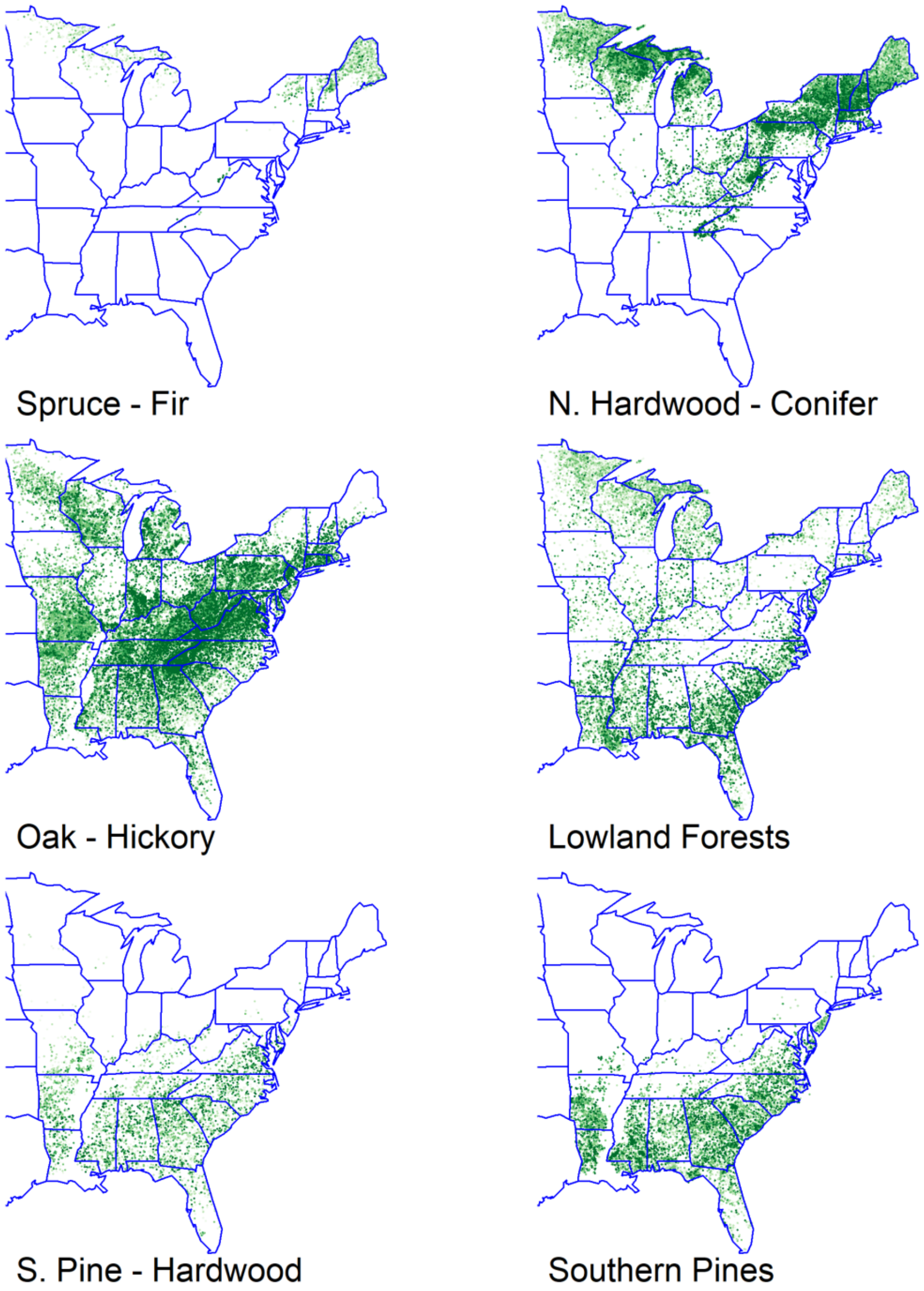
Cary Institute of Ecosystem Studies

Interactions between Climate Change and Other Human Impacts in Eastern Forests

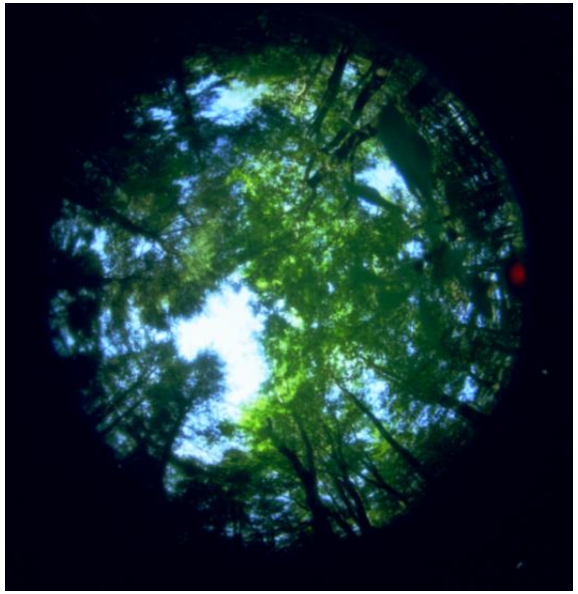
A quick summary of my beliefs after 35 years of research…

Charles Canham
Cary Institute of Ecosystem Studies

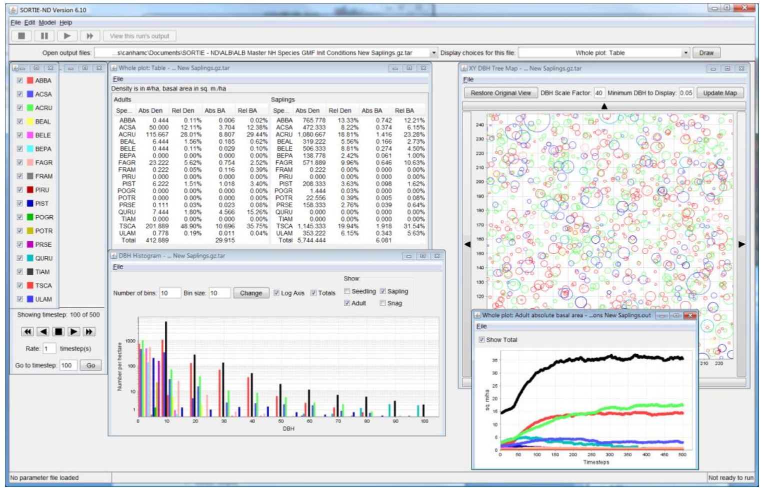


Phase 1: Great Mountain Forest and SORTIE (1990-1995)

- Field research:
  - Developed new methods to estimate – in the field - all of the critical parameters needed to predict the successional dynamics of the 9 tree species at GMF



- Modeling:
  - Developed SORTIE - a spatially explicit, individual-based simulation model to incorporate all of the field results



Pacala, S. W., C. D. Canham, J. Saponara, J. A. Silander, Jr., R. K. Kobe, and E. Ribbens. 1996. Forest models defined by field measurements: II. Estimation, error analysis and dynamics. *Ecological Monographs* 66:1-43.

