LCC-VP
LANDSCAPE CLIMATE CHANGE VULNERABILITY PROJECT

Tree species and ecological system responses to climate change: meta-analysis & new modeling

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The Landscape Climate Change Vulnerability Project (LCCVP) aims to assess the vulnerability of terrestrial landscapes in two Landscape Conservation Cooperatives (Appalachian [ALCC] and Great Northern [GNLCC]) to climate and land use change, with an emphasis on lands managed by the National Park Service (NPS). Our approach uses projections of climate and land use change to explore possible ecosystem and species level responses to those changes and the implications for management of high priority park resources.

We are currently focusing our efforts in the ALCC on three eastern US NPS units, Great Smoky Mountains National Park (GRSM), Shenandoah National Park (SHEN), and Delaware Water Gap National Recreation Area (DEWA), at three spatial scales: NPS unit, Protected Area Centered Ecosystem (PACE; Hansent et al. 2011), and Landscape Conservation Cooperative (LCC).

In late 2012 and early 2013, the LCCVP team met with eastern NPS collaborators to identify ecological systems that are potentially vulnerable to climate and land use change. These include pine-oak, spruce-fir, cove hardwood, northern hardwood, oak-hickory, mixed mesophytic, montane alluvial, and eastern hemlock. We then began a set of analyses that correspond to step two of the Glick et al. (2011) climate adaptation framework (Figure 1) and are focused on assessing sensitivity - as well as the interaction of sensitivity with exposure (potential impact) - of species and ecological systems to climate change.

Our analysis thus far can be divided into two parts:

1. A summary of spatial data underpinning published studies of modeled tree species response to climate change in the eastern US.

2. Species distribution modeling for a subset of tree species and ecological systems using new, downscaled climate datasets from collaborators at the NASA Ames Ecological Forecasting Lab (http:// ecocast.arc.nasa.gov/) (Thrasher et al. in review).

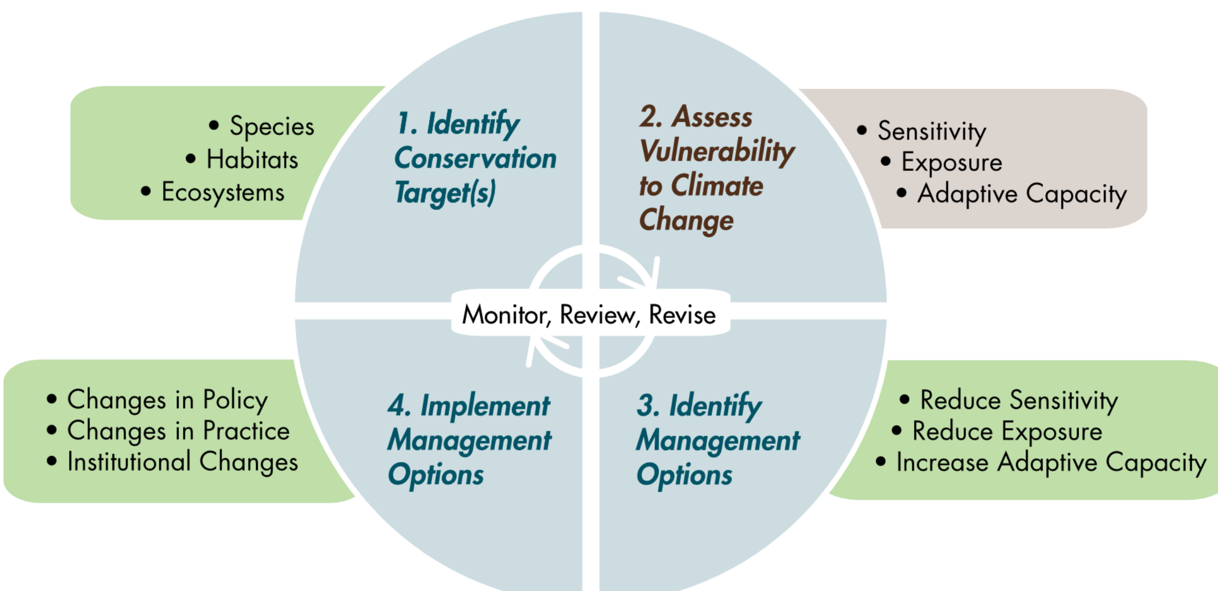

Figure 1. A framework for climate adaptation planning (Glick et al. 2011).

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Part 1. Synthesis of published studies on modeled tree species response to climate change across NPS units and PACEs within the ALCC

There is agreement between recent modeling efforts, using a variety of climate models and emissions scenarios (Table 1), that many tree species in the ALCC will lose suitable climate space. There is weaker agreement on which species will gain climate space and the amount gained (Figure 2) (Iverson et al. 2008, McKenney et al. 2011).

