Loblolly Pine Productivity Regional Simulations Under Changing Climate and CO_2 Concentrations

Growth & Yield

Harold Burkhart, Evan Brooks, Heather Dinon Aldridge, Charles Sabatia, Nabin Gyawali, Randolph Wynne, and Valerie Thomas

Overview

- Model
- Data
- Results
- Caveats
- Conclusion

Overview

How are productivity, carbon storage, and water cycling going to change over the 21st century?

Uses individual tree measurements for parameterization

Uses multiple stand biomass pools, experiments, flux towers, prior knowledge, PINEMAP collected data

Widely-used, scales leaf processes to large-scales; coarse resolution with global parameterizations

Implication of change on water cycle

Growth & Yield ⟷ 3PG DAPPER ⟷ CLM-BGC

WASSI

EMPIRICAL (statistical)

Hybrid (data-driven, semi-process)

PROCESS (physiology, biogeochemistry, hydrology)

EMPIRICAL

Model

- GenLob (Gyawali and Burkhart, 2015) is a stand-level growth and yield model
  - Inputs
    - Site Index (SI)
    - Initial Stocking
    - Stand Age
  - Outputs
    - Basal Area
      - Converted into Green Weight, Volume, and ***Carbon***
    - Survival
    - Dominant Height

NRC Research Press

ARTICLE

General response functions to silvicultural treatments in loblolly pine plantations

Nabin Gyawali and Harold E. Burkhart

Abstract: Forest growth and yield models that incorporate common silvicultural practices are essential for practicing intensive forest management. We present models for growth response to a wide range of silvicultural treatments in loblolly pine (*Pinus taeda* L.) plantations. Baseline models for basal area, dominant height, and survival were fitted using data from across the southeastern United States. Growth models for treated stands were developed by multiplying baseline models with modifier response functions accounting for effects of thinning, fertilization, and control of competing vegetation. Response to early control of competing vegetation was incorporated into baseline models through multiplier factors that were calculated from growth differences between treated and untreated stands. The thinning response function included duration and rate parameters and was sensitive to stand age at the time of thinning, time since thinning, and intensity of thinning. Fertilization response functions were based on the Weibull distribution; the magnitude of responses varies with time since application of fertilizers, type of fertilizer, and rate of application. A difference function, derived from a differential equation with age, initial stand density, and site index as predictors, served as the baseline survival model. The survival model was adjusted for thinning treatment by including an additional independent variable that represents thinning intensity. The resulting models were able to predict growth response when single, as well as multiple, treatments were applied.

Key words: modeling, growth and yield, thinning, vegetation management, fertilization, *Pinus taeda*.

Résumé : Des modèles de croissance et de production forestière qui tiennent compte des pratiques sylvicoles courantes sont essentiels pour réaliser un aménagement forestier intensif. Nous présentons des modèles d'impact d'une large gamme de traitements sylvicoles sur la croissance dans des plantations de pins à encens (*Pinus taeda* L.). Nous avons ajusté des modèles de base pour la surface terrière, la hauteur dominante et la survie à l'aide de données couvrant le sud-est des États-Unis. Les modèles de croissance des peuplements traités ont été mis au point en multipliant les modèles de base par des fonctions de réponse modificatrices qui tiennent compte des effets de l'éclaircie, de la fertilisation et de la maîtrise de la végétation concurrente. La réaction à la maîtrise précoce de la végétation concurrente a été introduite dans les modèles de base par des facteurs multiplicatifs calculés à partir de différences de croissance entre les peuplements traités et non traités. La fonction de réaction à l'éclaircie incluait des paramètres de durée et de taux, et est sensible à l'âge du peuplement au moment de l'éclaircie, au temps écoulé depuis l'éclaircie et à l'intensité de l'éclaircie. Les fonctions de réaction à la fertilisation étaient fondées sur la distribution de Weibull alors que l'amplitude des réactions varie en fonction du temps écoulé depuis l'application des fertilisants, le type de fertilisant et le taux d'application. Nous avons utilisé un modèle de base pour la survie fondé sur une fonction de différence, dérivée d'une équation différentielle et ayant comme prédicteurs l'âge, la densité initiale du peuplement et l'indice de qualité de station. Le modèle de survie a été ajusté pour le traitement d'éclaircie en introduisant une variable indépendante supplémentaire représentant l'intensité de l'éclaircie. Les modèles obtenus pouvaient prévoir la réaction de croissance lorsque des traitements simples ou multiples étaient appliqués. [Traduit par la Rédaction]

Mots-clés : modélisation, croissance et production, éclaircie, maîtrise de la végétation concurrente, fertilisation, *Pinus taeda*.

Introduction

Growth and yield models that quantify forest stand dynamics have been widely used in forest operations and management as an effective tool in decision making. Silvicultural practices such as vegetation control, thinning, and fertilization are commonly applied to improve the establishment, growth, quality, composition, and productivity of forest stands. To make management decisions, forest managers need growth models that are designed to incorporate these silvicultural practices and that can also accurately project growth.

Competing vegetation control is one of several silvicultural practices used to enhance productivity in forest stands. The importance of vegetation management is well established; for instance, Wagner et al. (2006) reviewed results from 60 long-term studies on vegetation management in Canada, the United States (US), Brazil, South Africa, New Zealand, and Australia. In a more recent review, McCarthy et al. (2011) summarized the state of forest vegetation management practices in Europe. Past studies on loblolly pine (*Pinus taeda* L.) plantations have documented that early herbaceous and longer term woody vegetation control can enhance growth (Tiarks and Haywood 1986; Glover and Zutter 1993; Miller et al. 2003) by decreasing competition for space, water, nutrients, and light.