Phase 2: Expanding the scope of the model at GMF (1996 – 2008)

- **Linking species dynamics and ecosystem processes** (with Adrien Finzi, Seth Bigelow, Feike Dijkstra, Nico Van Breemen, Gary Lovett and Gene Likens,)

- **Effects of vertebrate consumers** (rodents and deer) on tree population dynamics (with Rick Ostfeld, Jackie Schnurr and Chris Tripler)

- Dynamics of **invasion by exotic tree species** (with Patrick Martin, Lorena Gomez Aparicio and Peter Marks)

- **Impacts of pests and pathogens**: beech bark disease and hemlock wooly adelgid (with Erika Latty and Jennifer Jenkins)

Phase 3: Expanding the application of the field methods and model (1996 – 2012)

- **Sustainable Forestry**: use the field methods and the model in **British Columbia** (Dave Coates) and **Quebec** (Christian Messier) to explore alternatives to clearcutting in Canadian forests.

- **Conservation Biology**: effects of introduced vertebrates (rodents and deer) on native tree species in **New Zealand** forests (David Coomes, Elaine Wright, many others)

- **Effects of hurricanes** on tropical forests of **Puerto Rico**

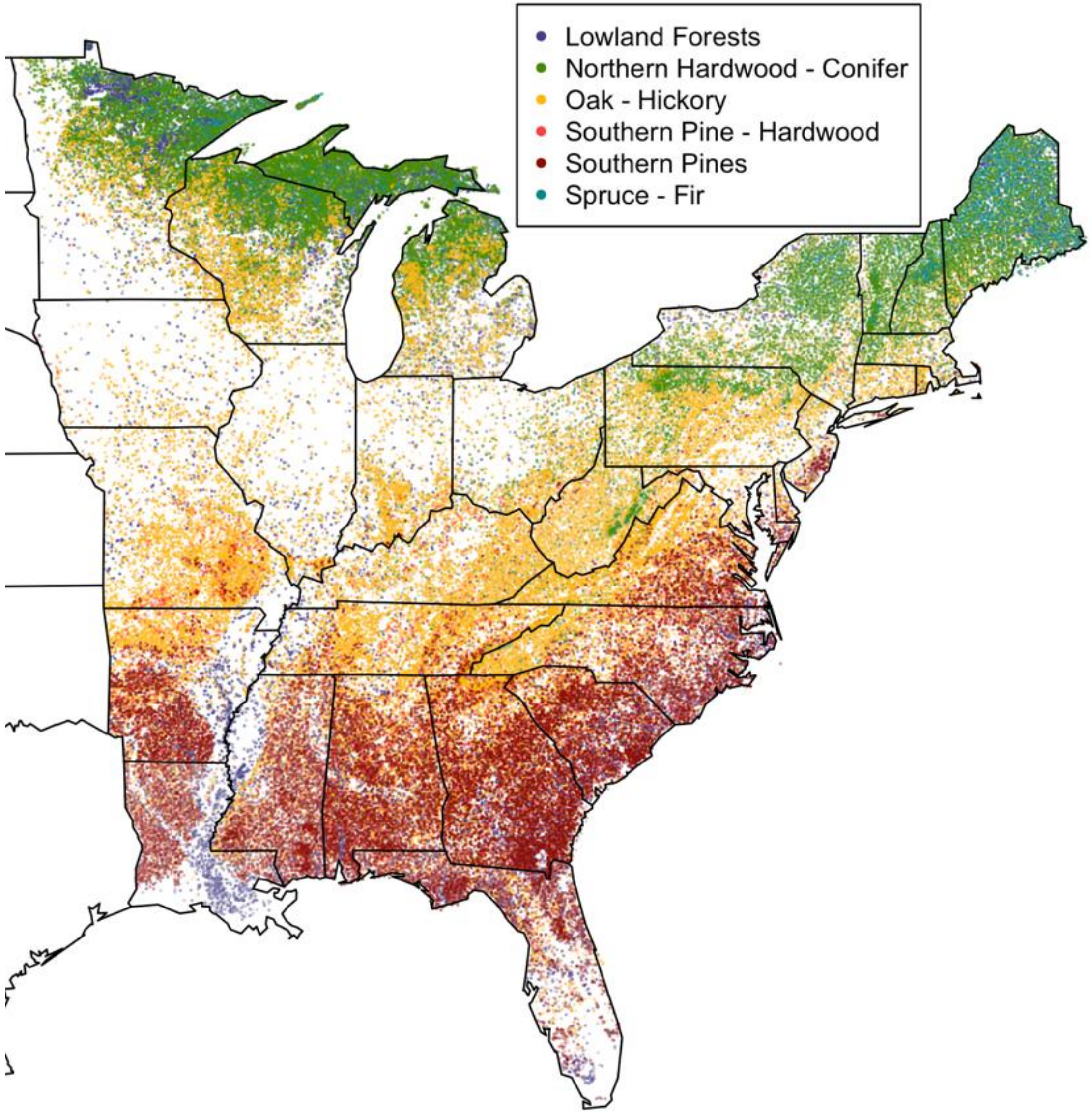
(Maria Uriarte and many others)

Phase 4: Broaden scope to predict regional scale dynamics of eastern U.S. forests (2010 – present), as a function of:

- ❖ Climate change
- ❖ Introduced pests and pathogens
- ❖ Air pollution (particularly nitrogen deposition)
- ❖ Logging

We have parameterized the effects of all of these from FIA data for the 50 most common tree species in eastern forests…

Study region



Development of the SORTIE-ND software architecture… (Lora Murphy)

❖Individual-based

- Simulates the birth, growth, and death of all seedlings, saplings and adult trees, including processes of natural and human disturbance, and effects of processes including pests and pathogens, air pollution, and climate change