The predicted redistribution of individual tree species' climate space varies by LCC, NPS unit, and PACE (Figure 3, 4). At the PACE scale, there are considerable differences in modeled trends of tree expansion, persistence and decline (Figure 4). The modeling algorithm, spatial resolution, predictor variables, and GCMs considered by each study most likely explain the observed differences. Iverson et al. (2008) used the Random Forests algorithm to model tree species distributions with 36 predictor variables including soil, climate, elevation, land use, and fragmentation. McKenney et al. (2011) used ANUCLIM to fit and project climate envelopes for each species based on a set of 19 bioclimatic variables. Differences in species included in each study are small and therefore unlikely to account for the large differences in outcomes. In the eastern US, the large range shifts (i.e., hundreds of km) and minimal overlap between current and future climate space predicted by some model forecasts suggest considerable challenges to the natural migration of tree species to newly suitable areas, including those that are within or adjacent to NPS units or their associated PACEs (Figure 5).

Table 1. General Circulation Models (GCMs) and emission scenarios considered in each study, and the predicted temperature increases associated with each emissions scenario. Emission scenarios provide projections of the amount and timing of CO_2 emissions under different assumptions of future economic growth. Changing CO_2 concentrations are key drivers of GCMs, which model physical processes like oceanic and atmospheric circulation, and provide gridded projections of temperature and precipitation.

Author	General Circulation Models (GCMs)	*Emissions Scenario	†Temp (˚C)
Iverson et al. (2008)	Parallel Climate Model (PCM), Geophysical Fluid Dynamics Laboratory (GFDL), HadleyCM3	A1fi	4.7
		B1	2.4
McKenney et al. (2011)	CSIRO-Mk3.5, CGCM3.1, CCSM3.0	A2	3.9
		B1	2.4

**A1fi emissions scenario represents an economically-driven, globalized future with intensive fossil fuel consumption.*
**A2 represents a future defined by regionally-driven economic development.*
**B1 represents an environmentally-friendly, regionalized future that is relatively more ecologically friendly.*
†Temperature increase in 2090 - 2099 relative to 1980 - 1999 (best estimate, °C, approximated from Rogelj et al. [2012]).

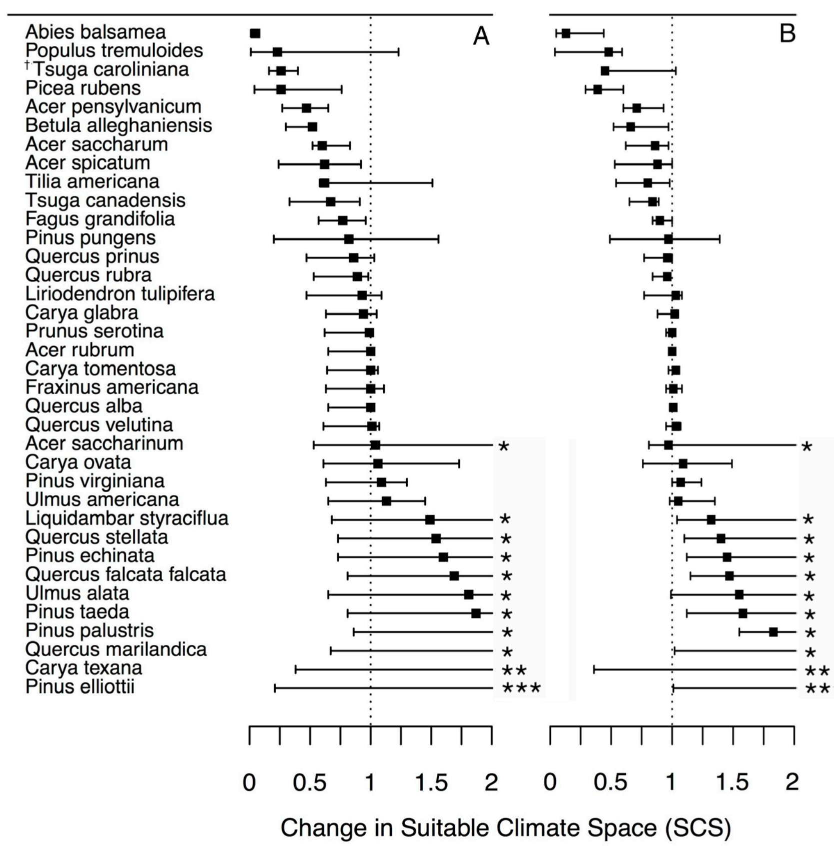


Figure 2. Range of change in suitable climate space (SCS) predicted by all six GCMs under (A) average high emissions and (B) average low emissions (Table 1). The data represent SCS change by 2100 for 36 tree species across the ALCC (Iverson et al. [2008], McKenney et al. [2011.]) Squares represent median SCS and the vertical stippled line represents the change threshold, values above and below which indicate an increase and decrease in SCS (i.e. > 1.0 and < 1.0, respectively). For example, 0.5 = ½ of existing area, 1 = no change, 2 = doubling in area. * = max SCS > 2; ** = max SCS > 10; * = max and median SCS > 10. †Species data were available from McKenney et al. (2011) only. Data shared by L. Iverson (USFS) and D. McKenney (Canadian Forest Service). Data processing and analyses conducted by Woods Hole Research Center.**