Thinning is another important silvicultural practice generally applied in plantation forestry to improve stand structure. Several studies have shown that thinning produces significant changes in the growth of loblolly pine plantations (Short and Burkhart 1992;

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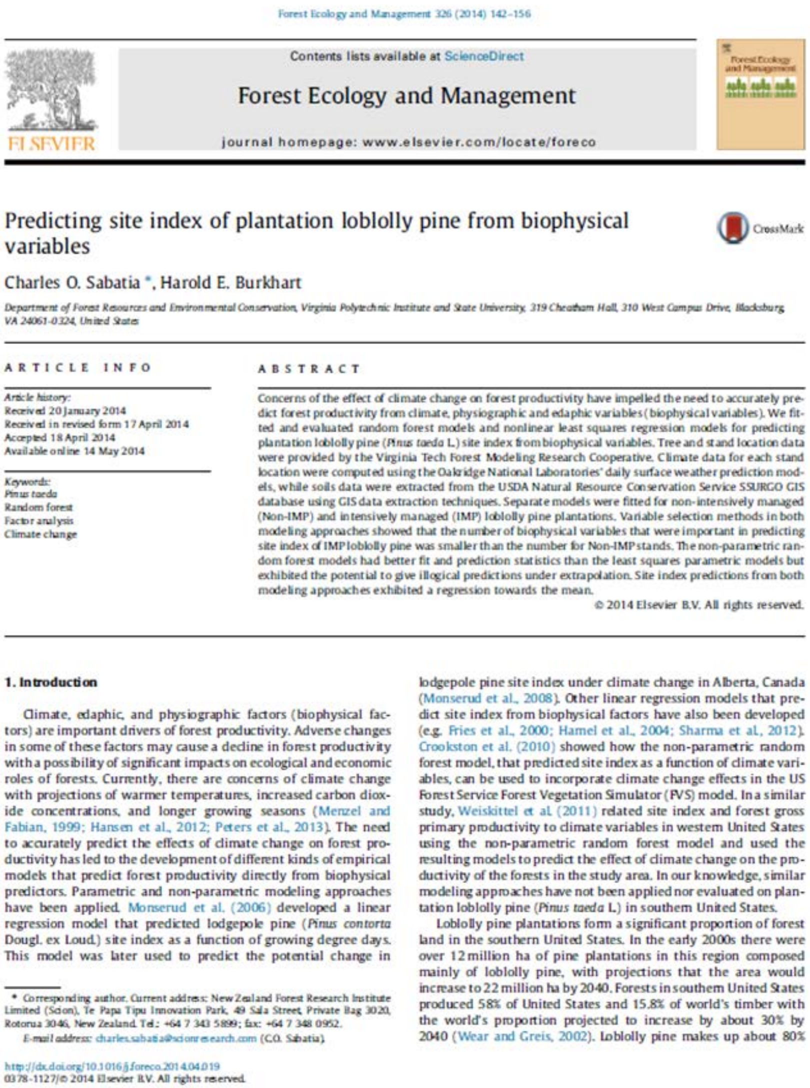
Model

- To obtain SI, we used a biophysical SI prediction model (Sabatia and Burkhart, 2014)
  - Inputs
    - Edaphic
      - Available Soil Water
      - Percent Sand
    - Climactic
      - Total Annual Precipitation
      - Growing Season Days [Temperature]
      - Summer Dryness Index [Temperature & Precipitation]
  - Outputs
    - SI



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Predicting site index of plantation loblolly pine from biophysical variables

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ABSTRACT

Concerns of the effect of climate change on forest productivity have impelled the need to accurately predict forest productivity from climate, physiographic and edaphic variables (biophysical variables). We fitted and evaluated random forest models and nonlinear least squares regression models for predicting plantation loblolly pine (*Pinus taeda* L.) site index from biophysical variables. Tree and stand location data were provided by the Virginia Tech Forest Modeling Research Cooperative. Climate data for each stand location were computed using the Oakridge National Laboratories' daily surface weather prediction models, while soils data were extracted from the USDA Natural Resource Conservation Service SSURGO GIS database using GIS data extraction techniques. Separate models were fitted for non-intensively managed (Non-IMP) and intensively managed (IMP) loblolly pine plantations. Variable selection methods in both modeling approaches showed that the number of biophysical variables that were important in predicting site index of IMP loblolly pine was smaller than the number for Non-IMP stands. The non-parametric random forest models had better fit and prediction statistics than the least squares parametric models but exhibited the potential to give illogical predictions under extrapolation. Site index predictions from both modeling approaches exhibited a regression towards the mean.

1. Introduction

Climate, edaphic, and physiographic factors (biophysical factors) are important drivers of forest productivity. Adverse changes in some of these factors may cause a decline in forest productivity with a possibility of significant impacts on ecological and economic roles of forests. Currently, there are concerns of climate change with projections of warmer temperatures, increased carbon dioxide concentrations, and longer growing seasons (Menzel and Fabian, 1999; Hansen et al., 2012; Peters et al., 2013). The need to accurately predict the effects of climate change on forest productivity has led to the development of different kinds of empirical models that predict forest productivity directly from biophysical predictors. Parametric and non-parametric modeling approaches have been applied. Monserud et al. (2006) developed a linear regression model that predicted lodgepole pine (*Pinus contorta* Dougl. ex Loud.) site index as a function of growing degree days. This model was later used to predict the potential change in lodgepole pine site index under climate change in Alberta, Canada (Monserud et al., 2008). Other linear regression models that predict site index from biophysical factors have also been developed (e.g. Fries et al., 2000; Hamel et al., 2004; Sharma et al., 2012). Crookston et al. (2010) showed how the non-parametric random forest model, that predicted site index as a function of climate variables, can be used to incorporate climate change effects in the US Forest Service Forest Vegetation Simulator (FVS) model. In a similar study, Weiskittel et al. (2011) related site index and forest gross primary productivity to climate variables in western United States using the non-parametric random forest model and used the resulting models to predict the effect of climate change on the productivity of the forests in the study area. In our knowledge, similar modeling approaches have not been applied nor evaluated on plantation loblolly pine (*Pinus taeda* L.) in southern United States.

Loblolly pine plantations form a significant proportion of forest land in the southern United States. In the early 2000s there were over 12 million ha of pine plantations in this region composed mainly of loblolly pine, with projections that the area would increase to 22 million ha by 2040. Forests in southern United States produced 58% of United States and 15.8% of world's timber with the world's proportion projected to increase by about 30% by 2040 (Wear and Greis, 2002). Loblolly pine makes up about 80%

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Model

- We treated CO_2 fertilization as a lift to SI via Westfall and Amateis (2003)

$$\Delta SI = \Delta CO_2^{\,1.61800} \exp(-0.06020\, SI)$$

  - where IPCC concentration trajectories were used as the input data

- In practice, we obtained lifted SI for a given year on an annualized basis:

$$SI_{lifted,\,year} = SI_{lifted,\,year-1} + \Delta SI_{baseline,\,year}$$

A Model to Account for Potential Correlations Between Growth of Loblolly Pine and Changing Ambient Carbon Dioxide Concentrations

James A. Westfall, *USDA Forest Service Northeastern Research Station, Newtown Square, PA 19703, and* **Ralph L. Amateis,** *Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.*

ABSTRACT: *Continuously increasing concentrations of atmospheric carbon dioxide (CO_2) may be leading to enhanced growth rates for loblolly pine. In order to plan effectively silvicultural regimes and harvesting schedules, managers of loblolly pine plantations may wish to account for these potential changes when making growth and yield projections. Data from 94 unthinned plots across the Southeast were used to develop an equation that utilizes change in ambient CO_2 concentration and initial site quality to predict change in site index (ΔSI). For a given change in CO_2 concentration, a greater increase in site index is afforded to lower quality sites. The ΔSI equation was incorporated into a loblolly pine growth model. Simulations with and without site index adjustments were performed and plot volume estimates were compared to observed values. Mean percent residual dropped from 9.7% with no adjustment to –0.5% when ΔSI was employed. Forest managers can use this model to evaluate how possible CO_2-induced growth increases may affect long-term timber yields and management strategies. South. J. Appl. For. 27(4):279–284.*

Key Words: Climate change, growth and yield, *Pinus taeda*, carbon dioxide.