❖Spatially-explicit

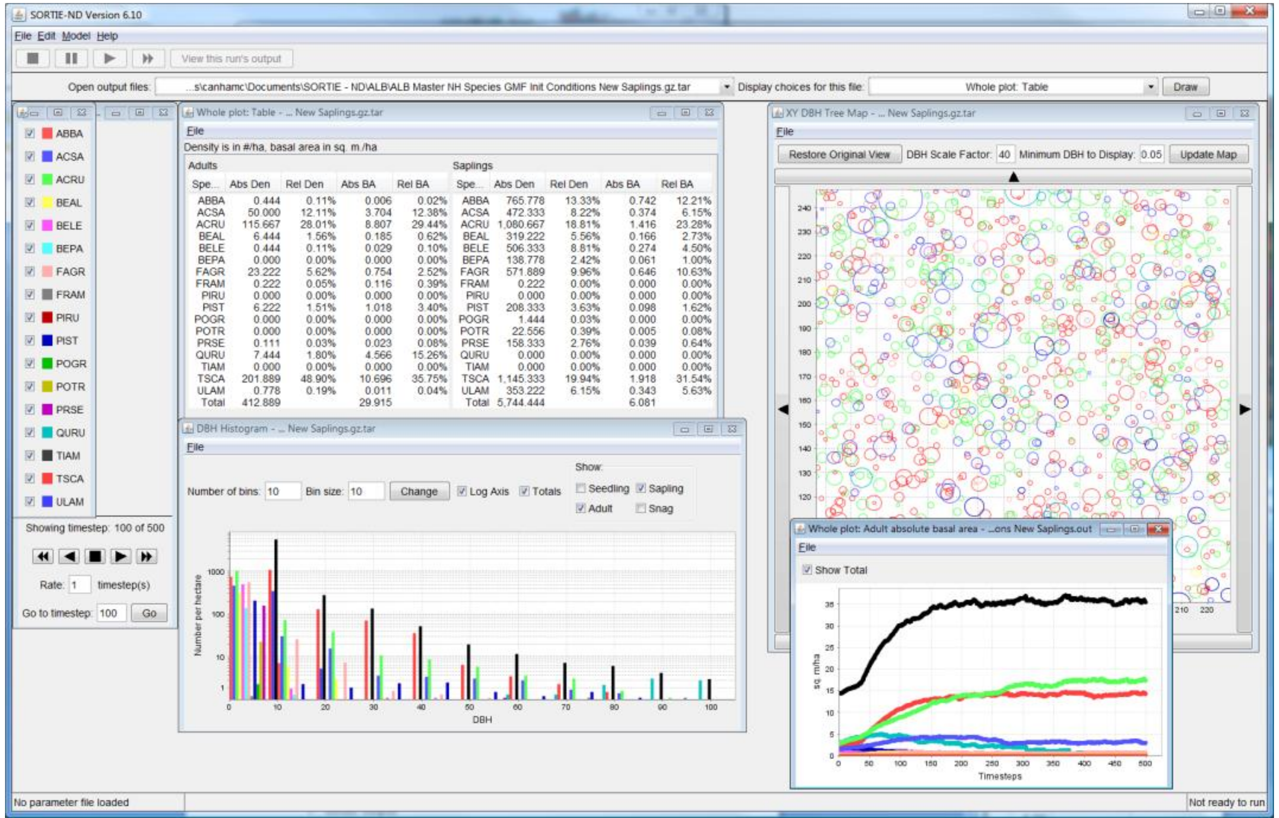
- The spatial locations of all individuals are tracked, and can be used in processes ranging from seed dispersal to resource competition

❖Adaptable

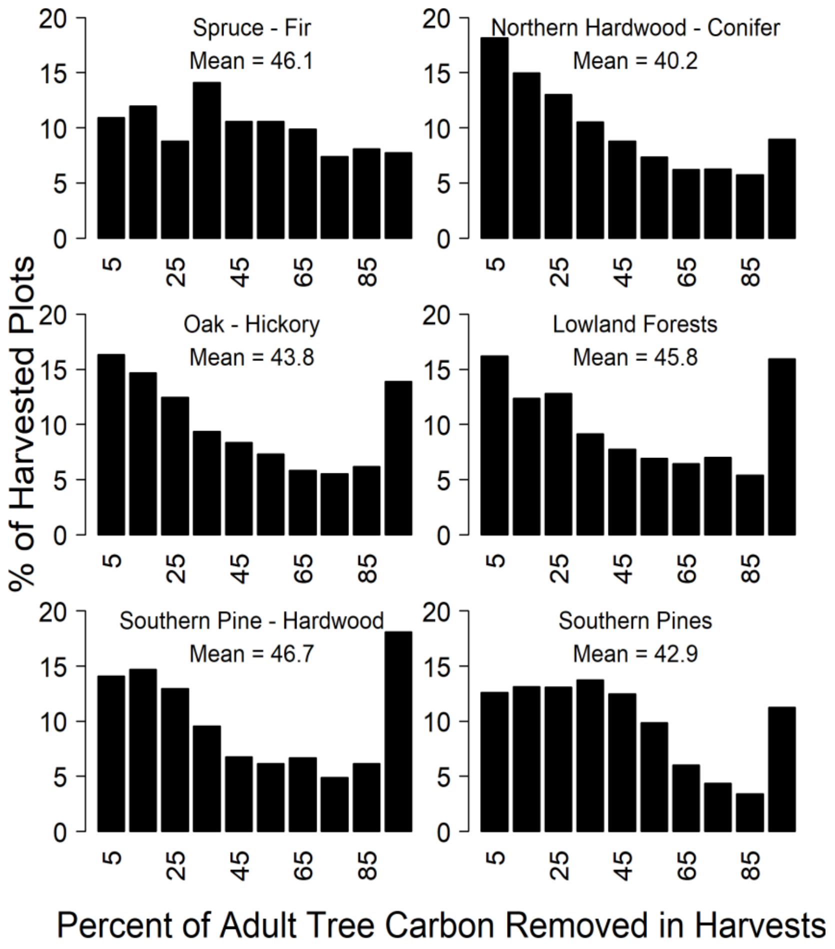
- Users create and assemble "behaviors" based on available field data

❖Open-source

- The source code and programming guides are available to all users (www.sortie-nd.org)
- changes made by any user are incorporated in the base model available to all



Ecologists don't seem to realize that logging is by far the most important disturbance in eastern forests!



- Logging accounts for roughly half of all adult tree mortality in eastern forests
- Clearcutting accounts for < 15% of area harvested in any year

Canham, C. D, N. Rogers, and T. Buchholz (2013). Regional variation in forest harvest regimes in the northeastern United States. Ecological Applications 23:515-522.

Thompson, J. R., C. D. Canham, L. Morreale, D. B. Kittredge, and B. Butler. 2017. Social and biophysical variation in regional timber harvest regimes. Ecological Applications 27:942-955.

Brown, M. L., C. D. Canham, L. Murphy, and T. M. Donovan. 2018. Timber harvest as the predominant disturbance regime in northeastern U.S. forests: effects of harvest intensification. Ecosphere 9(3):e02062. 10.1002/ecs2.2062.

Demographic responses of the 50 most common tree species to variation in climate: A verbal summary

- ❖ Seedling recruitment and survival (Canham and Murphy 2016a)
  - **Seedling survival shows strong sensitivity to climate**, with patterns that closely mimic current patterns of species distribution along at least a temperature gradient

- ❖ Sapling and adult survival (Canham and Murphy 2017)
  - **25 of the 50 species showed NO variation in survival along either the temperature or soil water deficit gradient**