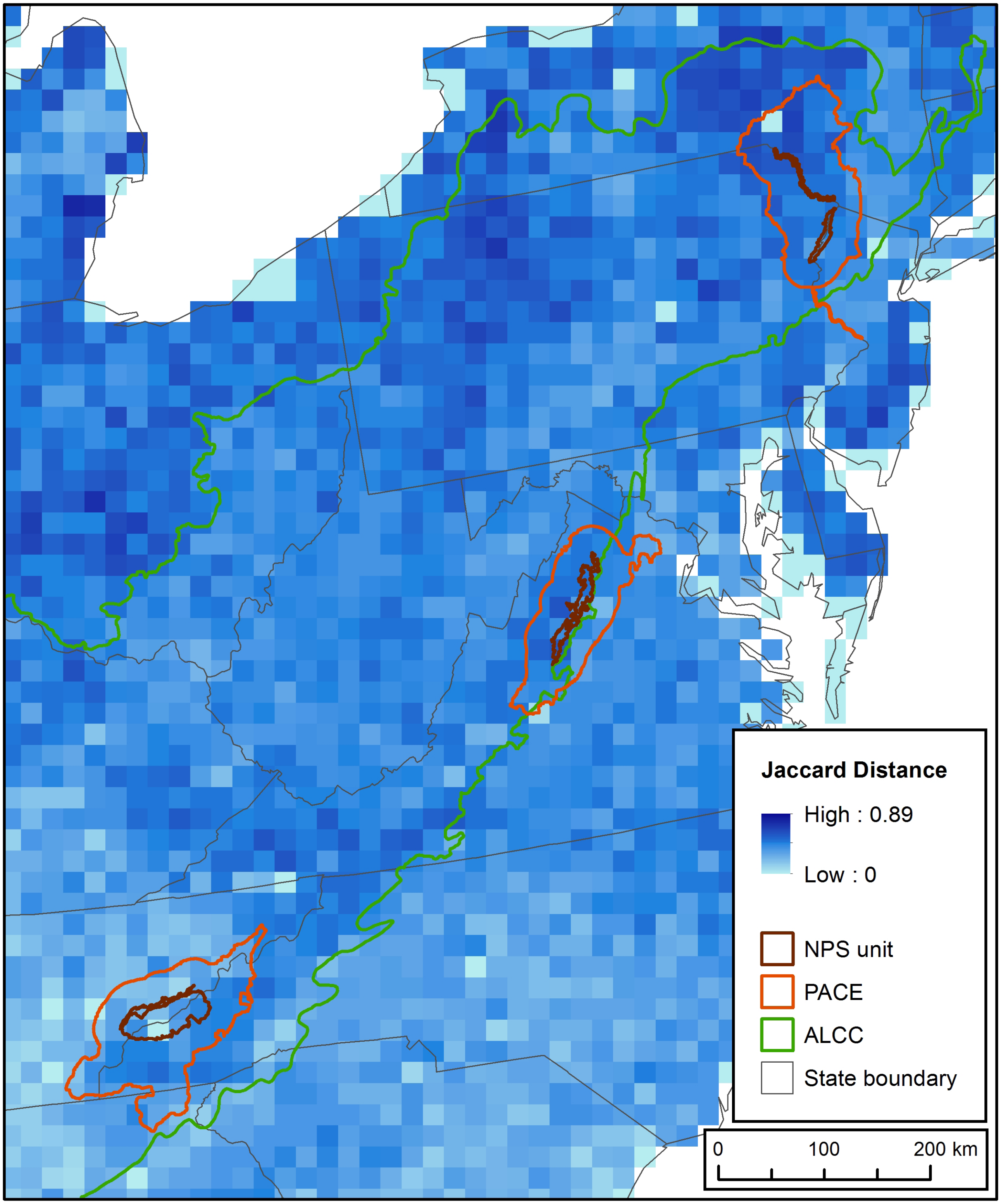


Figure 3. Jaccard distance metric between current modeled suitability and forecasted suitability for 2100 (HadleyCM3 A1fi climate scenario) for 35 tree species from Iverson et al. (2008). Jaccard distance is a metric of dissimilarity in species composition between two sites or at the same site at different points in time. For each pixel, we compared the set of species for which current conditions are suitable against the set of species for which future conditions are suitable. Values approaching 1, corresponding to dark blue on the map, indicate increasing dissimilarity. Dark brown outlines correspond to NPS units, red outlines correspond to protected area centered ecosystems, and the green outline corresponds to the Appalachian Landscape Conservation Cooperative.

