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Climate Change Atlas User Guide:

Version 1.0

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Abstract

This document provides descriptions and definitions to help users interpret and understand key concepts presented on the Climate Change Atlas website. Information is intended to support users in exploring and using the data and model outputs in the Climate Change Atlas. As users progress through this document, information builds upon previous concepts with exercises and examples. The guide concludes with a more in-depth description of the scientific methods used to model species habitat suitability, migration potential, and adaptability scores. This document will serve as an archive of information and methods used as subsequent versions of the models and website are developed.

Keywords: adaptive silviculture, forest management, habitat suitability, migration potential, relative abundance, species distribution model

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Preface

Our group began modeling habitat suitability of tree species in the eastern United States in the mid-1990s using a single regression tree, periodic records from Forest Service, Forest Inventory and Analysis data, and environmental data that were aggregated to counties. Since then, our methods have evolved to include an ensemble of regression trees, annual forest inventory data, and a hybrid grid modeling approach, among other improvements. Details can be found in the collection of published literature provided on the Climate Change Atlas “About the Models” website (<https://www.fs.usda.gov/nrs/atlas/models>). This document describes the most recent information to assist in using the Climate Change Atlas to explore and interpret potential changes to habitat suitability of tree species for many regional extents.

What’s New

04/2025 Initial release of User Guide

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1. Getting Started

Introduction

The Climate Change Atlas includes information on the current distribution of suitable habitat for tree and bird species based on recent inventories and highlights the environmental variables that contribute to defining habitat suitability for each species. Characterizing site conditions and environmental factors of suitable habitat for different species is important for forest management. Additionally, understanding how projected climate change could alter currently suitable habitat and create new habitat is vital to maintaining resilient forests. The Tree Atlas provides individual species models of relative abundance or importance values, rather than species presence or absence, which offers a more complete sense of the potential habitat distribution. Tree species importance values (IVs) are derived from the relative basal area and relative dominance (i.e., number of stems) and range from 0 to 100.

Our modeling approach has three components: (1) a habitat suitability model (DISTRIB-II), (2) a migration potential model (SHIFT), and (3) an assessment of the adaptive capacity of a species (MODFACS) (Fig. 1). DISTRIB-II is developed to identify current suitable habitat for a species and then applied to projections of future climates from three different climate models under both low and high scenarios of greenhouse gas concentrations to outline a range of possible future conditions.

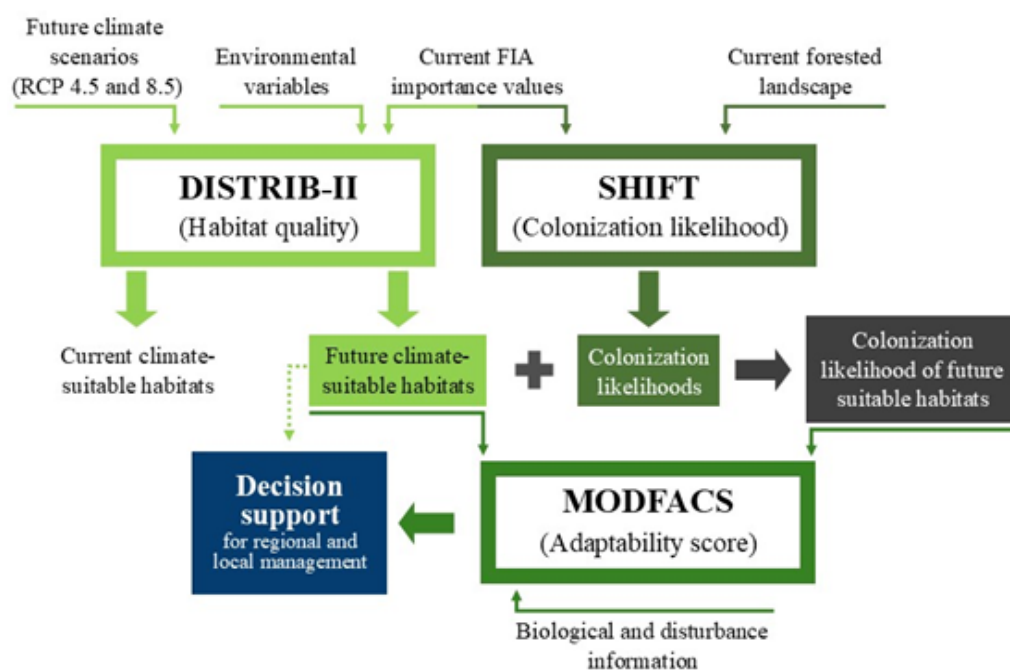


Figure 1.—Flow of information to and among models provided in the Climate Change Tree Atlas for decision support of forest management under climate change scenarios. The dotted line from Future climate-suitable habitats indicates that the DISTRIB-II model output may be used for decision support without the addition of SHIFT or MODFACS. Representative concentration pathways (RCPs) provide a range of possible climate conditions and Forest Service Forest Inventory and Analysis (FIA) data provide a baseline of forest conditions.

The Climate Change Atlas provides information on the current habitat suitability for most tree and nonmigratory bird species in the eastern United States (east of 100° W longitude) and predicts how these habitats may be affected by a changing climate. The Climate Change Tree Atlas (hereafter, Tree Atlas) version 4, released in 2020, includes current and potential habitats for 125 tree species. The current version of the Bird Atlas (version 2) incorporates information from version 3 of the Tree Atlas to describe distributions for 147 bird species. This user guide is designed to help natural resource professionals and others understand the models, data, and statistics presented in the Tree Atlas. Newer users who are not familiar with species distribution modeling or analyzing potential impacts of climate change may benefit the most from this information, along with experienced users of the Tree Atlas who may not be familiar with version 4.

Basic Description of Models

DISTRIB-II is a species distribution model that maps the predicted current habitat suitability of tree and bird species and the potential habitat distributions under future climate scenarios. DISTRIB-II uses the random forest statistical algorithm to create an ensemble of regression trees that predict habitat suitability representing species relative abundance from environmental data. Tree Atlas version 4 includes results for 125 tree species in the eastern United States. The DISTRIB-II potential future habitat distributions are used to derive habitat quality (HQ) to inform our migration model (SHIFT) and do not necessarily represent whether a species will actually be present across that landscape. Not all suitable habitats predicted by DISTRIB-II can be colonized, so we use SHIFT to calculate colonization likelihoods (CLs) based on historically plausible natural migration rates.

SHIFT computes colonization likelihoods in roughly 100 years for unoccupied cells (i.e., cells that currently do not have species presence according to the U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis [FIA] data) by using the current abundance of the species and its generation time (length of time until species can produce seeds). SHIFT uses an optimistic migration rate of about 50 km (31 miles) per century based on the average historical migration rates observed during the Holocene. SHIFT also uses forest availability in the “occupiable” cells (i.e., cells with high future HQ) to determine colonization. The computed CLs are intersected with the suitable habitats predicted by DISTRIB-II to provide an estimate of the likelihood that these habitats could be colonized in about 100 years. The migration potential simulated by SHIFT can be classified as either (1) “infilling”—the gaps within the current species range that have the potential to be colonized—or (2) “outfilling”—colonization of areas outside the current range of the species.

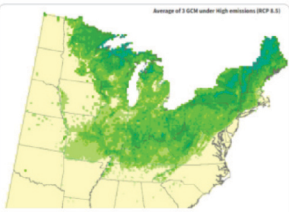
Basic Concept of Adaptability Scores

The DISTRIB-II and SHIFT models project where tree species could be found and how species may migrate to newly suitable habitats under selected climate scenarios. However, these models cannot account for biological and disturbance factors that may cause a species to persist or cope in these habitats, such as tolerance of fire or reduced susceptibility to insect pests. Therefore, we conducted a literature review to develop a scoring system that rates 9 biological and 12 disturbance factors for each species, collectively called Modification Factors (MODFACs). This scoring system assesses the uncertainty of the information and future relevance to each tree species. The MODFACs information is combined into a single adaptability score for each species to aid in decision making related to model interpretation and the potential impacts of climate change.

A Quick Tour of the Tree Atlas

The Tree Atlas is a collection of information for eastern U.S. tree species and can be accessed from the Climate Change Atlas [homepage](#) in two ways: (1) selecting the Tree Atlas panel on the left (top for mobile devices) or (2) entering the common or scientific name of a species in the search box to navigate directly to a species page (see the following images). Some information provided on the Tree Atlas page is also accessible from the Climate Change Atlas homepage and is described in the subsections “Searching” and “Individual Species Pages.”

1



Tree Atlas Version 4

Modeled potential suitable habitat for 125 tree species in the East, with an additional 23 species with current information only

[Latest Tree Atlas](#)

2

Search or Browse the Atlas

Search for Trees or Birds

▼

3

[List of Trees](#) | [List of Birds](#)

Q

4

Search or Browse the Atlas

x ▼

- Atlantic white-cedar - *Chamaecyparis thyoides*
- white spruce - *Picea glauca*
- eastern white pine - *Pinus strobus*
- northern white-cedar - *Thuja occidentalis*
- white ash - *Fraxinus americana*

Content Versions

Users may notice that there are several versions available. The current Tree Atlas is version 4, while the Bird Atlas is version 2 (developed using models from Tree Atlas version 3). The different versions relate to the data and modeling framework used, as well as the layout. As some of the datasets are updated, periods of records changed to reflect newer trends (e.g., climate and forest inventories). Individual species performance may change between modeling efforts, so we have introduced versions and offer archived content for users who may need access to previous information. Because the underlying inventory and climate data change between versions, it is helpful to think of each version as a snapshot based on the best available data. Therefore, we encourage users to access the most recent version, which reflects our current knowledge and understanding of potential climate change impacts on species distributions.

Cautions, Model Info, and FAQ

The “Cautions”, “Model Info”, and “FAQ” buttons available from the Tree Atlas main page and each species page provide information relevant to using and interpreting the models. Users are encouraged to review these sections of the Tree Atlas to understand the breadth and limitations of the Tree Atlas models. The FAQ section (also provided in section 4 of this guide) will be helpful in getting quick answers to some questions about various components of the Tree Atlas.

Searching

The Tree Atlas currently contains information on 148 eastern tree species, with future climate change information available for 125 species. There are 23 tree species for which model reliability is unsatisfactory for current climate conditions or future projected changes. We provide information about the current distribution reported by forest inventory data for all 23 species, as well as life history and MODFACs information for some of them but no future climate change information.

Tree species information can be accessed within the Tree Atlas in a variety of ways. To view a sortable list of species names, users can click on the List of Trees hyperlink found at the top right of any page within the Tree Atlas. Alternatively, the common or scientific name can be entered in either search box: Search Entire Atlas, or Search or Browse the Atlas. The Search Entire Atlas box will search the entire Climate Change Atlas site and return results for any page containing the entered search term.

Using the Search for Trees or Birds box allows the user to navigate directly to the corresponding species page. This search box also features a drop-down menu for scrolling through the list. As the user starts typing, the list is filtered to corresponding species names, as shown in the following example.

Individual Species Pages

The individual species pages each provide maps of species distributions (including Current Forest Inventory & Analysis and Modeled Habitat), and information related to life

history, climate change adaptability, predicted changes in spatial distributions, range and niche maps, a predictor analysis, and projections of future suitable habitat and migration potential. A paragraph on “Interpretation” provides information on how habitat suitability is modeled to change for the species under various scenarios of climate change. We briefly discuss these components here and offer greater detail in the example applications in section 2.

The About section lists the family of the species, guild (a grouping of species with a shared attribute), and functional lifeform (characterization of height and leaf retention); it also provides hyperlinks to life history and disturbance response traits. Additional resources include the Forest Service Silvics of North America (Burns and Honkala 1990a, 1990b) entry (if available), USDA Natural Resources Conservation Service (NRCS) PLANTS Database (USDA NRCS 2021), and a data archive where geographic files related to the models can be obtained.

The Climate Change Adaptability section contains an overall adaptability score and individual scores for the MODFACs biological and disturbance traits. Two lists of primary positive and negative traits are provided to indicate which, if any, of the 21 possible factors may influence the species under future climate change. More details are provided in the example applications in section 2.

The Summary of Predicted Changes section includes hyperlinks to a Mean Center of Distribution map and Summary Change Maps. The Mean Center of Distribution map shows the geographic centroid of suitable habitat within the eastern United States (unweighted) under current and future projections. An ellipse encompasses one standard deviation of the suitable habitat, and changes from the current locations indicate general direction and distances under future scenarios. The Summary Change Maps show a side-by-side view of the two representative concentration pathways (RCPs) for the three climate models. Changes in importance values are presented as distributional maps and calculated differences. Additional details are provided in the example applications in section 2.

The Range and Niche Maps provide a unique way to graphically explore the species niche, characterized using two variables for climate (annual precipitation and mean annual temperature), soil (percent clay and sand), and soil productivity (annual aridity index and soil productivity index). These graphs show the variable space (e.g., niche) within the eastern United States and indicate where Little’s Range extent (see “Little’s Range” in section 5). and importance values derived from FIA data occur. This information can be useful when interpreting the optimal conditions related to high abundance for the species and suggests unfavorable conditions where the species is absent.

The Predictor Analysis section provides a summary of the 45 environmental variables used to model habitat suitability. The Predictor Statistics hyperlink contains box plot graphs of the climate, elevation, and soil properties and summary statistics. The box plots show the value range for the species related to all species modeled. The Predictor Importance Value hyperlink provides a sortable list of the environmental variables indicating the relative importance of each variable for the model.

Regional Summary Tables and Other Products

The Tree Atlas website also contains regional tables that summarize the current and potential future changes for tree species within various geographic regions east of 100° W. The summarized information has been aggregated for national forests, national parks, 6-digit hydrologic unit code (HUC6) watersheds, states, urban areas, ecological sections (EcoMap; Cleland et al. 2007), Fourth National Climate Assessment regions (Wuebbles et al. 2017), and 1 degree × 1 degree grids. These summaries are accessible from individual species pages, the main page of the Tree Atlas, the Climate Change Atlas homepage, and the Tree Atlas Summaries page (<https://www.fs.usda.gov/nrs/atlas/combined/resources/summaries/>). Summaries are available as a spreadsheet, with a condensed version offered as a PDF file, and provide information about species current abundance, potential future changes in habitat suitability, adaptability and capability ratings, and migration potential. A reference map is available to indicate the area of the models being summarized. The regional summaries are useful when considering how climate change may impact many tree species for a selected region.

Additionally, we provide access to other products such as storymaps and publications that are related to climate change or use the information from the Tree Atlas. These products can be accessed from the Climate Change Atlas homepage (<https://www.fs.usda.gov/nrs/atlas/>) or the Products page (<https://www.fs.usda.gov/nrs/atlas/products/>).

Tutorial Videos

Four tutorial videos are available to illustrate key concepts and components of the Climate Change Atlas. These videos are intended to get users started exploring the information within the Tree Atlas. See section 3 for additional detail on each of the following elements.

1. An introduction to the Tree Atlas and the model components ([Introductory video](#))
2. How adaptability scores can be used to interpret the habitat models ([Adaptability Scores video](#))
3. How to select regional summary tables for an analysis ([Choosing Regional Output video](#))
4. How to interpret the information from the regional summary tables ([Regional Summaries video](#))

Publications

Published literature related to the Tree Atlas can be accessed from the Climate Change Atlas Publications [page](#). We have provided eight keywords to filter relevant documents and have included a search box to narrow down resulting lists. Using the search box, users can combine keywords or specific text from the titles. Selecting any of the eight keywords would return any entry with that term.

2. Example Applications

Purpose of Exercises

The next three subsections will guide users through parts of the Tree Atlas to access various information related to the tree species, models and environmental predictor variables, and regional summary tables. These exercises can be useful to new users as they explore the Tree Atlas, and to returning users who may not be familiar with the current version. In addition to three example exercises, we include a short description of how other groups and organizations have used the Tree Atlas to show how the information on current and potential future habitat suitability can be utilized. Please note there is some repetition among the examples to demonstrate the many ways that information from the Climate Change Atlas can be used.

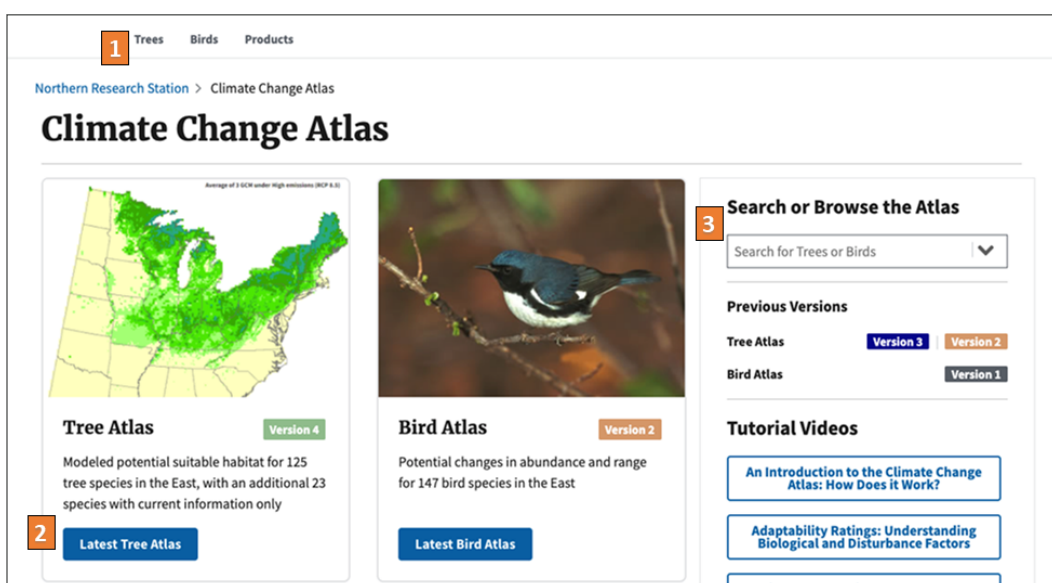
Examine and Interpret Potential Changes for a Single Species

This exercise will show how to access and interpret the individual species maps and will present a few questions that may be answered by the information provided on these pages.

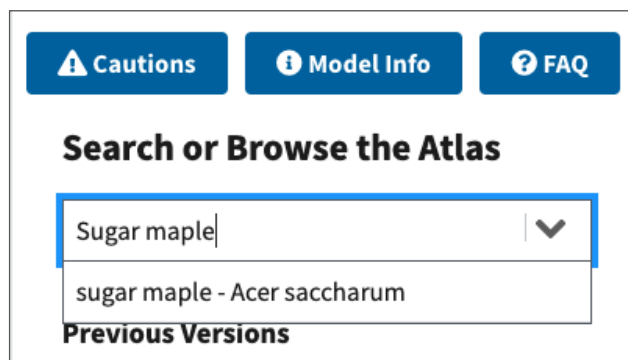
In this example we will be selecting a species that is commonly found throughout the eastern United States.

Accessing the maps and understanding the webpage content

There are several ways to access individual species in the Tree Atlas. First, users can go to <https://www.fs.usda.gov/nrs/atlas/>. From there they can either (1) click on the “Trees” button located in the menu in the upper left portion of the homepage, (2) scroll down to and select the “Latest Tree Atlas” button for version 4 results, or (3) use the “Search for Trees or Birds” bar on the right-hand side of the page, as shown in the following images.



Using option 3, enter the species “sugar maple” in the search bar on the right-hand side of the webpage. Users can also search for species by their scientific name or even a portion of either the common or scientific names. Once the species name appears, it can be selected from the menu, followed by clicking on the hyperlink under the search bar (see the following image).



The image shows a search interface for the Tree Atlas. At the top, there are three blue buttons: "Cautions" with a warning icon, "Model Info" with an information icon, and "FAQ" with a question mark icon. Below these buttons is the heading "Search or Browse the Atlas". Under the heading is a search bar with a blue border. The search bar contains the text "Sugar maple" and a dropdown arrow on the right. Below the search bar, a dropdown menu is open, showing the text "sugar maple - Acer saccharum". Below the dropdown menu is the text "Previous Versions".

On the sugar maple page, maps are located on the left side of the webpage, while additional materials relating to the species can be found in the right-hand column of expandable sections.

Users will see buttons for “Cautions”, “Model Info”, and “FAQ” on each species page and on the main page of the Tree Atlas (as shown in the following image). Users are encouraged to review these sections of the Tree Atlas to understand the breadth and limitations of the Tree Atlas models. The FAQ section (also provided in section 4 of this guide) will be helpful in getting quick answers to some questions about various Tree Atlas components. Additionally, there is an introductory tutorial video on the Tree Atlas that covers these basics ([Introductory video](#)).



The image shows three blue buttons arranged horizontally. The first button is "Cautions" with a warning icon. The second button is "Model Info" with an information icon. The third button is "FAQ" with a question mark icon.

The Interpretation section (see the following image) is intended to give an overview of the data that are provided and remind users of the breadth of information that should be considered when evaluating a species. The Interpretation describes the overall distribution and adaptability of the species, then its potential change in habitat suitability according to the models. Also mentioned is the overall “capability” of the species to cope or persist under climate change across the eastern United States, and the impact of the SHIFT model estimates of colonization within about 100 years.

! Interpretation

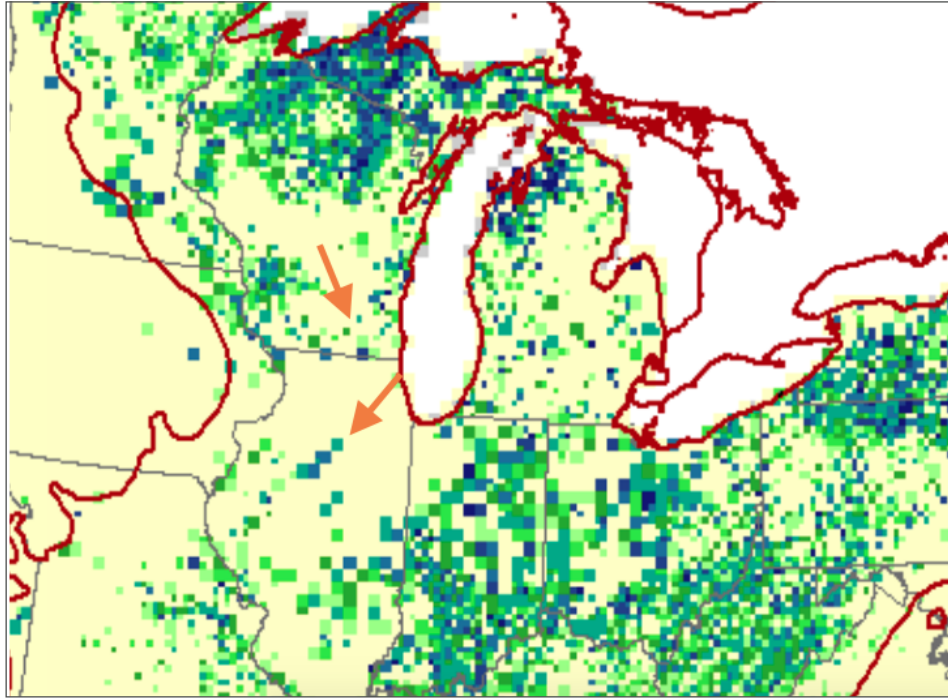
Sugar maple is widely distributed (21.3% of area), dense, and with high IV across much of the northern 2/3 of the Eastern US. It ranks fourth in overall abundance across the eastern US, behind loblolly pine, red maple and sweetgum. It rates as highly adaptable although under persistent drought or other 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).

RCP 4.5 SHIFT

RCP 8.5 SHIFT

The right-hand column also includes expandable buttons for life history information, adaptability ratings, and change summary maps for sugar maple, among other features. These will be presented in the next two parts of this walkthrough.

Now that the page layout and important features have been described, we can focus on the maps. The initial map shown on the individual species page (see the following image) depicts the tree abundance (importance value, or IV details; see “Little’s Range” in section 5 for details) information captured in FIA data that are gathered from over 85,000 field plots surveyed from 2000 through 2016. Darker greens and blues indicate a greater relative abundance for a species. A close look at the cells on the map will reveal that there are two different sizes present (indicated by orange arrows in the following image). This is a new feature of the Tree Atlas version 4 which increased the resolution of cells within the models to 10 km × 10 km (6 mile × 6 mile) cells if FIA forested plots were sufficiently dense. In areas where FIA forested plots are less common, we used the coarser 20 km × 20 km (12 mile × 12 mile) cell resolution from earlier Tree Atlas versions.



The red line shown on the FIA map represents Little's Range, a set of species boundaries developed in the 1970s based on herbarium specimens, expert opinions, and field surveys. Little's Range depicts the range extent for a species and not specifically the spatial distribution.

Below the map is summary information for the map being viewed (as shown in the following image). The summary values change depending on the selected map and future scenario selected. The information summarized includes the following.

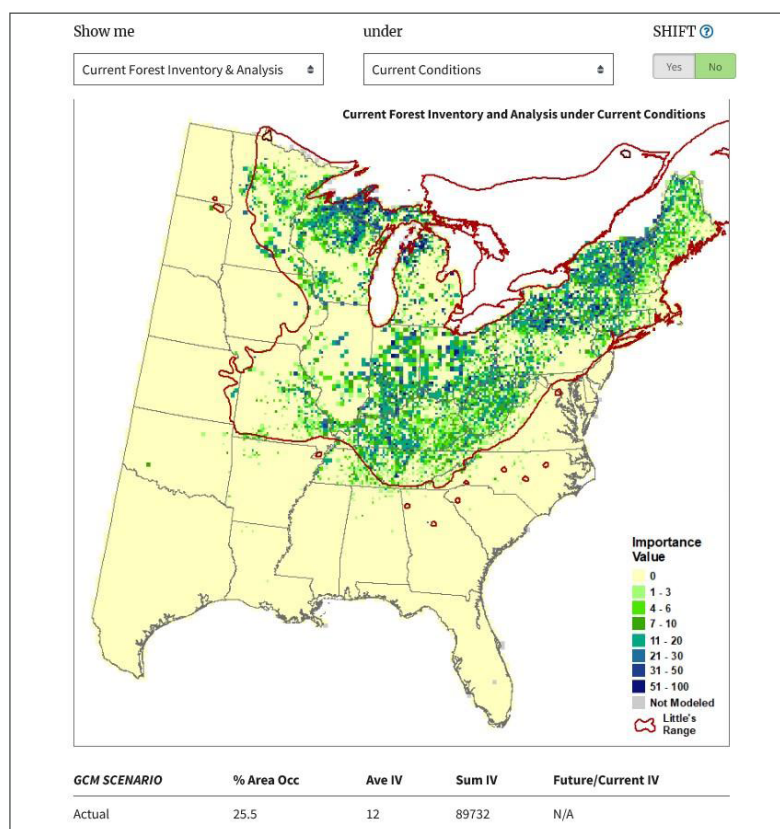
GCM Scenario: Indicates whether the map is displaying importance values for actual, current modeled, or one of eight future modeled conditions.

% Area Occ: Percent area occupied by the species in the eastern United States (as shown on the map).

Ave IV: Provides the average IV of the species across the map extent.

Sum IV: Provides the total sum of IVs for the species over the map extent.

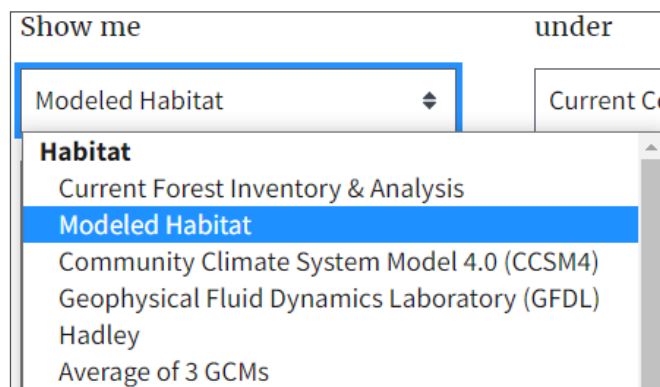
Future/Current IV: Describes the ratio of future IV to current IV. This section is applicable only when future scenarios are selected and indicates an overall increase (values greater than 1) or decrease (values less than 1) in habitat suitability.



Viewing and interpreting modeled maps

The FIA map shows the distribution and relative abundance of a species based on field data, and this information is used to train models under current climate conditions, along with other predictor variables. However, if the current range cannot be reliably modeled, usually because the species is too uncommon to generate adequate models, then users will see only the option to view FIA maps for the current distribution of the species as reported on FIA plots. The “FIA only” species account for 23 of the 148 species in the Tree Atlas. For the 125 species with modeled outputs, a model reliability score is provided that allows users to understand the level of confidence associated with the outputs. Model reliability can be found to the right of the species name. More information on model reliability can be found by clicking on the “FAQ” and “Model Info” buttons.

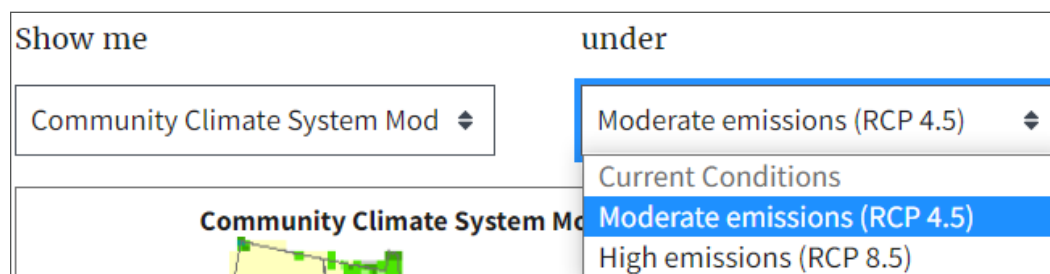
To view the current modeled habitat map, click on the drop-down menu located under “Show me” (see the following image). This menu contains the current FIA distribution map, the current modeled map, maps of habitat suitability under several future climate scenarios (general circulation models, or GCMs), and the 45 predictor variables. The GCMs incorporated into Tree Atlas version 4 are CCSM4, GFDL, and Hadley. The “average of 3 GCMs” map displays integrated results from those three models. For more information on the GCMs see the “FAQ” and “Model Info” sections of the Tree Atlas.



Once the “modeled habitat” map is selected, the resulting map looks slightly different, and more “filled in” compared to the FIA map. This is because the modeled habitat predicts where a species is likely to have suitable habitat based on the FIA data. One FIA plot occurs approximately every 6,000 acres (2,400 ha) of forest, so some gaps in the FIA map could be due to sampling constraints.

The modeled habitat map shows the current distribution of sugar maple. To see how suitable habitat may look for sugar maple by the year 2100, users can examine the GCM maps. The CCSM4 map may be selected from the “Show me” drop-down menu.

Once users have switched maps, they may have noticed that the drop-down menu next to the “Show me” menu, labeled “under”, has changed (see the following image). This is because the future scenarios are partially influenced by the level of greenhouse gas concentrations present in the atmosphere. The default display shows the RCP 8.5 or a “high climate change” scenario. To view the low climate change scenario, the menu may be clicked, and the RCP 4.5 option may be selected. For more information on the RCPs, see the “FAQ” and “Model info” sections of the Tree Atlas.

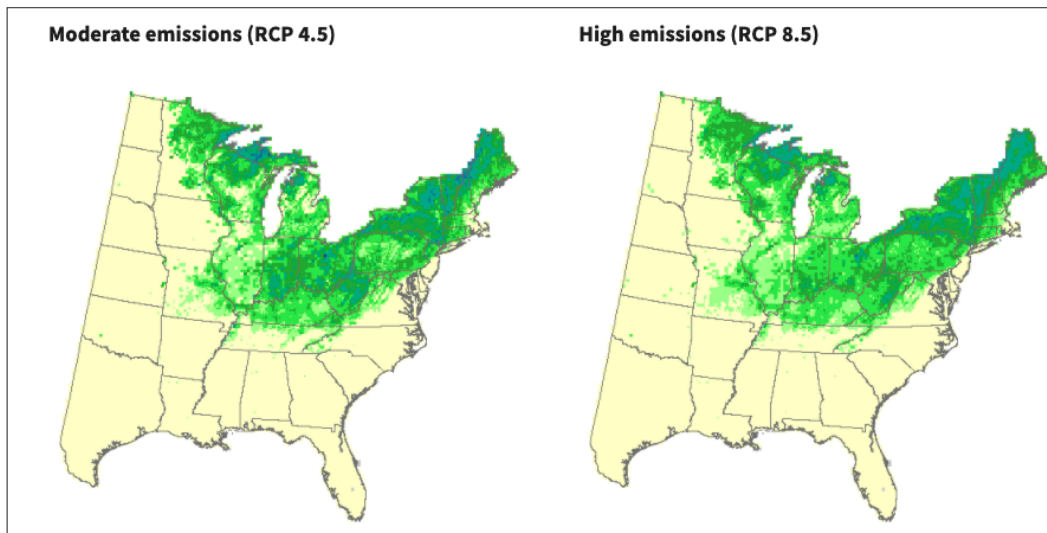


Users can switch back and forth between the two climate change scenarios. They should see that the results change notably depending on the RCP selected. These differences result from the climate scenarios representing gradients of warmer to hotter and drier to wetter conditions in the future.

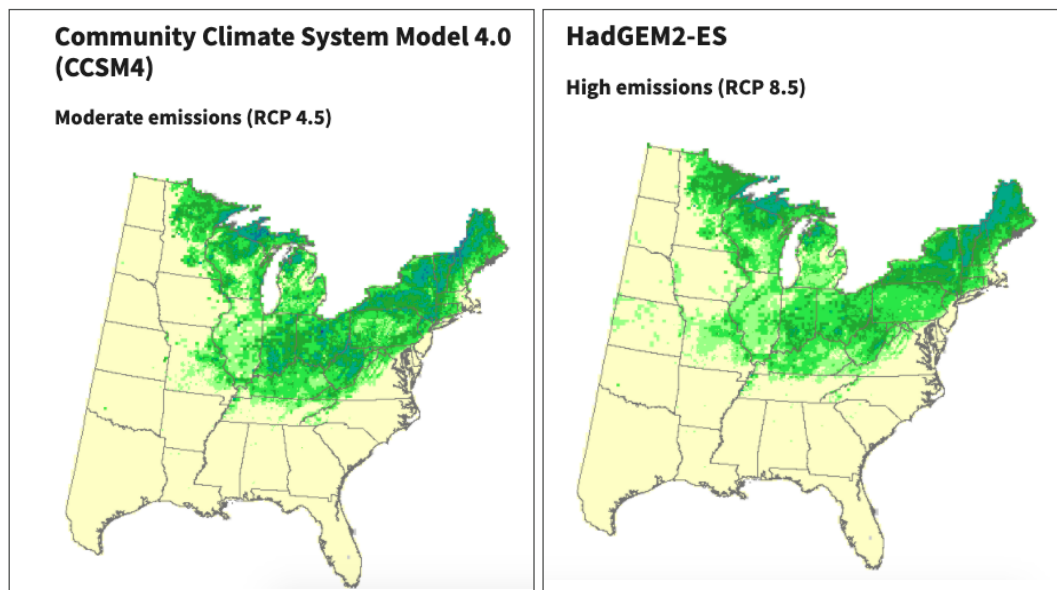
To view both maps side-by-side, users may select the “Summary of Predicted Changes” button located in the column of expandable menus on the right-hand side of the webpage (see the following image).

About sugar maple	+
Climate Change Adaptability	+
Summary of Predicted Changes	—
• Mean Center of Distribution • Summary Change Maps	
Range and Niche Maps	+

The “Summary Change Maps” hyperlink can be selected to see all the outputs side-by-side starting with the current FIA and modeled ranges to the outputs for all the future climate scenarios. The following image shows what habitat suitability could look like for the two CCSM4 models, which are considered to be conservative in the amount of projected warming. Subtle differences between the two scenarios for this GCM suggest that the area of suitable habitat for sugar maple may expand amid a slight reduction in overall predicted abundance. The percent area occupied (% Area Occ), sum IV, and future/current IV statistics under the main map can help with interpreting modeled changes in suitable habitat.

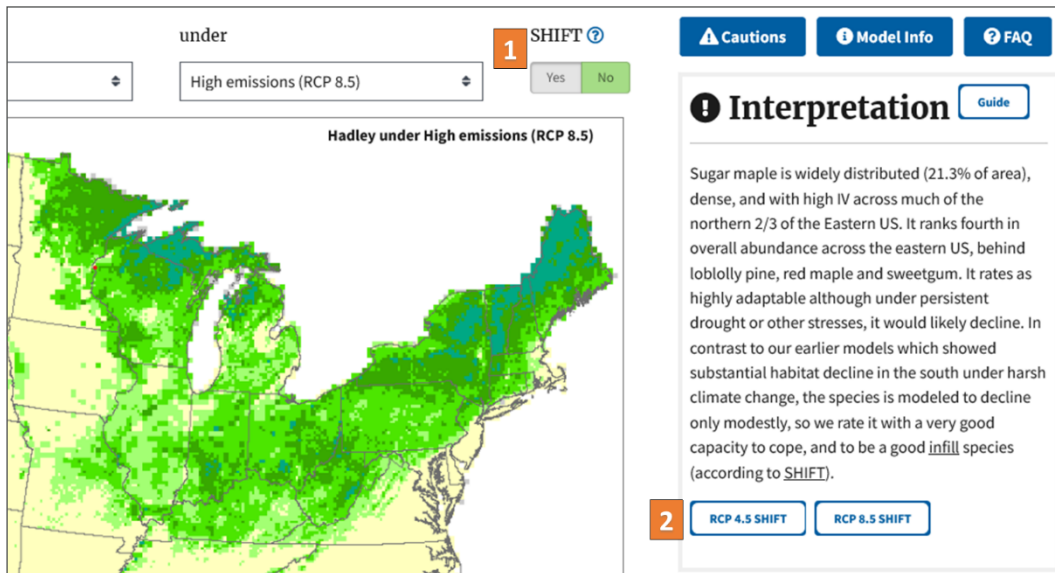


Among the three GCMs the amount of projected warming varies and it is useful to compare different modeled outputs to consider a range of potential impacts to habitat suitability. Examining and comparing results from the CCSM4 RCP 4.5 scenario with the Hadley RCP 8.5, we can get a sense of the “lower” and “upper” bounds of potential habitat suitability changes for a species (see the following images). In the “Show me” drop-down menu on the main page, Hadley can be selected to view this result or, within the “Summary Change Maps” section, users can scroll to the HadGEM2-ES results to see how they differ. Users will notice that across these two models the extents are similar, but the Hadley (HadGEM2-ES) output has a lower overall sum IV indicated by more lighter-green areas in Illinois, Indiana, and Pennsylvania.

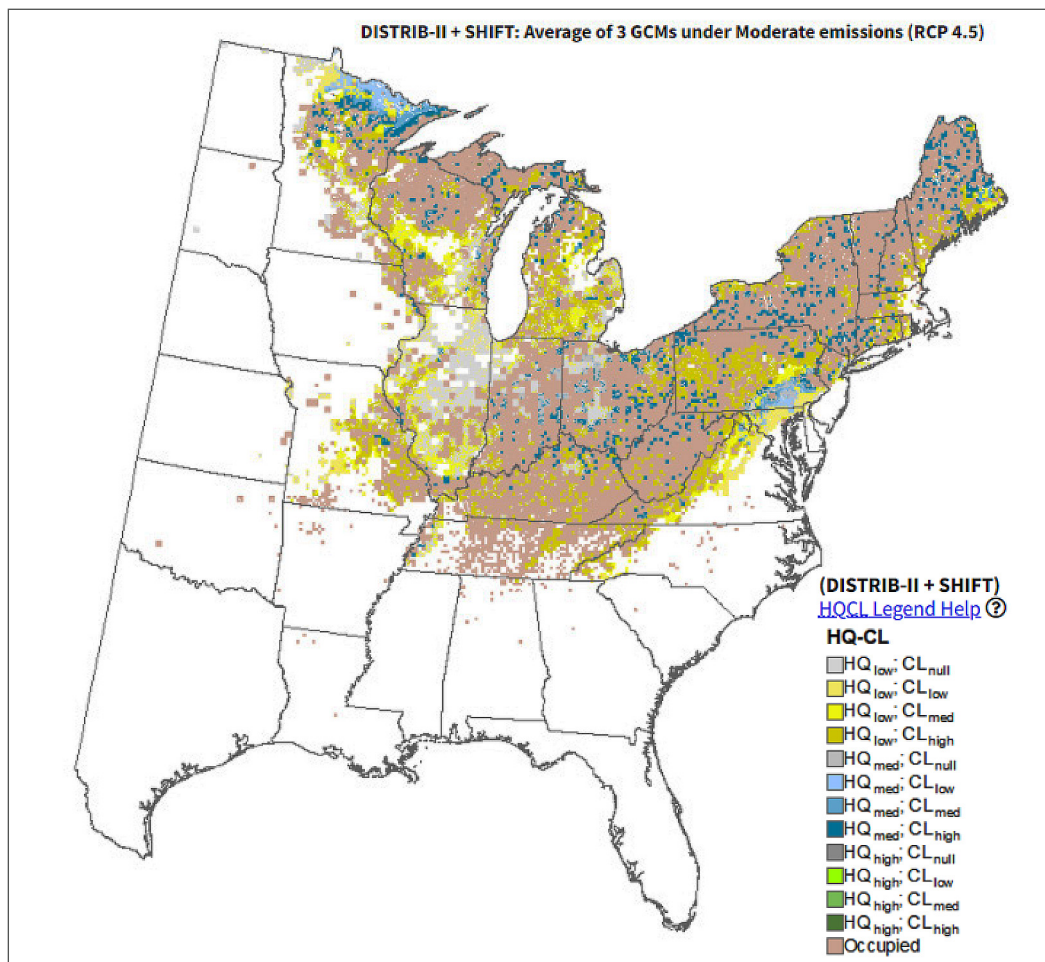


After closing the Summary Change Maps window, users may select “Average of 3 GCMs” from the “Show me” drop-down menu to see the combined results of potential suitable habitat under one of the RCP scenarios. The Average of 3 GCMs combines information from the three GCMs to reduce sensitivity from the individual GCM and represent the average potential changes in habitat suitability. It is helpful to use the suitable habitat projections when identifying where favorable conditions could exist for a species in the future, but it does not tell us whether a species could naturally migrate and colonize this suitable area.

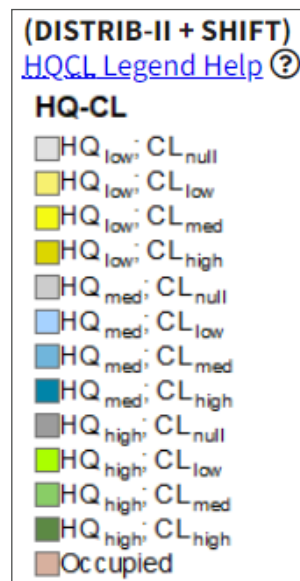
To get a sense of how likely a species is to migrate and colonize an area, users can view the SHIFT model results, which are available for 121 species. One way is to (1) select “yes” under the SHIFT heading, located just to the right of the “under” drop-down menu that we have been using (see left-hand panel in the following image). Alternatively, users can (2) select RCP 4.5 SHIFT from the Interpretation box, located in the right-hand column of the webpage for most species (see right-hand panel in the following image).



Now that SHIFT 4.5 is selected, users should see an output that looks like the following example.



The SHIFT legend is more complex (see the following image), but it simply maps combinations of where different levels of habitat quality (HQ: high, medium [med], low) occur relative to colonization likelihood (CL: high, medium [med], low, null). The darker shades of yellow, blue, and green indicate increasing CL for the three HQ classes, respectively. Null values are regions where there is no natural migration occurring according to the SHIFT model. Details on how HQ and CL are derived are provided under “The Models” in section 3. A detailed description of each class is accessible from the “HQCL Legend Help” hyperlink in the legend.

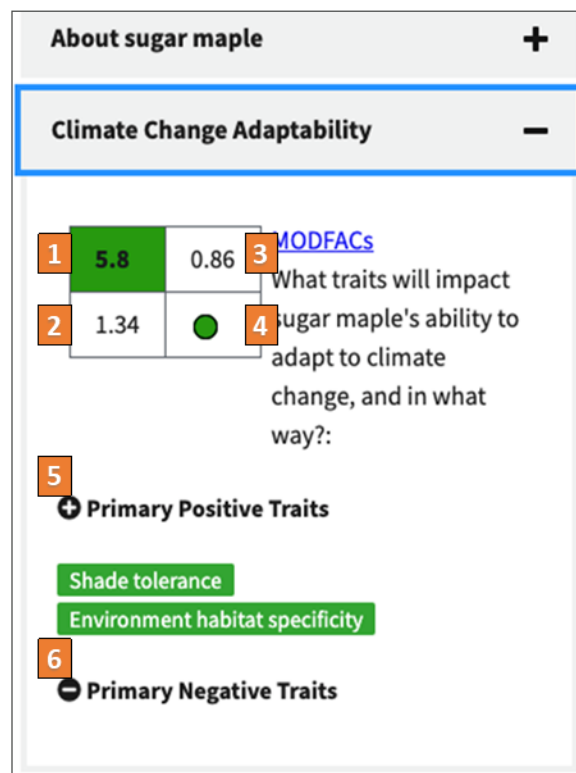


When looking through the different combinations on the map, users may notice that only a subset of the potential suitable habitat is projected to become colonized (yellow-, blue-, or green-colored legend where CL is above zero). Furthermore, there are subsets of future suitable habitat where, despite having higher HQ, the CL is low or null (gray classes in colored legend), making establishment much less likely. Therefore, combinations of higher HQ and higher CL capture the most suitable modeled conditions—for example, the darker blue areas in Minnesota and Pennsylvania. Users can also look for combinations of these higher suitable values that are outside the current range of the species for gauging outward migration potential (which we designate as “outfilling” to distinguish it from the within-species-range colonization, which we call “infilling”).

Combining map results with adaptability ratings

While the maps of potential habitat suitability and colonization likelihood include a wide range of environmental variables (see Table 1 in section 3 for a list of predictors), there are some factors which influence species distributions that cannot be directly included in the Tree Atlas models. This is where adaptability ratings can provide additional context.

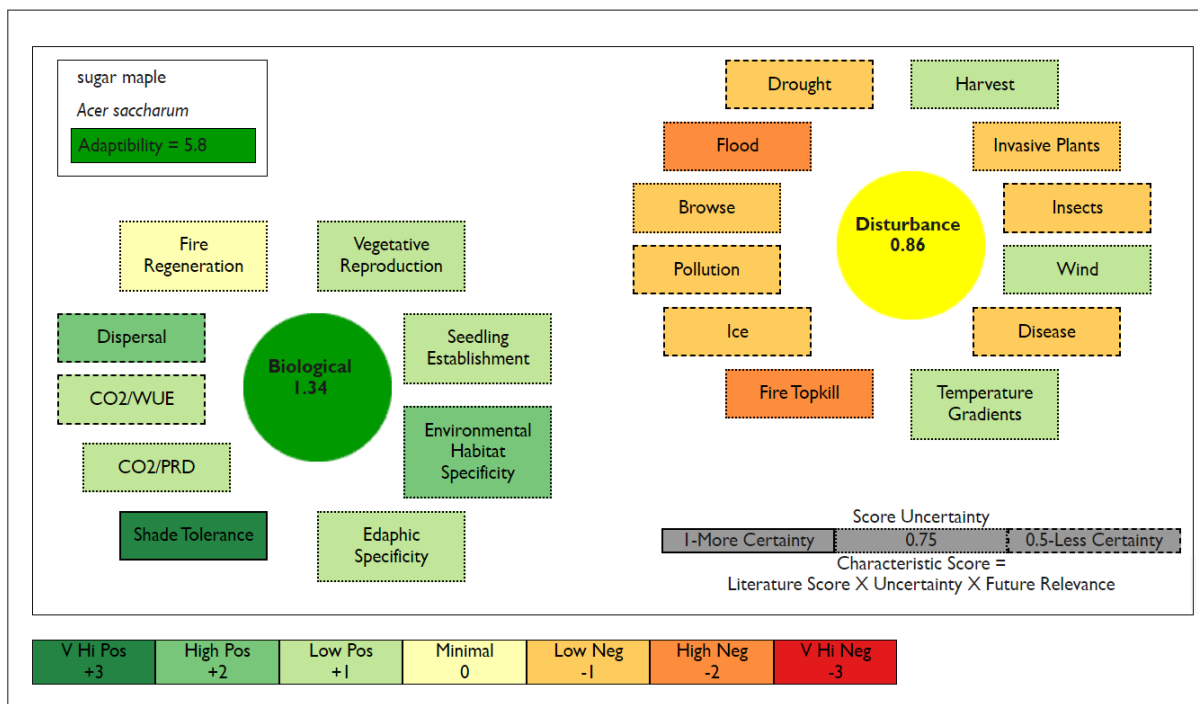
To locate the ratings, users can go to the column of expandable menus located on the right-hand side of the individual species webpage and select “Climate Change Adaptability”.



The information shown in the preceding image should appear. This is an overview of how 9 biological and 12 disturbance Modification Factors (MODFACs) are expected to influence a species. The information provided includes (1) the overall adaptability rating for sugar maple (5.8) with the green shading indicating a relatively high score when compared to the other species evaluated; (2) the score based on biological traits (1.34); (3) the score for disturbance factors (0.86); (4) the level of model reliability for the species, which is high, as indicated by the green circle; (5) a list of primary positive traits; and (6) a list of primary negative traits. The primary positive and negative traits provide a quick glance at the factors that are expected to largely influence the adaptability rating for a species. Note that all 21 traits influence the rating, but only the primary ones are presented here.

To view a more in-depth breakdown of the adaptability score, users can click on the MODFACs hyperlink. This will open a box that displays all biological and disturbance variables used in calculating the adaptability rating. Specific definitions for each term can be found in [Matthews et al. \(2011\)](#).

Note that the magnitude and uncertainty of each variable are shown by color and line type, respectively (see the following image). Positive variables are represented by three shades of green corresponding to very high (3), high (2), and low (1), with variables having a minimal impact (0) shown in pale yellow. Negative variables are represented by three shades of orange corresponding to low (-1), high (-2), and very high (-3). Three different line types are used to indicate uncertainty about the influence of the characteristics on the species as more certainty (1, solid), some certainty (0.75, dotted), or less certainty (0.5, dashed). The uncertainty either maintains or reduces the initial score.



By looking through these variables, users can see that the strongest positive biological traits are shade tolerance and environmental habitat specificity, while the most negative disturbance characteristics are flood and fire topkill. Even though dispersal and environmental habitat specificity are rated as +2 (high positive), environmental habitat specificity has a higher degree of certainty compared to dispersal. For the biological factors, many have a higher degree of certainty and contribute to a higher overall score for these traits. The disturbances tend to have both positive and negative scores for a species, which results in a moderate overall score when considered collectively for a species. Though this information is representative of the entire range of the species, local knowledge can be used to alter these default scores.

Summary

In this three-part walkthrough users learned how to change and view (1) different maps of potential habitat suitability; (2) output from the SHIFT model, which combines habitat suitability from DISTRIB-II with colonization likelihoods; and (3) how to view components of the adaptability rating. Navigating the various sections and products related to the individual species provides a wealth of information related to the current environmental conditions, physiological characteristics, current and potential future distributions, and the models. Examining the future habitat suitability and colonization likelihood maps offers insights into how climatic changes could impact the current distribution and abundance of a species, and the adaptability ratings help provide regional context when modified to account for local conditions.

When using the individual species maps, users are encouraged to keep in mind that there are other local factors to consider when planning management actions. It is important to consider factors like genetics, land use, and forest health in addition to the Tree Atlas results to develop a comprehensive management plan tailored to the region of interest.

Examine and Interpret Potential Changes for Many Species

This exercise will take users through the steps of choosing a regional output to best represent their area of interest, show users how to access and interpret the regional summary table, and present a few questions that may be answered by the regional summary tables.

This example will consider the area around Louisville, KY, and explore how the forests in the Trimble County area (north of Louisville) may change under future climate scenarios.

Accessing the tables and choosing a region

To access the tables, users may go to the Climate Change Atlas [homepage](#) and click on the “Products” button located in the menu in the upper left portion of the page.

Users can scroll down to the “Combined Species Outputs” section, as shown in the following image. There are several different regional divisions to choose from, including 1×1 ° Grid Summaries and Urban Areas. Since we are interested in the forests around Louisville, KY, we want to consider both of these regional summaries as possibilities.

Northern Research Station > Climate Change Atlas > Products

Climate Change Atlas Products

There are numerous products from the Climate Change Atlas in addition to the [Tree](#) and [Bird](#) Atlases.

Publications

[Browse Publications](#)

Combined Species Outputs

Summaries for tree species are available for a variety of geographies, in both PDF and Excel format. These summaries are based on [Version 4 of the Climate Change Tree Atlas](#)

- [National Forest Summaries](#)
- [National Park Summaries](#)
- [HUC6 Watersheds](#)
- [Ecoregional Vulnerability Assessments \(EVAS\)](#)
- [USDA Forest Service EcoMap 2007 Sections](#)
- [National Climate Assessment \(NCA\) 2016 Regional Summaries](#)
- [1 x 1 ° Grid Summaries](#)
- [Eastern United States](#)
- [Urban Areas](#)

[All Combined Species Outputs](#)

To get started, users can open the page “Urban Areas”, perhaps in a new browser tab. In the search bar on the right-hand side of the page, users can type “Louisville” to bring up the area used in this example. Alternatively, users can scroll through the options in the “Urban Areas Summaries” table until they find the “Louisville/Jefferson County, KY-IN” option. Note that only Urban Areas having an area of 200 sq. km (about 77 sq. miles) or greater are included in the list, so users may need to explore other summary tables that might capture the area of interest.

Urban Areas Summaries Version 4

Show entries

Search:

Urban Area	Name	State	Excel File	PDF File	Map File
51755	Louisville/Jefferson County, KY-IN	Kentucky; Indiana	Excel	PDF	Map

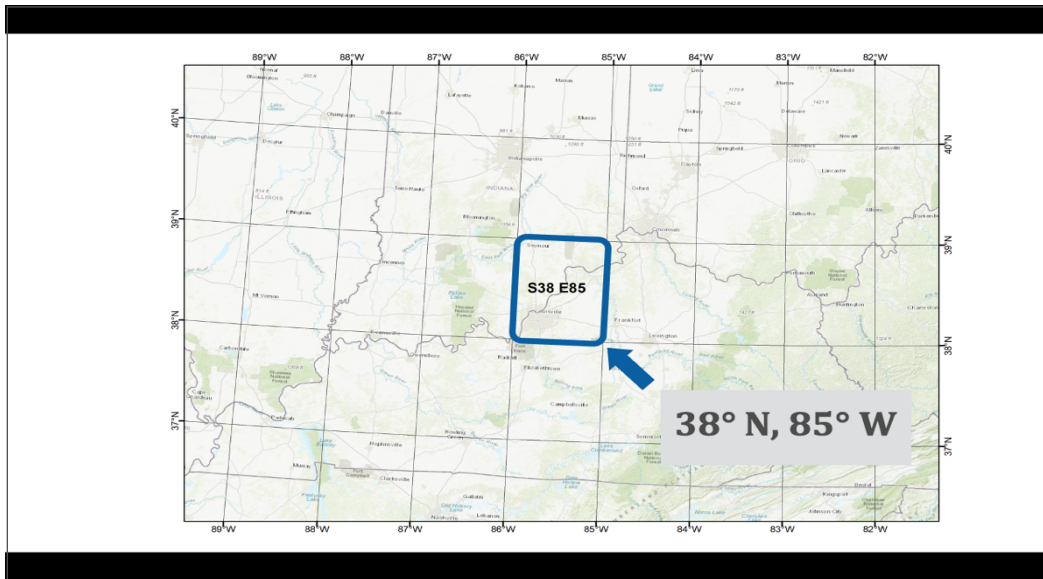
Showing 1 to 1 of 1 entries (filtered from 185 total entries)

Previous Next

The last column of the table is labeled “Map File” (see preceding image). To view the area being summarized, users can click on “Map” in the corresponding row. A map of the Louisville area (dotted region) will appear, with a thick black outline surrounding it, as shown in the following image. The black line indicates the buffered region around Louisville and is the extent of the regional summary. To learn more about how and why some urban areas are buffered, users may watch the tutorial video [“Choosing Regional Output”](#) for more information.



Next, users can go back to the Combined Species Outputs webpage and select the 1×1 ° Grid Summaries. On this page, the individual regions are listed in a format of “S” followed by two digits, an underscore, and “E” followed by two digits, representing the coordinates of latitude and longitude, respectively. Together, these coordinates indicate the location of the southeast corner of a grid cell.



To find the coordinates for an area of interest, an online mapping website can be used to search for the location. In this example, we will search for Louisville, KY. Once Louisville is found, users can click within the city boundaries to pull up coordinates for the area, which are likely to be found in the address bar of the user’s browser. The coordinates are roughly 38 degrees north by 85 degrees west. As seen in the preceding image, we now have the file name of the 1 degree × 1 degree grid that contains the Louisville area.

Users can return to the Climate Change Atlas webpage that contains the 1 degree × 1 degree summaries (<https://www.fs.usda.gov/nrs/atlas/combined/resources/summaries/grid>) and search “S38_E85” as was done with the urban area (see the following image).

1 x 1 Degree Grid Summaries Version 4

Show

25

▼

entries

Search:

S38_E85

Grid ▲	States	Excel File	PDF File	Map
S38_E85	Indiana, Kentucky	Excel	PDF	Map

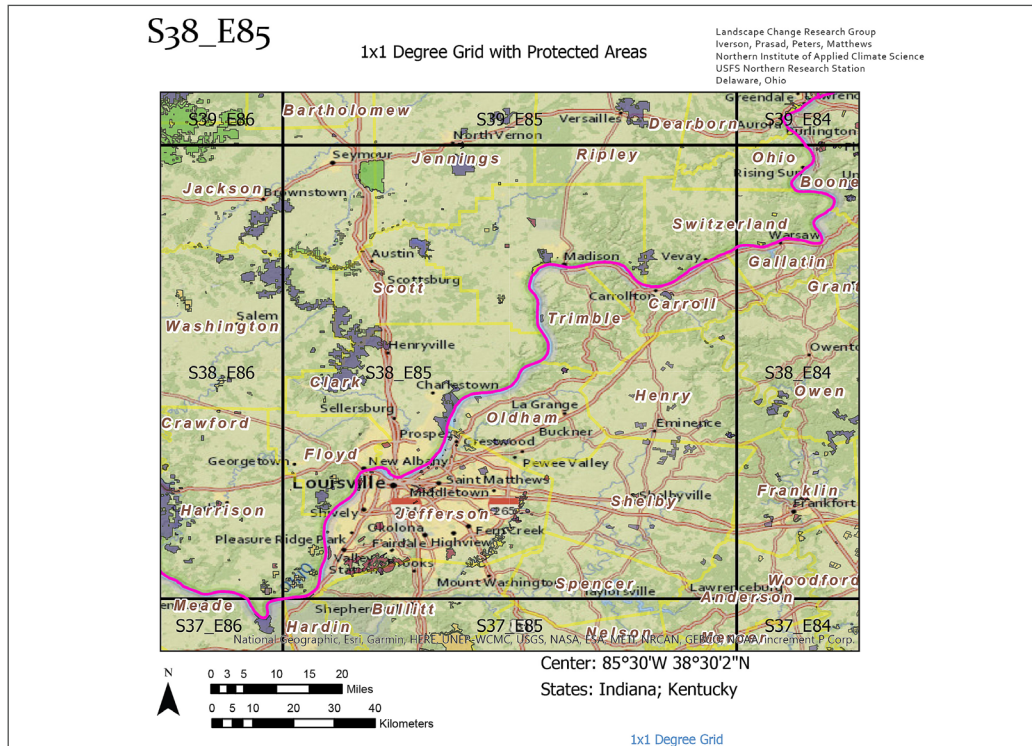
Showing 1 to 1 of 1 entries (filtered from 468 total entries)

Previous

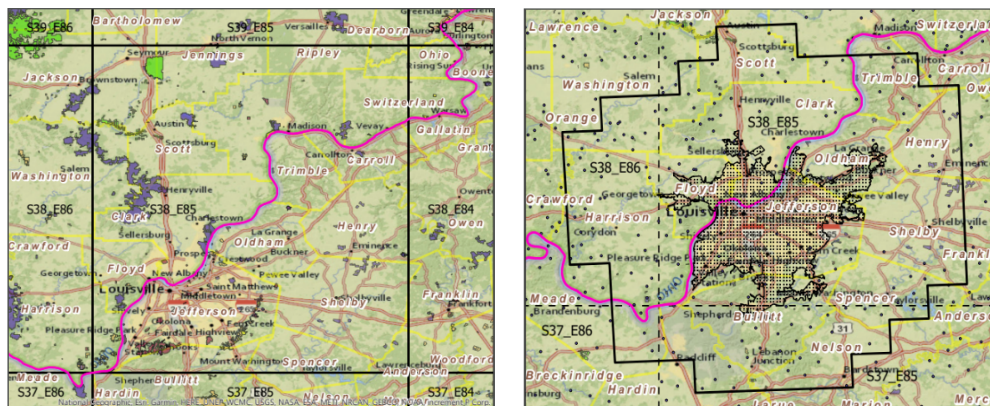
1

Next

To verify that the correct grid area has been selected, users can click on the “Map” hyperlink to open the PDF file containing the map of the summary area. The Louisville area should be located in the lower left portion of the map. The bold black lines indicate the 1 degree $\times$ 1 degree grid summary area (see the following image).



To choose a region that will best suit the area of interest in this example, users can compare the urban area map with the 1 degree $\times$ 1 degree grid map (see the following two images). Since our question relates to the region north of the Louisville area, Trimble County, the 1 degree $\times$ 1 degree grid summary is better suited to answer this question, as it captures this region better than the urban area output.



Downloading and using the summary tables

To download the 1 degree $\times$ 1 degree table used for this example, users can click on the “Excel” hyperlink under the Excel File column and download the file (see the following image). There is also a PDF version that shows the data from the “S38_E85-short” tab found in the Excel® (Microsoft®, Redmond, WA) sheet. This can be helpful for users who want to glance over the information, such as species listed, prior to downloading the Excel file.

Users should open the Excel file and take a minute to look around. The Definitions-short tab provides definitions and explanations for the columns found on the main data tab (S38_E85-short), which is a condensed version of the S38_E85-long tab. Additional tabs are as follows.

- **Species-Climate:** Provides a summary related to the species and habitat suitability information and includes trajectories of 30-year climate variables used in the DISTRIB-II models. This information is also included as the first page of the PDF file.
- **Definitions-short:** Briefly describes the column headers and explains what the contents of that column mean.
- **Questions of tables:** Offers potential discrete questions that may be answered by the regional summaries. This sheet also provides guidance on answering these questions.
- **Interpretations:** Functions as a guide to navigating the regional summary table. It provides common applications of the table as suggested by users (e.g., determining which species may migrate into the region) and outlines how to achieve the broader interpretations from the table.
- **Species Selection Options:** Defines the numeric codes for the species selection options (SSOs) column included in the short and long tabs. Users interested in planting species are encouraged to review this information to better understand how the SSO values can aid in the decision-making process of selecting species.
- **References:** Further reading is provided for users who desire a more in-depth understanding of the models and methods used in the Climate Change Atlas.
- **S--_E-- – long:** Provides the full version of the main sheet located at the start of the spreadsheet. This includes additional information for more in-depth evaluation of the data.
- **Definitions-long:** The final sheet of the document, this provides explanations for the various contents of the regional summary not included in the short tab.

On the Species-Climate tab, users can examine the values and line graphs under the “Potential Changes in Climate Variables” section to see how the six variables used in the DISTRIB-II models could change under each future scenario. These data may be helpful for understanding and interpreting the predicted changes in habitat suitability for this region.

While looking through the data in the S38_E85-short tab, users may have noticed the model reliability (MR) column. This column is a critical component of any analysis that uses data from the tables. Model reliability indicates the level of confidence in the results, so when MR is medium or high, we may be more confident of the summary output for the associated species.

As users begin working with the S38_E85-short tab, it is important to note that the initial sorting of the table is based on the “FIAsum” column. This column ranks abundance in the region based on area-weighted sums of importance values (see the Definitions-short or Definitions-long tabs for more information).

To get a sense of the number of species in the area, users can locate the column named “N” at the end of the S38_E85-short sheet (column Q). This column numbers each species to provide a total number of species included in this output. That means currently present species and species that may have new habitat in the area by 2100, some of which could migrate into the region by that time.

By scrolling to the bottom of the column (“N”), users can see that a total of 90 species are included in this output.

Next, users can locate the “% cell” column (column E). This shows for each of the species listed what portion of the summary region it occupies among the modeling cells. Users can find where the numbers in this column reach 0 percent; anything greater than 0 is currently present according to inventory records. By comparing this point in the “% cell” column with “N”, users can see that 72 species are currently found within this region. There are likely to be other tree species found in this region which are either not reported in the FIA data or not captured by the model. This is typically due to a low sampling density relative to the area modeled.

Common Name	Range	MR	%Cell	FIAsum	FIAiv	ChngC14S	ChngC18S	Adap	Abund	Capabil4S	Capabil8S	SHIFT4S	SHIFT8S	SSO	N
striped maple	NSL	Medium	1	0.5	0.5 Sm. dec.	Sm. dec.	Medium	Rare	Very Poor	Very Poor				0	69
yellow birch	NDL	High	0.1	0.4	0.0 Lg. dec.	Lg. dec.	Medium	Rare	Very Poor	Very Poor				0	70
white mulberry	NSL	FIA	1	0.4	0.4 Unknown	Unknown	NA	Rare	NNIS	NNIS				0	71
rock elm	NSLX	FIA	1	0.3	0.3 Unknown	Unknown	Low	Rare	FIA Only	FIA Only				0	72
ash/juniper	NDH	High	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat				0	73
shortleaf pine	WDH	High	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate ++	Migrate ++		3	74
slash pine	NDH	High	0	0	0 Unknown	New Habitat	Medium	Absent	Unknown	New Habitat				3	75
loblolly pine	WDH	High	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate ++	Migrate ++		3	76
mountain maple	NSL	Low	0	0	0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat				3	77
serviceberry	NSL	Low	0	0	0 Unknown	Unknown	Medium	Modeled	Unknown	Unknown				0	78
cittamwood/gum bumelia	NSL	Low	0	0	0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat				3	79
pecan	NSH	Low	0	0	0 New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat	Migrate +	Migrate ++		3	80
black hickory	NDL	High	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate ++		3	81
black ash	WSH	Medium	0	0	0 Unknown	New Habitat	Low	Absent	Unknown	New Habitat				3	82
cucumbertree	NSL	Low	0	0	0 Unknown	Unknown	Medium	Absent	Unknown	Unknown				0	83
pin cherry	NSL	Low	0	0	0 Unknown	Unknown	Medium	Absent	Unknown	Unknown				0	84
cherrybark oak; swamp rec	NSL	Medium	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +		3	85
blackjack oak	NSL	Medium	0	0	0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate +	Migrate ++		3	86
water oak	WDH	High	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate ++		3	87
willow oak	NSL	Low	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +		3	88
live oak	NDH	High	0	0	0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat				0	89
cedar elm	NDH	Medium	0	0	0 New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat				3	90

Next, users can click on the drop-down menu arrow in the “SHIFT85” column. Users can click “sort by A to Z” (ascending) to view the number of species that may experience new habitat expansion in the region (see the following image). Here, users should see that 18 species may experience infill or could migrate into the region by 2100. The term “Infilling” indicates that a species is sparsely present in the region but may expand in the summary area in the future. “Migrate” indicates that a species is not currently found in the region but may colonize newly suitable habitats in the future. The “+” or “++” at the end of these terms represents the magnitude of each possibility.

Common Name	Range	MR	%Cell	FIAsum	FIAiv	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	SSO	N
sugar maple	WDH	High	80.4	1195.6	11.9 Sm. dec.	Sm. dec.	High	Abundant	Good	Good				1	1
eastern redcedar	WDH	Medium	60.9	940.8	11.9 No change	Sm. inc.	Medium	Abundant	Good	Very Good				1	2
white ash	WDL	Medium	68.8	687.8	8.3 Sm. dec.	Sm. dec.	Low	Abundant	Fair	Fair				0	3
yellow-poplar	WDH	High	51.5	479.7	8.3 Sm. dec.	Lg. dec.	High	Common	Fair	Fair				1	4
red maple	WDH	High	48.6	437.8	7.9 Sm. dec.	Sm. dec.	High	Common	Fair	Fair				1	5
black walnut	WDH	Low	62.5	367.9	4.9 No change	No change	Medium	Common	Fair	Fair				1	6
white oak	WDH	Medium	34.6	328.8	5.9 Sm. inc.	Sm. inc.	High	Common	Very Good	Very Good				1	7
American elm	WDH	Medium	58.7	298.2	3.7 Sm. inc.	Sm. inc.	Medium	Common	Good	Good				1	8
sassafras	WSL	Low	46.3	282.5	4.6 Sm. dec.	Sm. dec.	Medium	Common	Poor	Poor				0	9
black locust	NDH	Low	36	273.2	6.4 No change	Sm. inc.	Medium	Common	Fair	Good				1	10
chinkapin oak	NSL	Medium	43.7	270.3	5.1 Sm. dec.	Sm. dec.	Medium	Common	Poor	Poor				0	11
shagbark hickory	WSL	Medium	45.5	235.1	3.6 No change	No change	Medium	Common	Fair	Fair				1	12
American beech	WDH	High	47	230.0	4.0 Sm. dec.	Sm. dec.	Medium	Common	Poor	Poor				0	13
green ash	WSH	Low	40.3	227.1	5.1 Sm. inc.	Lg. inc.	Medium	Common	Good	Very Good				1	14
black cherry	WDL	Medium	52.1	215.2	3.2 No change	No change	Low	Common	Poor	Poor				0	15
sweetgum	WDH	High	32.8	199.9	6.3 Lg. inc.	Lg. inc.	Medium	Common	Very Good	Very Good				1	16
hackberry	WDH	Medium	45.5	185.2	3.4 Sm. inc.	Lg. inc.	High	Common	Very Good	Very Good				1	17
pignut hickory	WDL	Medium	32.3	181.9	4.2 No change	No change	Medium	Common	Fair	Fair				1	18

Before we begin to develop and answer a few questions based on the table, users may take a minute to look over a few columns and read their definitions. Some columns to read over include model reliability (MR), change classes RCP 4.5 (ChngCl45) and RCP 8.5 (ChngCl85), adaptability score (Adap), abundance class (Abund), and capability classes RCP 4.5 (Capabil45) and RCP 8.5 (Capabil85).

Answering questions using the table

After users have read over the definitions of some of the columns, we can begin to answer a few questions to help us better understand Trimble County, both now and in the future. For an example list of questions, go to the “Questions of tables” tab. The following are several questions that can be answered using this table. Note that the images of the sorted and filtered table in the following images have some fields hidden to show only the relevant columns for this exercise.

Question 1: What are the five most common/abundant species in this area? Do these species have good model reliability?

The table can be sorted by “FIAsum” (descending; see the following image). The top five species listed by decreasing relative abundance are sugar maple, eastern redcedar, white ash, yellow-poplar, and red maple. Abundance is also descriptively characterized in the “Abund” column for these species, with the first three species listed as abundant and the latter two listed as common.

To assess model reliability, users can view the “MR” column. Here we can see that reliability is high for most of these species, with eastern redcedar and white ash having a medium level of reliability. Note: To better understand how model reliability is determined, see [Peters et al. \(2019\)](#).

Common Name	MR	%Cell	FIAsum
sugar maple	High	80.4	1195.6
eastern redcedar	Medium	60.9	940.8
white ash	Medium	68.8	687.8
yellow-poplar	High	51.5	479.7
red maple	High	48.6	437.8

Question 2: How might the suitable habitat of these species change in the future under low and high climate change scenarios?

To answer this question, users can view the “ChngCl45” column to learn about the low climate change scenarios and the “ChngCl85” column to learn about the high climate change scenarios (see the following image). Under the RCP 4.5 scenarios, users should see that the top five currently abundant species could have a small reduction in suitable habitat in this region, with the exception of eastern redcedar, which is predicted to have no change in suitable habitat. Under the RCP 8.5 scenarios, three of the five species may still have small decreases in suitable habitat. Yellow-poplar, which had only a small decline under the low climate change scenarios, could experience a larger decrease in this region under RCP 8.5. By contrast, eastern redcedar is expected to gain suitable habitat in the region by 2100 under the high climate change scenarios.

Common Name	ChngCl45	ChngCl85
sugar maple	Sm. dec.	Sm. dec.
eastern redcedar	No change	Sm. inc.
white ash	Sm. dec.	Sm. dec.
yellow-poplar	Sm. dec.	Lg. dec.
red maple	Sm. dec.	Sm. dec.
black walnut	No change	No change
white oak	Sm. inc.	Sm. inc.
American elm	Sm. inc.	Sm. inc.

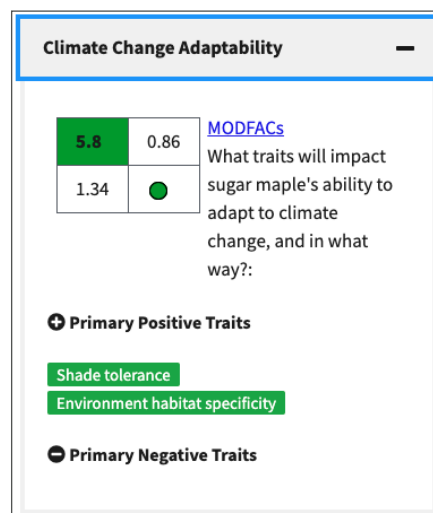
Question 3: What is the adaptive capacity of these species, accounting for biological and disturbance variables?

Users can go to the “Adap” column to view a description of adaptability. The following should be shown.

Common Name	Adap
sugar maple	High
eastern redcedar	Medium
white ash	Low
yellow-poplar	High
red maple	High
black walnut	Medium
white oak	High
American elm	Medium

This column describes how species may fare given a range of biological and disturbance factors assessed across the entire range of the species. These factors could influence the distribution of these species but could not be directly included in the model. For more information on these adaptability ratings, users may watch the Adaptability Ratings tutorial ([Adaptability Scores video](#)) and read [Matthews et al. \(2011\)](#).

Those interested in the numerical adaptability scores for each of these species can visit the Tree Atlas webpage and navigate to the individual species pages. Users may click on the Climate Change Adaptability tab located on the right-hand side of the webpage to view the adaptability rating. The following is an example of what the adaptability rating will look like using sugar maple. Further details are provided in “Combining Map Results with Adaptability Ratings” earlier in this section.



Question 4: What is the overall capability (i.e., the ability to cope or persist with a changing climate) of these species under low and high climate change scenarios?

To see how capable a species may be under future climate scenarios, users can go to the “Capabil45” and “Capabil85” columns. In these columns, capability is characterized as very good, good, fair, poor, very poor, lost, and new habitat. Capability is a metric derived from three other columns in the table: change class, adaptability, and abundance within the area of interest. When users look at the capability for the top five common or abundant species in the region, it should look like the following image. Under the low climate change scenarios (Capabil45), the capacity of the five species is characterized from fair to good. The capability ratings remain consistent under the high climate change scenarios, with the exception of eastern redcedar, which is characterized as having a very good capability to cope with the high climate change scenarios.

Common Name	Capabil45	Capabil85
sugar maple	Good	Good
eastern redcedar	Good	Very Good
white ash	Fair	Fair
yellow-poplar	Fair	Fair
red maple	Fair	Fair

Question 5: What currently present species could be at the highest risk/most vulnerable under future climate scenarios in this region?

To answer this question, users can filter the drop-down tabs at the top of each column to select a subset of data. First, in the “ChngCl45” column, users can click on the drop-down tab and select Lg. dec. and Very Lg. dec. to view the species that are likely to have a substantial reduction in suitable habitat conditions under the low climate change scenarios. There is a mixture of species with high, medium, and low model reliability (this information is found under the “MR” column). The results with the most confidence are the medium and high MR species, so users can use the drop-down tab to exclude species with low model reliability. Results should look like the following image and contain seven species that may be at greater risk under the low climate change scenarios in the region of interest.

Common Name	MR	ChngCl45	ChngCl85
Virginia pine	High	Lg. dec.	Lg. dec.
chestnut oak	High	Lg. dec.	Lg. dec.
eastern white pine	High	Lg. dec.	Lg. dec.
American basswood	Medium	Lg. dec.	Lg. dec.
bigtooth aspen	Medium	Very Lg. dec.	Very Lg. dec.
red pine	Medium	Very Lg. dec.	Very Lg. dec.
yellow birch	High	Lg. dec.	Lg. dec.

To compare these results with the high climate change scenarios, users can select the drop-down tab for “ChngCl45” and click “select all” to make all the species visible again. Note: This does not include species with low model reliability, as that remains unselected in the “MR” column. Users can go to the drop-down menu for “ChngCl85” and select only the Lg. dec. and Very Lg. dec. values. This list contains eight species. By looking at the “ChngCl45” column as shown in the following image, users can see that yellow-poplar was listed as having only a small decrease under the low climate change scenarios and is projected to have a large decrease of suitable habitat under the high climate change scenarios.

Common Name	MR	ChngCl45	ChngCl85
yellow-poplar	High	Sm. dec.	Lg. dec.
Virginia pine	High	Lg. dec.	Lg. dec.
chestnut oak	High	Lg. dec.	Lg. dec.
Ohio buckeye	Low	Lg. dec.	Lg. dec.
eastern white pine	High	Lg. dec.	Lg. dec.
American basswood	Medium	Lg. dec.	Lg. dec.
pawpaw	Low	Lg. dec.	Lg. dec.
swamp chestnut oak	Low	Lg. dec.	Lg. dec.
bigtooth aspen	Medium	Very Lg. dec.	Very Lg. dec.
swamp white oak	Low	Very Lg. dec.	Lg. dec.
red pine	Medium	Very Lg. dec.	Very Lg. dec.
yellow birch	High	Lg. dec.	Lg. dec.

Question 6: What species might migrate into the region by the year 2100?

Users should clear any filters that have been applied from the previous step. Users can sort the “SHIFT85” column by descending migration potential to view species that are predicted to migrate into the area by 2100. We can see that eight species have some migration potential under both the low and high climate change scenarios as shown in the following image. As we consider what species may migrate into the area, there are several other columns to consider. First, what is the model reliability? How adaptable is the species? If both factors are low, then we cannot be as confident in this species as a possible migrator. In this region, we can see that pecan has low values for model reliability and adaptability. Finally, we can compare the two emissions scenarios (SHIFT45 and SHIFT85) to see how migration may be influenced by future climate. For the potential migrators in this region, we can see that the likelihood of migration potential for a species will sometimes be greater under high emissions. Some examples would be pecan, black hickory, water oak, and shortleaf pine, as indicated by the “++” vs. “+”.

Common Name	MR	Adap	Capabil85	SHIFT45	SHIFT85
shortleaf pine	High	Medium	New Habitat	Migrate ++	Migrate ++
loblolly pine	High	Medium	New Habitat	Migrate ++	Migrate ++
pecan	Low	Low	New Habitat	Migrate +	Migrate ++
black hickory	High	Medium	New Habitat	Migrate +	Migrate ++
blackjack oak	Medium	High	New Habitat	Migrate +	Migrate ++
water oak	High	Medium	New Habitat	Migrate +	Migrate ++
cherrybark oak; swamp red	Medium	Medium	New Habitat	Migrate +	Migrate +
willow oak	Low	Medium	New Habitat	Migrate +	Migrate +

In this exercise, users have covered (1) how to choose a regional output based on a specific area of interest, (2) the purpose of each sheet or tab in the Excel documents of the summary tables, (3) the meaning of each column in the summary tables and how they are useful in interpreting the output, and (4) how to ask and answer specific questions of the tables to learn more about an area of interest. These summary tables may be coupled with the individual species maps and adaptability ratings for a more comprehensive understanding of how both regions and the individual species within may fare under possible future climate conditions.

When using the regional summary tables, users are encouraged to keep in mind that there are other, local factors to consider when planning the management of a species. It is also important to consider factors like genetics, land use, and forest health in addition to using the Tree Atlas results.

Developing Forest Management Plans: a Case Study for the Living Lab, St. Lawrence University, Canton, NY

This guide provides details from an ongoing case study where the Tree Atlas is being used to proactively manage a 120-acre parcel near the campus of St. Lawrence University, Canton, NY (<https://www.stlawu.edu/offices/environmental-studies/living-lab>).

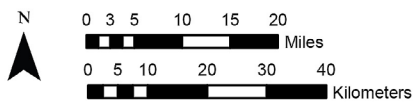
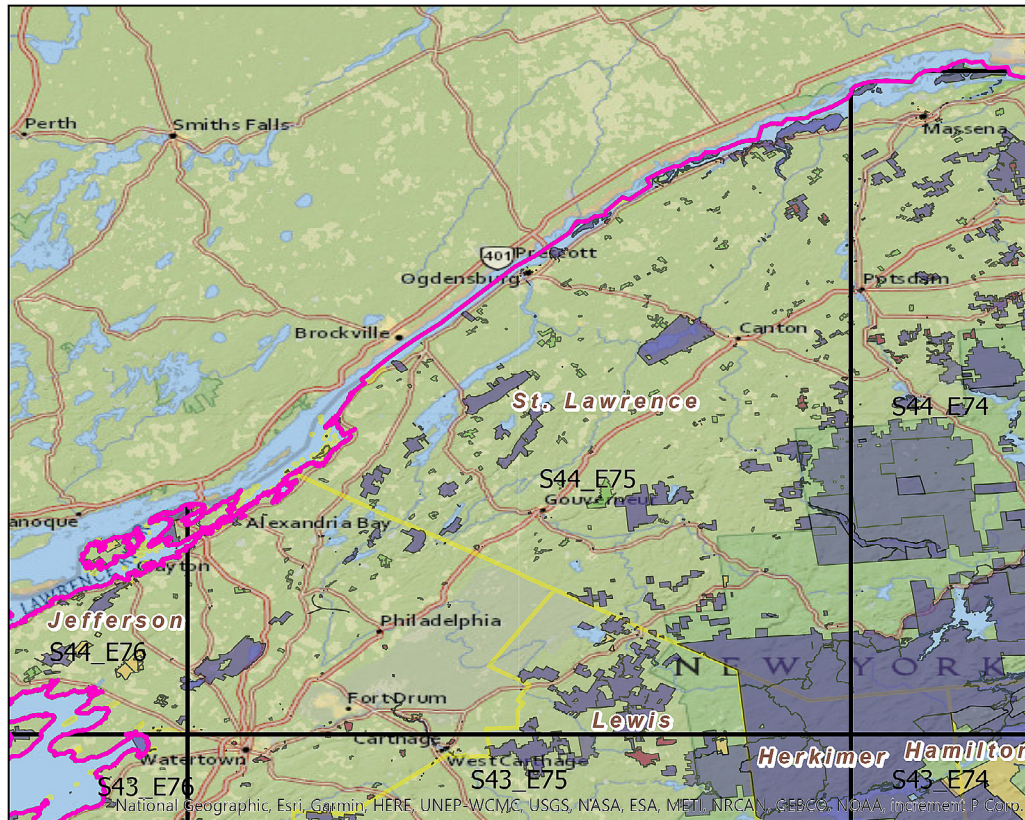
Researchers from the Forest Service and St. Lawrence University initiated a project to help develop an adaptive forestry management plan for the St. Lawrence University Living Lab (hereafter, Lab). The property is a forest-grassland-agricultural mixture, with the desired management goal to be proactive for climate change and invasive insect pest species and to support a diversity of tree species that provide wildlife habitat into the future. A table of candidate tree species was compiled for the range of Lab habitats that were potentially suitable for the projected climates of 2100, as projected for lower (RCP 4.5) and higher (RCP 8.5) greenhouse gas emissions trajectories (see details in section 5).

Trees were selected based on the summary output page (Excel file) from the Tree Atlas using the 1 degree $\times$ 1 degree latitude and longitude grid summary for S44_E75 that contains the Lab site (<https://www.fs.usda.gov/nrs/atlas/combined/resources/summaries/grid/>). Users may consult steps in consult steps in Downloading and Using the Summary Tables earlier in this section for instruction on downloading the summary file. The Lab is located in the northeast quadrant of the 1 degree $\times$ 1 degree grid. Currently, 13.3 percent of the cell is in a protected ownership category, as shown in the following image.

S44_E75

1x1 Degree Grid with Protected Areas

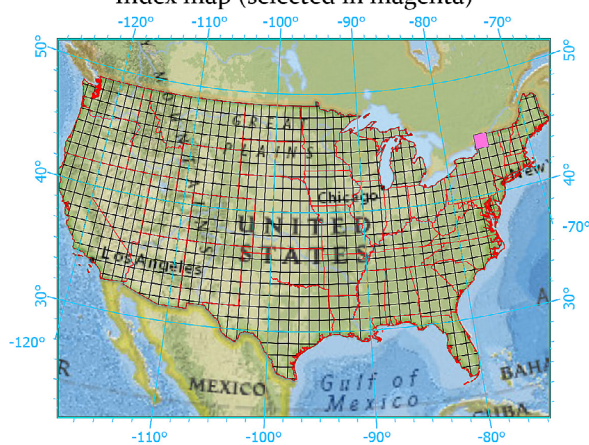
Landscape Change Research Group
Iverson, Prasad, Peters, Matthews
Northern Institute of Applied Climate Science
USFS Northern Research Station
Delaware, Ohio



Center: 75°30'W 44°28'58\"N

States: New York

Index map (selected in magenta)



1x1 Degree Grid

- 1x1 Degree Grid
- State Boundary
- USA Counties

Protected Areas 791.8 km² area (13.29%)

- American Indian Lands 0.0
- Federal 57.0
- Joint 0.0
- Local Government 9.8
- Non-Governmental Organization 5.4
- Private 1.2
- Regional Agency Special District 0.2
- State 718.3
- Unknown 0.0

The main table provides a list of 78 tree species that occur in the region or have the potential to gain suitable habitat by the end of century. The Tree Atlas summaries provide 14 descriptive factors for each species, including the current abundance of the species (e.g., weighted importance value), and projected changes in capability and suitable habitats as well as potential migration within the century according to RCP 4.5 (low emissions) and RCP 8.5 (high emissions; see [Iverson et al. 2019b](#) for full descriptions of methods and outputs). Species from habitats distinct from those on the Lab are also included and each species should be evaluated with local knowledge before moving ahead with adaptation planning. As such, the goal here was to provide a refined version of the general output table suited more specifically for the Lab.

Many of the summary table variables were used to arrive at a preliminary list of species to consider for planting or promoting within the Lab. This list should then be carefully reviewed and adjusted to align with manager needs and with local knowledge of the habitats present and their desired futures to reach a final candidate species list. Of course, the manager has final say over any decisions, including reinstating the “filtered out” species from this process. The following sections outline a potential sequence of filtering, first for the species already present in the region, and then for those not currently present in the region. The rule numbers listed next are presented in the table for clarifying this case study.

Expand or Promote. Rules 1 through 6 deal with species that are known to be present in the region. Rule 4 relates to invasive species, and we do not encourage planting or promoting these species. Rule 1 denotes species that have a poor capability and may not do well under future conditions. Rules 2 and 3 represent species where information is lacking—they may be acceptable if managers have positive local insights on them. Rules 5 and 6 include species which could be considered to facilitate expansion within modeled habitats.

Assisted Migration. Rules 7 through 9 pertain to species that are not known to be present in the region but are modeled to have suitable habitat by the end of century under the higher emissions of RCP 8.5 models. Of these, our SHIFT model was used to gauge the likelihood of colonization within 100 years; those with some likelihood of occupying the region under natural migration are scored the highest as candidates to plant as an assisted migration. In this case, users are advised to look at species with rule 7 first; rule 9 adds other criteria which may help narrow the species listed under rule 7. Species assigned to rule 8 may be considered, but only after rule 7 species have been thoroughly vetted.

Considerations for augmenting species already in the region

For each of the following steps, users can filter the table using one or more columns to assign the corresponding species to the rule. After each step, the filters will need to be removed to view the full list of species. Users can start by adding a column “Rule” after the column ‘N’, which has been hidden in the following images. It is possible for some species to be assigned to more than one rule.

1. To remove species with Poor, Very Poor, or Lost capability in both Capabil45 and Capabil85, users should first filter Capabil45 to remove other values, then filter Capabil85. Species may be assigned to rule *Explanation*: These species are not expected to thrive in the future because of a large loss in suitable habitat, especially if not initially common in the region, and their traits are not especially conducive to overcoming the conditions expected by 2100. In this case, 20 of 78 species, tabulated next, are *initially eliminated* by this criterion, and *should be considered for planting only under special situations*.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
northern white-cedar	High	431.1	Lg. dec.	Lg. dec.	Medium	Common	Poor	Poor			1
yellow birch	High	325.4	Sm. dec.	Lg. dec.	Medium	Common	Poor	Poor			1
red spruce	High	230.5	Lg. dec.	Lg. dec.	Low	Common	Very Poor	Very Poor			1
red pine	Medium	207.5	Sm. dec.	No change	Low	Common	Poor	Poor	Infill +	Infill +	1
gray birch	Low	202.8	Lg. dec.	Lg. dec.	Medium	Common	Poor	Poor			1
balsam fir	High	138.0	Sm. dec.	Sm. dec.	Low	Common	Poor	Poor	Infill +	Infill +	1
black ash	Medium	129.7	Lg. dec.	Lg. dec.	Low	Common	Very Poor	Very Poor			1
serviceberry	Low	103.5	Lg. dec.	Lg. dec.	Medium	Common	Poor	Poor			1
striped maple	Medium	61.0	Lg. dec.	Lg. dec.	Medium	Common	Poor	Poor			1
white spruce	Medium	47.3	Lg. dec.	Lg. dec.	Medium	Rare	Very Poor	Very Poor			1
swamp white oak	Low	41.5	No change	No change	Medium	Rare	Poor	Poor	Infill +	Infill +	1
black willow	Low	41.5	Sm. dec.	No change	Low	Rare	Very Poor	Very Poor			1
pin cherry	Low	38.9	Very Lg. dec.	Very Lg. dec.	Medium	Rare	Lost	Lost			1
tamarack (native)	High	35.3	Sm. dec.	Sm. dec.	Low	Rare	Very Poor	Very Poor			1
shagbark hickory	Medium	29.4	No change	No change	Medium	Rare	Poor	Poor	Infill +	Infill +	1
balsam poplar	Medium	22.2	Lg. dec.	Lg. dec.	Medium	Rare	Very Poor	Very Poor			1
American hornbeam; muskeg	Low	21.6	Lg. dec.	Sm. dec.	Medium	Rare	Very Poor	Very Poor			1
American mountain-ash	Low	1.4	Lg. dec.	Lg. dec.	Low	Rare	Very Poor	Very Poor			1
black spruce	High	1.1	Very Lg. dec.	Very Lg. dec.	Medium	Rare	Lost	Lost			1
mountain maple	Low	0.7	Lg. dec.	Lg. dec.	High	Rare	Poor	Poor			1

2. If the species is labeled “unknown” in the Capabil45 and Capabil85 columns, or if the SHIFT45 or SHIFT85 column contains “Likely + or ++”, it is modeled to be present in the region, but no FIA plots recorded it. The species may be considered a candidate for planting only if the manager has a special understanding and reason for selecting this species. Users can first filter the species where Capabil45 and Capabil85 are “unknown” and assign them to rule 2. Users should clear the filters and then select species where SHIFT45 or SHIFT85 contains “Likely + or ++” and assign them to rule 2. Only sweet birch and American holly meet these criteria.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
sweet birch	High	0	New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat	Likely +	Likely +	2
American holly	Medium	0	Unknown	Unknown	Medium	Modeled	Unknown	Unknown			2

3. If the species is labeled “FIA only” in Capabil45 or Capabil85, the species was found in FIA plots, but insufficient data were available to model. Again, *caution should be used when considering these species for planting* since information may be limited. In this situation, we know the species exists in the region, but we do not have evidence as to how well it will thrive under projected climate change. Butternut and chokecherry match this criterion in this case study.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
butternut	FIA	34.0	Unknown	Unknown	Low	Rare	FIA Only	FIA Only			3
chokecherry	FIA	1.2	Unknown	Unknown	Medium	Rare	FIA Only	FIA Only			3

4. If the species is labeled “NNIS” in Capabil45 or Capabil85, it is a known nonnative invasive species (NNIS) and should not be considered for planting. Scots pine and Norway spruce match this criterion in this case study. Additionally, although black locust is not officially an NNIS, several states do categorize it as such, and we do not encourage planting it for this project.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
Scots pine	FIA	12.0	Unknown	Unknown	NA	Rare	NNIS	NNIS			4
Norway spruce	FIA	7.7	Unknown	Unknown	NA	Rare	NNIS	NNIS			4
black locust	Low	3.1	Lg. inc.	Lg. inc.	Medium	Rare	Good	Good	Infill ++	Infill ++	4

5. Species with Fair, Good, or Very Good in either capability column should be considered first for augmented planting. Users should first filter on Capabil45 and assign species to rule 5, then clear the filter and select species from Capabil85 and assign to rule 5. These species have reasonable abundance in the region and appropriate traits for persisting within the area under a changed climate. In this example, 24 species are selected out of 78 listed, as shown in the following image. This list includes many of the most common species present but also several currently uncommon species that have the capability to expand.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
red maple	High	1449.2	No change	Sm. dec.	High	Abundant	Very Good	Good			5
American elm	Medium	867.3	Sm. dec.	Sm. dec.	Medium	Abundant	Fair	Fair			5
sugar maple	High	857.4	No change	No change	High	Abundant	Very Good	Very Good			5
eastern white pine	High	840.1	No change	Sm. dec.	Low	Abundant	Fair	Fair			5
black cherry	Medium	783.2	No change	Sm. dec.	Low	Abundant	Fair	Fair			5
eastern hemlock	High	511.6	Sm. dec.	Lg. dec.	Low	Abundant	Fair	Poor			5
American beech	High	454.2	No change	Sm. dec.	Medium	Common	Fair	Poor			5
white ash	Medium	364.7	Sm. inc.	Sm. inc.	Low	Common	Fair	Fair			5
bitternut hickory	Low	230.0	Sm. dec.	Sm. dec.	High	Common	Fair	Fair			5
American basswood	Medium	217.1	No change	No change	Medium	Common	Fair	Fair			5
northern red oak	Medium	207.7	Lg. inc.	Lg. inc.	High	Common	Very Good	Very Good			5
quaking aspen	High	206.2	Sm. inc.	Sm. inc.	Medium	Common	Good	Good			5
eastern hophornbeam; ironw	Low	198.7	Sm. dec.	Sm. dec.	High	Common	Fair	Fair			5
green ash	Low	135.3	Lg. inc.	Lg. inc.	Medium	Common	Very Good	Very Good			5
silver maple	Low	119.2	No change	No change	High	Common	Good	Good			5
bigtooth aspen	Medium	100.3	Sm. inc.	No change	Medium	Common	Good	Fair			5
bur oak	Medium	85.6	Lg. dec.	Lg. dec.	High	Common	Fair	Fair	Infill +	Infill +	5
paper birch	High	71.7	Lg. inc.	Lg. inc.	Medium	Common	Very Good	Very Good			5
eastern redcedar	Medium	59.1	Sm. inc.	Lg. inc.	Medium	Rare	Fair	Good	Infill +	Infill ++	5
slippery elm	Low	48.1	No change	Sm. inc.	Medium	Rare	Poor	Fair			5
white oak	Medium	29.8	Lg. inc.	Lg. inc.	High	Rare	Good	Good	Infill ++	Infill ++	5
pignut hickory	Medium	12.6	Sm. inc.	Lg. inc.	Medium	Rare	Fair	Good	Infill +	Infill ++	5
hackberry	Medium	11.8	No change	No change	High	Rare	Fair	Fair	Infill +		5
boxelder	Low	4.2	Lg. inc.	Lg. inc.	High	Rare	Good	Good	Infill ++	Infill ++	5

6. Species with Infill +/Infill ++ or Likely +/Likely ++ in the SHIFT45 or SHIFT85 columns can be added back as potential candidates for planting, even if they were already listed in rules 1 through 3. Users should first filter on SHIFT45 and append any species with rules 1 or 2 with rule 6, then clear the filter and select species from SHIFT85 to append with rule 6. These species are present (rarely) or likely to be present (missed by FIA plots) in the area and the SHIFT model shows them to have the potential to expand (Infill + or Infill ++) within the next 100 years. In this case, five species are added back to the list for consideration: red pine, balsam fir, swamp white oak, shagbark hickory, and sweet birch (Likely present but rare).

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
red pine	Medium	207.5	Sm. dec.	No change	Low	Common	Poor	Poor	Infill +	Infill +	1,6
balsam fir	High	138.0	Sm. dec.	Sm. dec.	Low	Common	Poor	Poor	Infill +	Infill +	1,6
swamp white oak	Low	41.5	No change	No change	Medium	Rare	Poor	Poor	Infill +	Infill +	1,6
shagbark hickory	Medium	29.4	No change	No change	Medium	Rare	Poor	Poor	Infill +	Infill +	1,6
sweet birch	High	0	New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat	Likely +	Likely +	2,6

The 24 species from rule 5 and 5 species from rule 6 together represent the priority candidate list of species present now at or near the Lab. These species can be considered as priorities for management, provided that suitable forest types and site conditions exist for them on the property, but users are urged to remember that other species from rules 1 (20 species), 2 (2 species), and 3 (2 species) are options as well in certain situations.

Questions to ask of the list include the following. (These questions should be answered using local knowledge of site conditions and information on species abundance from the summary table. Modeled changes to suitable habitat, model reliability, migration potential, and capability scores should be considered to aid in selecting specific species to plant. These questions are intended to assist in the decision-making process.)

- Which species are already common at the Lab so that no planting is necessary (e.g., red maple)? In this case, the FIAsum column can be used to assess the current abundance within the region, and this value can be compared against estimates of abundance at the property (e.g., how closely does the species abundance or rank at the Lab match the overall conditions in the region?).
- Which species have a pest or pathogen threat that should take them out of contention (e.g., ashes with emerald ash borer or elms susceptible to Dutch elm disease)? Local knowledge will be useful to gauge individual species and regional trends, but information for the entire range of the species can be accessed at the MODFACs hyperlink on the individual species page. See details under “Basic Concept of Adaptability Scores” in section 1 and “Modification Factors and Adaptability Scores” in section 3 and the Forest Service [Silvics of North America](#).

- Which species are considered undesirable or “invasive” and no augmentation or encouragement is desired (e.g., black locust, considered invasive in New York)? Species that have been designated as NNIS by the USDA NRCS PLANTS Database are indicated in the summary table; however, some localities may have additional restrictions that may need to be considered.
- Which species are rare at the Lab but are ones that managers want to encourage to enhance biological diversity of woody plants (e.g., oaks and hickories)? A recent inventory of the property can be useful, but the summary table provides information for the surrounding area based on FIA surveys under the FIAsum column; data from the surveys have been classified under the Abund column.
- Which less-common species hold particular traits that managers want to encourage (e.g., white oak, for its hosting of many insects and other organisms to enhance biodiversity)? Local knowledge should be used to determine species and services that will be important to project objectives.
- Which species just do not have the habitat requirements present at the Lab (e.g., eastern hemlock)? Local knowledge of site conditions and habitat requirements should be used to determine which species will not have favorable habitat.
- Which species have local or southern seed sources available for planting? Local knowledge and availability of seed or nurse stock should be considered when selecting species.
- Which species have aesthetic, cultural, or other favored characteristics that managers wish to consider in the decision process? Or which species have undesirable traits that managers may want to avoid? In answering these questions, decision makers have the option to bring back any species previously eliminated (i.e., rules 1 through 3) should there be an inclination to do so.

Considerations for assisted migration

1. For species not currently known to be present in the region, but with potential to migrate within 100 years, we focus on the species noted as “New Habitat” in the Capabil45 or Capabil85 columns. These are species that are modeled to have newly suitable habitat in the future (under either low or high emissions). Initially, we select those species with a higher probability of naturally migrating (within 100 years) to the area of study. We do this by creating a subset of species with Migrate + or Migrate ++ in the SHIFT45 or SHIFT85 columns. Users should filter the SHIFT45 column for Migrate +, Migrate ++, or Blanks, then filter the SHIFT85 column for Migrate + or Migrate ++. In this case, 15 species are selected for the Lab and assigned to rule 7. Of these, nine species are indicated to potentially migrate into the region under low emissions (SHIFT45), and an additional six may migrate under high emissions (SHIFT85).

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
jack pine	Medium	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate ++	Migrate +	7
Virginia pine	High	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate +	7
mockernut hickory	Medium	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
flowering dogwood	Medium	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate +	7
black walnut	Low	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
sweetgum	High	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate ++	7
yellow-poplar	High	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat		Migrate +	7
blackgum	Medium	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
sycamore	Low	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
eastern cottonwood	Low	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
scarlet oak	Medium	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
pin oak	Low	0	New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7
chestnut oak	High	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat		Migrate +	7
black oak	High	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate ++	Migrate ++	7
sassafras	Low	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate +	7

2. Species showing “New Habitat” under Capabil45 or Capabil85 but having no probability of naturally migrating (within 100 years) to the area (blank under SHIFT45 and SHIFT85) are worth considering if managers have a special affinity or reason to experiment with the species. The models suggest the species could have suitable habitat in the region by 2100, but limited potential for natural migration. However, model reliability (MR) and local knowledge about these species (e.g., more confidence in the medium or high MR species than the poor MR species) should be considered. Users can filter Capabil45 for New Habitat and Unknown species, then SHIFT45 and SHIFT85 for blanks to assign 12 species to rule 8.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
cittamwood/gum bumelia	Low	0	Unknown	New Habitat	High	Absent	Unknown	New Habitat			8
pecan	Low	0	Unknown	New Habitat	Low	Absent	Unknown	New Habitat			8
black hickory	High	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat			8
sugarberry	Medium	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat			8
eastern redbud	Low	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat			8
common persimmon	Low	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat			8
honeylocust	Low	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat			8
northern pin oak	Medium	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat			8
shingle oak	Medium	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat			8
chinkapin oak	Medium	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat			8
Shumard oak	Low	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat			8
post oak	High	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat			8

3. From the 15 species selected in rule 7, a series of additional queries can further prioritize potential species. However, users are encouraged to consider the appropriateness of these species based on habitat, social, or other requirements. Users can start by filtering the Rule column for 7, then consider the following.

3a. If the species has Migrate ++ under SHIFT45, it has the highest potential to migrate into the region, even under the lower emissions scenario; thus, it may be the first priority if the species matches habitat requirements at the Lab. Users can filter SHIFT45 for Migrate ++ and append 9a to the rule. In this case, only jack pine and black oak are selected.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
jack pine	Medium		0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate ++	Migrate +	7,9a
black oak	High		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate ++	Migrate ++	7,9a

3b. If the species has Migrate + under SHIFT45 and Migrate + or Migrate ++ under SHIFT85, this may be the next level of priority, as the species may enter the region under either scenario of climate change within 100 years. Users should filter SHIFT45 for Migrate + and append 9b to the rule. Seven species match this criterion in this case study: mockernut hickory, black walnut, blackgum, sycamore, eastern cottonwood, scarlet oak, and pin oak.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
mockernut hickory	Medium		0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b
black walnut	Low		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b
blackgum	Medium		0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b
sycamore	Low		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b
eastern cottonwood	Low		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b
scarlet oak	Medium		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b
pin oak	Low		0 New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat	Migrate +	Migrate +	7,9b

3c. Next in priority may be those species that have Migrate ++ under only SHIFT85, suggesting the species have a high potential to naturally migrate into the region under the higher emissions scenario. Users should filter SHIFT85 for Migrate ++ and append 9c to the rule. In this case, only sweetgum meets the criterion.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
sweetgum	High		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate ++	7,9c

- 3d. Finally, those species with Migrate + under SHIFT85 (not SHIFT45) are those species with some potential to migrate into the region under the higher emissions scenario. Users should filter SHIFT85 for Migrate + and append 9d to the rule. Five species match this criterion: Virginia pine, flowering dogwood, yellow-poplar, chestnut oak, and sassafras.

Common Name	MR	FIAsum	ChngCl45	ChngCl85	Adap	Abund	Capabil45	Capabil85	SHIFT45	SHIFT85	Rule
Virginia pine	High		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate +	7,9d
flowering dogwood	Medium		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate +	7,9d
yellow-poplar	High		0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat		Migrate +	7,9d
chestnut oak	High		0 New Habitat	New Habitat	High	Absent	New Habitat	New Habitat		Migrate +	7,9d
sassafras	Low		0 New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat		Migrate +	7,9d

- 3e. As before, a careful scrutiny by managers is required to finally select species. Many other criteria are likely to be more important than this fine level of categorizing the “New Habitat” species. For example, the desire to plant several oak species on the site may have overriding influence in the manager’s decisions. Nonetheless, the level of assessment made possible by the process demonstrated here allows for extra support during the final decision process.

This systematic series of queries and categorization of species from the Tree Atlas summary for a geographic unit of interest represents the level of detailed information that can assist with forest management planning. However, decisions as to prioritization of species to plant and where to plant them should be made by local managers. It is beyond the scope of this guide to present the detailed reasoning behind all local decisions for priority, but some of the factors going into the decisions are as follows.

- What is the potential for the species to be impacted by pests or pathogens? In this study, all ash species were omitted due to the imminent threat of the emerald ash borer, which has been found in the region and can cause high rates of mortality. Similarly, American elm and slippery elm were excluded due to pressure from Dutch elm disease.
- How abundant is the species presently on site? Common species on the Lab property (Abund = “Common” in table) requiring no additional consideration need not be considered for planting. In this study, species such as red maple and seven others were removed from consideration for planting.

- What habitat characteristics best match the traits of potential species to be planted? Ecological and physiological traits of potential species can provide further information on the tree species to help with matching the specific habitats on the property. In this study, tree species were classified according to their tolerance of soil moisture (coefficient of wetness; Reznicek et al. 2014), shade tolerance, life span, and maximum height from the Tree Atlas Life History and Disturbance Response information, pH tolerance (Burns and Honkala 1990a, 1990b; Cornell University, n.d.), and blooming period (for angiosperms) (A. Iverson, n.d.; Eldblom and Johnson 2010; Lady Bird Johnson Wildflower Center 2021; Missouri Botanical Garden, n.d.; Smoak 2018; Sorensen 2011).

This set of criteria and traits provides an example to be considered for final prioritization, but any number of traits and local knowledge could be used to create the final list of species to consider for planting. The summary table, after scrutiny illustrated here for the Lab, provides a starting point for the creation of an adaptive management plan. Local managers therefore have an improved perspective on proactive management in the face of changing climate conditions.

It is important to emphasize that the Tree Atlas model outputs should be used in tandem with local forest management to maximum species–site matching and avoid planting in excess or with species that may become a nuisance. For the St. Lawrence Living Lab, this tree list with consideration rules for expanding or promoting and assisting with migration will provide a valuable resource for its future management. The combination of life history and preferred habitat conditions for each listed species will allow managers to precisely select trees for specific habitats.

Examples of How Tree Atlas Has Been Used

Climate Change Response Framework

The Climate Change Response Framework (CCRF; <https://forestadaptation.org>) facilitates collaboration among scientists, managers, and landowners to incorporate climate change strategies into natural resource management. The six-step approach developed and led by the [Northern Institute of Applied Climate Science](#) can be modified and applied to many locations and environments (Fig. 2).

Within the 20-state footprint of the Forest Service's Northern Research Station, the CCRF approach has been applied to several regions. Tree Atlas results were integrated into vulnerability assessment reports for eight ecoregions in the Midwest and northeast United States. Access to the reports associated with Tree Atlas version 3 is provided at <https://www.fs.usda.gov/nrs/atlas/products/>. Newer regional summary tables using Tree Atlas version 4 models are available from <https://www.fs.usda.gov/nrs/atlas/combined/resources/summaries/EVAS/>.

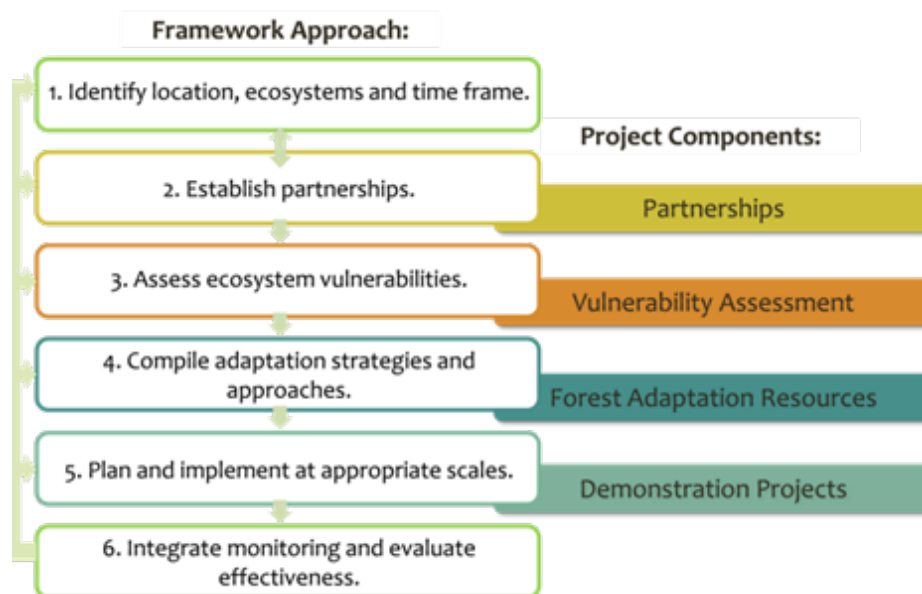


Figure 2.—Diagram of six-step approach used by the Climate Change Response Framework to promote collaboration for forest management. Reproduced from Swanston et al. (2016).

New England StoryMap

The Climate Change and Adaptation StoryMap (<https://usfs.maps.arcgis.com/apps/MapSeries/index.html?appid=a4babe8e2fe849739171e6824930459e>) provides background and key findings from the ecosystem vulnerability assessment and synthesis report for the forests of New England and northern New York (Janowiak et al. 2018). This regional report documents potential changes in climatic conditions and possible impacts to forests resulting from potential changes in habitat suitability for many tree species which are highlighted in the StoryMap. Information and maps of suitable habitat from the Tree Atlas for a few species are included in the StoryMap, along with 14 example projects that have used the Climate Change Response Framework described in the preceding two paragraphs.

Urban forestry applications

Though land-use and land cover information was not directly used to develop the habitat suitability and colonization likelihood models, the forest inventory data represent natural forest landscapes. Thus, these models are best suited for forested areas with low-intensity development. This does not preclude use of the models for urban settings but does require a certain approach to interpret the information. To provide a higher level of confidence when interpreting the models, we suggest that a minimum area of 8,000 sq. km (3,088 sq. miles) be used to summarize the model results. Some of the areas used to report the regional summary tables have been buffered to represent this minimum area. For the Urban Areas, this buffered area more appropriately reflects the surrounding forested land and the species composition, which may differ from the urban tree canopy.

Using the regional summary tables to select tree species for urban plantings may require additional considerations, such as availability of nursery stock, salt tolerance for locations that treat roads during winter, impacts of the urban heat island effect, and rooting characteristics, to name a few. Some traits like tolerance to drought, floods, and light may be less important if supplemental watering is provided, water diversion and collection are implemented, and competition is limited (Brandt et al. 2021). The habitat suitability models use species relative abundance, which could underestimate suitability of a species in urban settings when competition from other species and individuals is low compared to forested areas. Users are encouraged to review additional resources specific to urban forestry such as information provided in <https://www.fs.usda.gov/research/urbanfieldstations> and <https://forestadaptation.org/>. However, the overall information provided in the Climate Change Atlas can assist urban foresters by describing the forest composition of the surrounding landscape and presenting species that could gain newly suitable habitat by the end of the century. The regional summaries are not intended to provide answers, but rather to be a starting point for further analysis and consideration.

3. Science Behind the Atlas

Introduction

The Climate Change Atlas contains information related to the current and potential future distribution of eastern U.S. tree species. Because national inventories sample only a portion of the forested landscape, we rely on habitat suitability models to fill gaps and predict into future climates. A migration model is used to estimate probabilities of natural colonization into newly suitable habitats. These models cannot account for biological and disturbance factors, which have been incorporated into a scoring system to help modify how projected habitat suitability and migration likelihoods are interpreted. This section provides details about these models and the climate scenarios used in Tree Atlas version 4. This information has been published in several articles (see Further Reading) but is synthesized here for a more complete framework.

The Models

Current and future potential habitat suitability is modeled using a species distribution model called DISTRIB-II. These data are then combined with the model SHIFT to assess the colonization likelihood of newly suitable habitats and determine how far species would need to travel. Estimated distances are compared against historical rates of migration. Methods are also described in detail in the publications accessible from the Climate Change Atlas Publications [page](#).

DISTRIB-II—habitat suitability model

A species distribution model is used to map the current habitat suitability of tree species and then model potential habitat distributions (or habitat quality) under future climate scenarios. Tree Atlas version 4 includes modeled results for 125 tree species in the eastern United States. DISTRIB-II—uses the random forest statistical algorithm (Prasad et al. 2006), which uses an ensemble of regression trees to develop statistical relationships between the relative abundance of a species (i.e., importance value) and a suite of environmental predictor variables. Each regression tree is built with a subset of the training data and at each branch or node along the tree, a random sample of data records and eight of the predictor variables are used to assess the best correlation. The ensemble average is then used to represent the modeled relative abundance for the species. DISTRIB-II—uses a hybrid lattice of 10 km × 10 km and 20 km × 20 km grids determined by the density of forest inventory records (Fig. 3); previous versions used a uniform grid of 20 km. Species were modeled if at least 60 grid cells containing a minimum of 2 inventory plots were available, as previous efforts using fewer grids resulted in poorly performing models.

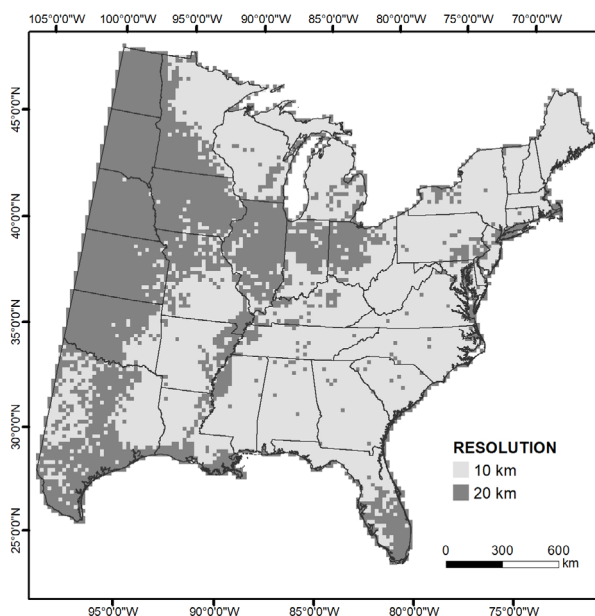


Figure 3.—Map of eastern United States showing locations of 10 km × 10 km and 20 km × 20 km grids.

Data

The DISTRIB-II—models include climate, elevation, and soil variables for 45 environmental predictors (Table 1). Individual tree species records from the Forest Service Forest Inventory and Analysis (FIA) database were processed to obtain importance values for each species during the period 2001 through 2016. For each species at an inventory plot, the number of stems (e.g., relative density) and basal area (e.g., relative dominance) are used to calculate an importance value or relative abundance among other species present. The number of individual trees of a species with a diameter of 5 inches (12.7 cm) or more at breast height (4.5 feet or 1.3 m) was divided by the total density or dominance of all species recorded at the inventory plot, multiplied by 50, and added together to calculate an importance value for a species that ranged from 0 to 100 , as shown in the following equation.

$$Importance\ Value_x = \left(50 \times \frac{basal\ area_{(x)}}{basal\ area_{(all\ species)}} \right) + \left(50 \times \frac{number\ of\ stems_{(x)}}{number\ of\ stems_{(all\ species)}} \right)$$

where x is a single species.

Thus, within a modeling cell, the importance value for a particular tree species (x) represents the relative abundance for its potential suitable habitat relative to all other species. Importance values from multiple inventory plots within modeling grids are averaged together.

Climate values for the period 1981 through 2010 were obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset and used to calculate annual and growing season (May through September) precipitation, mean annual and mean growing season temperature, monthly mean temperature of the coldest and warmest months, and an annual aridity index (Table 1).

Table 1.—Environmental data used to predict habitat suitability of eastern U.S. tree species. Data were either aggregated to 10 km × 10 km and 20 km × 20 km grids or derived from aggregated data. Table from Peters et al. (2019).

Category	Variable	Description	Native resolution
Climate ¹	[PANN] Annual precipitation	Mean 30-year (1981 through 2010) monthly precipitation (mm)	800 m
Climate ¹	[PGrow] May through September precipitation	Mean 30-year (1981 through 2010) monthly precipitation for May through September (mm)	800 m
Climate ¹	[TANN] Annual mean temperature	Mean 30-year (1981 through 2010) monthly temperature (°C)	800 m
Climate ¹	[TGrow] May-Sept. mean temperature	Mean 30-year (1981 through 2010) monthly temperature for May through September (°C)	800 m
Climate ¹	[TWINavg] Mean temperature of coldest month	Mean 30-year (1981 through 2010) monthly temperature of coldest month (°C)	800 m
Climate ¹	[TSUMavg] Mean temperature of warmest month	Mean 30-year (1981 through 2010) monthly temperature of warmest month (°C)	800 m
Climate ¹	[Aridity] Aridity Index ²	A conditional ratio of precipitation and Thornthwaite potential evapotranspiration (see Koch et al. 2013)	10 and 20 km
Elevation ³	[ElvMIN] Minimum	Minimum value	90 m
Elevation ³	[ElvMEAN] Mean	Mean value	90 m
Elevation ³	[ElvMAX] Maximum	Maximum value	90 m
Elevation ³	[ElvMEDIAN] Median	Median value	90 m
Elevation ³	[ElvMIN] Range	Range between minimum and maximum values	90 m
Elevation ³	[ElvStdDev] Standard deviation	Amount of deviance among elevation	90 m
Elevation ³	[ElvCV] Coefficient of variation	The coefficient of variation of elevation	90 m
Solar ⁴	[DayLenCV] Day length coefficient of variation	The coefficient of variation of 12 monthly day lengths derived from the latitude of grid cells	10 and 20 km
Soil ⁵	[AWC] Available water capacity	The quantity of water that the soil is capable of storing for use by plants (cm)	30 m
Soil ⁵	[AWS] Available water supply (cm)	The total volume of water that should be available to plants when the soil, inclusive of rock fragments, is at field capacity (cm)	30 m
Soil ⁵	[BD3RDBAR] Bulk density (g/cm ³)	The oven-dry weight of the soil material <2 mm in size per unit volume of soil at water tension of 1/3 bar (g/cm ³)	30 m
Soil ⁵	[CACO3] Calcium carbonate	The percentage of carbonates, by weight, in the fraction of the soil <2 mm in size	30 m
Soil ⁵	[CEC7] Cation-exchange capacity	The total amount of extractable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH	30 m
Soil ⁵	[DEP2WATTBL] Depth to water table	Depth to a saturated zone in the soil (cm)	30 m
Soil ⁵	[KSAT] Permeability	Saturated hydraulic conductivity or the ease with which pores in a saturated soil transmit water (cm/hr)	30 m
Soil ⁵	[KFACTRF] Erosion K factor	The susceptibility of a soil to sheet and rill erosion by water estimated by percentage of silt, sand, and organic matter and dependent on soil structure and saturated hydraulic conductivity	30 m

Continued on next page

Table 1 (continued).

Category	Variable	Description	Native resolution
Soil ⁵	[TFACTOR] Erosion T factor	An estimate of the maximum average annual rate of soil erosion by wind or water (or both) that can occur without affecting crop productivity over a sustained period (tons/acre/year)	30 m
Soil ⁵	[CLAY] Percent clay	The fraction of mineral soil particles that are <0.002 mm in diameter	30 m
Soil ⁵	[SAND] Percent sand	The fraction of mineral soil particles that are 0.05 to 2 mm in diameter	30 m
Soil ⁵	[SILT] Percent silt	The fraction of mineral soil particles that are 0.002 to 0.05 mm in diameter	30 m
Soil ⁵	[OM] Organic matter content (% by weight)	Plant and animal residue in soil material <2 mm in diameter at various stages of decomposition	30 m
Soil ⁵	[PH] pH	A measure of acidity or alkalinity	30 m
Soil ⁵	[SIEVE10] Percent passing sieve No. 10	Soil fraction passing a number 10 sieve (2.00 mm square opening)	30 m
Soil ⁵	[SIEVE200] Percent passing sieve No. 200	Soil fraction passing a number 200 sieve (0.074 mm square opening)	30 m
Soil ⁵	[SProd] Soil productivity ⁶	Productivity Index derived from family-level soil taxonomy information	30 m
Soil ⁵	Soil taxonomic order	The percentage of each of nine taxonomic orders: Alfisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Spodosols, Ultisols, and Vertisols	30 m
Soil ⁵	Soil texture	The percentage of texture class as defined by USDA standard terms: clayey, loamy, sandy, or other	30 m

¹ PRISM Climate Group (2014).

² Koch et al. (2013).

³ Farr et al. (2007).

⁴ Forsythe et al. (1995).

⁵ Soil Survey Staff (2016).

⁶ Schaetzl et al. (2012).

Projected climate values for the period 2070 through 2099 were obtained from the NASA Earth Exchange Downscaled Climate Projection dataset (Thrasher et al. 2013) for three general circulation models (GCMs; CCSM4, GFDL CM3, and HadGEM2-ES) and two representative concentration pathways (RCPs; RCP 4.5—low emissions and RCP 8.5—high emissions) to define the upper and lower bounds of potential climate change (Fig. 4). Details for the GCMs and RCPs are provided under “Future Climate Scenarios” in this section. The amount of projected change (deltas) between the GCM simulated historical period (1981 through 2010) and the future period (2070 through 2099) was calculated and used to adjust PRISM data to create a consistent baseline dataset among each GCM and RCP scenario. Values for each of the climate variables were then aggregated to 10 and 20 km² grids. See Future Climate Scenarios for additional details. Elevation values obtained at 3 arc-seconds (about 295 feet or 90 m) were processed to derive the minimum, maximum, mean, median, range, standard deviation, and coefficient of variation for each 10 km × 10 km and 20 km × 20 km grid among the lattice (Table 1).

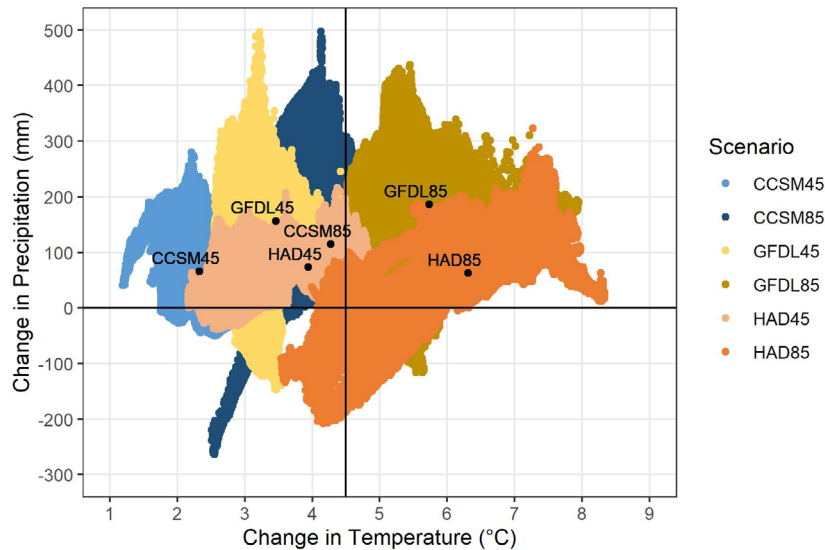


Figure 4.—Projected changes in annual precipitation and mean annual temperature under the six climate scenarios for the eastern United States. Figure from Iverson et al. (2019a).

Soil characteristics and properties from the USDA Natural Resources Conservation Service gridded County Soil Geographic (gSSURGO) database including soil available water capacity, available water supply, bulk density, percent calcium carbonate, cation exchange capacity, depth to water table, permeability, erosion K and T factors, percentage of clay, sand, and silt, organic matter content, pH, percent passing sieves 10 and 200, and percentage of soil taxonomic order and texture classes were aggregated to the hybrid lattice (Table 1). A soil productivity index derived from family-level soil taxonomy information was also included as a predictor variable.

Assumptions and limitations

Species relative abundance is used to represent habitat suitability by correlating combinations of environmental conditions with current species abundance. However, modeled habitat suitability indicates conditions that are favorable for the species to occur in varying amounts of abundance. Our models do not include site conditions such as competition, disturbances, and land use, each of which can influence species occurrence at local scales. Additionally, our models do not include events and phenomena related to disturbances, which are difficult to include in correlative models, partly due to a lack of available and consistent information.

Habitat suitability models require information about species occurrence, which are often provided by national surveys such as those conducted by the FIA program. The density of FIA survey locations varies across the landscape, as a result of state-supplemented inventories. This uneven distribution of survey plots and the randomized location of plots within the forested landscape can exclude large areas, resulting in underrepresentation

of some species in the survey. Examples include riparian or lowland species, which may be concentrated in relatively small forested areas in an otherwise unforested landscape. Absence of a species within the inventory data does not necessarily equate to a site being unsuitable for the species, and modeled habitat suitability can provide information for these unsampled areas.

The models and information provided by the Tree Atlas attempt to represent broad macro-level trends of habitat suitability for a species. The spatial density of FIA records does not permit the DISTRIB-II models to be implemented at the fine-scale resolutions at which local forest managers operate. Interpretation of habitat suitability and colonization likelihoods should consider the local land use, forest fragmentation, and influence of site conditions in the context of the broader landscape represented by the modeling grids.

The random forest algorithm generates many regression trees; at each split (node) along the tree the average value of a random subset of the training records is used. Therefore, the predicted values tend to be lower due to modeling mean values. To limit predictions of low values or values influenced by outliers, the DISTRIB-II models used the median value when the median of 1,001 regression trees equaled 0 and the coefficient of variation among all mean values was 2.75 or greater ([Peters et al. 2019](#)).

Model performance is assessed for each species and indicated as high, medium, or low for the entire eastern United States. While habitat suitability values are available for each of the 29,357 cells in the hybrid lattice, we prefer to interpret and analyze modeled values aggregated to a minimum area of 8,000 sq. km (3,088 sq. miles), which is often slightly larger due to the iterative buffering. This reduces the potential for a few outlier predicted values to skew the general trend of habitat suitability. Therefore, when examining regional summaries or maps, especially for smaller regions, considering the broader landscape provides additional context for the modeled results. In this way, the focus is not too local, where site conditions can deviate from those used to model habitat suitability.

SHIFT—colonization likelihood model

The SHIFT model computes colonization likelihoods (CLs) for each 1-km² cell using an inverse-distance migration model that captures both short- and long-distance migrations based on current abundance, historical migration rates, current habitat fragmentation, and a search window distance function ([Prasad et al. 2013, 2020](#); [Schwartz 1992](#)).

The likelihood of an unoccupied cell becoming colonized by a particular species during each generation is a function of the abundance of that species in the surrounding cells, the habitat quality of the unoccupied cell (which must have at least 10 percent forest cover to ensure that it is a habitable cell), and a search window distance function. The calibration constant was chosen to achieve an approximate migration rate of 50 km per century by simulating multiple rates from 10 to 150 km (6 to 93 miles) per century. The colonization likelihood for each unoccupied cell is calculated by summing over all occupied cells at each generation. The stochastic nature of the tail of the long-distance migration is simulated by drawing a random number from an even distribution and comparing it with the calculated likelihood to determine whether the cell gets colonized. Simulation for multiple species was made feasible by using convolution and Fast Fourier Transforms to keep the computation time to a minimum ([Prasad et al. 2013](#)). We use an optimistic, but

historically defensible, migration rate of 50 km per century for all species and a generous search window of 500 km (311 miles) to accommodate stochastic long-distance dispersals as the limit for migration within each generation.

A recent improvement to this model (cf. [Prasad et al. 2013](#)) involved relaxing the requirement for a rigid source–sink boundary along the migration front by allowing the species to opportunistically colonize suitable cells throughout the current range of the species. This produces a more realistic migration scenario, where colonization can happen within the gaps in the current distribution (infilling or interpolating) as well as at range boundaries (migrating or outfilling). Each species is allowed to migrate based on current distribution and generation time for approximately 100 years to match the DISTRIB-II model outputs of future suitable habitats. This ensures that despite having a common migration rate, the landscape is colonized based on individualistic species responses, and ensures that outputs from DISTRIB-II (HQ) can be combined with outputs from SHIFT (CLs) (Fig. 5). The number of generations (model iterations) required to simulate roughly 100 years of migration varies among species depending on their generation time. For example, for purposes of our models, sugar maple requires about 33 years per generation—that is, time to maturity (3 generations in 100 years)—and newly colonized cells can only contribute to colonization in the next generation after the propagules have time to mature. For more details on the migration model, see [Prasad et al. 2013](#) and [Schwartz et al. 2001](#).

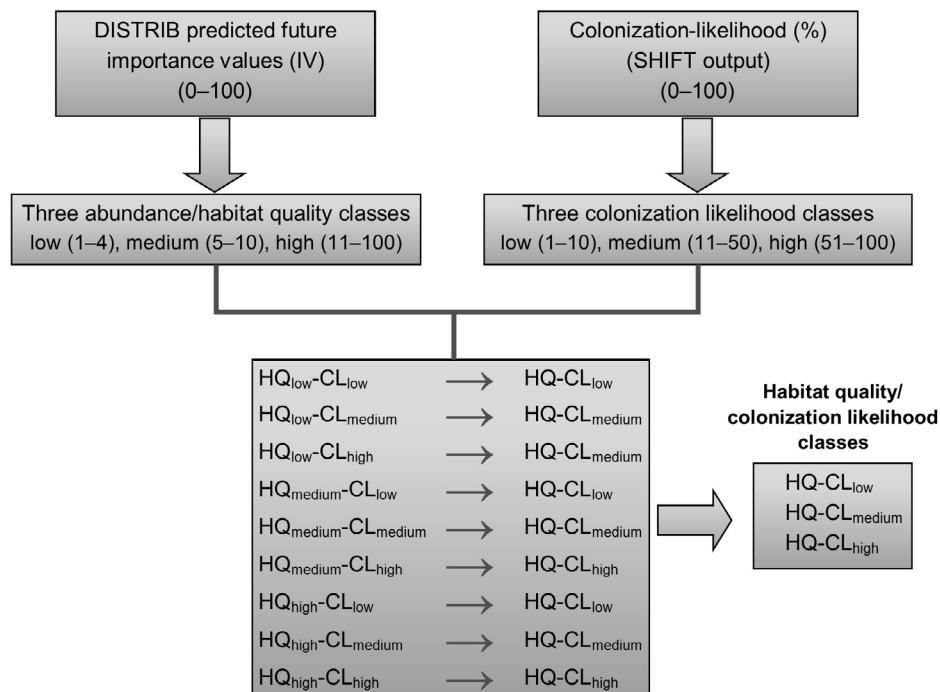


Figure 5.—Reclassification scheme to convert DISTRIB-II and SHIFT numeric values into categorical values of low, medium, and high. Habitat quality (HQ) indicates future suitable habitat, which is combined with colonization likelihoods (CLs) to indicate which newly suitable habitats species could naturally migrate to. Figure from Prasad et al. (2016).

Data

To calculate the percent forest within “occupiable” cells (which SHIFT uses to calculate species CL), we used the 2006 National Land Cover Database to determine percent forest cover within the 1-km² grids. Information for generation times of individual species, or the period of time until a species is reproductively mature, was obtained from the Forest Service [Silvics of North America](#).

Assumptions and limitations

We make the following assumptions with the SHIFT model.

- We assume an optimistic migration rate of 50 km per century (31 miles per century) and a generous search window of 500 km (310 miles) for stochastic long-distance dispersal for all species. We deliberately chose not to parameterize individual species migration rates based on dispersal type owing to large uncertainties in life histories and dispersal patterns among the tree species ([Iverson et al. 2004](#)).
- We assume that the colonized species overcomes competitive exclusion and generates propagules for the next generation—this assumption is necessary because the data and computation required to test establishment and reproduction are beyond the scope of our model.
- Local ecological population dynamics that occur within 1-km² (0.4 sq. mile) patches are ignored, as data for these dynamics are not available throughout the range of the species.
- We assume that there are no climatic constraints to migration.

Modification Factors and Adaptability Scores

The DISTRIB-II and SHIFT models provide important information on where species could be found and how species may migrate to newly suitable habitats under climate scenarios. However, these models cannot account for biological and disturbance factors that may enable a species to persist or cope in habitats affected by a changing climate. Therefore, we conducted a literature review of relevant life-history factors and developed a scoring system that rates the effect of 9 biological and 12 disturbance factors, collectively called Modification Factors (MODFACs) (Table 2). Our scoring system also assesses uncertainty of the information and future relevance. Information was obtained from the USDA NRCS [PLANTS Database](#) (USDA NRCS 2021), the Forest Service [Silvics of North America](#) (Burns and Honkala 1990a, 1990b), and the Forest Service Fire Effects Information System (Zouhar 2015) to rate each factor. Ratings considered the entire range of a species, although regional conditions and disturbances can vary, becoming more or less favorable. Forest managers and other users can use local and regional expertise to modify the tabular scoring system to obtain more relevant or customized outputs and inform management decisions.

Information from the individual Modification Factors is combined into a single adaptability score to aid decision making related to model interpretation and the potential impacts of climate change. The adaptability score can also be used to compare relative adaptive capacities among species. Species with similar Adaptability ratings may have similar capacities within a region, while species with diverging values will have opposite capacities. For example, red maple is rated with a high adaptability score of 8.5, while balsam fir is rated low, indicating that each species may perform better and worse, respectively, than what the models suggest.

Future Climate Scenarios

We used a range of models and scenarios to capture projections of future temperature and precipitation. Values projected by three general circulation models (GCMs) and two representative concentration pathways (RCPs) were used to provide six scenarios. Across the entire eastern United States, annual temperature is projected to increase by 2.5 °C (4.5 °F) with CCSM under RCP 4.5 (CCSM45) to 6.5 °C (11.7 °F) with HadGEM2-ES under RCP 8.5 (HAD85), with an overall mean increase of 4.5 °C (8.1 °F), by 2100. The potential change in precipitation was higher for all scenarios by end of century, but for many locations, a reduction in future precipitation is projected (note that Figure 3 points below the horizontal 0 change line), especially for HAD85 and GFDL85.

Table 2.—Modification Factor descriptions and codes

Biological factors	Code	Disturbance factors	Code
Carbon dioxide (CO ₂) and productivity (PRD)	CPR	Browse	BRO
CO ₂ and water use efficiency (WUE)	CWU	Disease	DISE
Dispersal	DISP	Drought	DRO
Edaphic specificity	ESP	Fire topkill	FTK
Environmental habitat specificity	EHS	Flood	FLO
Fire regeneration	FRG	Harvest	HAR
Seedling establishment	SES	Ice	ICE
Shade tolerance (competition-light)	COL	Insect pests	INS
Vegetative reproduction	VRE	Invasive plants	INP
		Pollution	POL
		Temperature gradients	TGR
		Wind	WIN

Greenhouse gas scenarios

DISTRIB-II and SHIFT use two scenarios of future greenhouse gas (GHG) concentrations included in the Intergovernmental Panel on Climate Change (IPCC) [Fifth Assessment Report](#) (IPCC 2014): RCP 4.5 and RCP 8.5. These pathways help contrast possible climate futures, which depend on the amount of greenhouse gases emitted in the years to come.

- RCP 4.5 projects 4.5 watts per sq. meter with about 650 ppm carbon dioxide (CO₂) equivalent by 2100. This scenario assumes that efforts to significantly reduce CO₂ and other GHG emissions will occur to stabilize atmospheric concentrations by mid-century and decline to 2100.
- RCP 8.5 projects 8.5 watts per sq. meter with about 1,370 ppm CO₂ equivalent by 2100. This scenario assumes steady increases of GHG emissions through the century.

These two RCPs bracket most of the future emissions as outlined by the IPCC's evaluation of emissions scenarios. These RCPs result in peak GHG emissions at roughly double (650 ppm–RCP 4.5) and quadruple (1,370 ppm–RCP 8.5) the preindustrial levels for CO₂ (about 300 ppm, excluding non-CO₂ emissions). We also averaged the habitat suitability outputs of the three GCM models for each RCP scenario to yield suitable habitat under an average high and average low set of conditions.

Climate models

Climate projections during this century are generated by numerical models of various physical processes that regulate temperature and precipitation. There are several groups that have developed and maintain these GCMs and we have chosen three—CCSM4 (Gent et al. 2011), GFDL CM3 (Donner et al. 2011), and HadGEM2-ES (Collins et al. 2011, Jones et al. 2011)—to represent a variety of future conditions (e.g., warm-dry or hot-wet) rather than using an ensemble average (Table 3). GCMs produce climate projections at very coarse spatial resolutions, about 2 degrees latitude and longitude, for computational efficiency. These coarse values are not very informative to models with finer resolutions, such as species distribution models; thus, many GCMs have been statistically downscaled to resolutions of 800 m to about 12 km (0.5 to 7.4 miles) using gridded observations. The NASA Earth Exchange Downscaled Climate Projections (Thrasher et al. 2013) have a resolution of 800 m and, to remove bias among the GCM values, the amount of projected change (deltas) between the GCM simulated historical period (1981 through 2010) and the future period (2070 through 2099) was calculated and used to adjust the baseline climate data.

Table 3.—Average climate conditions in the eastern United States currently (1981–2010) and for the three models (CCSM4, GFDL CM3, and HadGEM2-ES) under representative concentration pathways (RCPs) 4.5 and 8.5 in the future (2070–2099). Table adapted from Iverson et al. (2019a).

Variable	Current climate	Climate scenario: CCSM4 under RCP 4.5	Climate scenario: CCSM4 under RCP 8.5	Climate scenario: GFDL CM3 under RCP 4.5	Climate scenario: GFDL CM3 under RCP 8.5	Climate scenario: HadGEM2-ES under RCP 4.5	Climate scenario: HadGEM2-ES under RCP 8.5
Annual precipitation (mm)	1048.0	1113.0	1162.0	1203.0	1233.0	1121.0	1110.0
May–September precipitation (mm)	509.0	527.0	519.0	573.0	585.0	504.0	457.0
Mean annual temperature (°C)	12.7	15.2	17.1	16.3	18.6	16.8	19.2
Mean May–September temperature (°C)	21.6	24.0	26.3	26.0	28.4	25.7	28.4
Mean temperature of warmest month (°C)	24.8	26.6	28.1	28.1	29.7	28.0	29.9
Mean temperature of coldest month (°C)	-0.9	1.2	2.1	1.6	2.0	1.3	3.3
Absolute minimum temperature (°C)	-11.3	-8.6	-6.5	-7.2	-5.7	-7.4	-4.0
Absolute maximum temperature (°C)	33.8	35.9	39.3	39.1	42.5	38.5	41.9

Further Reading

This section provides the suggested citation for the online Climate Change Tree Atlas. We ask that users cite the Climate Change Atlas when using any information in publications, presentations, or other research products. We also recommend reading the listed literature related to the habitat suitability model, colonization likelihood model, and species adaptability scores to learn more about the models and information.

How to cite the Atlas

Peters, M.P.; Prasad, A.M.; Matthews, S.N.; Iverson, L.R. 2020. **Climate Change Tree Atlas, version 4**. Delaware, OH: U.S. Department of Agriculture, Forest Service, Northern Research Station and Northern Institute of Applied Climate Science. <https://www.fs.usda.gov/nrs/atlas> (last date of access).

Habitat suitability model publications

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4. Frequently Asked Questions

I don't see the species I'm interested in.

Currently, we have modeled potential suitable habitat for 125 tree species east of the 100th meridian, using forest inventory data and 45 environmental variables. Other species are present within the eastern United States, but there are insufficient data to accurately model these species under current and future conditions. Additionally, we provide relative abundance for 23 species which we were unable to model but were reported by recent forest inventory data.

How realistic are the DISTRIB-II models?

DISTRIB-II uses the statistical learning algorithm of random forest to correlate 45 environmental predictors across the eastern United States with tree species importance values (IVs) derived from forest inventory data. Because we use many predictor variables other than the seven climate variables, DISTRIB-II is not a “climate envelope model” but could be referred to as a “realized-niche model.”

All statistical models lack the capability to include various disturbance and biological features of the species being modeled and assume that the species is in equilibrium with its environment. It is also assumed that the species has integrated those other features over a long time (e.g., capacity to withstand drought, ice storms, competition) to allow the species to survive in particular places.

How reliable is a model with low model reliability?

We assign model reliability as high, medium, and low based on five performance metrics (see [Peters et al. 2019](#) for details). Species with low model reliability have poor prediction performance due to low model fit (equivalent of R-squared).

Often poor models are the result of low sampling abundance within the forest inventory data. Poor model outputs also may occur if the species is relatively rare or occupies a small geographic area. For these species, the surveyed distribution does not allow DISTRIB-II to accurately predict suitable habitat. The results from low-model reliability should be used with extreme caution.

Where are the forest type maps corresponding to version 4 of the Tree Atlas?

Efforts are under way to evaluate the methods previously used to define and classify suitable habitat for individual species. Development of a new method is being explored; see [Peters et al. 2022](#).

Are the geographic information systems (GIS) data used to create the maps in the atlas available for my own use?

We provide maps of importance values derived from the current forest inventory and modeled under current and future climates for each of the 125 species for which we were able to model suitable habitat, as well as the current forest inventory data for 23 species we were unable to model. These shapefiles are available at <https://www.fs.usda.gov/rds/archive/catalog/RDS-2019-0029>.

Why are the models confined to the eastern United States?

Ecosystems do not follow political boundaries, so it seems odd for ecosystem models to use these boundaries. However, datasets generated by various agencies and governments often do not use the same methods for sampling or definitions for reporting.

For reasons related to data incompatibility between the USDA Forest Service Forest Inventory and Analysis data and the Canadian equivalent, our model outputs reported here do not extend north of the border between the United States and Canada. Nor have we ventured west of the 100th meridian because other groups had been actively modeling this region. However, efforts are under way to expand the scope of our models to the western United States as well as into Canada. Please stay tuned!

Can I view results for multiple species?

It would be difficult to visualize mapped modeled results for multiple species, but we have summarized information for various regions (state, national forests, national parks, six-digit hydrologic unit code [HUC6] watersheds, 1 degree × 1 degree of latitude and longitude), pertaining to the current and potential future changes to suitable habitats, adaptability, capability, and colonization likelihoods for species currently present or modeled to have suitable habitat now and into the future. See “Individual Species Pages” in section 1.

What is the smallest area that should be used for analysis or interpretation?

We recommend that the average size of 1 degree × 1 degree grids or at least 8,000 sq. km (3,088 sq. miles) (about the size of [Beltrami County](#) in Minnesota) be considered when interpreting the model outputs. This area, when averaged, will allow reasonable confidence in the outputs, helping to ensure that spurious model outliers are not driving the results. Summaries of combined species outputs for areas less than 8,000 sq. km have been buffered to the minimum area, but are often slightly larger through an iterative process.

How can the models be applied to urban forests?

Land-use information is not directly used in our models; however, forest inventory data require the sampling area to contain at least 10 percent forest cover. Additionally, we aggregate forest inventory records into modeling grids of 10 km × 10 km and 20 km × 20 km which contain a mixture of land uses. For the regional summary tables, information is obtained from a minimum area of 8,000 sq. km to provide a higher level of confidence. Therefore, summaries for urban areas are likely to reflect the surrounding forested land and the species composition, which may differ from the urban tree canopy. More details are provided under “Urban Forestry Applications” in section 2.

5. Essential Concepts

Information contained in the Climate Change Atlas references models, modeling techniques, and terminology that can have different meanings when applied to other sectors. The following subsections define common terms referenced in the Atlas.

Species Distribution Model (SDM)

Species distribution models are a type of computer model that predicts a species distribution in geographic space using environmental information. There are two primary types of SDMs: statistical models, which correlate environmental predictors to a response variable, and process-based models, which use biophysiological information about a species to estimate population dynamics (establishment, growth, reproduction, dispersal, mortality) under environmental conditions. An SDM is also referred to as an environmental niche model or habitat suitability model.

DISTRIB-II

DISTRIB-II is an empirical statistical modeling framework that uses machine learning algorithms (e.g., random forest) to predict values based on updated training data and a hybrid grid approach. We use DISTRIB-II to model the potential distribution of suitable habitat for 125 tree species under current and future climate conditions. More details about the modeling methods are found in Further Reading in section 3.

SHIFT

SHIFT is a spatially explicit cell-based simulation model that considers current abundance of the species, landscape fragmentation, and historical migration rates to compute the likelihood of colonization in approximately 100 years depending on the generation time of the species (i.e., years to seed production maturity). When combined with DISTRIB-II, it estimates the colonization likelihood of future suitable habitats. This allows us to examine the extent of newly suitable habitat beyond the current range boundary of a species, in addition to the gaps within the current species boundaries that could be colonized by a species.

Adaptability

Outputs from DISTRIB-II do not consider many biological or disturbance factors which favor or limit tree establishment, growth, or mortality. We have scored each species by 12 disturbance factors and 9 biological factors, collectively called Modification Factors (MODFACs). These factors are based on information obtained from the literature (USDA Natural Resources Conservation Service [PLANTS Database](#) [USDA NRCS 2021], Forest Service [Silvics of North America](#) [Burns and Honkala 1990a, 1990b], Forest Service Fire Effects Information System [Zouhar 2015]), to help interpret DISTRIB-II models.

For example, the life history characteristics of red maple allow it to thrive under most conditions, and this species is likely to do better under climate change than the outputs of the DISTRIB-II models suggest.

The Adaptability variable is a single score derived from the Modification Factors and is one way to locally integrate our models into management decisions.

Current

The term “current” is relative and can refer to different periods of time among various variables included in the Tree Atlas.

Climate: we use “current” to refer to the 30-year period of climate (1981 through 2010) used as a baseline.

Forest inventory: we used the most recently completed inventory cycle from each state during the period 2000 through 2016 to represent trends in species abundance.

Suitable habitat: modeled habitat suitability for a species under the baseline climate conditions.

Future

The term “future” refers to a period of time in which our models attempt to forecast potential suitable habitat based on estimated climate projections for 2070 through 2099. In our habitat suitability models, the nonclimate environmental variables, such as elevation and soils, are assumed to remain constant into the future.

Weather vs. Climate

The major difference between “weather” and “climate” is the measure of time. “Weather” refers to events that occur over a short period of time (i.e., hours, days, weeks), while climate refers to trends (average weather) over a longer period (i.e., months, years, decades). Our models use average climate values for a 30-year period.

General Circulation Model (GCM)

A general circulation model is a complex mathematical model parameterized with information about the atmosphere, Earth, and oceans to simulate hourly or daily climatic conditions. General circulation models are run for a length of time prior to the period of future simulations in order to assess the accuracy of known events. The Intergovernmental Panel on Climate Change (IPCC) has incorporated results from many GCMs into its assessments. Each GCM differs in the sensitivity of climate to respond to various levels of CO₂ in the atmosphere. We present the results for three GCMs obtained from NASA Earth Exchange Downscaled Climate Projections. More information on the GCMs we used can be found under “CCSM4, GFDL CM3, and HadGem2-ES Models” later in this section.

General Circulation Model (GCM) vs. Representative Concentration Pathways (RCPs)

General circulation models simulate climatic conditions based on information related to the atmosphere, Earth, and ocean, whereas RCP scenarios provide information about global populations, greenhouse gas emissions, socioeconomic interactions, technological advances, land use, conservation efforts, and other aspects which could influence conditions that affect climate within the GCM. The RCPs were developed by various groups and the IPCC chose four that provide unique trajectories through the century (Moss et al. 2008). The combination of GCM and RCP scenario dictates the climate conditions predicted into the future.

Representative Concentration Pathway (RCP) Scenarios 4.5 and 8.5

Of the various RCP scenarios included in the IPCC Fifth Assessment Report (IPCC 2013), scenarios 4.5 and 8.5 represent the lower and upper bounds of greenhouse gas (GHG) emissions levels, respectively.

RCP 4.5 projects that GHG emissions peak at about 650 ppm of CO₂ equivalents mid-century and are substantially reduced due to technological advances and conservation efforts, resulting in 4.5 watts per sq. m of radiative forcing or increases of 1.1 to 2.6 °C (2.0 to 4.7 °F) globally by 2081 through 2100 relative to 1986 through 2005.

RCP 8.5 assumes the current GHG emissions trends continue, resulting in a quadrupling of CO₂ equivalent (1,370 ppm) by the end of the century and increases of 2.6 to 4.8 °C (4.7 to 8.6 °F) globally.

CCSM4, GFDL CM3, and HadGEM2-ES Models

These three GCMs represent a wide range in sensitivity to CO₂ in the atmosphere. Each has been run with RCP 4.5 and 8.5 GHG emissions and downscaled with a consistent approach. Thus, the combinations of GCMs and RCPs are intended to provide a realistic range of possibilities for changes in suitable habitat.

In particular, averaged across the eastern United States, the HadGEM2-ES and RCP 8.5 combination projects the greatest increase in mean annual temperatures (6.3 °C or 11.4 °F), while the CCSM4 and RCP 4.5 combination projects the least change in mean annual temperatures (2.3 °C or 4.2 °F).

Similarly, the GFDL CM3 and RCP 8.5 combination projects the greatest increase in annual precipitation (18.6 mm or 0.7 inch), while the HadGEM2-ES and RCP 8.5 combination projects the smallest increase of 6.2 mm or 0.2 inch annually.

Locally and among regions within the eastern United States, the end-of-century projected changes will vary in the amount of change (positively or negatively) as will the interannual variability.

Importance Values (IVs)

Forest Inventory and Analysis records from more than 84,000 plots surveyed during 2000 through 2016 were used to calculate importance values (IVs) for 148 tree species in the eastern United States. For each species at an inventory plot, the number of stems (e.g., relative density) and basal area (e.g., relative dominance) are used to calculate an importance value or relative abundance among other species present. The total for individual tree species with a diameter of 5 inches (12.7 cm) or more at breast height (4.5 feet or 1.3 m) was divided by the total density or dominance of all species recorded at the inventory plot, multiplied by 50, and added together to calculate an importance value for a species that ranged from 0 to 100, as shown in the following equation.

$$Importance\ Value_x = \left(50 \times \frac{basal\ area_{(x)}}{basal\ area_{(all\ species)}} \right) + \left(50 \times \frac{number\ of\ stems_{(x)}}{number\ of\ stems_{(all\ species)}} \right)$$

Little's Range

Elbert L. Little developed range boundaries for many tree species across North America and published these ranges in a series of atlases during the 1970s. The ranges defined by Little used data from field surveys, herbarium records, and expert knowledge to delineate boundaries to encompass the natural distribution of a tree species. We use “Little’s Boundaries” in many of the maps represented here as one estimate of the range boundary for the species. Even though these boundary estimates are now rather old, these data remain the primary estimate of range boundaries for the trees of North America.

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