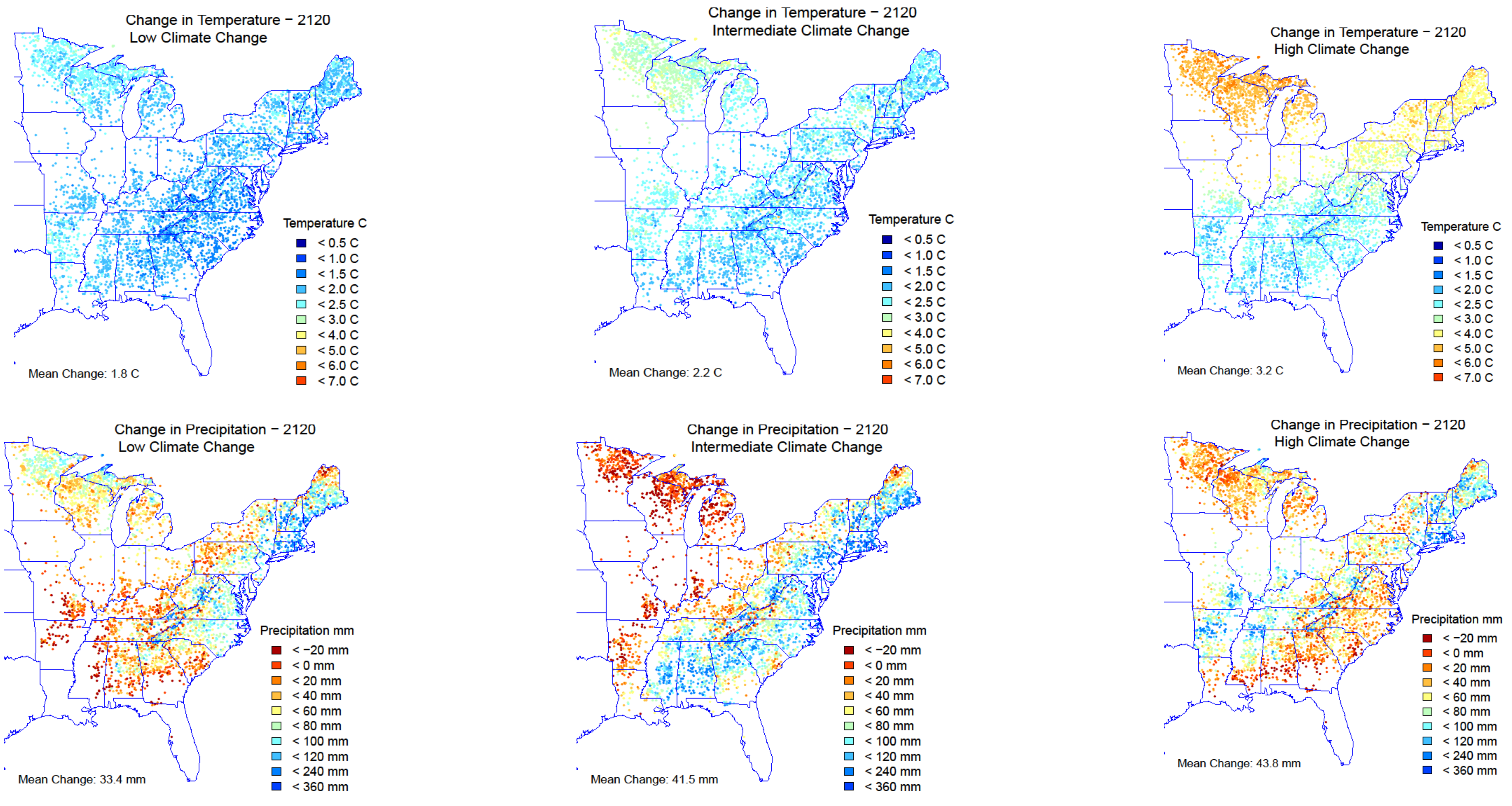
- ❖ Sapling and adult growth (Canham and Murphy 2016b)
  - 48 of 50 species showed variation in growth along either temperature or precipitation gradients
  - Shapes of the response functions sometimes mirrored current distribution of abundance of species along the gradient, **but often did not**

- ❖ Sapling and adult growth (revisited) (Canham et al. 2018, and new analyses)
  - 2018 analysis of 24,000 tree cores of 14 northeastern tree species – all showed local differentiation
  - We recently developed imputation methods to use annual variation within census intervals for analysis of FIA plot data
    - 41 of the 50 species show **strong local adaptation/acclimation** to local climate conditions

Bottom line:

- ❖ Temperate trees may be the most climate-resilient species on the planet!
- ❖ Changes in species composition will lag climate change by 1-2 generations (i.e. a century or more)!
- ❖ And the nature of local adaptation/acclimation (evolution!?) will be critical

Downscaled predictions of 3 different GCMs, under RCP 4.5, for 5000 randomly selected FIA plot locations



GCM: GFDL-ESM2G

GCM: CCSM4

GCM: MIROC_ESM

Running the SORTIE-ND simulations

- Randomly select 5,000 FIA plots from the 31 state region, to be used to initialize the 5,000 separate runs
  - Limited to plots in 1 of the 6 broadly-defined forest types (representing 98% of forests in the region)
  - Initialize runs with the composition and size structure of the individual FIA plots
  - Each run simulates dynamics of all seedlings, saplings, and adult trees in a 4 ha stand

- Scenarios
  - No climate change – use recent climate variability to characterize interannual variability in monthly climate from 2000 – 2250
  - No climate change, no harvesting
  - No climate change, 30% of forests reserved from harvesting
  - RCP 4.5 Low Climate Change GCM (GFDL_ESM2G)
  - RCP 4.5 Intermediate Climate Change GCM (CCSM4)
    - Assuming local differentiation is genetic*
    - Assuming local differentiation is phenotypic‡
    - Assuming local differentiation is genetic – but with 30% of forests reserved from harvesting
    - Assuming local differentiation is genetic – but with no harvesting
  - RCP 4.5 High Climate Change GCM (MIROC-ESM)