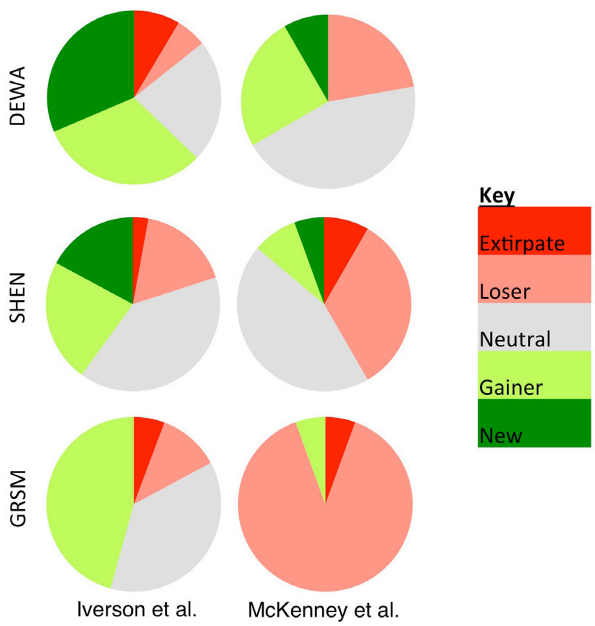


Figure 4. Trends in the relative change of species' persistence (by 2100, based on SCS change) under HadleyCM3 (A1fi; Iverson et al. [2008]) and CGCM3.1 (A2; McKenny et al. [2011]) climate scenarios are included as pie charts for the PACE associated with each park unit. DEWA, SHEN, and GRSM refer to Delaware Water Gap National Recreation Area, Shenandoah National Park, and Great Smoky Mountains National Park, respectively. The modeling approach and predictor variables considered by each study most likely explain the observed differences. Iverson et al. (2008) use Random Forests to model future tree species redistribution based on 36 predictor variables including soil, climate, elevation, land use, and fragmentation. McKenney et al. (2011) used ANUCLIM, a multivariate non-parametric surface fitting approach, to create climate maps using 19 bioclimatic variables relating to temperature and precipitation. Differences in species included in each study are small and therefore unlikely to account for the large differences in outcomes.

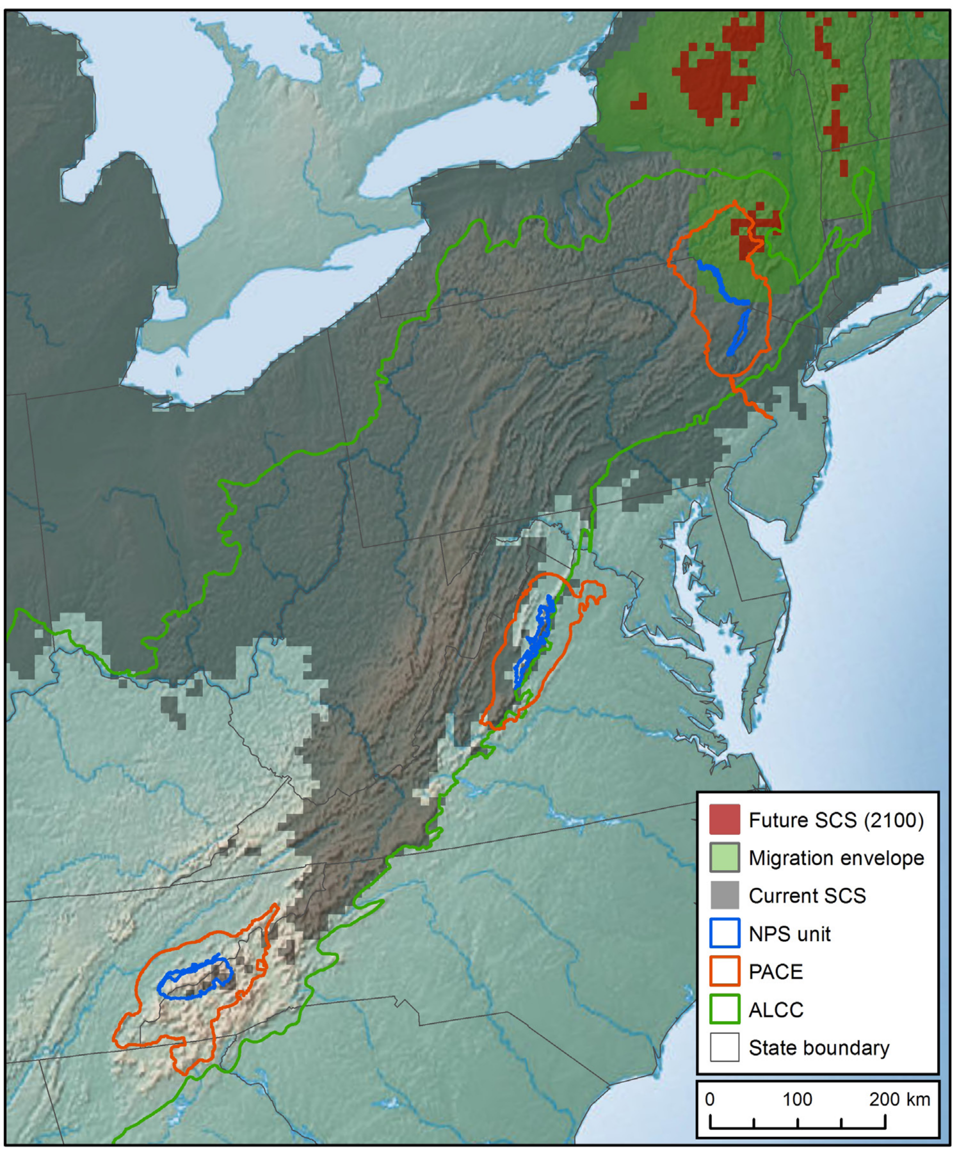


Figure 5. Current and future predicted ranges of Balsam fir across the eastern US. The "migration envelope" delineates a reasonable migration distance (50 km, based on the literature) within which tree species might migrate to the future range (excluding multiple factors; e.g., fragmentation). Data shared by D. McKenney; data processing and analyses conducted by Woods Hole Research Center. Spatial data for 2100 considered the CGM3.1 A2 climate scenario.

