PINEMAP

Pine Integrated Network: Education, Mitigation, and Adaptation Project

Final Report | March 2015-February 2019

Mapping the future of southern pine management in a changing world

ACKNOWLEDGMENTS

This report highlights research results and programs from the PINEMAP project during the final two funded years of the project, plus a period of no-cost extension work (March 2015-February 2019). We acknowledge the dedication and hard work of the entire PINEMAP team throughout the course of this long-term, regional project (see pages 80 through 83 for complete team list).

We would like to give special thanks to Dr. Eric Norland, our NIFA National Program Leader. Dr. Norland was ideally suited to guide our project through its many phases, and was a ready source of wisdom, advice, and encouragement for the entire team.

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PINEMAP

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USDA United States Department of Agriculture | National Institute of Food and Agriculture

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Introduction

Welcome to the final Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP) report. PINEMAP was a Coordinated Agricultural Project funded in 2011 by the United States Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA). PINEMAP focused on the 20 million plus acres of planted pine forests managed by private landowners in the Atlantic and Gulf coastal states from Virginia to Texas, plus Arkansas and Oklahoma. These forests provide critical economic and ecological services to citizens of the United States. Southeastern forests contain one third of contiguous U.S. forest carbon and form the backbone of an industry that supplies 16% of global industrial wood, 5.5% of the jobs, and 7.5% of the industrial economic activity in the region.

NIFA funded PINEMAP to create, synthesize, and disseminate knowledge that enables southern pine landowners to

- manage forests to increase carbon sequestration;
- increase the efficiency of nitrogen and other fertilizer inputs; and
- adapt forest management approaches and plant improved tree varieties to increase forest resilience and sustainability under variable climates.

The PINEMAP team assembled to achieve these goals consisted of over 100 scientists, students, and staff at eleven southeastern U.S. land grant universities and the U.S. Forest Service. We collaborated with several partner networks to conduct interdisciplinary research and integrate research, education, and Extension activities.

This final report provides an overview of some of the major PINEMAP accomplishments, with a focus on productivity and carbon sequestration, genetics, education, economics and policy, and outreach. More detail on these and other outputs and outcomes can be found in previous PINEMAP reports. While the research, outreach, and education work produced by PINEMAP is invaluable, perhaps our biggest accomplishment was summarized by Extension team member Leslie Boby: "PINEMAP essentially started the climate conversation with southern foresters. Prior to PINEMAP, there was little dialog in the region concerning climate and planted pine forestry." We trust that the science produced, synthesized, and disseminated by PINEMAP will enable this conversation to continue into the future for those that manage this important resource.

Outcome Themes

PINEMAP is charged with producing real-world outcomes, and accordingly, the tasks are organized around a set of outcome themes. The articles in this report are tagged with icons symbolizing one or more of the outcome themes supported by the research they describe.

Increased carbon (C) sequestration from silvicultural and genetic enhancement of productivity and efficiency of fertilizer use, and resilience to climate variability and disturbance.
Planted southern pine forests already contribute to climate change mitigation by taking up and storing (sequestering) enormous amounts of atmospheric CO_2*, both in trees and soil, and in long-lived wood products. PINEMAP produces knowledge necessary to increase the amount of* CO_2 *sequestered through enhancement of forest productivity, more efficient use of fertilizers, and management of forests for resilience to climate variability and disturbance.*

Engaged and literate public with the capacity to make informed, practical decisions related to climate, forest ecosystems, and forest management.
In a democratic society, rational public policy and decision making depend to a large extent on public understanding of and engagement with societal problems. PINEMAP's education programs are designed to help nonscientists better understand and grapple with the complex issues surrounding climate and forest management.

Public policy that supports sustainable management of planted pine under future climate scenarios.
The biophysical and human dimensions research produced by PINEMAP provides information critical for guiding the development of rational natural resource policy.

Enhanced capacity for regional, interdisciplinary collaboration among climate and forest scientists and Extension and education professionals.
PINEMAP's unprecedented coalition of more than 120 forestry researchers, educators, Extension professionals, and students is building new networks and new infrastructure for cutting-edge, collaborative, and outcome-based science.

Enhanced connections between corporate and noncorporate forest landowners and forestry and climate researchers and education and outreach professionals.
Research performed in isolation has little impact on society. PINEMAP strives to strengthen existing and build new connections to on-the-ground forest management so that the science can be quickly translated to outcomes that benefit society.

A more robust and resilient forest-based economy in the Southeast U.S.
PINEMAP research enables pine landowners in the Southeast U.S. to continue producing economic and ecological services that benefit society.

PINEMAP Team

- 59 principal investigators
- 34 research/technical staff
- 12 postdoctoral research associates
- 66 graduate students

Team members were associated with the USDA Forest Service and the following 11 southeastern land grant universities:

- Alcorn State University
- Auburn University
- Mississippi State University
- North Carolina A&T University
- North Carolina State University
- Oklahoma State University
- Texas A&M University
- University of Florida
- University of Georgia
- Virginia Polytechnic Institute and State University (Virginia Tech)
- Virginia State University

See Appendix A for a complete team list.

PINEMAP Partnerships and Networks

A key element of PINEMAP's success is the ability to leverage and expand existing, successful networks. PINEMAP partnerships and networks include the following:

State climate offices and the multi-state Southeast Climate Consortium
State climatologists, primarily located at participating universities, have a common mission to support the advancement of climate information, science application, and education. These scientists serve as local resources on climate. The Southeast Climate Consortium (SECC) is a multidisciplinary, multi-institutional team that uses advances in climate sciences to provide scientifically sound information and decision support tools for agricultural ecosystems, forests and other terrestrial ecosystems, and coastal ecosystems in the southeastern United States.

Southern Regional Extension Forestry
Southern Regional Extension Forestry (SREF) is working with the PINEMAP Extension team to disseminate emerging knowledge, practices, and decision support tools to enable corporate and noncorporate landowners to increase forest carbon sequestration, nitrogen fertilizer efficiency, and forest resilience under variable climates.

Project Learning Tree®
Project Learning Tree® (PLT), an award-winning national environmental education program, is partnering with PINEMAP to assist in the development and implementation of a new secondary module on climate change and southern pine forests.

University-Corporate-Governmental Forestry Research Cooperatives
Members of forestry research cooperatives in the Southeast have tremendous impact on the management of more than 20 million acres of planted forests in the region (about 55% of the privately owned planted southern pine forestland). Corporate members of research cooperatives also produce 95% of the pine seedlings planted in the region each year. Partnerships with these research cooperatives enable PINEMAP to translate research results into practical applications for industrial land managers in the Southeast. These research cooperatives also share data with PINEMAP to establish regional carbon, nutrient, and water baselines. Research cooperative partners include the following:

- *Cooperative Forest Genetics Research Program*
- *North Carolina State University (NCSU) Cooperative Tree Improvement Program*
- *Forest Biology Research Cooperative*
- *Forest Modeling Research Cooperative*
- *Forest Productivity Cooperative*
- *Plantation Management Research Cooperative*
- *Southern Forest Resource Assessment Consortium*
- *Western Gulf Forest Tree Improvement Program*

United States Department of Agriculture Forest Service
Researchers from the USDA Forest Service Southern Research Station Eastern Forest Environmental Threat Assessment Center, Southern Institute of Forest Genetics, and Southern Institute of Forest Ecosystems Biology assist with PINEMAP research efforts.

1. Carbon Summary

Timothy Martin
University of Florida

Increased carbon (C) sequestration from silvicultural and genetic enhancement of productivity and efficiency of fertilizer use, and resilience to climate variability and disturbance.

One of the primary goals for PINEMAP was to improve our understanding of how forest productivity and carbon sequestration will be affected by future predicted climate and how management and other factors might impact that response. Our scientific approach was anchored by data collected in a three-tiered monitoring network deployed across the region and integrated within the context of climate and policy by a large-scale modeling effort.

Regional monitoring network

The Tier I legacy network (Figure 1.1) consisted of hundreds of existing silviculture experiments and growth-and-yield plots blanketing the region, which provided extensive, spatially explicit information on regional variability in productivity. Data from Tier I provided information about plantation productivity on an unprecedented scale and enabled our modeling team to perfect the building and validation of the regional models.

The Tier II active experiments network (Figure 1.2) contained 127 active silvicultural trials that covered the full range of climate and soils in the region on which detailed carbon (C) and nutrient balance were measured. Notably, this network provided probably the most thorough set of measurements of deep (to 1 meter) soil carbon in the region. A final update on those measurements is contained later on in this report. Other than some subtle effects of thinning on forest floor and deep soil C components, no management approach had a major, detectable impact (positive or negative) on plantation carbon pools. This suggests that the substantial carbon sequestration capacity of southern pine plantation forests is robust to the existing variation in management, climate, and soils in the Southeast U.S.

Finally, the Tier III throughfall reduction x fertilization network (Figure 1.3) was established on four sites situated at the edges of the loblolly pine range. In these studies, nutrients and water were manipulated through fertilization and ~30% reduction of rain falling through the forest canopy (throughfall). The Tier III study provided the most comprehensive, range-wide experimental assessment of loblolly pine carbon sequestration response to water and nutrients to date. This study showed that growth and carbon

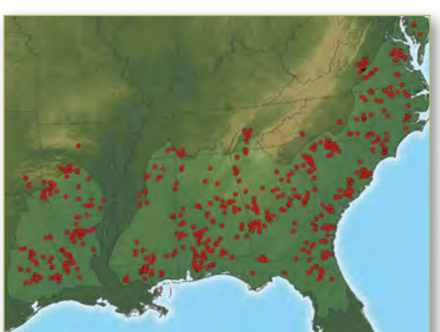

Figure 1.1. Tier I legacy network.

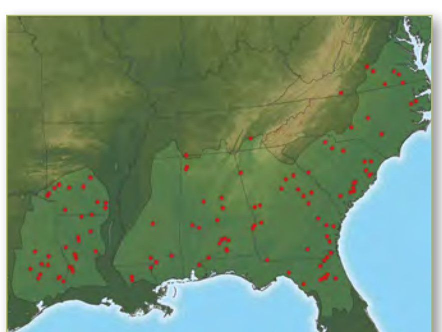

Figure 1.2. Tier II active experiments network.

Figure 1.3. Tier III throughfall reduction x fertilization network.

The overarching theme of these simulations was that under future conditions predicted by state-of-the-art climate models, southern pine plantation productivity and carbon sequestration will likely increase over the next 50 years throughout most of the region.

sequestration were consistently increased by fertilization under both ambient and decreased throughfall, and that fertilization did not exacerbate the negative impacts of drought on growth or carbon sequestration.

Modeling to understand future risks and opportunities

All models have strengths and weaknesses, depending on their structure, their intended purpose, and how they are applied. Accordingly, PINEMAP used a suite of independent models which enabled us to better understand how planted pine may respond to future conditions. We used six models: an empirical growth and yield model, Water Supply Stress Index model (WaSSI), Physiological Principles in Predicting Loblolly Growth (3-PGlob), the Community Land Model (CLM), the Daily CENTURY model (DAYCENT), and the Subregional Timber Supply model (SRTS). We also used model outputs to simulate future trends in the life cycle carbon balance of southern pine forestry. Details of how these models were developed and applied can be found in this and previous PINEMAP reports, and interactive maps presenting the results of these simulations are available in the PINEMAP Decision Support System (http://pinemapdss.org).

The overarching theme of these simulations was that under future conditions predicted by state-of-the-art climate models, southern pine plantation productivity and carbon sequestration will likely increase over the next 50 years throughout most of the region. Relative (percent) increases in productivity will be largest at the northern, cooler part of the range, and negative effects on productivity begin to manifest toward the end of the simulation period, in warmer (southern) and drier (western) parts of the region. Important caveats for these simulations include that they did not incorporate the potential effects of disturbance factors such as insect and disease outbreaks, wildfire, or hurricanes and windstorms, all of which may be altered by changing climate. Regardless, the simulations do suggest that with vigilant management for resilience to disturbance, planted southern pine will be increasingly important for sequestering carbon and producing biomass over the next half-century.

2. Forecast of Productivity at the Regional Scale Using the Physiological Principles in Predicting Growth (3-PG) Model

R. Quinn Thomas[1], Annika Jersild[2], Evan Brooks[1], Valerie Thomas[1], Randolph Wynne[1], Eric Ward3, Timothy Albaugh[1], Heather Dinon-Aldridge[4], Harold Burkhart[1], Jean-Christophe Domec[5], Thomas Fox[1], Carlos Gonzalez-Benecke[6], Timothy Martin[7], Asko Noormets[5], David Sampson[8], Robert Teskey[9]

[1] Virginia Polytechnic Institute and State University, [2] Georgia Institute of Technology, [3] United States Geological Survey, [4] State Climate Office of North Carolina, [5] North Carolina State University, [6] Oregon State University, [7] University of Florida, [8] Arizona State University, [9] University of Georgia

Averaged across the region, we forecast productivity to increase by 31% between 2010 and 2055 with the largest gains in the HUC-12 units in the northern extent of the loblolly pine natural range (Figure 6.3; Thomas et al. 2018) – results that agree well with plot-based simulations of the 3-PG using a different parameterization (Gonzalez-Benecke et al. 2017) and from the Growth and Yield simulations (Burkhart et al. 2018).

Physiological Principles Predicting Growth (Landsberg and Waring 1997) is one of a suite of models used by PINEMAP's integrated modeling group to provide robust and complementary estimates of changes in loblolly pine (*Pinus taeda* L.) productivity over the remainder of the 21st century. The other models in the program include growth and yield (G&Y), the Water Supply Stress Index (WaSSI), and the Community Land Model (CLM). As a process-based model, Physiological Principles Predicting Growth (3-PG) focuses on the physiological components of growth and provides forest growth and health-related outputs (volume, basal area, and leaf area index) and carbon storage-related outputs (biomass accrual, net primary productivity, and gross primary productivity). The PINEMAP project developed regionally applicable parameters that govern the physiological processes, developed the capacity to run regional simulations, and developed techniques for quantifying and partitioning the uncertainty among the dominant sources. Based on these foundations, we published the first mid- 21st century forecast of pine productivity across the native range of loblolly pine that fully specifies the uncertainty in the forecast.

We developed a novel hierarchical Bayesian approach to estimating the distribution of 3-PG model parameters using regionally distributed observations from the Tier 3 drought x fertilization experiment, other historical global change experiments in the region (i.e., Duke CO_2 fumigation experiment), eddy-covariance towers, and university-industrial cooperative studies (Tier 1 and Tier 2) (Thomas et al. 2017). In addition to the using the observations, the Bayesian approach used prior knowledge to inform the parameterization. This allowed us to quantitatively use the parameters reported in prior studies published as part of the PINEMAP project (Bryars et al. 2013, Gonzalez-Benecke et al. 2016) to inform the parameter distributions. The hierarchical Bayesian approach (Data Assimilation to Predict Productivity for Ecosystems and Regions [DAPPER]) explicitly separates the contribution of parameter uncertainty from the contribution of the structure of the model. This is critical for the partitioning of uncertainty in the future projections. The manuscript describing the approach won the 2018 Ecological Forecasting Prize presented by the Ecological Society of America, thus highlighting the novelty and impact of the work.

In order to provide opportunities for model intercomparisons, 3-PG was adapted to run at the same USGS 12-digit hydrologic unit (HUC-12) spatial scale as WaSSI (Figure 2.1). This scaling also makes a regional run of 3-PG computationally feasible, with approximately 10,000 HUC-12 units in the generally recognized range of loblolly pine. Soil data were obtained for all states in the PINEMAP region from the USDA's Natural Resource Conservation Service's Soil

Averaged across the region, we forecast productivity to increase by 30% between 2010 and 2055 with the largest gains in the HUC-12 units in the northern extend of the loblolly pine natural range.

Survey Geographic Database (SSURGO). Since the SSURGO spatial resolution is finer than the HUC-12 scale, we spatially aggregated soil data to the HUC-12 unit scale using area-weighted averaging, which was then used either directly or converted into soil classes for use in 3-PG_{lob}. In cases where the gridded SSURGO data included a representative site index value for loblolly pine, those estimates were extracted and spatially aggregated to the HUC-12 units. Enough site index estimates were present across the recognized range of loblolly pine to generate a regional map of site index at HUC-12 resolution (Figure 2.1). We were then able to translate these site index estimates into the "fertility rating," a key input into 3-PG (Figure 2.1).

We obtained climate data and derived variables via Multivariate Adaptive Constructed Analog (MACA) downscaling of the 1-degree Idaho climate data, commonly used in global climate modeling efforts and in PINEMAP's Community Land Model. The MACA data used for 3-PG_{lob} cover a baseline historical period of 1950–2005 and a series of future predictions for 2006–2095 according to two radiative forcing scenarios: (1) greenhouse gases are emitted in the future at the same rate as today, which equals the business as usual scenario, and (2) at a reduced emissions scenario. In all, 20 different global climate models (GCMs) were downscaled, converted to 3-PG_{lob} input variables, and aggregated to the HUC-12 level by area-weighted averaging. The high number of GCMs used allowed us to estimate variability due to the uncertainty in climate predictions.

Our projections of future productivity were run until 2055, where the concentration of CO_2 in the atmosphere is projected to exceed the level in the Duke CO_2 fumigation experimental study that was used in the parameter estimation. The forecasts

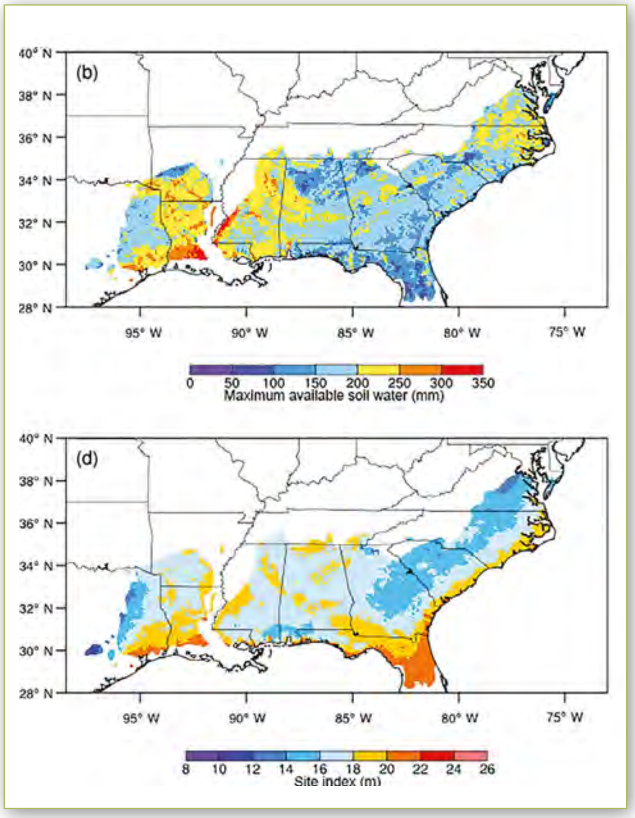

Figure 2.1. Stand characteristic used as inputs to the regional 3-PG simulations (Thomas et al. 2017).

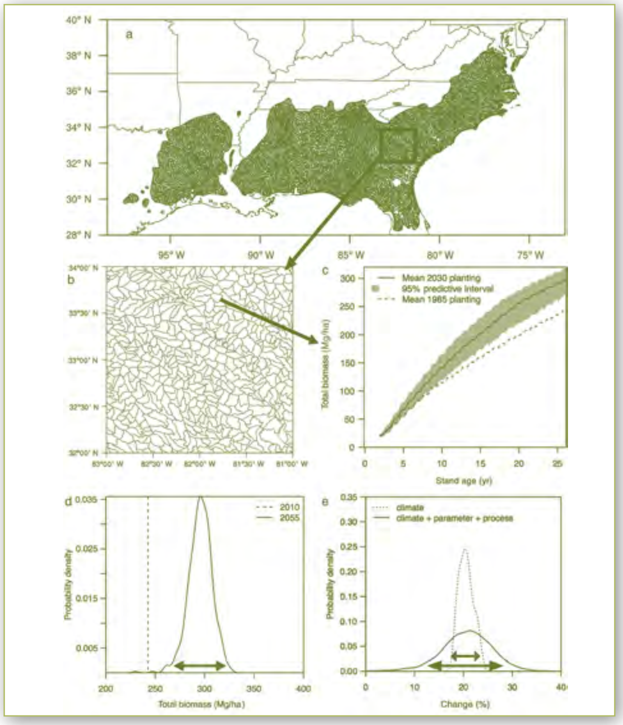

Figure 2.2. A schematic of how the regional forecasts were developed. For each HUC-12 unit in the loblolly pine native range (panels a and b), the biomass was simulated for a stand planted to reach age 25 at 2010 and at 2055, with total forecast uncertainty propagated for the 2055 stand (panel c). The distribution of the biomass at age 25 was compared between the 2010 and 2055 stand (panel d) and used calculate the percentage change (panel e) (Thomas et al. 2018).

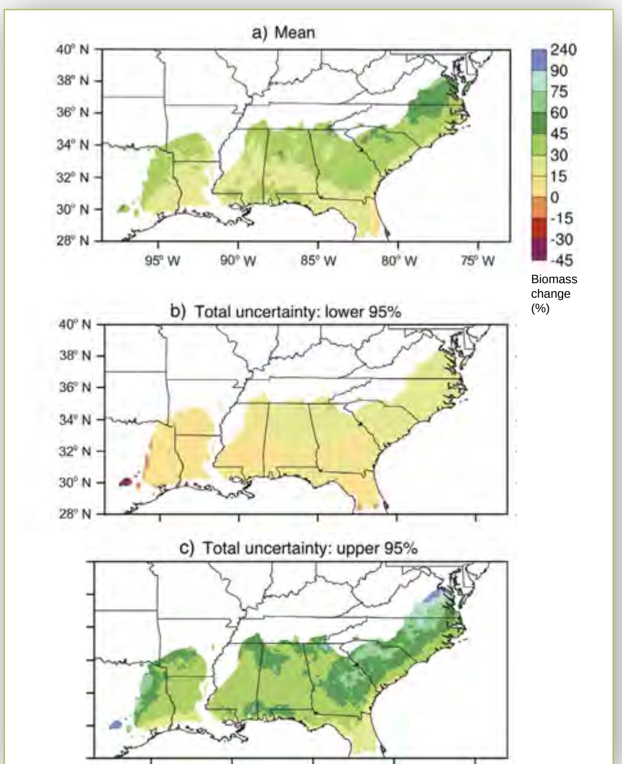

Figure 2.3. Regional mean (a) and predictive intervals (b,c) for the forecasted change in total biomass at age 2010 and 2005 (Thomas et al. 2018).

propagate uncertainty in the 3-PG model parameters, the 3-PG model structure, and climate model projections (Figure 2.2). Averaged across the region, we forecast productivity to increase by 30% between 2010 and 2055 with the largest gains in the HUC-12 units in the northern extend of the loblolly pine natural range (Figure 2.3; Thomas et al. 2018) – results that agree well with plot-based simulations of the 3-PG using a different parameterization (Gonzalez-Benecke et al. 2017) and from the G&Y simulations (Burkhart et al. 2018). At mid-century, results were similar between the two climate model scenarios evaluated (RCP 8.5 and RPC 4.5).

The forecast showed considerable uncertainty, with the average width of the uncertainty in each HUC-12 unit covering 30 percentage units (Figure 2.3; Thomas et al. 2018). HUC-12 units in the southern and in the western extent had distributions that overlapped zero (Figure 2.3), indicating that the level of uncertainty in the forecast includes a chance that growth rates decline by mid-century. Our analysis of uncertainty demonstrated that the structure of the models contributed more to total forecast uncertainty that either climate model or parameter uncertainty. This finding highlights a need to focus efforts on constructing models that better explain observed variation in growth rates across the region and in ecosystem experiments (i.e., the Tier 3 drought experiment). By developing the DAPPER approach that allows automated estimation of model parameters, future work that updates the forest productivity model or collects more data can easily leverage PINEMAP efforts to develop state-of-the-art predictions.

These results have been used as key inputs in economic models in PINEMAP and beyond. The model outputs from3-PG forecasts have been integrated into PINEMAP's decision support system (DSS) so that Extension agents and landowners have access the most up-to-date estimates and uncertainty for both regional-scale and local-scale loblolly production in the 21st century.

3. Regional Growth and Yield Model Projections Suggest Strong CO_2 Fertilization Effect

Evan B. Brooks[1], *Harold E. Burkhart*[1], *Randolph H. Wynne*[1]

[1]*Virginia Polytechnic Institute and State University*

Forest growth and yield models have long been used to project forest productivity under varying soil and silvicultural scenarios. Unfortunately, traditional growth and yield models typically rely on past growth performance from field trials, and are unlikely to give acccurate projections under future climate. We updated a loblolly pine growth and yield model to incorpoate the effects of both climate and elevated CO_2 concentration. The resulting projections showed an average of 30% increase in loblolly pine productivity by mid-century, similar to projections from other modeling approaches.

Multiple modeling frameworks were employed in the PINEMAP project, including use of forest growth and yield models. An empirical growth and yield modeling approach, based on a rich historical database, was applied to simulate the impacts of changing climate and increasing ambient CO_2 concentration on future productivity of loblolly pine in the southeastern United States. The growth and yield modeling approach produced estimates of loblolly pine (*Pinus taeda*) productivity that aggregate well across the region.

Methods

A parametric model (Sabatia and Burkhart 2014) was fitted to estimate site index from a combination of edaphic and climatic variables, including temperature, precipitation, soil water availability, and soil texture. Downscaled climate data from 20 general circulation models (GCMs; Abatzoglou and Brown 2012) were used when projecting to 2059 under two representative concentration pathways (RCPs). We considered two scenarios: RCP 4.5 (with greenhouse gas emissions peaking circa 2050) and RCP 8.5 (increasing emissions through 2099) (Meinshausen et al. 2011). Soils data were downloaded from the national soil survey database (SSURGO; Service 1995). The GenLob growth and yield model (Gyawali and Burkhart 2015) was fitted with region-wide field-plot measurement data from even-aged loblolly pine stands. The model inputs of site index (average height in the dominant cohort of a stand at a reference age of 25 years) and stand density predict basal area, dominant height, and number of surviving trees at any target stand age. From these outputs, allometric

equations were used to derive volume, green weight, and ultimately, above-ground carbon stocks. For simplicity, we assumed a constant planting density of 1,235 trees per hectare and a constant harvest age of 25 years. The spatial unit used in our analysis was the 12-digit hydrologic unit (HUC; Henley 2006); climate and soil inputs were aggregated to this level as part of preprocessing.

Since the site index input to GenLob is driven in part by changes to climate, growth and yield estimates of productivity automatically incorporated effects due to climate change. However, we were also interested in the enhanced growth effects of additional CO_2 on tree growth. Accordingly, we used a model relating changes in ambient CO_2 to changes in the corresponding site index (Westfall and Amateis 2003). Additionally, by holding climate data constant at a 1980–2005 baseline, we were able to explore main and interaction effects on pine productivity due to climate change and CO_2 increases.

Full details of our approach and results may be found in Burkhart et al. (2018); a brief summary follows here. For each GCM/RCP combination (40 in total), 30-year climate normals were computed for the 1950–2059 period and estimated site index on a year-by-year basis was estimated for1980–2059. With these site index trajectories, GenLob was applied to predict pine productivity in the form of above-ground carbon for 25-year rotations based on plantings in each year. The carbon predictions were then parsed into 20-year bins and aggregated by stand age, resulting in up to 20 predictions per age per bin. For example, the 15-year-old stand predictions for 2020–2039 were based on simulated stands planted in 2006–2025. Finally, we aggregated across all GCMs per RCP per bin and compared these future predictions against values similarly derived for the baseline 1980–2005 period.

Results

GenLob predicted region-wide increases in loblolly pine productivity at harvest age under both the RCP 4.5 and RCP 8.5 scenarios (Table 3.1). This effect was strongest under RCP 8.5 and when CO_2 increases were included. Climate change had a similar but weaker influence. Increases in productivity were predicted throughout the region when both CO_2 fertilization and climate change were considered (Figure 3.1).

	2020–2039	2040–2059		2020–2039	2040¬2059
RCP 8.5 (increasing emissions)			RCP 4.5 (stabilized emissions)		
Climate Only	3.5% ± 3.6%	7.1% ± 6.3%	Climate Only	3.0% ± 3.4%	6.5% ± 5.6%
CO_2 Only	7.2% ± 4.7%	19.7% ± 8.3%	CO_2 Only	6.1% ± 4.4%	13.2% ± 6.5%
Climate + CO_2	14.9% ± 5.7%	30.9% ± 10.4%	Climate + CO_2	14.6% ± 5.5%	30.6% ± 10.0%

Table 3.1 (Burkhart, et al. 2018). Region-wide summaries of percent change in wood carbon at age 25 years. Values are the mean percent difference across the study area against the 1980–2005 baseline period, +/- the standard deviation of those differences.

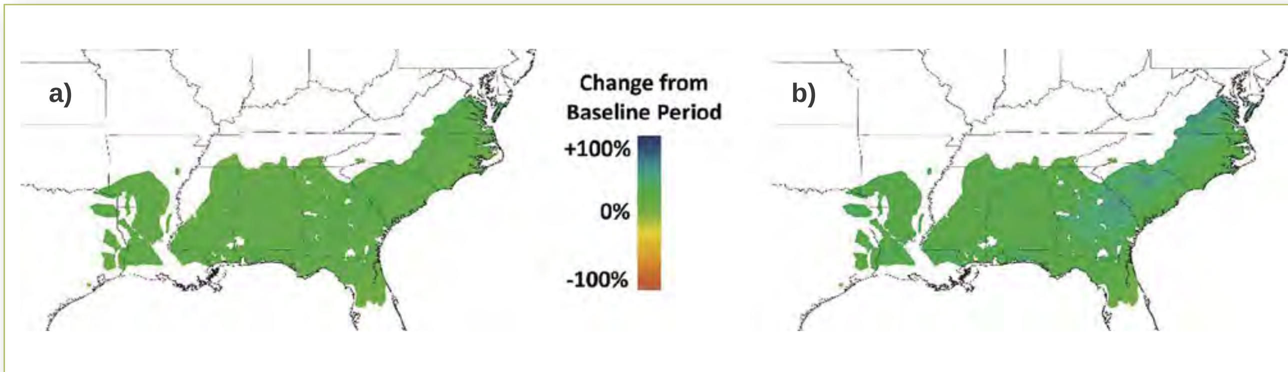

Figure 3.1 (Burkhart, et al., 2018, Figure 6). Percent change in stemwood carbon at age 25 years under both climate and CO_2 enrichment effects, against a baseline period of 1980–2005 for a) 2020–2039, b) 2040–2059. White spaces in the maps result from missing soils and/or climate data from the various downscaled climate models.

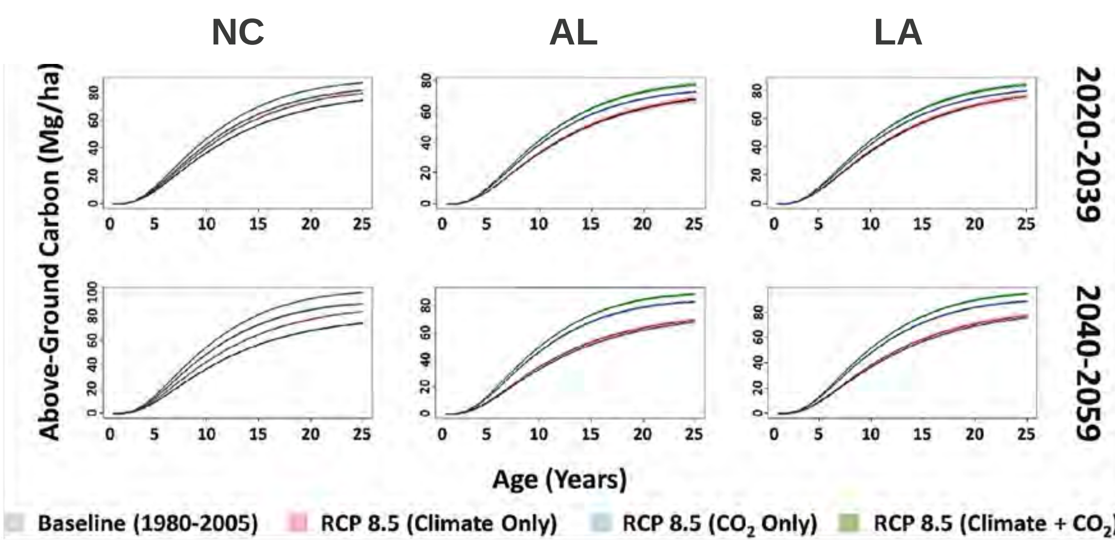

Figure 3.2 (Burkhart, et al., 2018, Figure 7). Comparison of cases for three example HUCs from across North Carolina (NC), Alabama (AL), and Louisiana (LA), over the two future time periods. The CO_2 effect indicates an increase in productivity, even in the first time period.

Similar results were observed across all ages, with CO_2 effects driving substantial increases in above-ground carbon even when climate change did not (Figure 3.2).

Conclusion

We note that while our results indicate increases in productivity, suggesting that the loblolly pine region may be a beneficiary of changes to the climate and ambient CO_2, our results do not account for the potential decreases in productivity due to climate-related disturbances such as fire, insect, and storm damages. Similarly, we did not consider policy and economic influences on land use decisions, nor did we consider water use impacts due to conversion of land for urban and agricultural uses. Accordingly, the growth and yield predictions may be considered as an upper bound on future pine productivity. Conversely, we also did not incorporate potential gains in productivity due to advances in genetics and enhanced silviculture.

The growth and yield model results indicate that (1) productivity of loblolly pine will likely increase over the coming decades, (2) future climate is predicted to have moderate impacts on productivity, and (3) increased atmospheric CO_2 concentration is expected to have a positive impact on productivity.

4. Regional Water Balances of Loblolly Pine Forests under a Changing Climate in the 21st Century

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[1] USDA Forest Service, [2] Oak Ridge national Lab, [3] North Carolina State University

The Water Supply Stress Index ("WaSSI") model was used to understand how future climate might impact water availability from forested watersheds. Regional simulations suggest that future increases in forest evapotranspiration due to increased temperatures my reduce water yield from forested watersheds.

Environmental Controls on Forest Water Balances

The southern United States is known for its abundant water resources, which support the world's "timber basket", and a vibrant economy in agriculture, transportation, and tourism (Sun et al., 2008; Caldwell et al., 2014). The quality and quantity of water resources are intimately tied to the forest area that covers more than 30% of the land area in the southern United States (McNulty et al., 1996; Susaeta et al., 2016). However, water availability in the south is projected to be more variable and uncertain in the 21st century (Vose et al., 2012). Identified stressors include increased human water use, climate change, sea level rise, land use change, and intensive forest management (Sun et al., 2008). We need to better understand the hydrological variability of forested watersheds under changing climate so that measures can be taken to adapt to the projected effects of climate change on water supply for both people and forest ecosystems.

Water supply at the annual, decadal, and longer timeframes in a watershed is largely dependent on water yield, which is the difference between precipitation and water loss through evapotranspiration (ET). Climate change has direct and indirect effects on water yield. First, climate change has direct impacts on the amount, timing, and forms of precipitation. Secondly, ET is the sum of water evaporation from soil and plant surfaces and plant transpiration. Transpiration is in turn controlled by precipitation, radiation, and land cover characteristics (Sun et al., 2011). A large rise in atmospheric carbon dioxide (CO_2) concentration can greatly reduce leaf stomatal conductance, reduce plant transpiration, and increase plant water use efficiency (WUE) (Mccarthy et al., 2007; Keenan et al., 2013). However, increasing WUE does not necessarily mean that forest ecosystem ET will decrease. The effect of CO_2 concentration changes on ecosystem or watershed level ET is uncertain because the shifts of forest plant species and leaf biomass (or aboveground productivity) can both alter ET rates.

Predicting Water Balances at the Watershed Scale in a Changing Climate

The PINEMAP Tier III precipitation manipulation experiments at four sites within the loblolly pine range show variable hydrological responses across a climatic gradient. These experiments provide empirical evidence that droughts can significantly influence ecosystem processes, including water balance. PINEMAP employed simulation modeling to expand the scope and applicability of results beyond relatively expensive and time-consuming, short-term foreststand level experiments. This allowed us to capture the spatial variability of climate, soil, and nutrient conditions across the entire loblolly pine range and through entire plantation forest rotations.

We previously used the Water Supply Stress Index (WaSSI) model (Sun et al., 2011) to examine the sensitivity of water yield to drought (2014 PINEMAP Year 3 Annual Report). This study focused on modeling future water balances across the loblolly pine range. At the spatial scale of a watershed (12 digit Hydrological Unit Code, HUC12), WaSSI simulates monthly evapotranspiration, streamflow, soil water storage, gross primary productivity, ecosystem respiration, and ecosystem net carbon exchange. The monthly time-step ET model for a 17-year old loblolly pine stand was derived from an AmeriFlux site (NC2) on the lower coastal plain in North Carolina where ET was estimated as:

ET = 0.725*PET + 5.0 *LAI; R2=0.86, RMSE = 14 mm/month, n =120 months.

Future climate will likely reduce forest water yield through the increase in forest evapotranspiration.

We modeled monthly forest water balances using a data set that included historic climate data (i.e., training data for bias-correction of General Circulation Models [GCMs]) and projected climate data by 20 GCMs under two greenhouse gas emission scenarios (RCP4.5 and RCP8.5) for selected periods in the 21st century. We examined climate impacts on water balances for two stages (7 and 17 years) of forest development.

Results

Regionally, the 20 GCMs predicted that during the next 35 years (2050) mean air temperature will rise about 1.5oC, which is a much faster rate than in the previous 60 years under both RCP4.5 and RCP8.5. After 2050, the warming trend is projected to continue to accelerate under RCP8.5 but decelerate under RCP4.5 (Figure 4.1a). Annual precipitation is projected to increase somewhat over the next 35 years under both RCP scenarios at the regional scale (Fig 3.1b).

The water balance of the southeastern U.S. is dominated by precipitation and ET, and future climate change likely will not alter this pattern. On average, water yield is only 30% of annual precipitation and 70% of precipitation is returned to the atmosphere. The simulated combination of increasing air temperature and increased variability of precipitation resulted in a complex water balance pattern over time (Figure 4.2) and space (Figure 4.3). At the regional scale, potential ET and actual ET is projected to increase, resulting in a decrease in water yield from watersheds in areas where precipitation does not increase significantly (Figure 4.3). The largest decreases in water yield were found in the state of Texas and western Alabama. Water yield is expected to decrease more after 2050 under the RCP8.5 scenario (>4-13% regionally) as air temperature continues to increase (Figure 4.3).

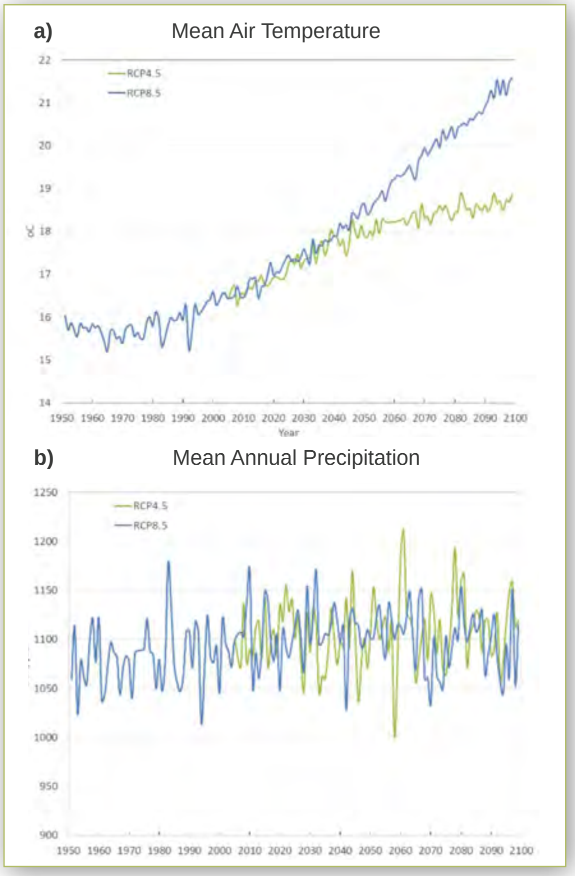


Figure 4.1. Climate change (a) mean annual air temperature, (b) mean annual precipitation as projected by 20 GCMs showing a substantial warming trend and increasing variability of precipitation in the next 100 years in the southern U.S.

Figure 4.2. WaSSI model simulated mean water balances of watersheds covered by mid-rotation loblolly pine plantations (age 17) for selected time periods (2030, 2050, 2070, 2090) under 20 GCMs and two greenhouse gas emission scenarios (RCP4.5 and 8.5). (a) Precipitation, (b) Potential ET, (c) Actual ET, and (d) Water yield.

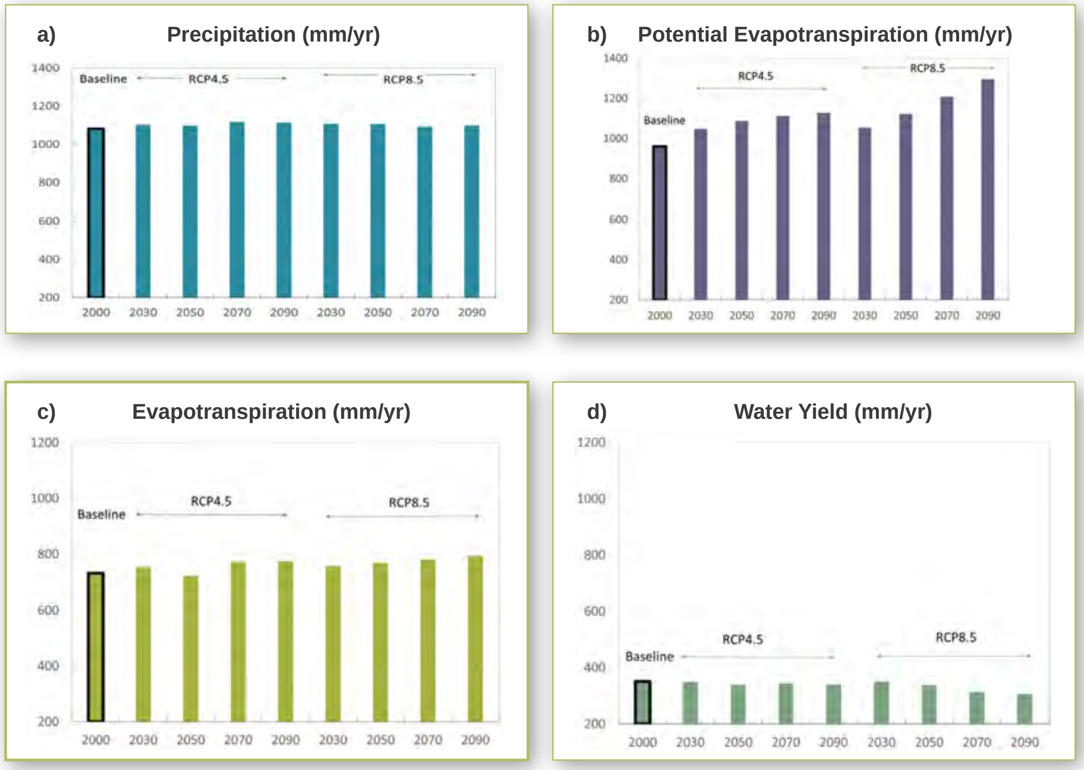
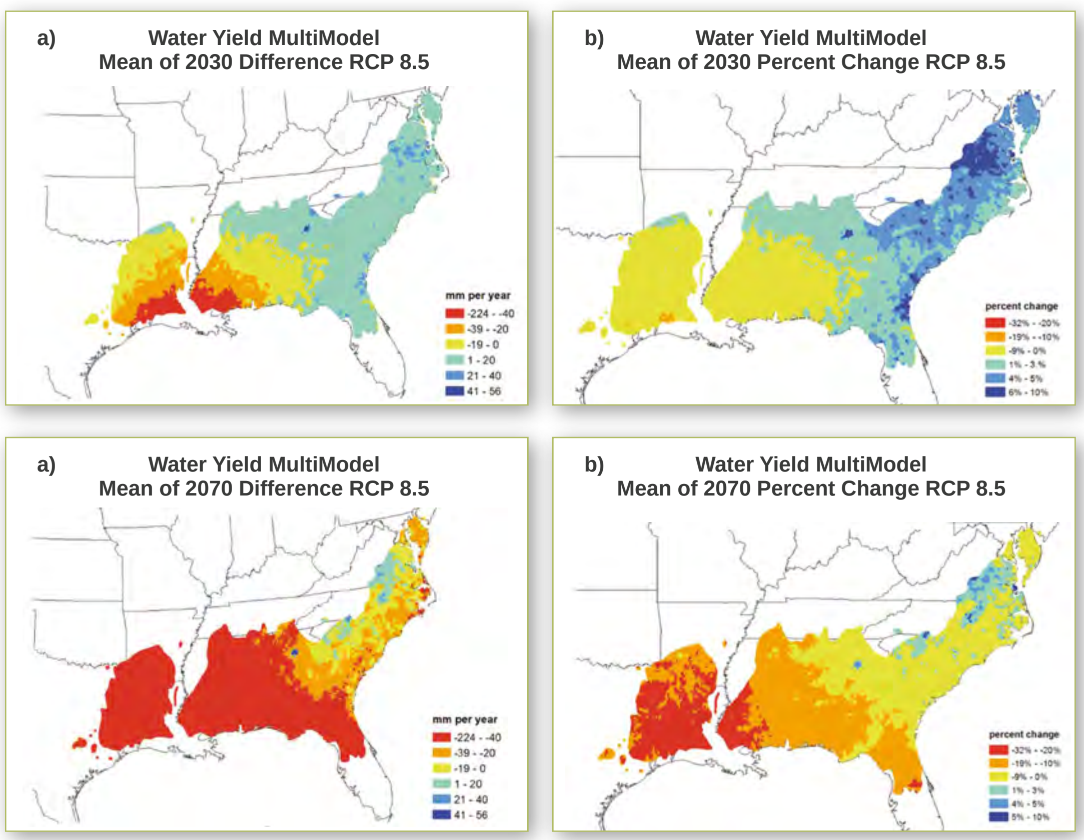


Figure 4.3. WaSSI model simulated spatial distribution of mean impacts of climate change (RCP8.5) on annual water yield of watersheds covered by mid-rotation loblolly pine plantations (age 17). (a) Absolute change (2030), (b) Relative change (2030), (c) Absolute change (2070), and (d) Relative change (2070).



5. Estimating How Forest Management Approaches Affect C Dynamics in Loblolly Pine Plantations: The Tier II Network

Jason G. Vogel[1], Madison Akers[2], Ralph Amateis[3], Allan Bacon[1], Joshua Cucinella [1], Carlos Gonzalez-Benecke[1], Andy Laviner[3], Mike Kane[2], Tom Fox[3], Eric Jokela[1], Harold Burkhart[3], Sabine Grunwald[4], Adam J. Marquis[9], Brian Strahm[3], Ge Sun[5]

[1] School of Forest Resources and Conservation, University of Florida, [2] Warnell School of Forestry and Natural Resources, University of Georgia,
[3] Department of Forest Resources and Environmental Conservation, Virginia Tech, [4] Soil and Water Sciences Department, University of Florida,
[5] USDA Forest Service Southern Research Station Eastern Forest Environmental Threat Assessment Center

The Tier II network of sites was drawn from established research installations maintained by the industry-university research cooperatives participating in PINEMAP. The purpose of the network was to evaluate how ecosystem C accumulation in multiple pools is affected by silvicultural decisions. Silvicultural treatments which increased tree productivity increased carbon in tree components, as expected. Effects of silvicultural treatments on soil carbon were subtle and more complex.

When pine ecosystems are managed to maximize wood production, management also effectively maximizes the rate of carbon (C) sequestration into plant biomass. Thus, the accumulation of C into pine biomass is a well-understood process in managed plantations. Less understood is how the C that is stored in other pools, such as the forest floor, soil, coarse woody debris, and understory, will respond to management approaches or even to increases in the rate of biomass accumulation. This is a fundamental unknown that needs to be understood before clear links can be made between management and the dynamics of C pools in the ecosystem.

The Tier II network of sites was drawn from established research installations maintained by the industry-university research cooperatives participating in PINEMAP. The network of 125 sites and 458 measurement plots encompasses a wide range of environmental conditions (Figure 5.1) and silvicultural treatments. The purpose of the Tier II network was to evaluate how ecosystem C accumulation in multiple pools is affected by silvicultural decisions, one of PINEMAP's outcome themes.

The measured pools of C were soil to 1 meter, forest floor, understory biomass, tree roots, soil detritus, and coarse-woody debris (CWD). The tree biomass was estimated from tree height and diameter measurements provided by each of the research cooperatives. Across all sites the soil C pool to 1 meter was slightly greater than that of the tree biomass (Figure 5.2); however, the average age of the forests at the time of measurement was 17 years, which is 7-13 years before the final clear-cut harvest, depending on location. Thus, tree biomass would likely continue to accumulate for several more years before the final harvest. Nonetheless, this data highlights the importance of the soil C, and to a lesser degree, forest floor C in the total ecosystem C storage of planted pine ecosystems.

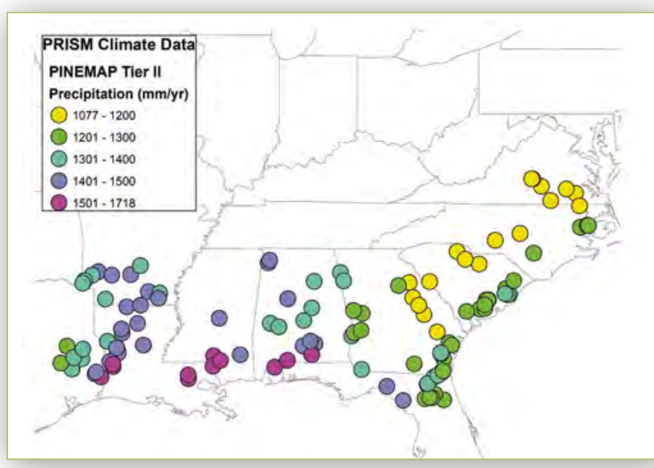


Figure 5.1. Precipitation estimated from PRISM historic climate data (1991–2010) for each Tier II research installation. Each dot represents a research installation where multiple treatments are being examined.

On average, at age 17 years the amount of carbon stored in soils to a depth of 1 meter was about equal to that stored in tree biomass.

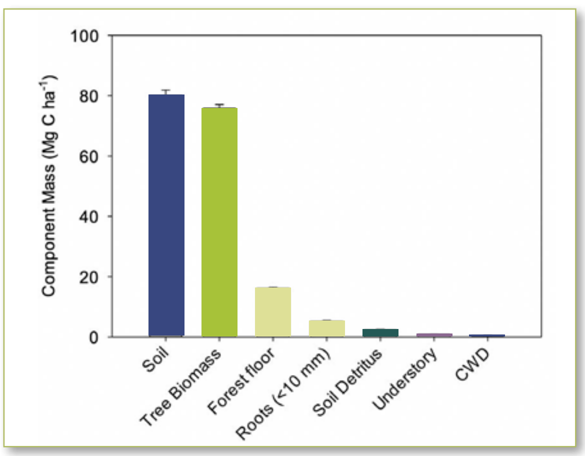


Figure 5.2. Ecosystem C distribution across the Tier II network.

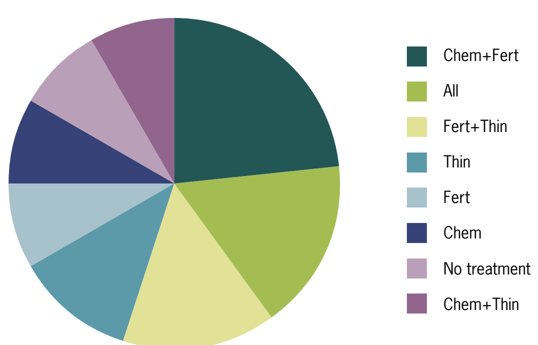


Figure 5.3. Distribution of plots in the Tier II network having different combinations of experimental treatments including fertilization (fert), chemical weed control (chem), thinning (thin), all treatments, and no treatment.

The treatments in the experimental sites encapsulated most management approaches used by foresters in the region, and the network spanned the range of climactic factors present on the landscape. The most common treatment category in the network was chemical understory weed control plus fertilization (Chem+Fert) (Figure 5.3). The next most common treatment category was a combined "all" treatment of thinning (thin), fertilization (fert), and chemical understory weed control. Each category of treatment contained at least 32 individual research plots located across the range of loblolly pine (Figure 5.1), allowing for a robust assessment of treatment effects across the full range of climate and soils across the region.

The clearest effect on the amount of C accumulated in tree biomass and the forest floor was management through thinning. Removing trees before the end of a rotation unsurprisingly reduced tree biomass. This treatment decreased the forest floor pool of C by a small amount and resulted in an increased sensitivity of soil C concentration in the deep soil horizons when combined with other treatments (fertilization and competition control). These results suggest that predicting management effects on ecosystem C in pine plantations is possible for pools (tree biomass, forest floor) closely associated with tree growth and tree density. However, predicting the soil C pool's response to management will require a mechanistic understanding of the underlying controlling processes; assigning binary responses based on management schemes will likely prove inadequate in predicting soil C response.

6. Regional Soil Respiration: Measurement, Validation, and Modeling

Brian Strahm[1], Rosvel Bracho-Garrillo[2], Yuan Fang[4], Dan Markewitz[3], Kristin McElligott[1], Guofang Miao[4], Wen Lin[4], Asko Noormets[4], Lisa Samuelson[5], John Seiler[1], Jason Vogel[2], Bingxue Wang[3], and Rod Will[6]

[1] Viriginia Polytechnic Institute and State University, [2] University of Florida School of Forest Resources and Conservation, [3] University of Georgia Warnell School of Forestry and Natural Resources, [4] North Carolina State University Department of Forestry and Environmental Resources, [5] Auburn University, [6]Oklahoma State University

The amount of carbon retained in forest soils is dependent on the rate of emission of soil carbon by plant roots and by soil organisms. Intensive measurement and analysis of plant-related and soil organism-related soil carbon loss across PINEMAP monitoring networks showed remarkable consistency in the ratio of these rates under different climate, management, and stand developmental conditions.

Managing forests for carbon sequestration requires improved understanding of the controls over belowground carbon retention and how those controls vary across the region and with stand dynamics. While there are robust models predicting aboveground productivity of loblolly pine across such climate and edaphic gradients in the Southeast US, our ability to predict belowground carbon retention across the same gradients is much more limited. Ultimately, carbon sequestration in soil depends on the balance between the inputs to and losses from this pool. Inputs are often derived from easily measureable aboveground properties, like tree height; however, estimating soil carbon losses is more difficult. This is due to the inherent variability in soil respiration (R_S) and the challenge of estimating how much of that R_S carbon flux is from plant-derived autotrophic respiration (R_A) versus microbe-derived, heterotrophic respiration (R_H; Fig. 1). Thus, two of the major emphases of PINEMAP have been to (1) develop a region-wide model to predict R_S, the second largest carbon flux in forest ecosystems (behind gross primary productivity [GPP], or an ecosystem-level measure of photosynthesis); and (2) improve our understanding of the partitioning of that R_S flux into its R_H and R_A components, and how environmental and management factors affect that balance.

Managing forests for carbon sequestration requires improved understanding of the controls over belowground carbon retention and how those controls vary across the region and with stand dynamics.

Regional R_S Modeling

One of the great strengths of the PINEMAP research approach is its ability to leverage existing data sets and apply them to PINEMAP-specific questions or challenges. Development of a region-wide model for R_S is a prime example. Even in a study of the scope and scale of PINEMAP, developing this information de novo was not practical. PINEMAP scientists combined years of historic research from more than 121 study plots in 11 states spanning the natural range of loblolly pine in order to derive a region-wide model as a starting point for estimating R_S (Templeton et al., 2015). An explicit test of this model against a small number of intensively monitored sites showed the need for improvement, particularly with respect to considerations of stand age. Thus, PINEMAP scientists added to this already large data set in ways that helped make the R_S modeling more robust. These new efforts yielded two R_S models: one based only on soil temperature; and another four-parameter model that included soil temperature, soil moisture, stand age, and a stand age-temperature interaction term. The single parameter, soil temperature model explained 59% of the variability in R_S. The four- parameter model, inclusive of stand age, explained more of the variability in the data (62%, Figure 6.2).; however, incorporation into regional modeling efforts must consider the challenges associated with obtaining input data for additional parameters relative to the improvement in model performance, and thus, a

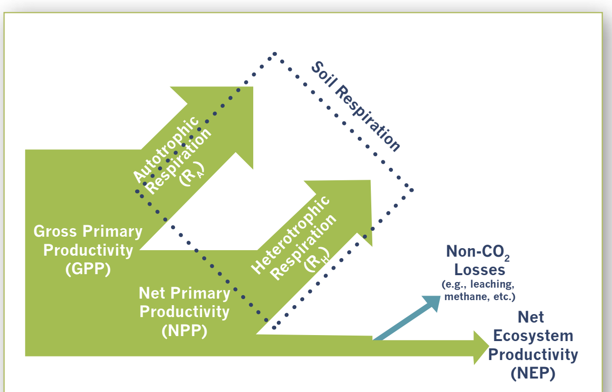


Figure 6.1. Carbon flow in forest ecosystems leading to net ecosystem productivity (NEP), or carbon sequestration.

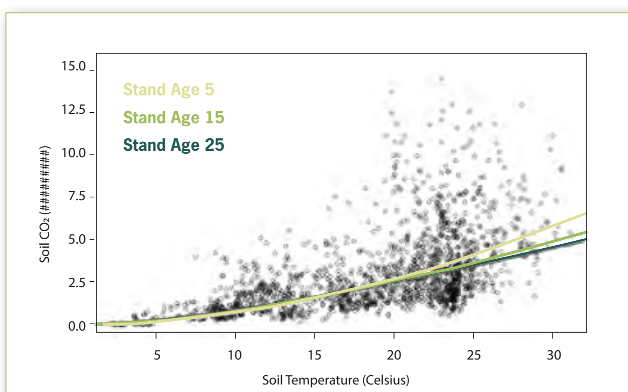


Figure 6.2. Region-wide model of soil respiration as a function of soil temperature, across a range of stand ages.

single parameter, temperature-dependent model might be the best option in some cases.

Regional R_H Modeling

Ultimately, PINEMAP scientists needed to know the R_H carbon flux from soils in order to predict net ecosystem productivity (NEP) from 3PG-derived model estimates of tree growth and carbon allocation. In order to do this, we essentially multiplied results from the R_S model described previously, with estimates of a partitioning coefficient, R_H / R_S. This coefficient is derived experimentally through root-severing cores that represent R_H in comparison to adjacent measurements of R_S. These root-severing cores were used in Tier II and III plots, and also in additional experimental plots (Tier IV) to test the potential effects of management, climate, soil properties, and other factors on R_H:R_S. Early PINEMAP work showed surprisingly little effect from the Tier III experimental treatments (Figure 6.3), suggesting that fertilization and/or drought might not play a large role in altering R_H:R_S. These results were further corroborated in the Tier II network where silvicultural treatments, including fertilizer and herbicide application, showed no significant difference across study site or treatment (Figure 6.4). These observations empowered PINEMAP researchers to use the Tier II and IV sites to more explicitly test the effects of soil and stand factors. Across all sites, excluding outliers, a partitioning coefficient of 0.66 was observed, meaning that 66% of R_S is derived from soil heterotrophs and can be subtracted from estimates of net primary productivity (NPP) to get NEP. However, there was tremendous variability in observed measurements of R_H:R_S, which have proven difficult to explain. In a single study, McElligott et al. (2016) showed a significant decrease in R_H:R_S over the course of stand development (Figure 6.5); however, other region-wide efforts have not been able to explain more than 12% of the variability in R_H:R_S. These include the use of the quantitative process-based model DAYCENT to estimate R_H:R_S. DAYCENT successfully captured expected seasonal patterns in R_S; however, estimates of the proportion of R_H:R_S did not match observed patterns, and suggested that subsoil (>20 cm) process (i.e., deep roots) may need to be better accounted for in these forest ecosystems.

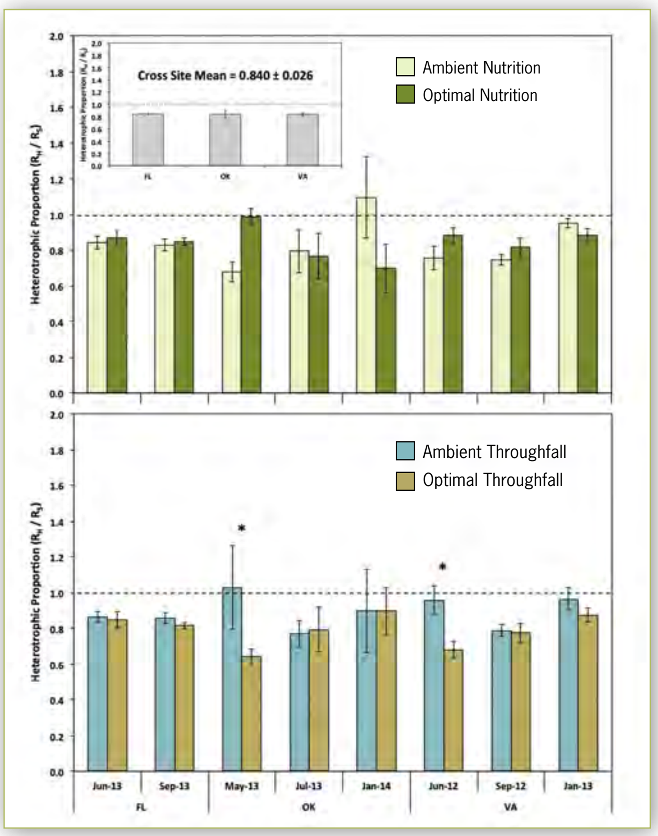


Figure 6.3. Proportion of total soil respiration (RS) that is from heterotrophic, microbial respiration (RH) at the PINEMAP Tier III sites in Florida (FL), Oklahoma (OK), and Virginia (VA) at multiple points in time. Upper panel shows main effect of fertilization; lower panel shows main effect of throughfall reduction. Inset provides site and regional means. Asterisks represent significant main effect differences ($p < 0.05$).

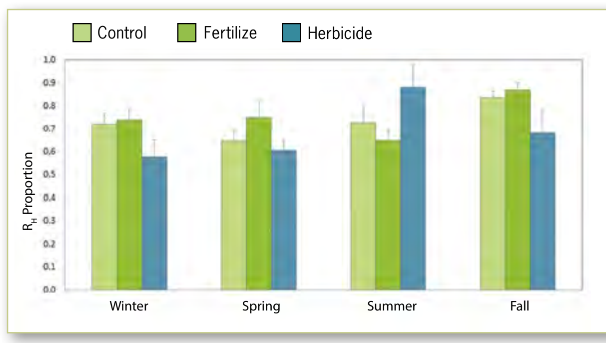


Figure 6.4. Proportion of RS as RH by season and silvicultural treatment for Piedmont and Coastal Plain combined (mean ± 1 SE), n=6.

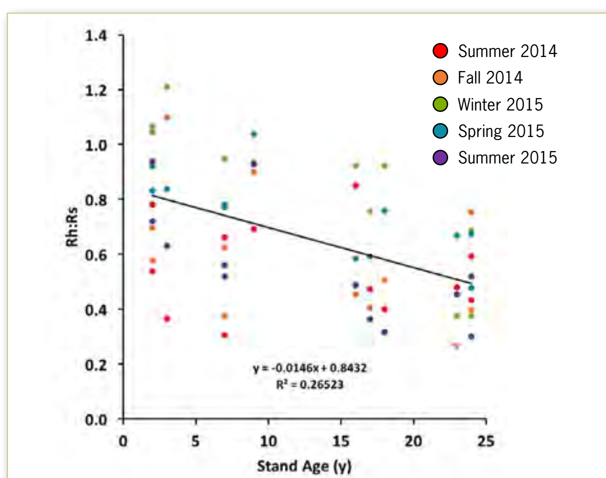


Figure 6.5. Partitioning coefficient (RH:RS) as a function of stand age, as described in McElligott et al. (2016).

7. Future Loblolly Pine Carbon Storage in Forests and Wood Products

Puneet Dwivedi[1], Carlos Gonzalez-Benecke[2], Asiful Alam1, Gary F. Peter[3], Robert O. Teskey[1], Timothy A. Martin[3]

[1]Warnell School of Forestry and Natural Resources, University of Georgia, [2] Forest Engineering, Resources & Management, College of Forestry, Oregon State University, [3]School of Forest Resources and Conservation, University of Florida

While substantial carbon can be stored in managed pine forests, products harvested from these forests also serve to store carbon during their useable life cycles. This life cycle analysis quantifies how future changes in climate may alter the storage of carbon in both forests and forest products.

Loblolly pine is widely planted in the southeastern U.S., is highly productive, and responds well to fertilizer inputs and other management treatments. As a result, the species is vital to maintaining the leadership position of the southern United States as a major supplier of roundwood products at the national and global levels. Apart from supplying wood products and economic benefits, this species also sequesters carbon not only in forests *(in situ),* but also in finished wood products which are manufactured from harvested wood *(ex situ).* Climate change is predicted to affect the productivity of loblolly pine, and this change in productivity will vary across the region. To assess the effects of these changes in climate and productivity on *in situ* and *ex situ* loblolly pine carbon storage, we used the calibrated and validated 3-PG biophysical model for ascertaining the growth and yield of loblolly pine across 36 sites spread across the southern United States (Figure 7.1) for three climate scenarios (Baseline, RCP 4.5, and RCP 8.5) and several silvicultural scenarios over a simulation period of 70 years. We also evaluated the impacts of changes in site productivity and forest management on growth and yield. Then, we applied a consistent system boundary (Figure 7.2) and set of common assumptions for ascertaining the total *in-situ* and *ex-situ* carbon sequestered at the end of the simulation period.

Carbon accumulation in *in-situ* and *ex-situ* pools associated with managed forest plantation systems is highly dependent on growth rate and the production and distribution of product types yielded by the particular management regime applied to those systems. This study showed increases in sequestered carbon (relative to present) associated with climate change scenarios in almost all conditions, with variation in growth stimulation caused by changing climate and/or by variation in site index (Figure 7.3). Given similar site index, the greatest *in-situ* and *ex-situ* carbon accumulation was on sites toward the southern portion of the range with higher mean temperatures.. However, the response of carbon accumulation to climate change scenarios also depended on location and site index. Sites with cooler mean temperatures or lower site index tended to experience large relative increases in carbon storage. At sites with warmer mean temperature, toward the southern side of the species range, the relative change caused by climate change was small, or even negative on very warm sites. These results are consistent with previous PINEMAP simulation studies, which showed that loblolly pine productivity is likely to increase over the coming century (Burkhart et al. 2018, Gonzalez-Benecke et al. 2017, Thomas et al. 2018). Gonzalez-Benecke et al. (2017) showed that the cause of productivity increases varied across the region. At the warmer end of the loblolly natural range, growth increases were attributable almost entirely to the elevated carbon dioxide in the atmosphere, and effects were smaller or even negative on the very warmest sites. On cooler sites, both elevated carbon dioxide and elevated temperature are predicted to increase growth by a large, relative margin.

The size and persistence of the *ex-situ* carbon pool depend greatly on the volume of large-diameter trees because sawtimber products have much longer

Figure 7.1. Locations of the 36 sites used for the simulation.

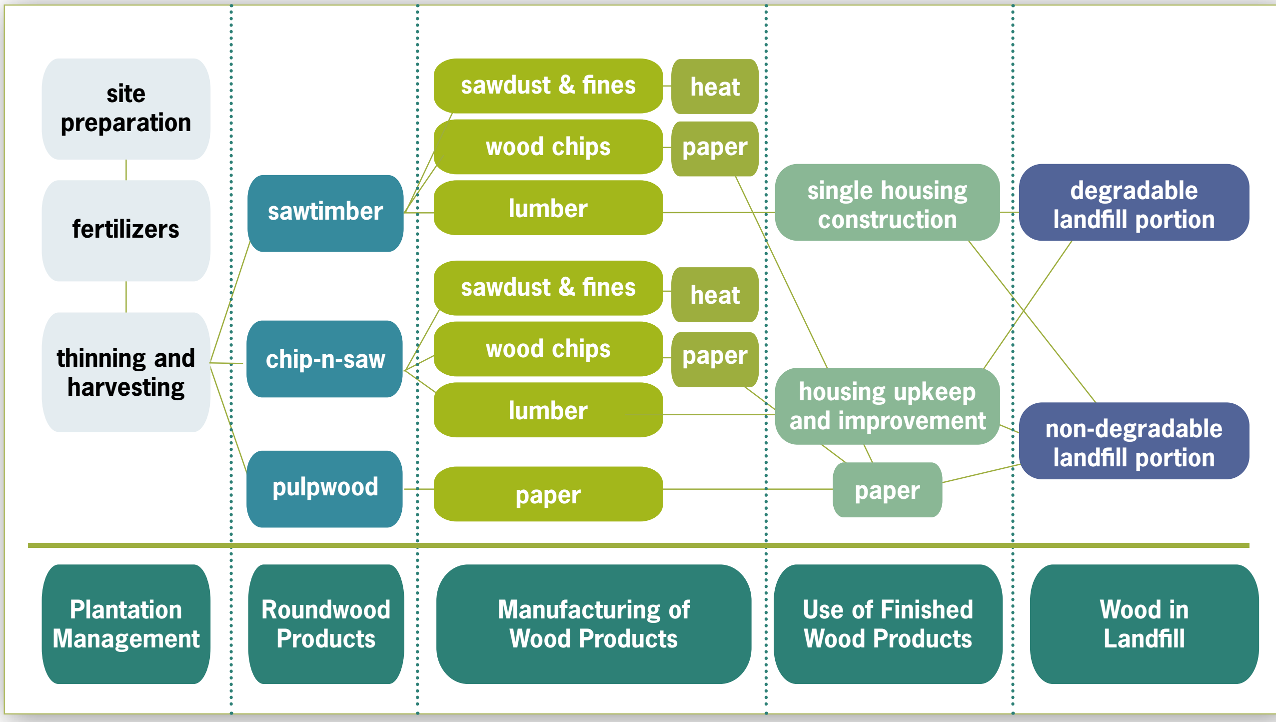


Figure 7.2. System boundary for estimating ex-situ carbon in wood products and wood in landfills.

half-lives compared to wood products derived from small-diameter trees (e.g., pulpwood). Management scenarios which include longer rotations and thinning can also be used to increase the relative production of large-diameter roundwood products, and so are a potential tool for manipulating the storage of *ex-situ* carbon.

While management factors were secondary to climate and site index in determining carbon storage in this study, experimental evidence shows that management may mitigate some climate change effects. Bracho et al. (2018) reported on the Tier III experiment in which both fertilizer application and rainfall input was manipulated in loblolly pine plantations. They showed that across the region, fertilizer application increased carbon accumulation. On sites where drought decreased carbon accumulation, fertilizer application counterbalanced these effects. This supports a role for intensive management in maintaining *in situ* and *ex situ* loblolly pine carbon storage capacity in the face of climate change impacts such as drought.

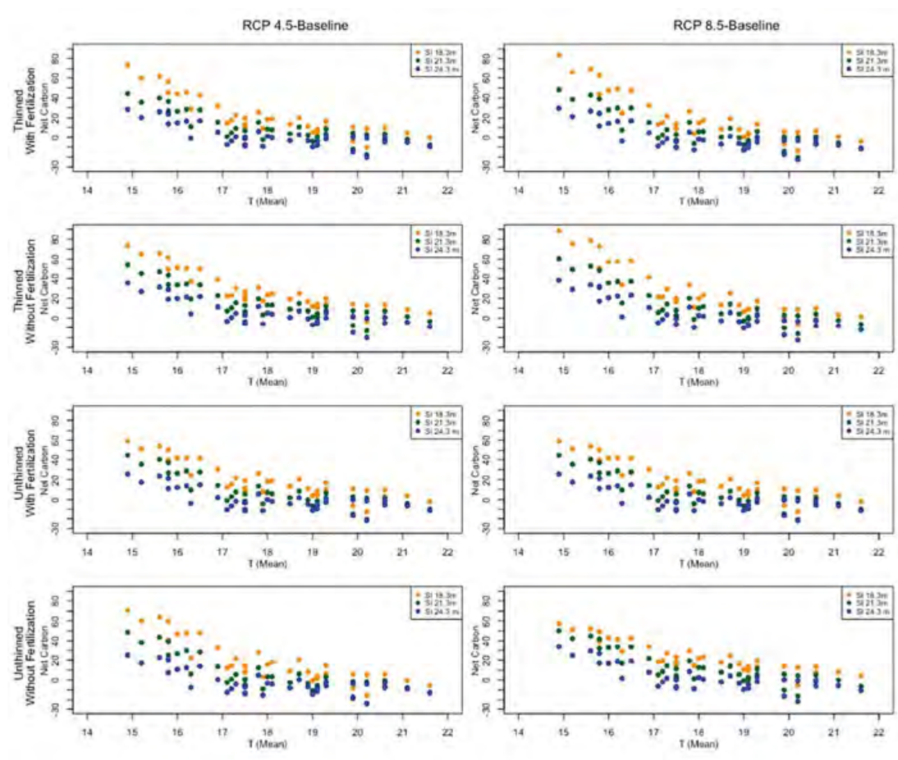


Figure 7.3. Percentage differences in total (in-situ and ex-situ) carbon sequestered at the end of the simulation period across selected sites in the US South relative to the Baseline climate scenario for a range of silvicultural scenarios and site indices. Results are plotted against mean annual baseline temperature for the sites.

8. CO_2 Fertilization and Forest Markets: Pine Forests in the Southeast U.S.

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Forest growth projections from 3-PG were incorporated into the Subregional Timber Supply Model to understand the long-term, large-scale effects of climate on wood inventory and prices. Though CO_2 fertilization does increase carbon stored in forests, a negative price impact works in opposititon. Policies that increase demand for pine sawtimber could help to mitigate this effect.

In the coming decades climate change and carbon dioxide fertilization will affect the productivity pine forests in the Southeast U.S. The resulting changes in loblolly pine (*Pinus taeda*) growth will impact forest markets and regional carbon sequestration. In this section, we examine this impact in the context of a baseline scenario of pine pulpwood and pine sawtimber. To investigate these impacts, we used above-ground biomass data generated from the 3-PG forest growth model based on 20 climate models and Representative Concentration Pathways (RCPs) scenarios 4.5 and 8.5. A regression of these data on age class and planting year by Forest Inventory Analysis (FIA) survey units provides a spatio-temporal matrix of pine yield. We examined forest market and carbon sequestration impacts using the Sub-Regional Timber Supply model (SRTS), with and without climate change-related growth.

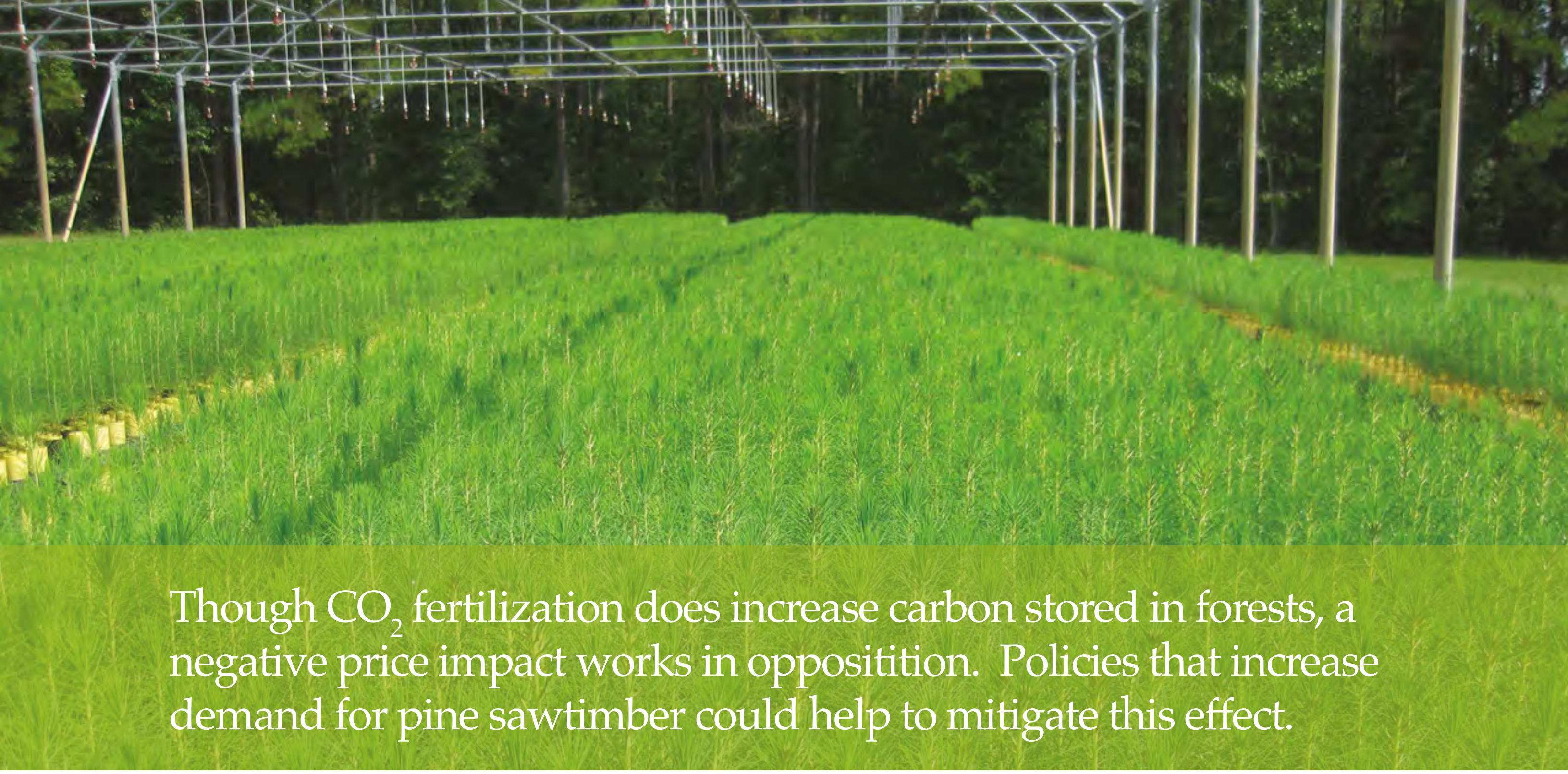
Introduction

Pine forests in the southeastern U.S. will be affected by climate change in the coming decades. This problem was a motivation behind the Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP), which produced state-of-the-art forest productivity measures as related to climate change (Thomas, Brooks, et al. 2017; Thomas, Jersild, et al. 2018). We present preliminary findings on the question of how impending CO_2 fertilization will interface with and affect forest product markets in the region. We developed methods to combine empirical inventory and removal data with projected climate-induced growth changes to simulate the dynamic interaction of forests and markets in the Southeast U.S.

Methods

Spatial Conformity

SRTS spatially optimizes timber harvests for a market-wide demand subject to subregional supply curves that reflect price and inventory constraints. Subregions can be customized on the order of multiple counties, and the default subregions are FIA survey units. Since the overlap of counties in the PINEMAP 3-PG database did not completely overlap with FIA survey units, outlier counties were merged into custom subregions based on proximity to whole FIA survey units. For example, counties in West Tennessee counties were merged into the North Mississippi subregion. This process resulted in 33 subregions, with most exactly matching FIA survey units. County level FIA inventory and removal data was then extracted and totaled for each survey unit, retaining heterogeneous features of ownership (corporate, noncorporate), management type, species, age class, and diameter-at-breast-height (dbh) distributions by physiographic region.



Though CO_2 fertilization does increase carbon stored in forests, a negative price impact works in oppositition. Policies that increase demand for pine sawtimber could help to mitigate this effect.

Summarizing 3-PG Data

3-PG is fully documented in (Landsberg and Waring 1997) and (Landsberg and Sands 2011). The model was further developed during the PINEMAP project (Thomas et al., 2017 and Thomas et al, 2018). County level results from 3-PG covering the historical range of loblolly pine (Virginia Polytechnic Institute and State University) were retrieved for use with the Sub-Regional Timber Supply model (SRTS) (Abt, Cubbage and Abt 2009). This dataset includes simulated projections of above-ground biomass growth by county for 20 climate models and two RCPs: 4.5 (Clarke, et al. 2007) and 8.5 (Riahi, Grübler and Nakicenovic 2007).

SRTS relies on FIA data, which is more accurate at multicounty scales (i.e., FIA survey units). Therefore, we aggregated the 3-PG data to survey unit regressions of aboveground biomass (WS) by: age class (AC), age class squared (AC2), planting year (PY), climate model (i), RCP scenario (j), and survey unit (k) prior to incorporation into SRTS:

$$(WS\_mean=\beta\_0+\beta\_1\ AC+\beta\_2\ AC\^{}2+\beta\_3\ PY)\_ijk$$

Results from these regressions produced highly accurate 3-PG summary models (R2 ~ 0.96) in which every term was significant (p-value < 0.0001). Table 26.1 *(see page 70)* shows an example coefficient matrix that was imported into SRTS for a model run. It is worth noting that a positive relationship exists between planting year and aboveground biomass, which captures the increasing effect of CO_2 fertilization over time. These tables did not replace the empirical growth or age class distributions in SRTS, but instead were used to perturb the empirical growth over the course of the model run.

Demand Scenarios

We used an annually increasing demand scenario to drive demand for timber products, with a compounding rate of 2% per year that leveled off in 2035 (Figure 8.2). Empirically, economic growth and demand see interruptions due to recessions or other economic fluctuations. Particularly with forest products, these stumpage price changes may substantially impact forest inventory stocks and reforestation. However, in this study the rate of increase in demand was chosen to maintain consistency with the economic growth assumptions associated with RCPs within the 2035 limit.

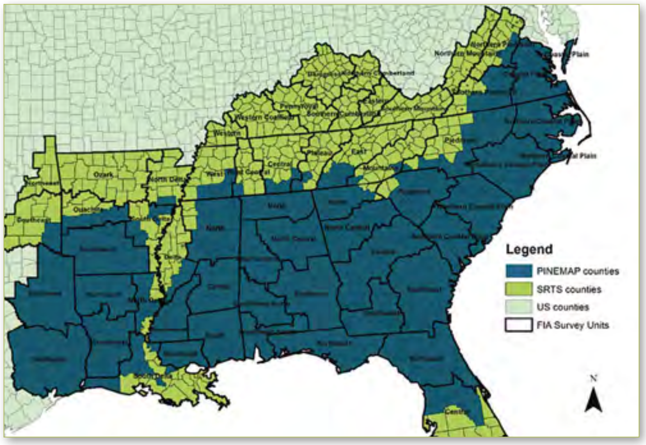


Figure 8.1. Spatial crossover of counties in the PINEMAP 3-PG database (blue), counties in SRTS (green and blue), and default borders of FIA survey units (black lines).

Commentary

These preliminary results reveal some important features of the interaction of forests, carbon, and economics. The results show an increase of forest inventory in all climate change cases relative to the case without climate change. The long-term difference between cases with and without climate change baselines are on the order of the spread among climate model results (Figure 8.3). The overall effect on southeastern forests at large is perhaps smaller than one would expect based on a stand level analysis. This is because existing pine trees must be harvested before new pine trees can take their place to capitalize on the increasing effect of CO_2 fertilization. In addition to inventory effects, CO_2 fertilization reduces prices for both pine sawtimber and pine pulpwood relative to the case without climate change (Figure 8.4). