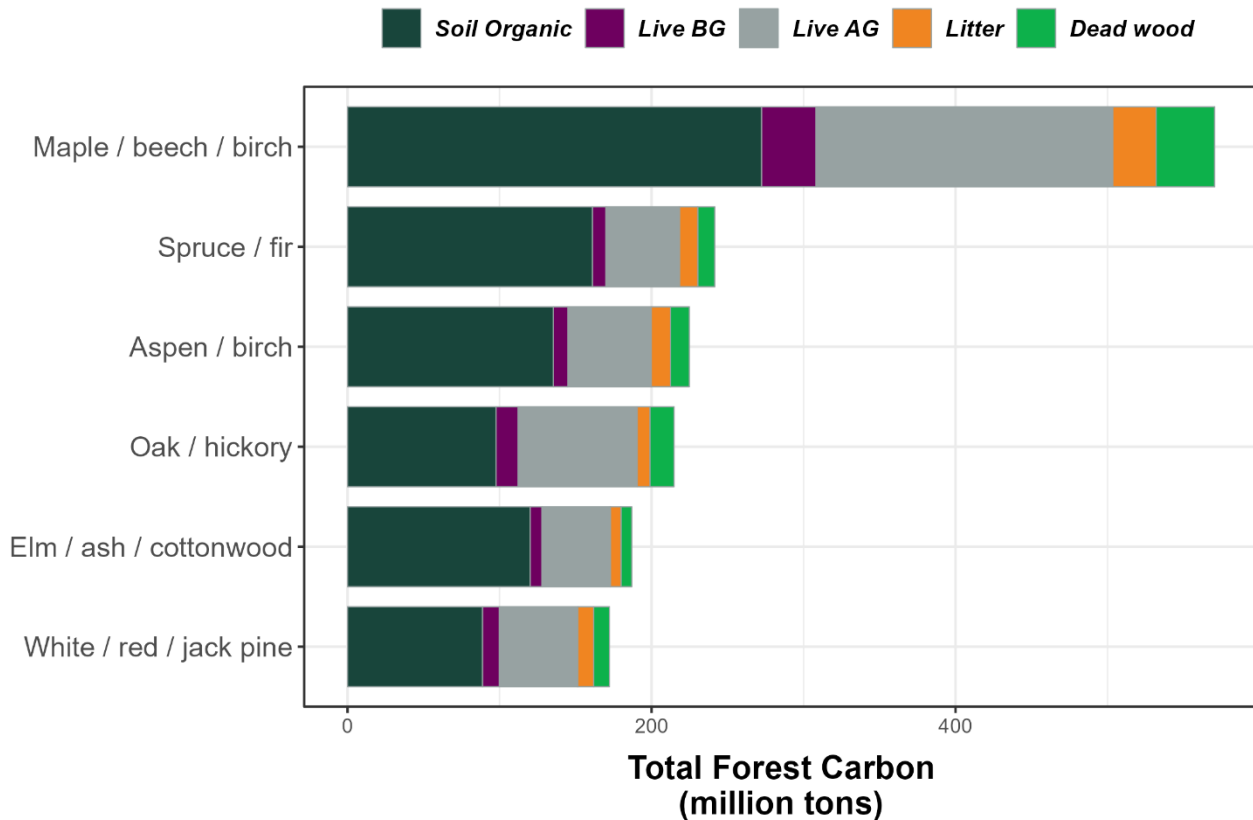
Data: USDA Forest Service, 2024

Michigan is dominated by 6 key forest cover types: Maple/beech/birch, Aspen/birch, Spruce/fir, Oak/hickory, White/red/jack pine, 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, Maple/beech/birch is the dominant forest type of Michigan, spanning an area upwards of 2.25 million hectares and storing over 550 million tons of carbon statewide. With coverage levels ranging from ~750,000-1,125,000 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, Aspen/birch forests cover more land area than Spruce/fir stands in Michigan (**Figure 7**), yet when it comes to carbon, Spruce/fir stands store slightly more carbon than their Aspen/birch counterparts (**Figure 8**). Similarly, White/red/jack pine forests are more abundant than Elm/ash/cottonwood, yet Elm/ash/cottonwood forests outrank White/red/jack pine stands in terms of statewide carbon storage.

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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 Michigan.
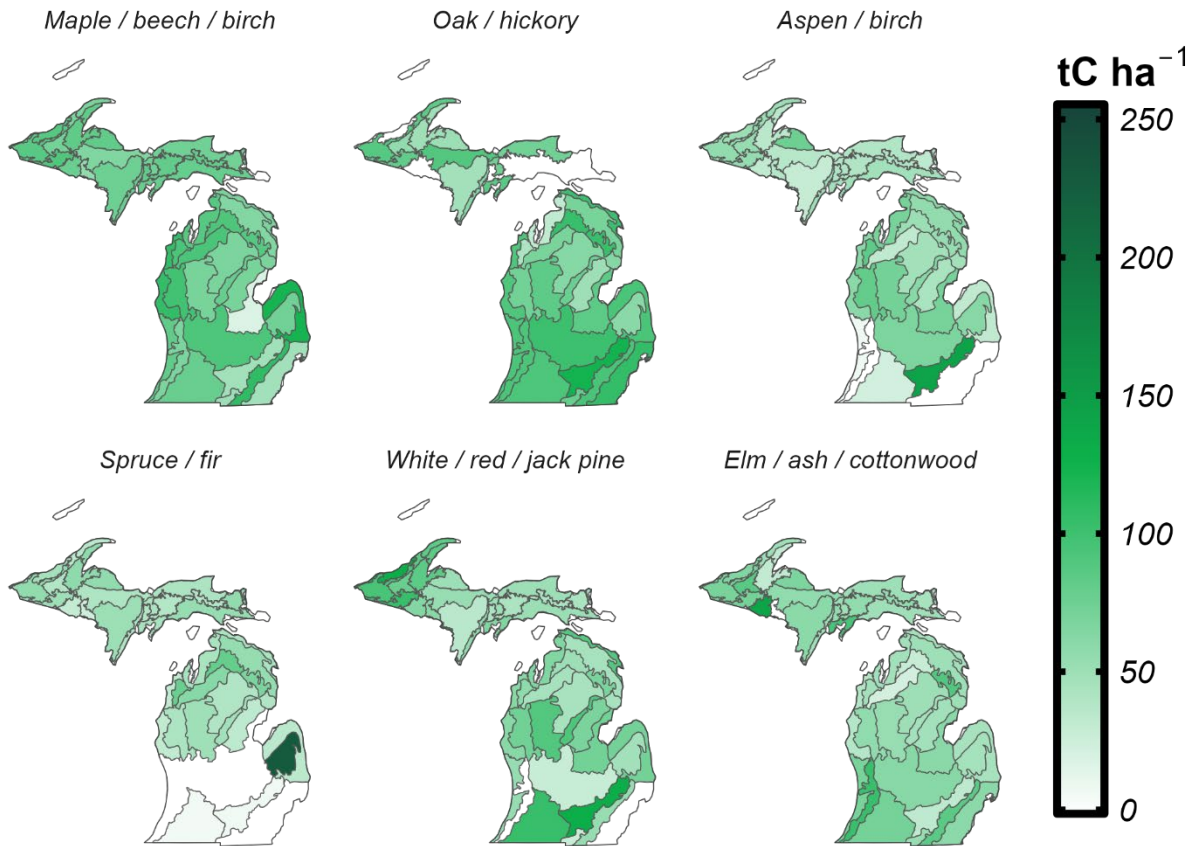

Data: USDA Forest Service, 2024

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 Michigan. 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. Michigan 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 and Elm/ash/cottonwood forests allocate over 2/3 of their total stored carbon to belowground pools, whereas forest types like Oak/hickory and Maple/beech/birch store only slightly more carbon in belowground pools than aboveground. 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 Michigan's Maple/beech/birch forests on their own contain more stored carbon than the total aboveground carbon (live AG biomass + litter + dead wood) contained by the Elm/ash/cottonwood group.

Forest Carbon Density

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

Average Forest Carbon Density by Ecosection: Aboveground Live

Data: USDA Forest Service, 2024

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 Michigan. Of these, Spruce/fir 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 eastern portion of the Lower Peninsula. By contrast, other forest cover types have a much lower carbon density per unit area in this ecosection. Across much of their extent, Elm/ash /cottonwood 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 Climate Considerations

Climate change is expected to impact the distribution of species into the future. The Climate Change Tree Atlas is a tool that lets you explore current tree species traits and suitable habitats in the Eastern U.S. and how they are likely to be affected by a changing climate. Researchers with the USDA Forest Service developed a set of models that form the basis of the Tree Atlas. The Tree Atlas brings together information about habitat suitability, migration potential, and tree species traits to understand current and potential distributions for 125 tree species (https://doi.org/10.2737/Climate-Change-Tree-Atlas-v4).

Core Climate Change Atlas Components:

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

Summaries for tree species are available for a variety of geographies, in both PDF and Excel format.

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 Ecoregional 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://doi.org/10.2737/Climate-Change-Tree-Atlas-v4 along with short video tutorials on the Climate Change Atlas website.
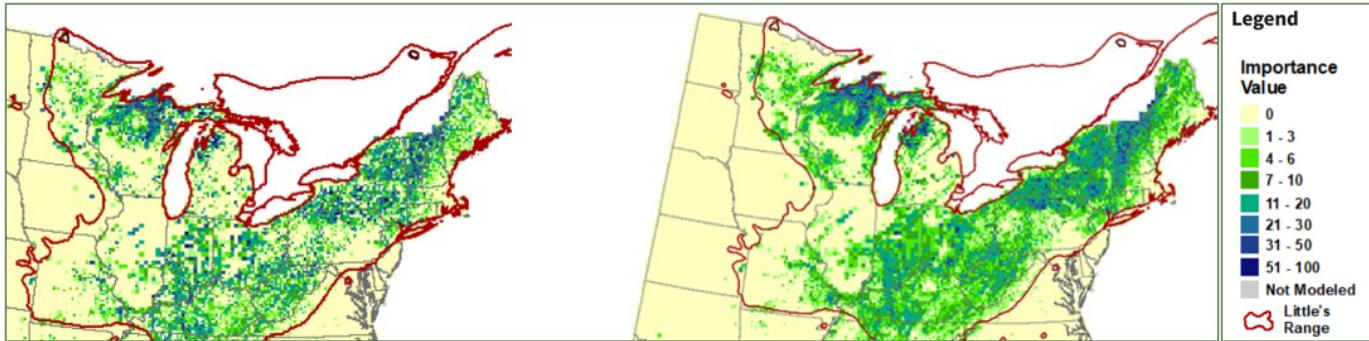
Habitat Suitability and Migration Models

The Tree Atlas brings together information about habitat suitability, migration potential, and tree species traits to understand current and potential distributions for 126 tree species. The following maps and figures are examples of Tree Atlas model results for one species of importance in this state: sugar maple (*Acer saccharum*). We highly encourage reading the interpretive narrations and tutorials on the Tree Atlas website: https://doi.org/10.2737/Climate-Change-Tree-Atlas-v4.

Key Species Example: Sugar Maple (Model Reliability: High)

Current Forest Inventory and Analysis   Current Modeled Habitat (1981 to 2010)

Legend

Importance Value
- 0
- 1 - 3
- 4 - 6
- 7 - 10
- 11 - 20
- 21 - 30
- 31 - 50
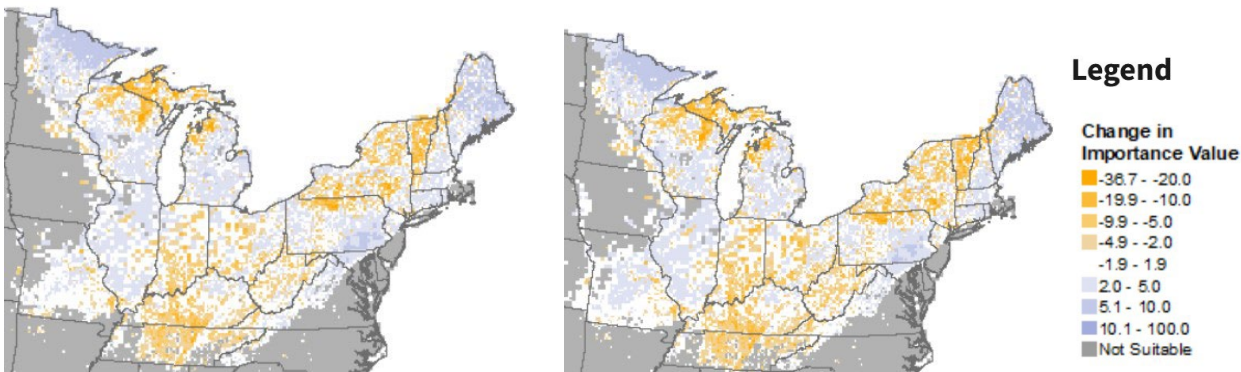- 51 - 100
- Not Modeled
- Little's Range

Summary of Change Maps for Sugar Maple

Maps depicting changes in habitat quality (represented as Importance Values) and the difference between the modeled habitats for an average of three general circulation models under two representative concentration pathways (RCP 4.5 and 8.5) for the period 2070 to 2099.
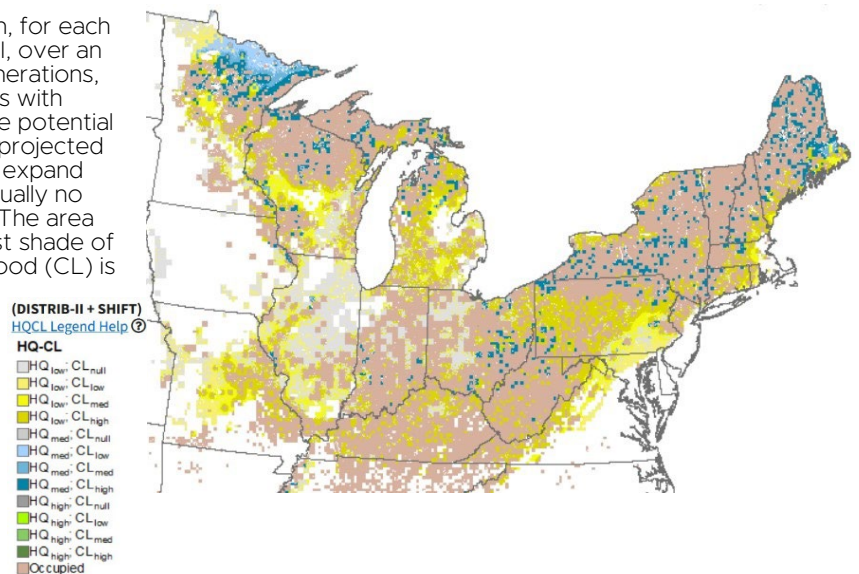
Moderate Emissions (RCP 4.5)   High Emissions (RCP 8.5)

Legend

Change in Importance Value
- -36.7 - -20.0
- -19.9 - -10.0
- -9.9 - -5.0
- -4.9 - -2.0
- -1.9 - 1.9
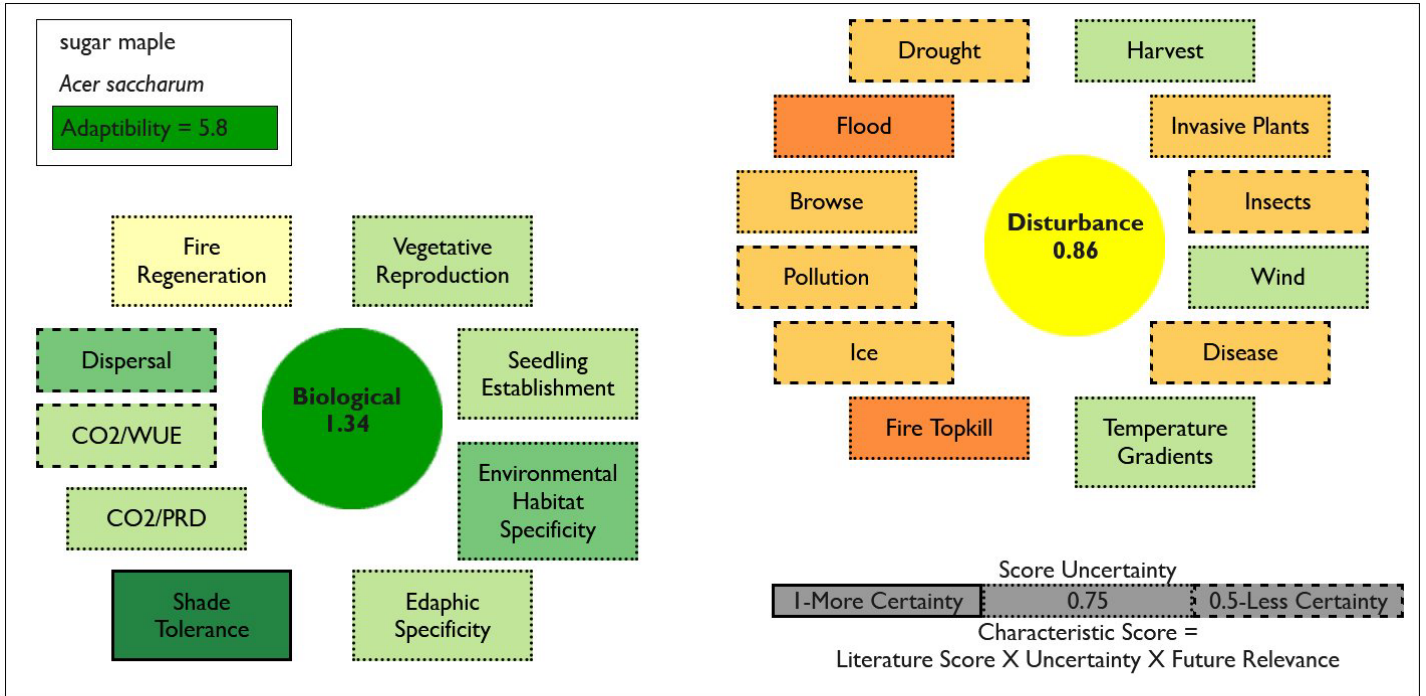- 2.0 - 5.0
- 5.1 - 10.0
- 10.1 - 100.0
- Not Suitable

Migration Potential

The SHIFT model estimates the likelihood of colonization, for each 1x1 km cell, for suitable habitats designated by DISTRIB-II, over an approximately 100-year period consisting of multiple generations, depending on the tree species. Merging SHIFT outcomes with DISTRIB-II outcomes provides the power to evaluate the potential for the species to migrate naturally into the new habitat projected by the DISTRIB-II model. For many species, habitat may expand greatly (especially under high emissions), but there is virtually no chance for much of that area to get colonized naturally. The area most desirable for managed relocation will be the darkest shade of green: habitat quality (HQ) is high and colonization likelihood (CL) is high.

(DISTRIB-II + SHIFT)
HQCL Legend Help

HQ-CL
- HQ_{low}: CL_{null}
- HQ_{low}: CL_{low}
- HQ_{low}: CL_{med}
- HQ_{low}: CL_{high}
- HQ_{med}: CL_{null}
- HQ_{med}: CL_{low}
- HQ_{med}: CL_{med}
- HQ_{med}: CL_{high}
- HQ_{high}: CL_{null}
- HQ_{high}: CL_{low}
- HQ_{high}: CL_{med}
- HQ_{high}: CL_{high}
- Occupied

Adaptability Ratings

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

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

Citations:

Data Sources:

Iverson, L.R., Prasad, A.M., Peters, M.P., Mathews, 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

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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

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