Part 1. Synthesis of published studies on modeled tree species response to climate change across NPS units and PACEs within the ALCC (*continued*)

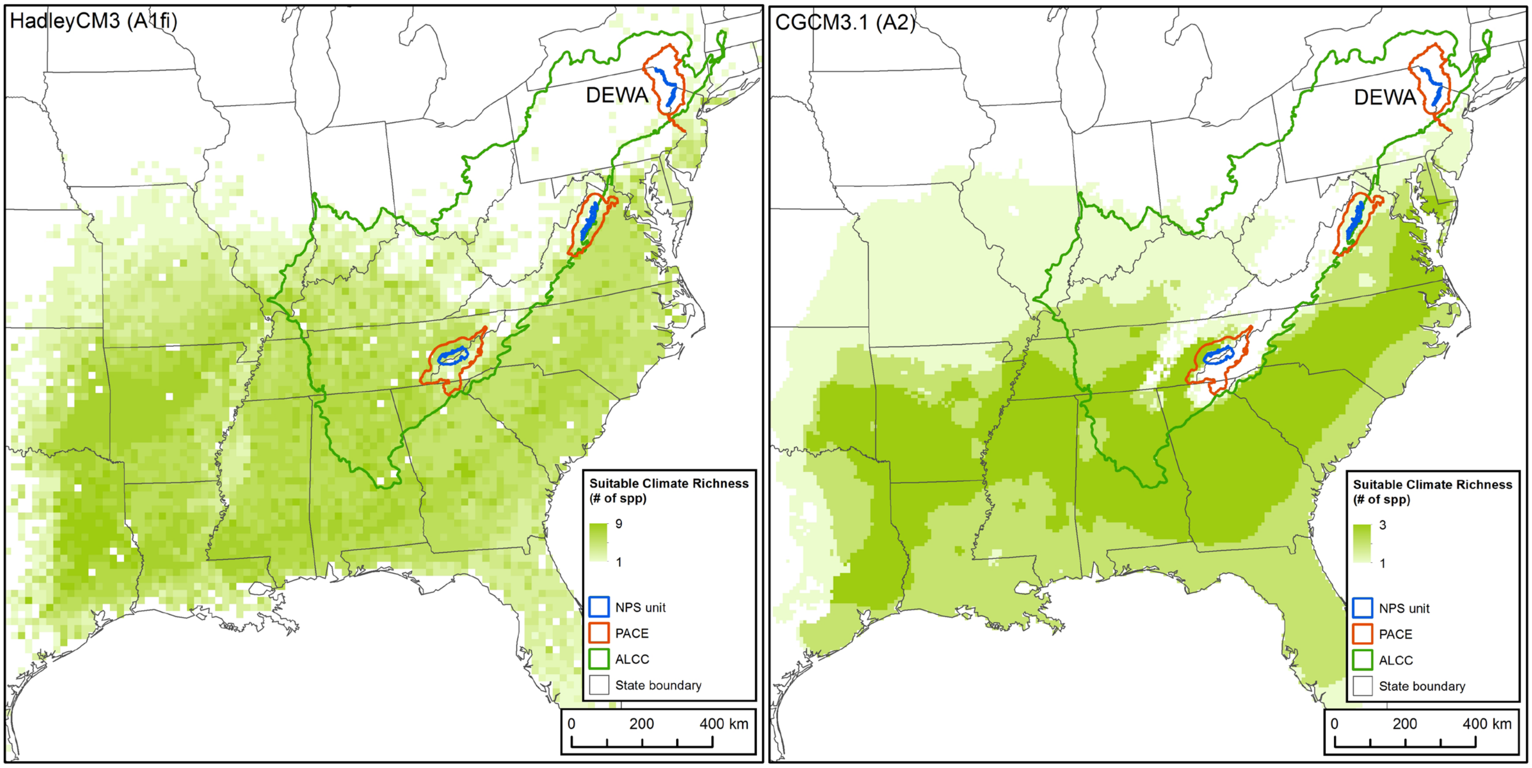


Figure 6. Current richness of species predicted to be new in the DEWA PACE by 2100, under HadleyCM3 (A1fi) and CGCM3.1 (A2) (Iverson et al. [2008] and McKenney et al. [2011], respectively). Note the different species abundances in each dataset.