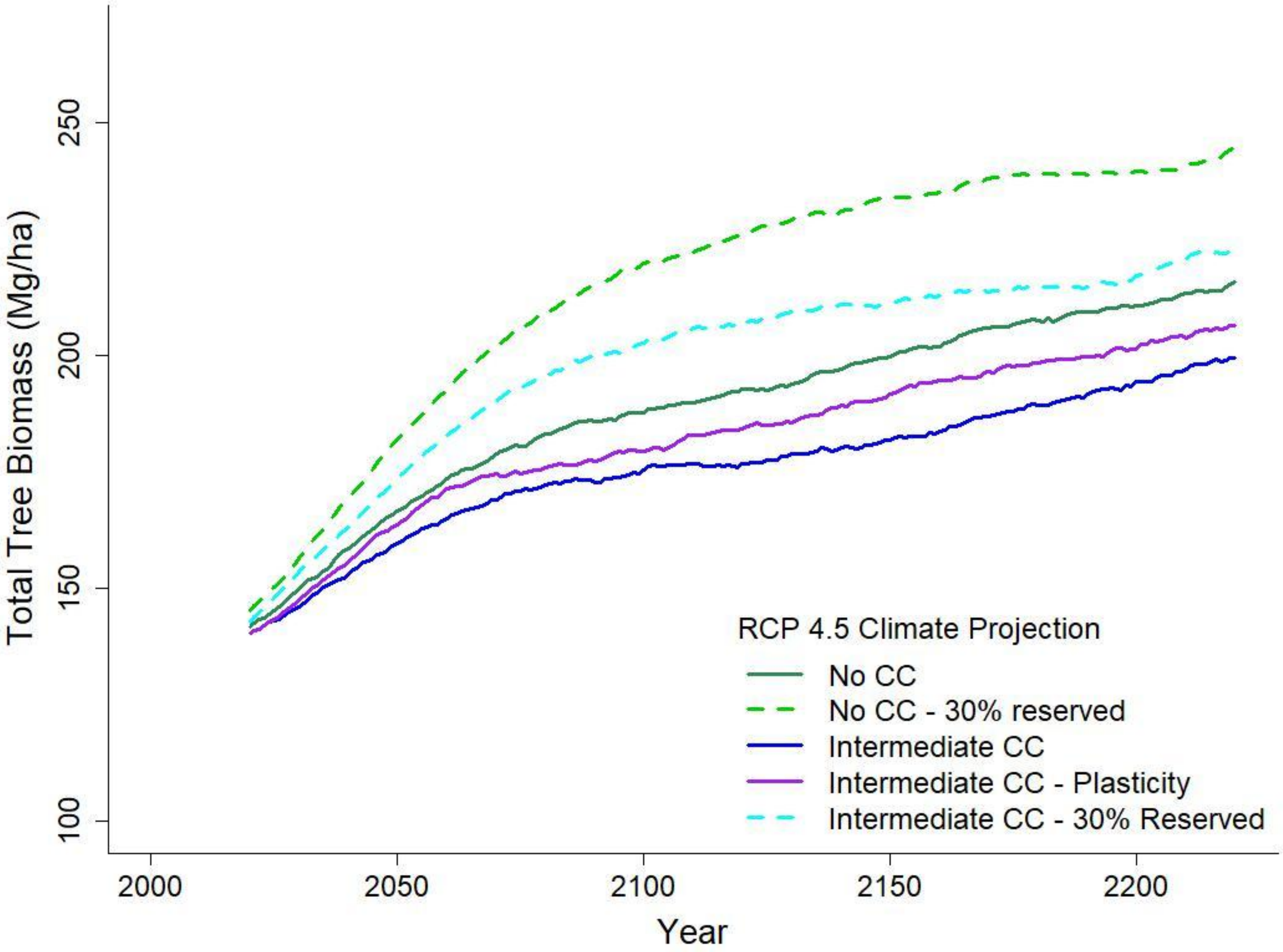
** Fix long-term mean temp and precip to the reference period 1960-1999*

‡ Long-term means set to the trailing 40 years

The bottom line:

Trends in total tree biomass from 2020 to 2220

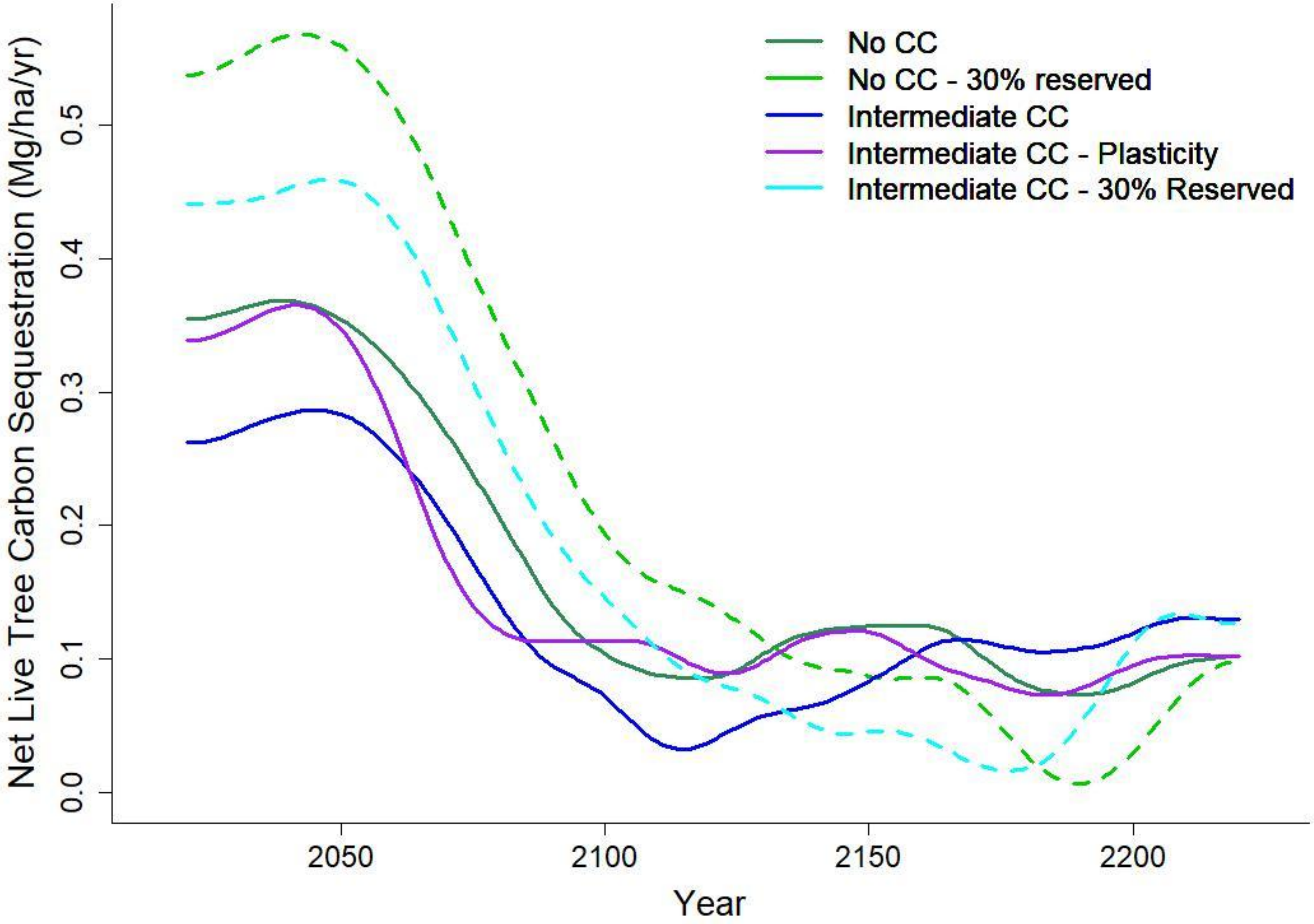
(all 31 eastern states)



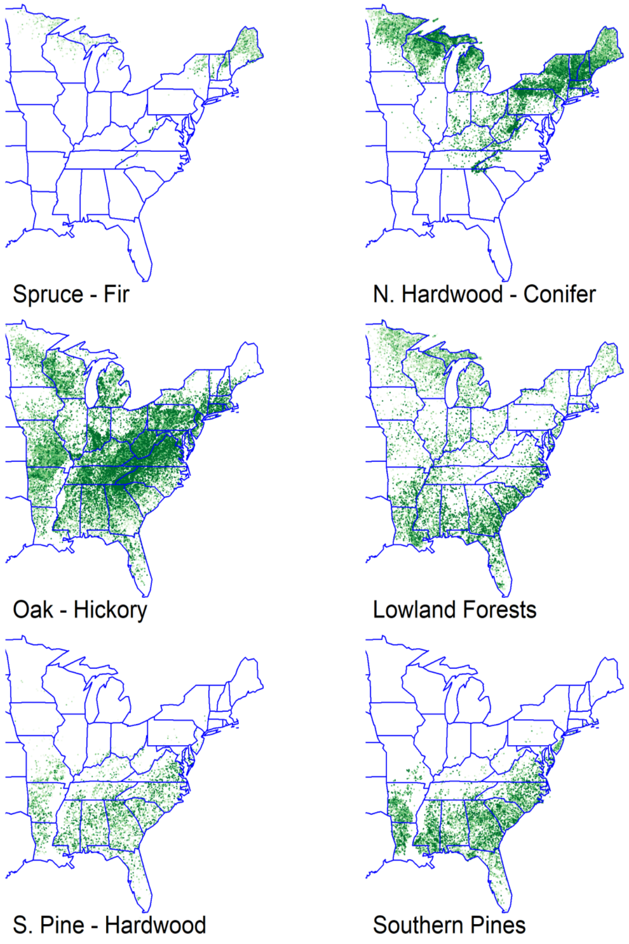
Carbon sequestration rates

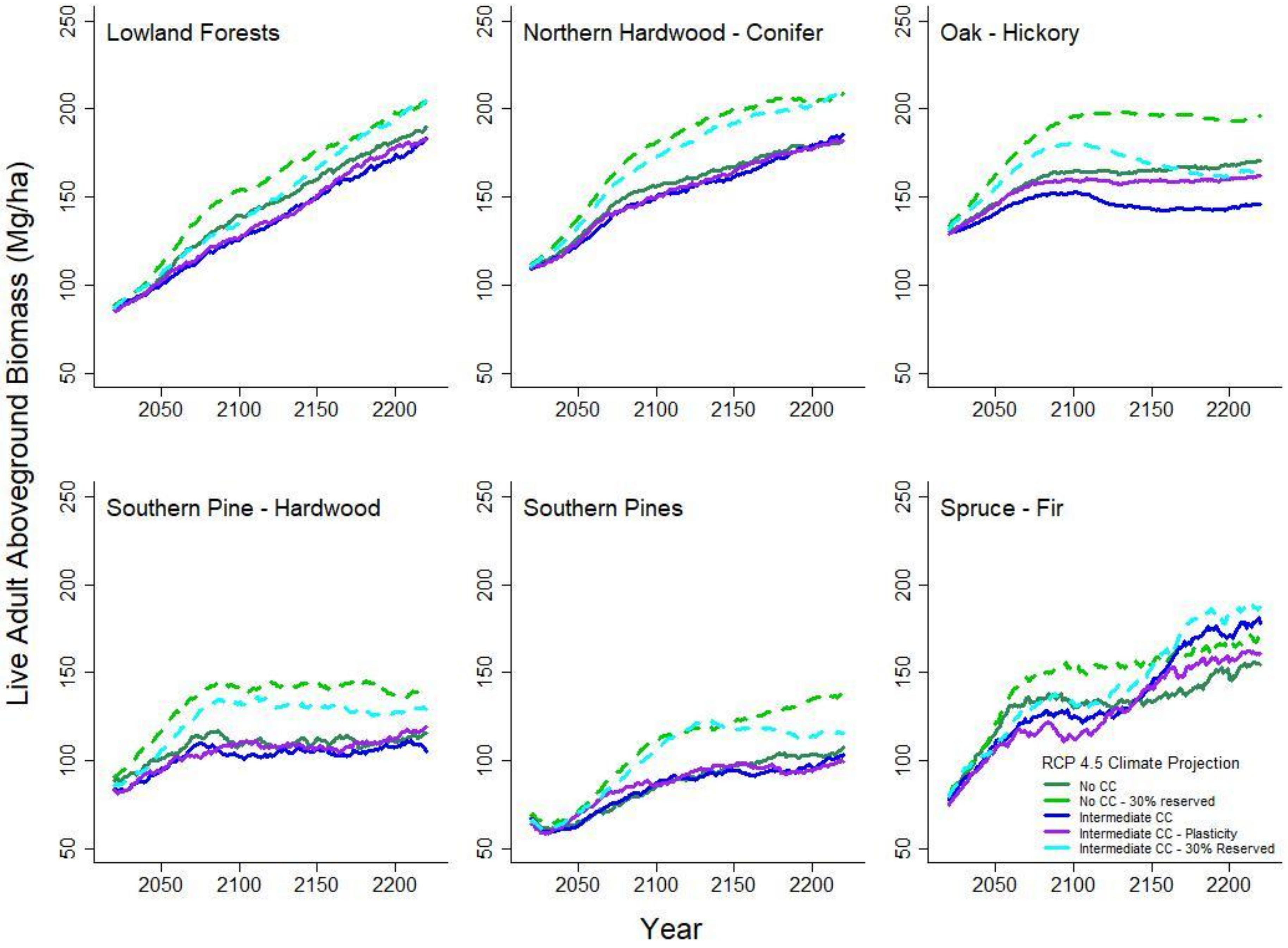
i.e. the first derivative (slope) of the curves for trends in total tree carbon.

Note: curves have been smoothed to remove interannual variability



Trends by forest type

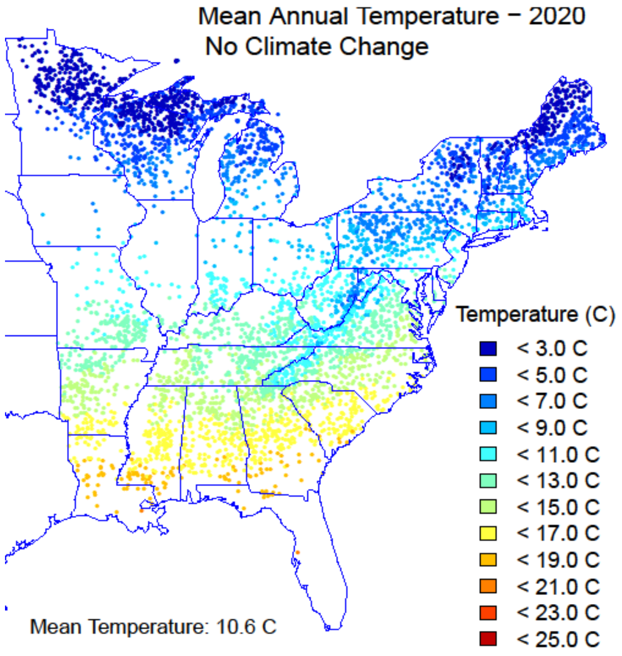


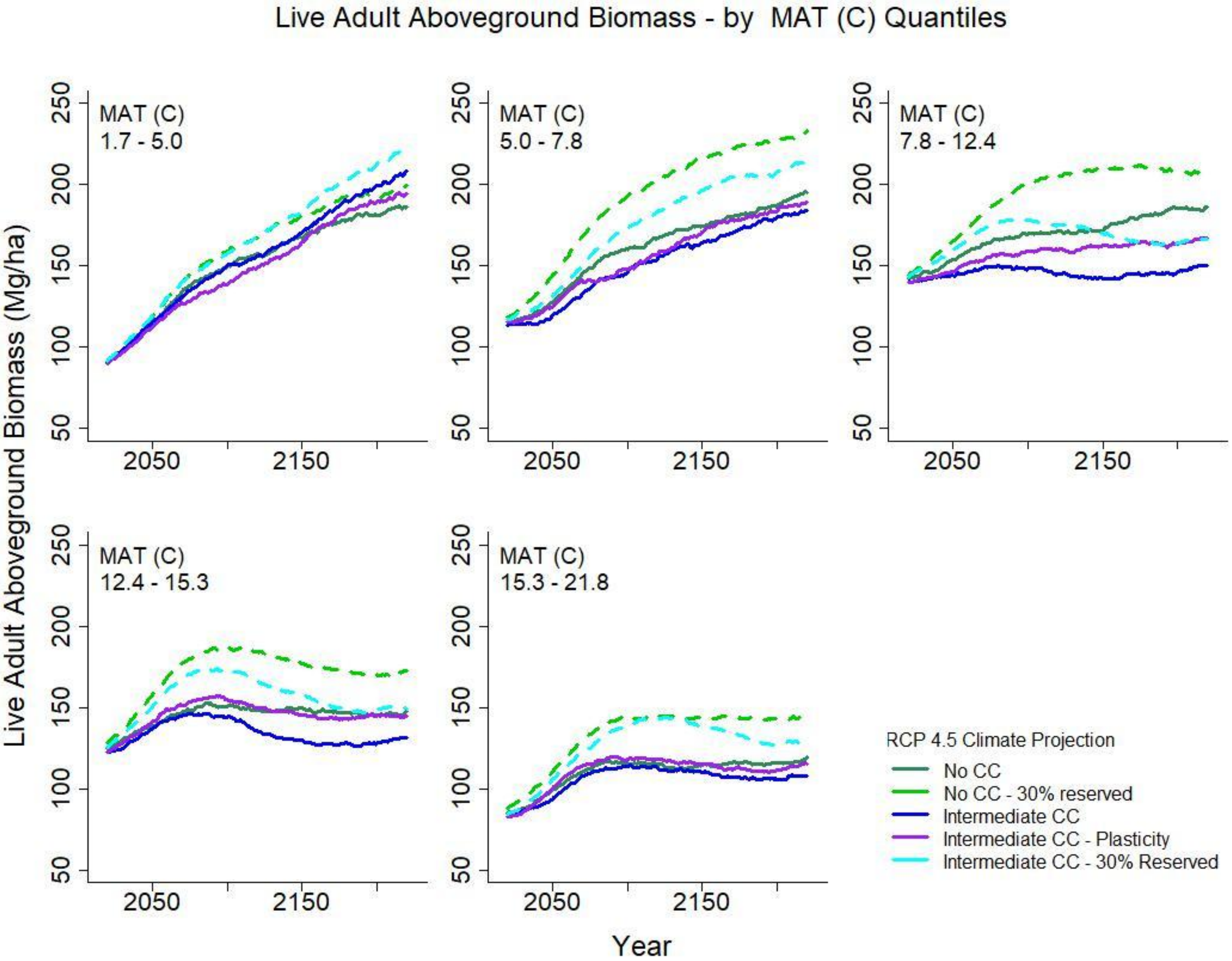


Trends by temperature quantiles

The 5000 plots were divided up into 20% quantiles according to mean annual temperature (MAT) (1960-1999)

Locations with MAT < 5° C are in the upper Midwest and northern Maine





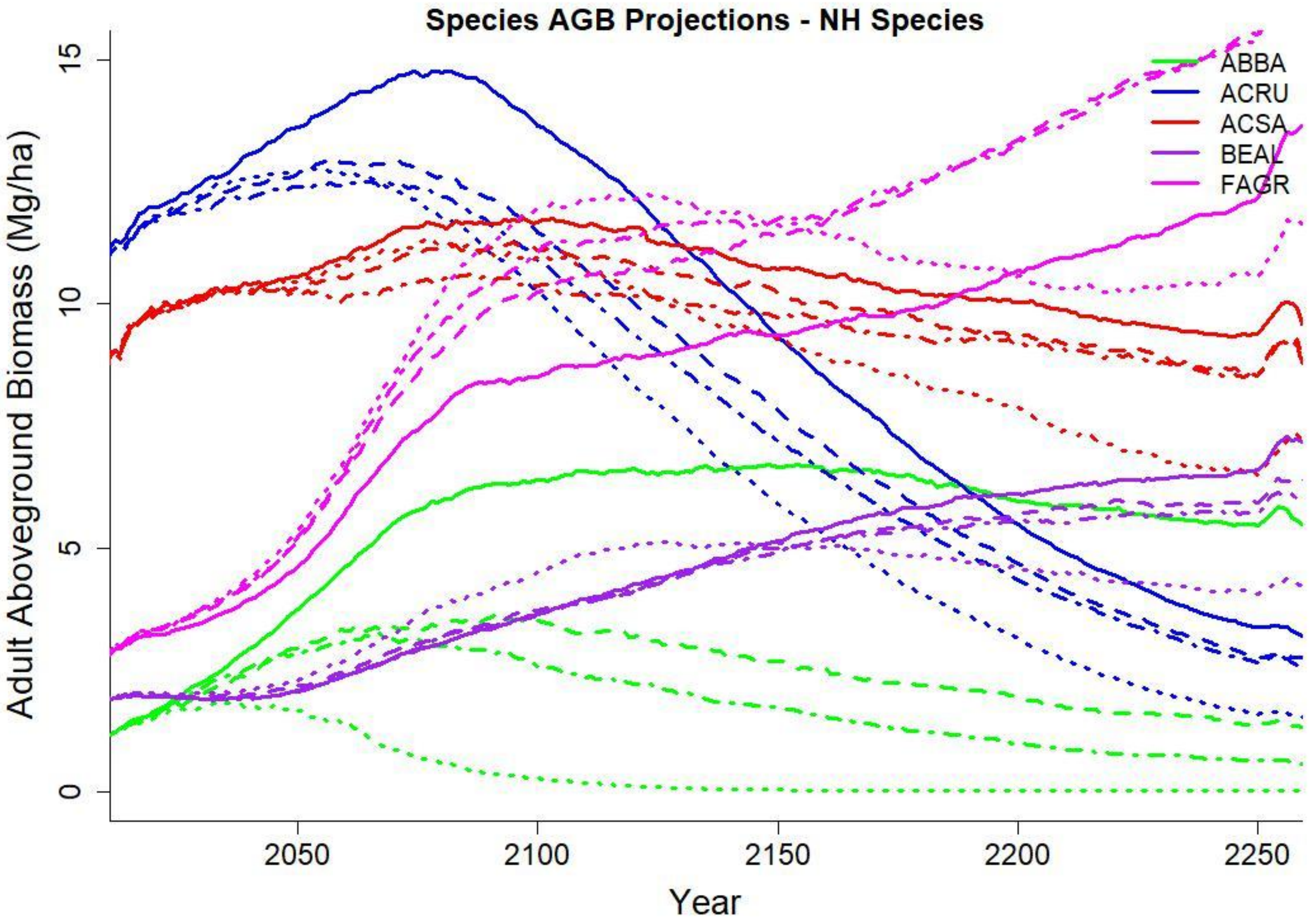
A sample of projected species sensitivities to climate change*

Declines:
ABBA (Balsam fir)
ACRU (Red maple)
ACSA (Sugar maple)

Increases:
FAGR (Beech)

Insensitive:
BEAL (Yellow birch)

across the entire 31-state region



Line Types: No Climate Change: solid, Low Climate Change: dashed, Intermediate Climate Change: dotdash, High Climate Change: dotted

How will climate change alter the ranges of eastern tree species?

- At both the warm and cold ends of the ranges of both eastern and western US tree species, their **presence** (% of stands in which they occur) **declines**, but their **relative abundance** (when present) **does not**.
- And almost all temperate tree species have very broad ranges along temperature gradients, typically > 10° C.
- So the most likely response is a slow **"infilling"** within the current northerly portions of species ranges, **rather than significant changes in range limits**, at least over the next century.

Canham and Thomas (2010)
Ecology 91:3433-3440

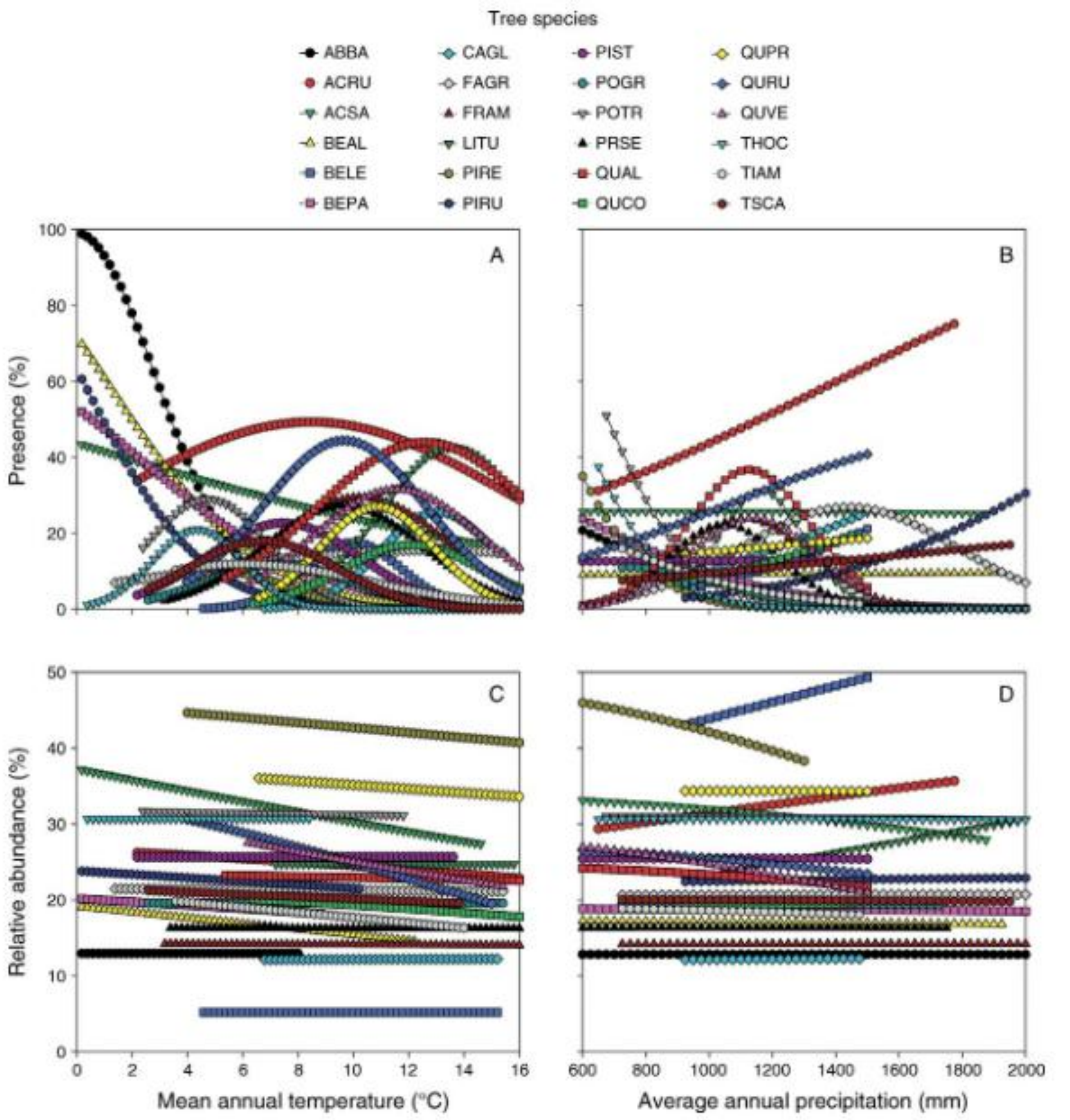


FIG. 1. (A, B) Predicted variation in frequency (presence, the percentage of plots in which the species occurs) and (C, D) relative abundance (percentage of aboveground biomass, when present) for adult trees of the 24 study species, as a function of annual mean temperature and annual precipitation. Maximum-likelihood estimates and two-unit support intervals for the parameters of all of the functions are given in Appendix B. Species abbreviations consist of the first two letters of the genus and specific epithet. The full species names are listed in Table 1.

What have I concluded…
(the basic ecological stuff, regardless of climate change)

- ❖Forests have enormous demographic inertia – change is slow (in the absence of direct human intervention)
- ❖Land-use history (forestry in the mountains, agricultural abandonment and reforestation in the valleys) has impacts that will last for centuries
- ❖Effects of introduced forest pests and pathogens can persist for centuries to millennia!
- ❖The basic dynamics of forest succession are inexorable and predictable, and are defined by shade tolerance
- ❖But the notion of “steady state” is largely meaningless (both practically and theoretically).

How does climate change alter those expectations?

- ❖Even under climate change, **successional dynamics** traced to past land-use and the **current harvest regime** are the dominant driver of future forest dynamics

- ❖Eastern forests will continue to provide important (but gradually declining) **carbon sequestration** for the remainder of this century, even under inevitable climate change
  (… but with little chance that this can be increased significantly!)

- ❖There will be **winners and losers** in the changes in the distribution and abundance of species, determined by the nature of the **adaptation/acclimation** of their demographic responses to **climate**

- ❖But actual **range shifts** in species distributions will be slow and modest