Environmental conditions are always changing due to natural phenomena and human activity. The effects of these changes and the effects on the earth as a whole are topics for debate. Regardless, it seems to be a safe assumption that environmental conditions in the future will not be the same as those of today. For instance, long-term data from Mauna Loa, Hawaii show that atmospheric carbon dioxide (CO_2) levels have maintained a roughly linear rate of increase of 1.4 ppm/yr since the late 1950s (Conway et al. 1994). If this trend continues, the ambient CO_2 concentration will increase by approximately 40% over the next century. Houghton et al. (1995) suggest CO_2 concentrations of 650–700 ppm by 2075, essentially a doubling of current levels.

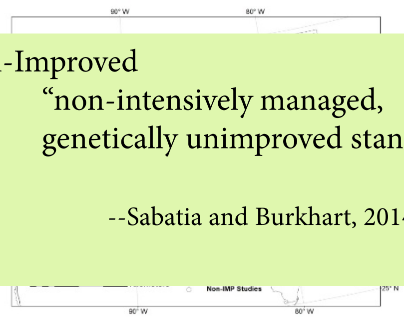
The potential impact of increased CO_2 concentrations should be of interest to commercial forest managers as long-term projections of growth and yield are necessary to create and implement appropriate management plans. Research on loblolly pine has shown that photosynthetic rates increase as CO_2 concentrations are increased (Tissue et al. 1993, Ellsworth et al. 1995, Hennessey and Harinath 1998). While increases in photosynthesis do not necessarily equate to faster growth, study results indicate that increases in growth are being realized under elevated CO_2 concentrations (Teskey 1997, Alemayehu et al. 1998, Saxe et al. 1998). Increased growth rates due to enhanced CO_2 concentration would likely affect the planning of silvicultural regimes and harvest scheduling (Groninger et al. 1999).

Enhanced rates of growth for loblolly pine would be accompanied by increasing site index values. Valentine et al. (1999) estimated that site index would increase approximately 9.4% over a 20 yr period using results from the carbon-balance process model Pipestem. Baldwin et al. (2001) presented a linked growth and yield/process model system that takes environmental conditions into account when making growth projections. Results from that study suggest a mean increase in site index of 0.28 ft/yr for loblolly pine plantations in the Southeast. While these results are useful, they require model simulation runs in order to be applicable to a given stand

NOTE: James A. Westfall can be reached at (610) 557-4043; Fax: (610) 557-4250; E-mail: jameswestfall@fs.fed.us. Ralph L. Amateis can be reached at (540) 231-7263; E-mail: ralph@vt.edu. The authors gratefully acknowledge the support of the Loblolly Pine Growth and Yield Research Cooperative at Virginia Tech. Manuscript received July 23, 2002, accepted January 22, 2003.

Sources of Variability

Management Cases x1



Non-Improved
“non-intensively managed, genetically unimproved stands”

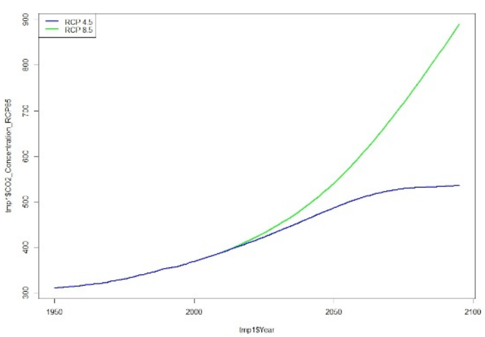
--Sabatia and Burkhart, 2014

Climate Scenarios (RCPs) x2

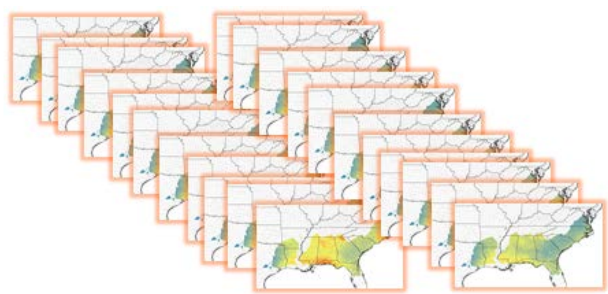
Future Time Slices x4

- 2020-2039
- 2040-2059
- 2060-2079
- 2080-2099

CO_2 Level x2
(1 per RCP)



Global Climate Models (GCMs) x20



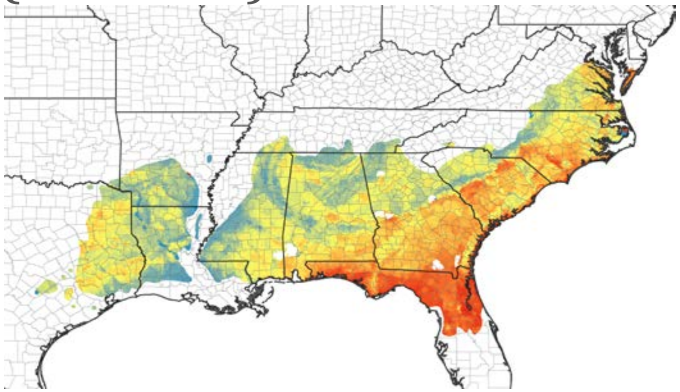
Stand Ages x25

- 1-25 years

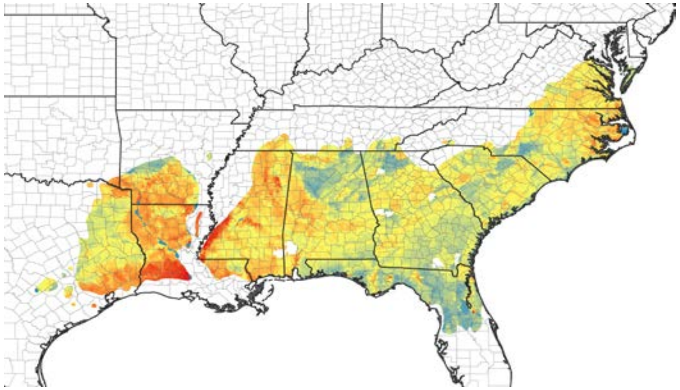
CO_2 concentration was treated as uniform across the region
Soil variables were treated as constant through time

Data

- Soils (SSURGO)

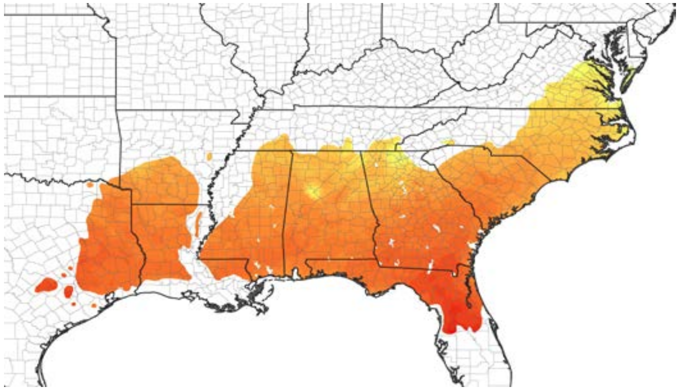


Percent Sand

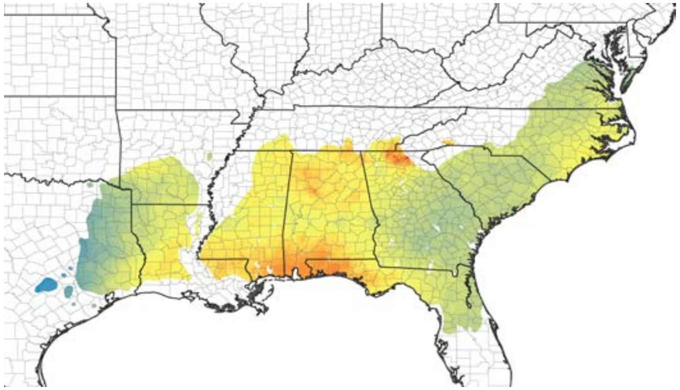


Available Soil Water

- Climate (MACA)