Part 2. New species distribution modeling using new, downscaled climate data

Since we last met, we have made several advances in our modeling efforts:

We expanded our suite of predictors from 19 to 29 variables for all ecological systems (Figure 7). Our first models contained only bioclimatic variables. In addition to the original variables, our new "kitchen sink" models utilize several soils layers (e.g., pH, available water capacity, sand-silt-clay components, etc.), a topographical wetness index, growing degree days, and solar radiation. Solar radiation is the most important factor explaining the current distribution of cove forests but holds relatively little explanatory power for spruce-fir forest types, for example, highlighting the importance of including a suite of variables that capture the distinct climatic and topographic conditions that help structure the spatial distribution of vegetation communities.

We have generated these "kitchen sink" models for several ecological systems in GRSM: spruce-fir, hemlock (typic type), hemlock (white pine type), spruce-hemlock, oak-hickory (red oak type), and cove forests (Figure 8). We are still working on generating the forecasts for some of these systems and are eager to start modeling additional systems.

Additionally, we have increased the temporal frequency of our forecasts. Initially, we were modeling at 3 time steps in the future: 2006-2035, 2036-2065, and 2066-2095. We continue to forecast to 30-year averages, but we are now incrementing yearly (e.g., 2006-2035, 2007-2036, 2008-2037, etc.).

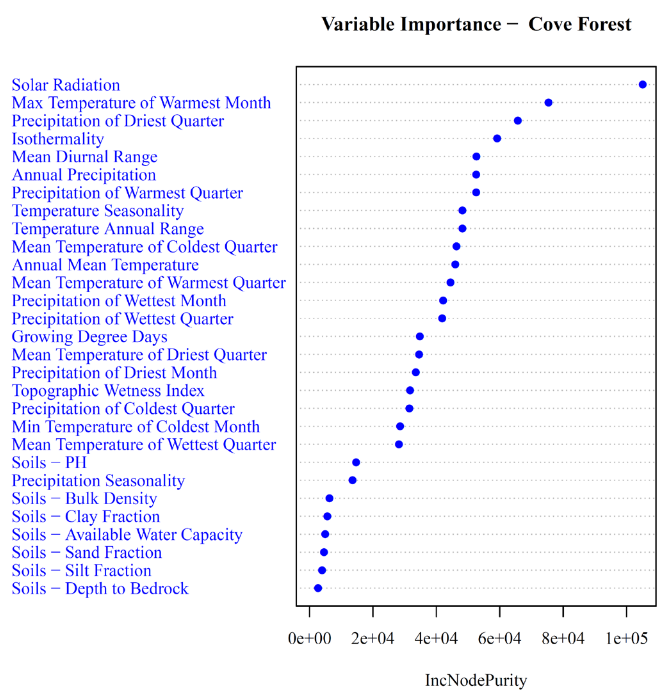
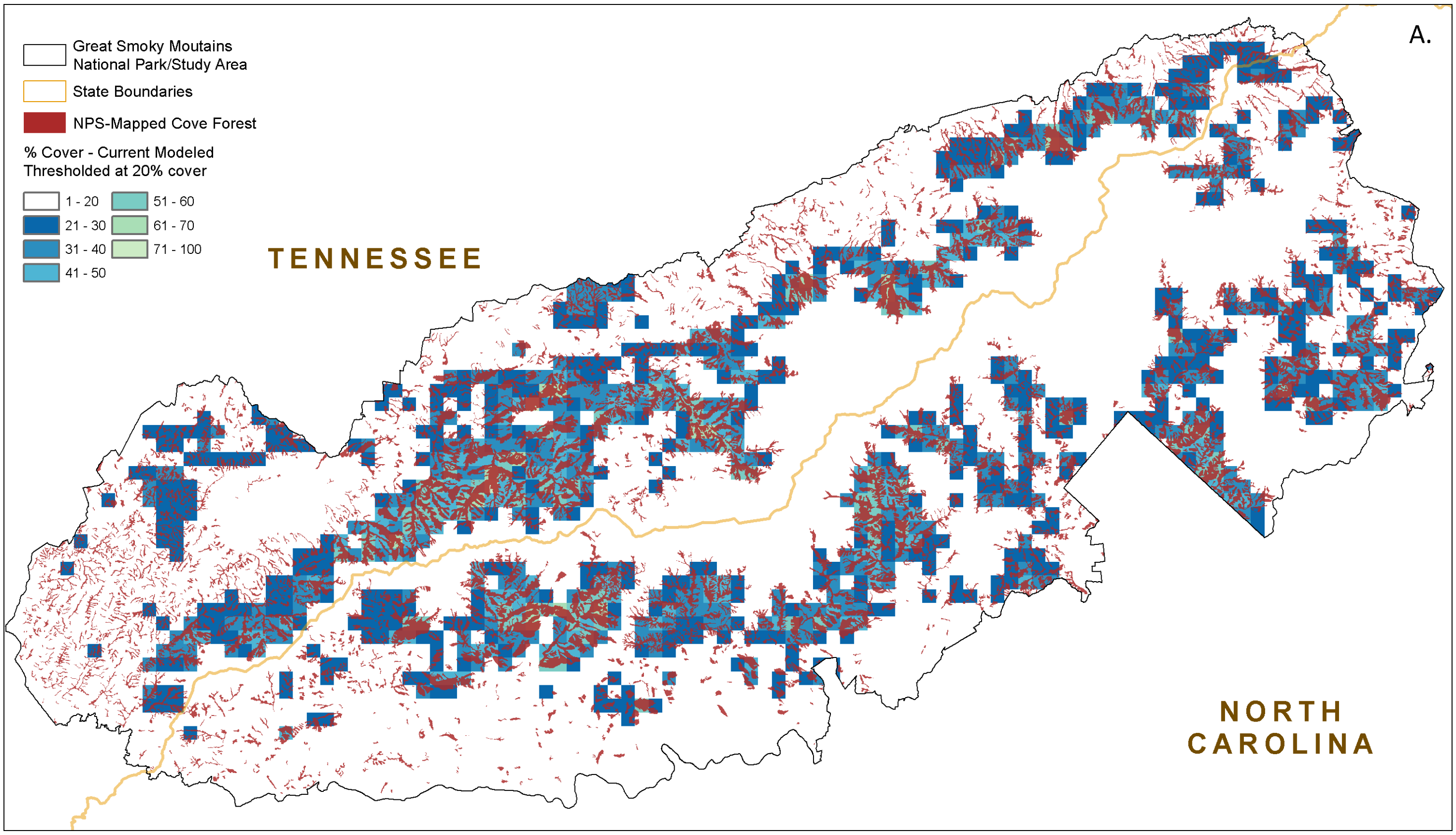


