BULLETIN

Modeling Future Forests

APRIL 28, 2016 / BY JENNIFER HUSHAW

Understanding how forests responded to past changes in the Earth's climate has been a long-standing area of research, but in recent years there has also been growing interest in anticipating how modern climate change may lead to shifts in tree species abundance and distribution. Of course, climate is just one of many factors that determine why trees grow where they grow, including soils, competition, land-use history, and synergistic relationships with other species, e.g. seed dispersers. Partly as a result of this complexity, there is a lot of uncertainty in the results of vegetation models that estimate future habitat suitability or distribution of tree species.

> There is limited evidence of range shifts in response to climate change so far, but research suggests some tree species migrated at a rate of 1-10 km/decade in response to warming at the end of the last ice age (Pearson 2006; Iverson & McKenzie 2014), which was, notably, a far more gradual warming than today. If this represents maximum migration speed for many species, especially if reality is on the slower end of estimates, most species won't be able to match the velocity of current climate change, since the average speed required to keep pace with temperature is estimated to be 3.5, 1.1, and 4.3 km/decade for temperate broadleaf/mixed forests, temperate coniferous forests, and boreal forests/taiga, respectively. Mountainous biomes require the slowest velocities because in these areas small movements in space result in large changes in temperature. (Loarie et al 2009)

Two things we can say for sure are that (1) tree species will respond independently to changing conditions, so we may see novel species associations and forest types in some locations in the future and (2) there will be significant time lags in forest response (see box, right).

In this bulletin, we briefly review several modeling efforts and how they compare, as well as highlighting potential limitations and best practices for utilizing the results.

Vegetation Models: An Overview

The vegetation models used to assess potential tree species shifts can be broadly sorted into two categories on either end of a spectrum, from empirical (i.e. statistical) to process-based (i.e. mechanistic) models.

Empirical models quantify statistical relationships between species occurrence data, such as plot data from the US Forest Service Forest Inventory and Analysis (FIA), and relevant environmental variables, such as soils and climate, then use those correlations to project into the future. These are often referred to as species distribution models, niche models or bioclimatic envelope models.

> *Example*: DISTRIB, the core model used in development of the Climate Change Tree Atlas (see table below), uses a statistical approach known as regression tree analysis to define the ecological niche of a species based on (1) a series of climate, soil, elevation, and landuse

predictor variables and (2) data from FIA about the relative abundance of a species in the overstory. More specifically, it utilizes a relatively new ensemble data-mining technique called Random Forests, which has some improvements that are designed to avoid "overfitting" the data. For more detail on the technique read this paper by Prasad et al 2006. Based on these results, the model has been used to map where the habitat (in terms of climate conditions, soil characteristics, etc.) is suitable for a particular species now and in the year 2100. This tells us something about how likely a species is to persist in particular area.

Note: In the future, the Climate Change Tree Atlas will use DISTRIB in conjunction with a simulation model called SHIFT to go beyond predictions of future suitable habitat and estimate actual species movement in terms of the likelihood of colonization.

Process-based models are generally more complex because they simulate the actual underlying processes, such as disturbance, growth, and regeneration. Forest gap models, ecosystem models, forest landscape models, and dynamic global vegetation models (DGVMs) fall under this category.

Example: LANDIS PRO is a spatially explicit forest landscape model that simulates processes at the species- (e.g. growth, seedling establishment, mortality), stand- (e.g. competition, stand development), and landscape-scale (e.g. disturbance from fire, insects, harvest, etc.). By "growing" the forests in this way, LANDIS can be used to compare species in the future under a climate change and no climate change scenario. This tells us something about how likely a species is to become established in a particular area.

These categories are not mutually exclusive and there are an increasing number of hybrid approaches used in research. Nor is one approach necessarily better than another—each has its strengths and weaknesses depending on scale, data availability, and the particular research question. A helpful summary of key differences is below:

Table 1: Relative differences in empirical and process-based modeling approaches. (Source: Adams et al 2013)

	EMPIRICAL	**PROCESS-BASED**
Relationship type	Correlative	Causal
Relative comprehensiveness	Less comprehensive	More comprehensive
Incorporation of mechanism	Implicit	Explicit
Primary source of error	Extrapolation	Unknown parameters and processes
Model uncertainty	Lower	Higher
Data requirements	Lower	Higher
Spatial scale for calibration	Smaller to larger	Smaller
Spatial scaling of prediction	Best at scale of calibration	Smaller to Larger

For more detailed information on this topic, we recommend visiting the Landscape Analysis section of the US Forest Service Climate Change Resource Center website.

Table 1 in this paper by Littell et al (2011) also has a useful comparison of the strengths and weaknesses of different types of empirical and process models, for reference.

Model Comparison

The table below compares several modeling efforts that estimate changes in habitat suitability or distribution for U.S. tree species under future climate change. Model names are hyperlinks that take you to the project website where you can view results, including maps (in some cases), for different species. This table is intended to help forest managers quickly navigate to existing projections of species shift and weigh the merits and characteristics of each approach.

Comparing the results from different models reveals whether they generally agree (lending greater confidence) or disagree on the outlook for particular species. Some of this work is being carried out by the US Forest Service through their on-going series of Vulnerability Assessments (see final row in the table below) and the CSLN will alert Network members to similar comparative efforts as they arise.

BEST PRACTICES

"*Models incorporate imperfect information and are a simplified version of reality, but by understanding these imperfections, we can use models to decrease the uncertainty associated with the future*." ~ Littell et al 2011

Do…

- Remember there will be significant time lags.
- Consider projections for individual species, rather than forest types.
- Use models to help reduce uncertainty about the future by identifying potential surprises and vulnerabilities[1], potential magnitude of effects, and insight into mechanisms.[2]
- Use more than one type of model (wherever possible) to assess likely vegetation shifts[1]—we can have greater confidence where different models agree.
- Understand the assumptions in a given model and the implications of those assumptions.[1]
- Use MODFACs, a decision support framework that scores adaptability for different tree species, in conjunction with models to determine whether a species is likely to fare better or worse than modeled projections.

Don't…

- Mistake maps of *habitat suitability* for depictions of where a tree species will actually be growing at that point in the future.
- Use model projections as exact predictions of what *will* happen with future forest shifts.

[1] Littell et al 2011 [2] Kerns & Peterson 2014

Model or Project Name	Source/ Vintage	Type	Geographic Extent/ Resolution	Metrics	Number of Species	Time-frame(s)	Predictor Variables	Future Climate
Climate Change Tree Atlas [a]	USFS Northern Research Station 2007–on-going	Empirical	30+ states in Eastern U.S. 20 km^2	Potential suitable habitat; species Importance Value [b]	134	2100	38 predictors, including: 7 climate variables, 5 elevation classes, 9 soil classes, 13 soil properties and 4 landuse variables	High and low scenarios from three GCMs (Hadley CM3, GFDL, & PCM)
ForeCASTS	USFS Eastern Forest Environmental Threat Assessment Center & NC State 2009	Empirical	Continental U.S.; Global 4 km^2	Future suitable habitat; straight-line minimum required migration distance from current suitable habitat to nearest favorable future habitat	213	2050; 2100	17 variables, including climatic, soil-related, and topographic	High and low scenarios from two GCMs (Hadley CM3 & PCM)
Canada's Plant Hardiness Site [c]	Natural Resources Canada 2007	Empirical	(Non-spatial)	Average change in area and latitude of climate habitat per species	130	2011-2040; 2041-2070; 2071-2100	Climate variables only (climate envelope developed for each species)	High and low scenarios from three GCMs (CGCM, CSIRO, & HADCM3)
Canada's Plant Hardiness Site: Species-specific Models and Maps [d]	Natural Resources Canada	Empirical	North America 300 arc sec (~10km^2)	Climate suitability zone (range and core range for each species)	3,000	2011-2040; 2041-2070; 2071-2100	Climate variables only	High, moderate, and low scenarios from five GCMs (CanESM2, HadGEM2-ES, CESM1(CAM5), MIROC-ESM-CHEM, & composite-AR5)
USFS Moscow Lab: Plant Species and Climate Profile Predictions	USFS Rocky Mountain Research Station, Moscow Lab 2014	Empirical	11+ states in Western U.S. 30 arc sec (~0.65 km^2)	Species viability scores in the range of 0 to 1 (where low numbers indicate that the climate is not consistent with where the species grows and high numbers indicate consistency)	76	2030; 2060; 2090	Climate variables only	High, moderate, and low scenarios from three GCMs (CGCM3, HADCM3, & GFDLCM21)