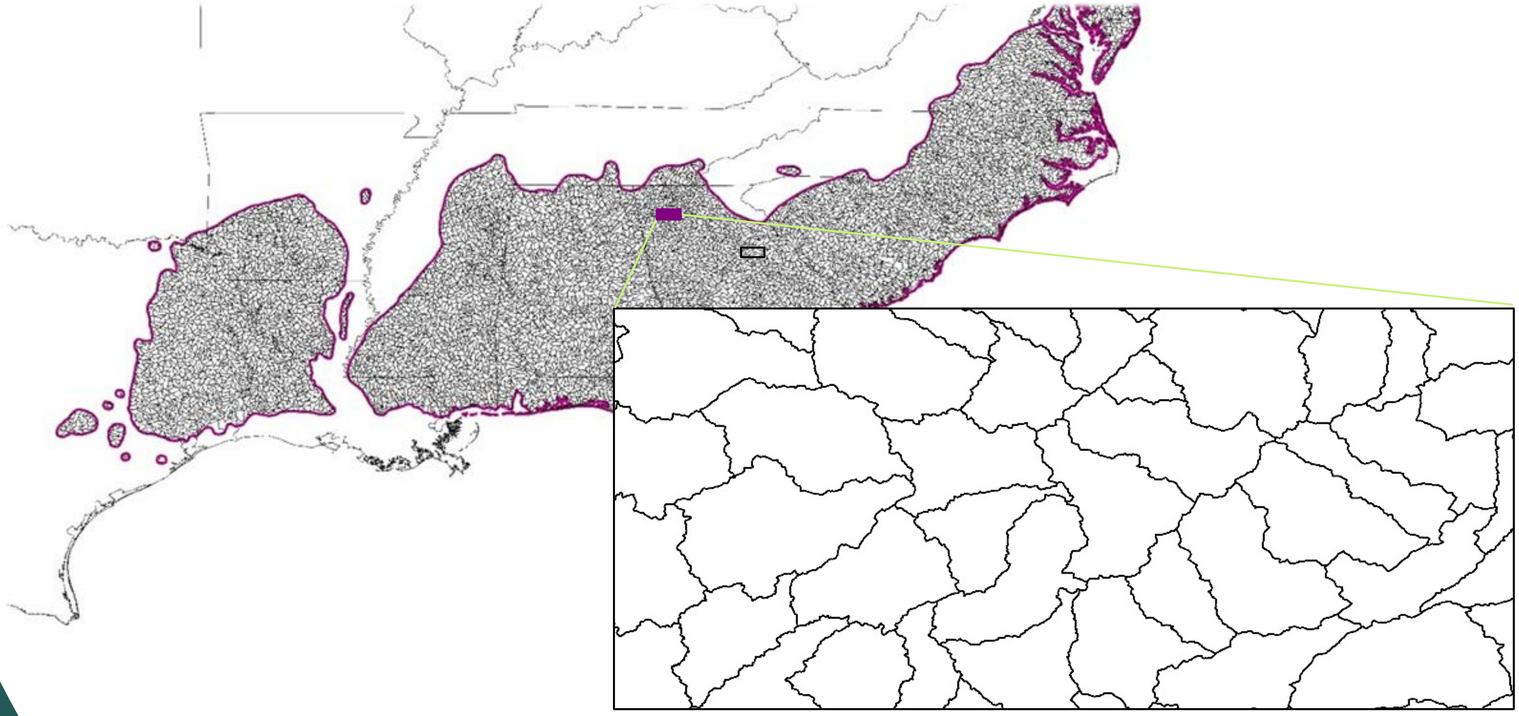
Temperature



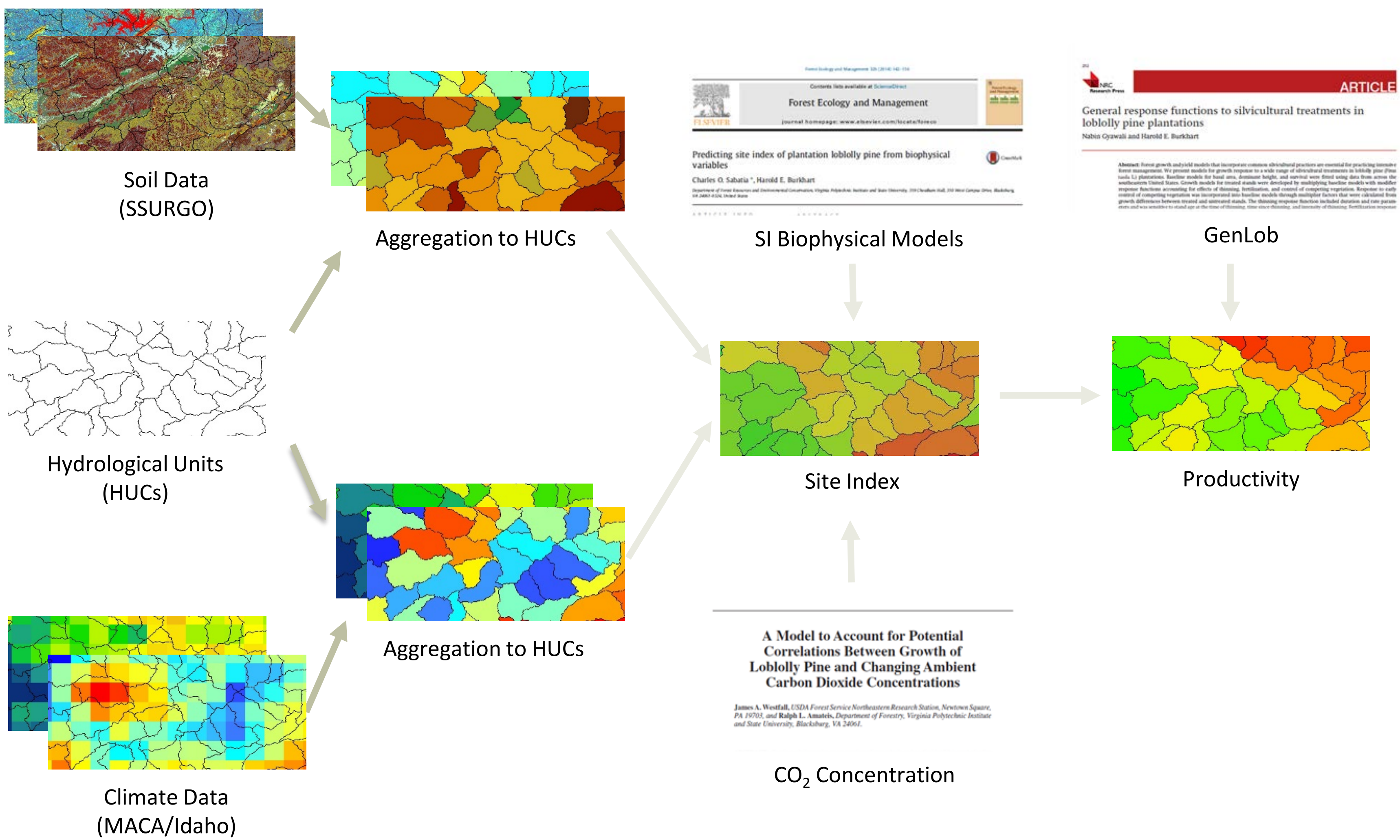
Precipitation

Data

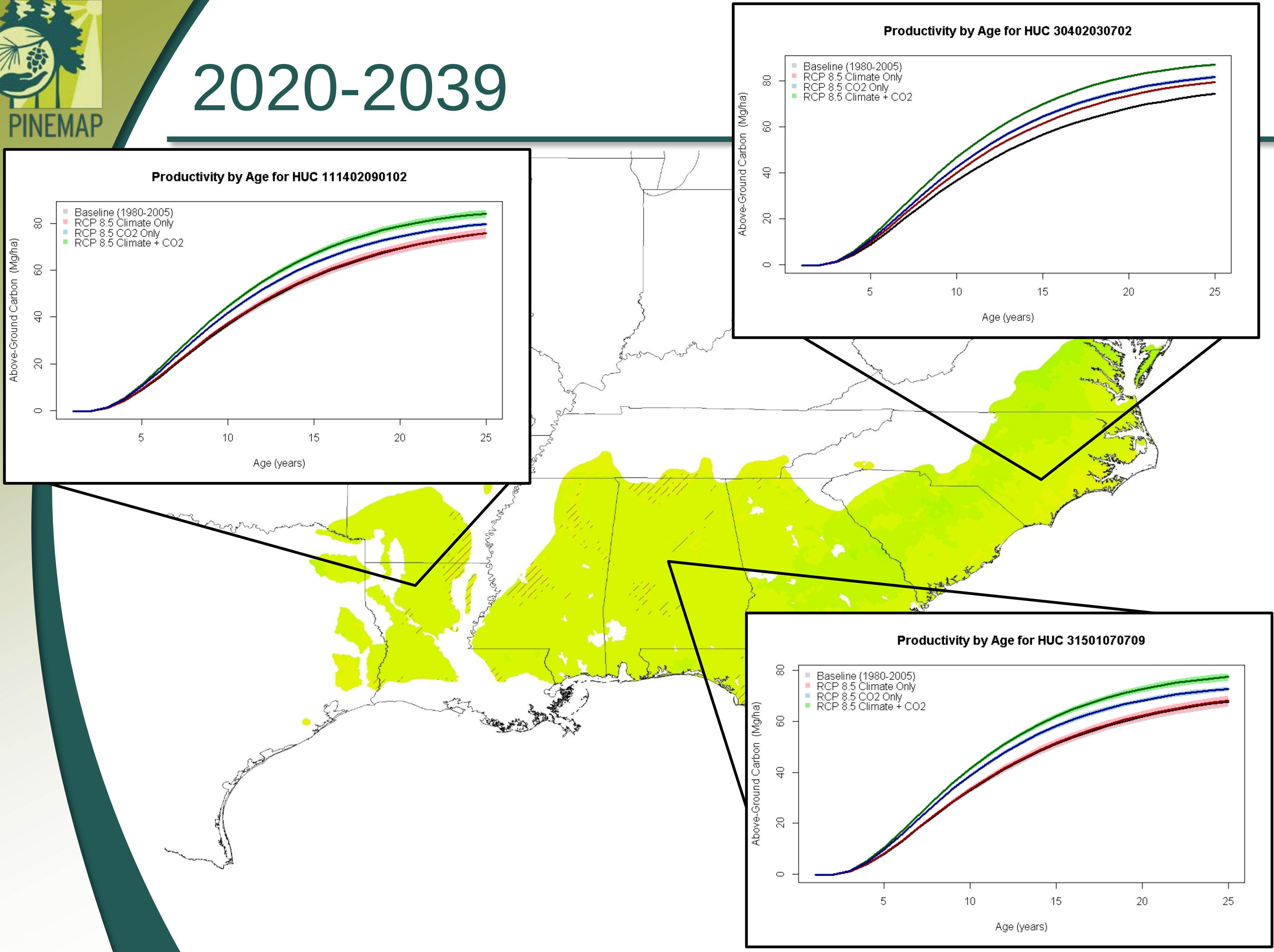
- Primary spatial unit is 12-digit hydrological unit code features (HUCs) from the USGS
  - Chosen to facilitate model intercomparison
  - Balances spatial scope with tractability
  - ~18000 HUCs across the PINEMAP region of interest
    - Median size: ~22000 acres



Regionalization Process

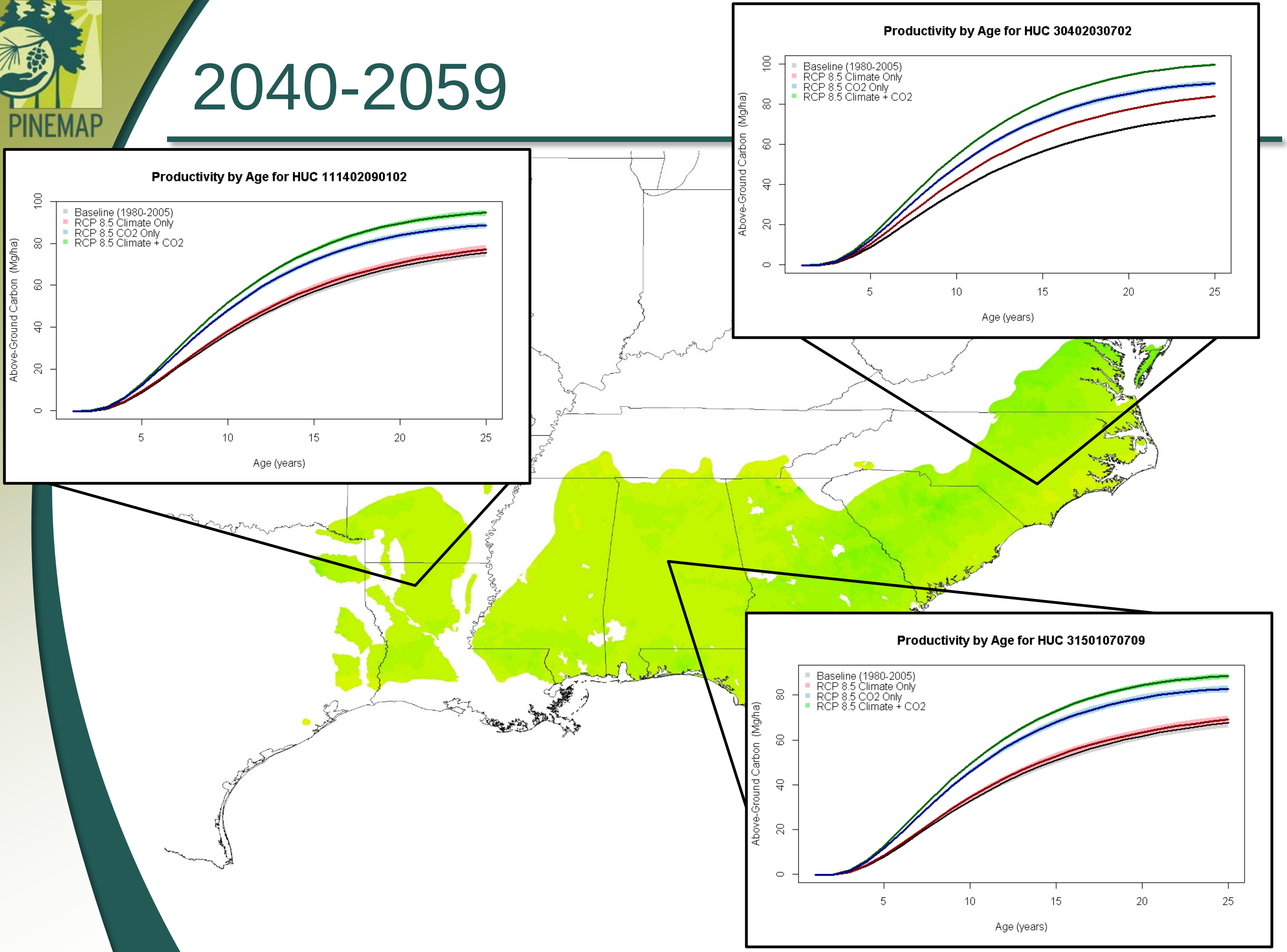


2020-2039



Productivity by Age for HUC 111402090102
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0
20
40
60
80
5
10
15
20
25
Age (years)
Productivity by Age for HUC 30402030702
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0
20
40
60
80
5
10
15
20
25
Age (years)
Productivity by Age for HUC 31501070709
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0
20
40
60
80
5
10
15
20
25
Age (years)

2040-2059



Productivity by Age for HUC 111402090102
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
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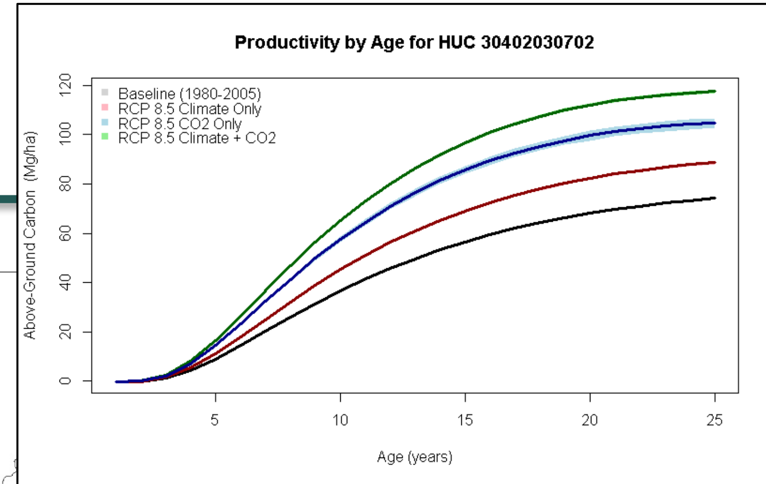
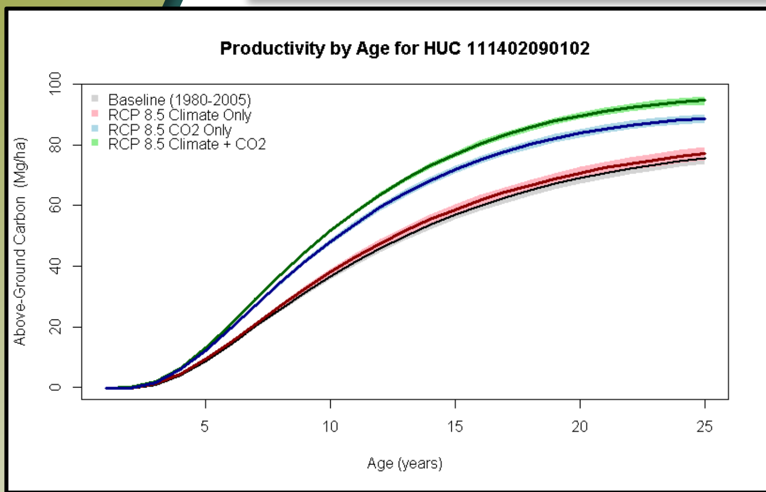
20
25
Age (years)
Productivity by Age for HUC 31501070709
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0
20
40
60
80
5
10
15
20
25
Age (years)

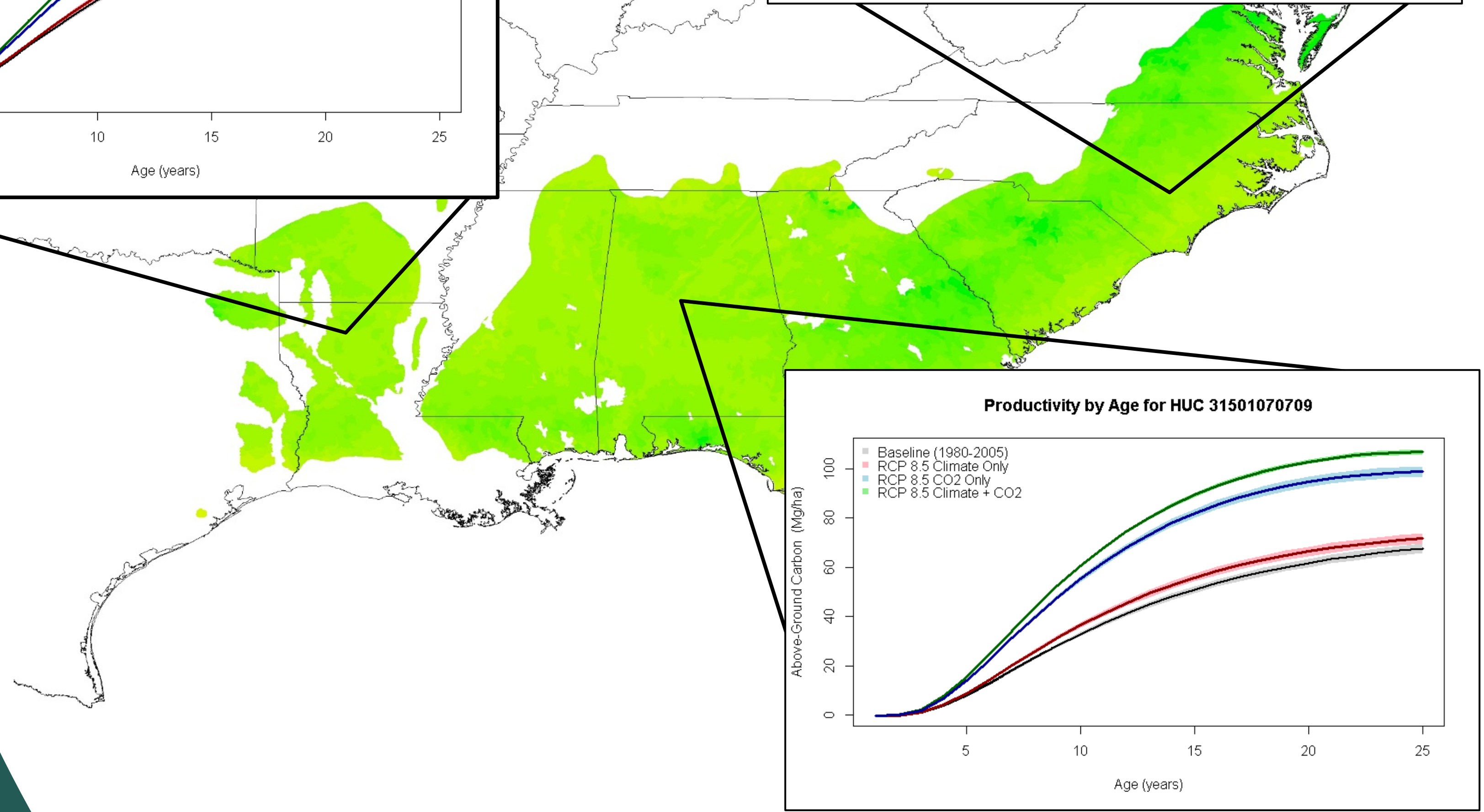
2060-2079



Productivity by Age for HUC 30402030702
Above-Ground Carbon (Mg/ha)
Age (years)
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2

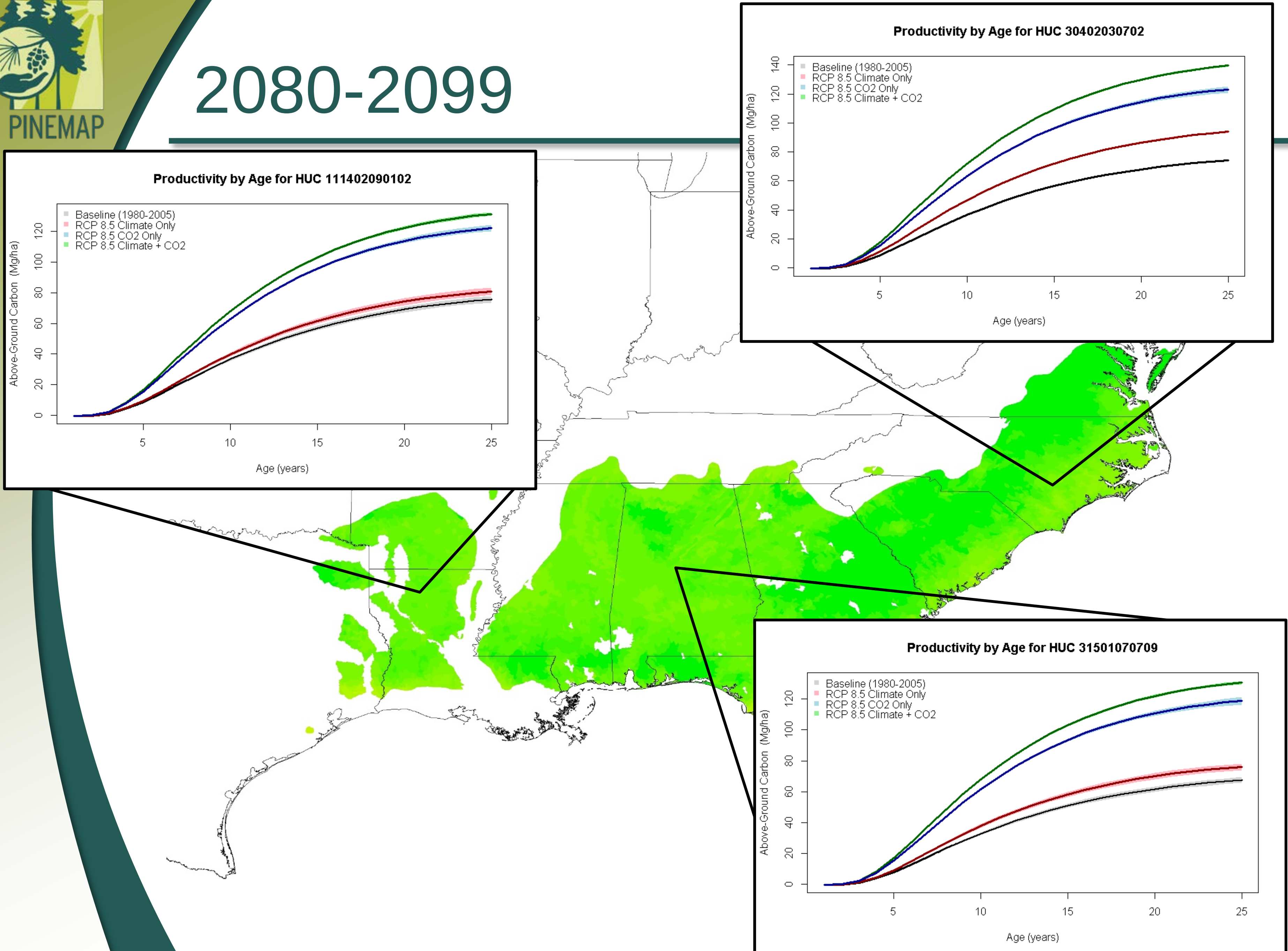


Productivity by Age for HUC 111402090102
Above-Ground Carbon (Mg/ha)
Age (years)
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2



Productivity by Age for HUC 31501070709
Above-Ground Carbon (Mg/ha)
Age (years)
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2

2080-2099


Productivity by Age for HUC 30402030702
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0 20 40 60 80 100 120 140
5 10 15 20 25
Age (years)
Productivity by Age for HUC 111402090102
Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0 20 40 60 80 100 120
5 10 15 20 25
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Baseline (1980-2005)
RCP 8.5 Climate Only
RCP 8.5 CO2 Only
RCP 8.5 Climate + CO2
Above-Ground Carbon (Mg/ha)
0 20 40 60 80 100 120
5 10 15 20 25
Age (years)

PINEMAP

Results

RCP 8.5 (business as usual)	2020-2039	2040-2059	2060-2079	2080-2099
Climate Only	3.5% ± 3.6% (30.9% significant)	7.1% ± 6.3% (49.8% significant)	12.2% ± 9.6% (66.3% significant)	17.9% ± 12.6% (76.8% significant)
CO_2 Only	7.2% ± 4.7% (44.3% significant)	19.7% ± 8.3% (94.4% significant)	39.7% ± 13.8% (98.9% significant)	65.1% ± 20.1% (100.0% significant)
Climate + CO_2	14.9% ± 5.7% (97.0% significant)	30.9% ± 10.4% (98.4% significant)	55.2% ± 16.6% (99.7% significant)	84.2% ± 24.2% (100.0% significant)
RCP 4.5 (peak emissions ca. 2040)				
Climate Only	3.0% ± 3.4% (25.5% significant)	6.5% ± 5.6% (44.2% significant)	10.0% ± 7.5% (62.6% significant)	12.7% ± 9.4% (69.0% significant)
CO_2 Only	6.1% ± 4.4% (38.7% significant)	13.2% ± 6.5% (81.5% significant)	19.7% ± 8.4% (94.4% significant)	22.7% ± 9.2% (95.7% significant)
Climate + CO_2	14.6% ± 5.5% (96.3% significant)	30.6% ± 10.0% (98.4% significant)	52.9% ± 15.6% (99.6% significant)	78.9% ± 22.0% (100.0% significant)

Caveats

- GenLob runs on an annual time step
  - Insensitive to disturbance conditions
    - Drought, Insects, Fire, Disease (DIFD)
- Optimal CO_2 fertilization presented here require sufficient complementary Nitrogen deposition
- Management practices (silviculture, site preparation) and genetic improvements were not considered here
  - Baseline runs
- Other sources of variability
  - Accounted for: Climate, RCP, Age
  - Not accounted for: Parameter, Process, Measurement

Conclusion

- From the empirical, stand-level perspective, loblolly productivity receives beneficial effects from warmer, wetter climate and additional atmospheric CO_2

- Further work includes…
  - Publication (Paper currently in preparation)
  - Intercomparison with other PINEMAP models
  - Accounting for additional sources of variability
  - Incorporation of results into the DSS

Thank You!

- Selected references:

  - Sabatia, Charles O., and Harold E. Burkhart. "Predicting site index of plantation loblolly pine from biophysical variables." *Forest Ecology and Management* 326 (2014): 142-156.
  - Gyawali, Nabin, and Harold E. Burkhart. "General response functions to silvicultural treatments in loblolly pine plantations." *Canadian Journal of Forest Research* 45.3 (2014): 252-265.
  - Westfall, James A., and R. L. Amateis. "A model to account for potential correlations between growth of loblolly pine and changing ambient carbon dioxide concentrations." *Southern Journal of Applied Forestry* 27.4 (2003): 279-284.