Figure 7. Variable importance plot generated by the Random Forests algorithm for cove forests in GRSM. Variables near the top of the plot are most important for explaining the current distribution of cove forests.



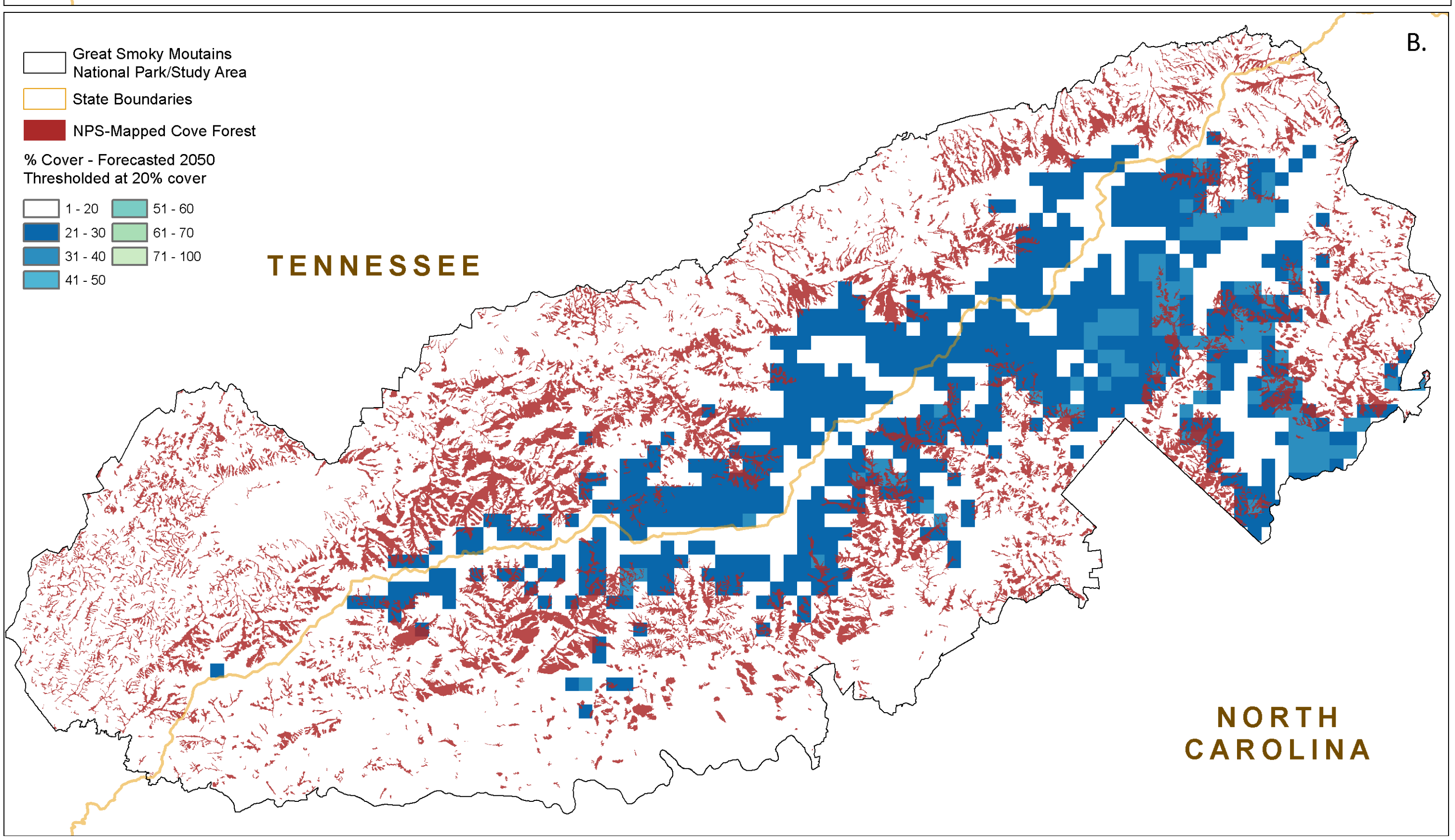


Figure 8. (A, Top map) Modeled distribution of cove forests in GRSM derived from NPS vegetation mapping program data and trained on current climate conditions (1980 – 2010). (B, Bottom map) Projected cove forest distribution for a period centered on 2050 using ensemble mean climate projections for RCP 8.5 at 800 m resolution (Table 2, Rogelj et al. 2012). Lighter blue colors correspond to higher cover values and are assumed to be more suitable for cove forests. Very little of the current mapped cove forest extent overlaps with suitable areas in 2050. Climate projections used in the published studies synthesized in part 1 are driven by SRES scenarios while the climate projections we used for modeling cove forest distributions in GRSM are driven by RCPs. Each RCP or SRES contains specific assumptions about the degree and timing of climate change. SRES A2 (see Table 1), for example, represents a global temperature increase of 3.9 °C while RCP 8.5 represents an increase in global temperature of 4.6 °C. RCPs differ from SRES scenarios in that they do not use particular socioeconomic narratives in order to arrive at levels of radiative forcing associated with changing CO_2 concentrations. Rather, RCPs represent a range of possible radiative forcings that can be arrived at by any number of pathways of socioeconomic growth and change.

Part 2. New species distribution modeling using new, downscaled climate data (*continued*)

Table 2. Similarities and differences between Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathways (RCPs) (from Rogelj et al. 2012).

RCP	SRES scenario with similar median temperature increase by 2100	Particular differences
RCP3-PD	None	The ratio between temperature increase and net radiative forcing in 2100 is 0.88 °C $(\mathrm{W\,m^{-2}})^{-1}$ for RCP3-PD, whereas all other scenarios show a ratio of about 0.62 °C $(\mathrm{W\,m^{-2}})^{-1}$; that is, RCP3-PD is closer to equilibrium in 2100 than the other scenarios.
RCP4.5	SRES B1	Median temperatures in RCP4.5 rise faster than in SRES B1 until mid-century, and slower afterwards.
RCP6	SRES B2	Median temperatures in RCP6 rise faster than in SRES B2 during the three decades between 2060 and 2090, and slower during other periods of the twenty-first century.
RCP8.5	SRES A1FI	Median temperatures in RCP8.5 rise slower than in SRES A1FI during the period between 2035 and 2080, and faster during other periods of the twenty-first century.

Next steps

Synthesizing current knowledge to assess vulnerability: We are in the process of assembling data and scripts to allow summaries and comparisons between NPS station data and gridded PRISM climate. We will use these summaries to generate spatially explicit maps of exposure to climate change. Part of this analysis will include an assessment of error and bias associated with gridding and interpolating climate station data. This will help inform park managers of the strengths and weaknesses of the datasets underpinning our analyses.

We will continue to work on a manuscript that details our synthesis of published studies of tree species response to climate change. We have agreement from collaborators to supply additional tree species models, which will improve our mapping of potential source zones for tree species moving into PACEs.

New Science: Our collaborators at NASA Ames have generated downscaled climate projections and projections of ecosystem processes which we will begin to summarize across different spatial scales in the eastern US. We also plan to optimize our species distribution modeling efforts by integrating both automated and expert-driven variable selection procedures to ensure that redundant or unnecessary variables are excluded.

In the examples presented for cove forest, we chose an arbitrary threshold of 20% for display, below which we surmise that other ecological factors would make establishment or persistence less likely. We will be investigating objective ways of calculating this ecological threshold. Although validation data are difficult to acquire, vegetation databases associated with state natural heritage programs, the USGS national GAP analysis program, and the USFS Landfire mapping program provide opportunities for assessment of model performance.

As we finish model development, we will begin to generate and forecast models for a larger group of ecological systems that emerged from our meeting with collaborators: pine-oak, spruce-fir, cove hardwood, northern hardwood, oak-hickory, mixed mesophytic, montane alluvial, and eastern hemlock.

To complement these park-scale distribution models, we have assembled a set of predictor variables for the eastern US that we will use for range-wide distribution models for a subset of tree species that appear to be most at risk from climate change. This subset will be based on our analysis of published studies and models of ecological systems.

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Acknowledgments

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More Information

Landscape Climate Change Vulnerability Project
http://www.montana.edu/lccvp/index.html

Woods Hole Research Center
http://www.whrc.org/

NASA Ames Ecological Forecasting Lab
http://ecocast.arc.nasa.gov/