USFS Vulnerability Assessments (see appendices in the following documents): • Central Appalachians • Central Hardwoods • Northern Wisconsin & Western Upper Michigan • Northern Lower & Eastern Upper Michigan • Minnesota • Northern Wisconsin • New England & Northern New York (*in press: 2016*) • Mid-Atlantic (*on-going*)	USFS, Northern Institute of Applied Climate Science	Empirical & Process-based models (DISTRIB, LINKAGES, LANDIS PRO) 2011 – on-going	(non-spatial)	Metrics vary depending on model, from species importance values (DISTRIB) to biomass per species (LINKAGES) and basal area or trees/acre (LANDIS PRO).	Variable	2010-2039; 2040-2060; 2070-2099 or 2040; 2070; 2090; 2100 (depending on model)	Variables include climate, soils, landuse, and elevation, depending on the model.	High and low scenarios from two GCMs (PCM & GFDL)

Note: Most models use US Forest Service Forest Inventory and Analysis (FIA) data for species occurrence.

GCM = Global Climate Model

[a] Includes estimates of model reliability for each species.

[b] A measure of relative abundance, which is calculated from FIA based on basal area and number of stems.

[c] Also see original paper from McKenney et al (2007).

[d] As of 4/25/16 their servers are down, with no access to the species maps, but they are expected to be up again within a few weeks. CSV files of the climate envelopes are available for download and users can also query what species models intersect/overlap any selected location.

Underestimating Adaptability

As we noted in a previous bulletin, there are some limitations associated with modeling efforts that rely on statistical relationships between environmental variables and current species distributions derived from FIA data (i.e. the realized niche), since that represents only a portion of the possible conditions under which a species *could* grow (i.e. the fundamental niche). Revisit [part of our July 2015 bulletin]() on uncertainty and forest response for a brief explanation of how the absence of data on the fundamental niche can lead to underestimating the potential adaptability of some tree species. This is not to say that forests aren't vulnerable in other ways, such as increasing damage from exotic pests and extreme weather, but they may be more adaptable in terms of temperature tolerance than some results suggest.

Take-Home Message

As an initial step, we recommend CSLN members spend a little time perusing the results of the modeling efforts listed above, to get a sense for the *general* outlook for species that dominate their economic or management concerns. Noting where (and if) the models agree can highlight potential areas of vulnerability (or opportunity) to be explored further. Members who have an interest in digging-in on projections for a particular species, can contact the CSLN staff for additional assistance.

All the modeling efforts agree on at least one thing—conditions are going to change. Most tree species will begin to experience novel climate conditions in some portion of their range and, in some cases, that may lead to local extirpation. Ultimately, the uncertainty is in knowing exactly *where* and *when* these species distribution shifts will happen. Generally, we expect species range expansion at the leading edge, in northern and higher elevations, and range contraction at the trailing edge, in southern and low-altitudinal limits. In particular, look for initial forest composition changes at range margins because it is regeneration success or failure there that will determine whether a species persists or migrates.

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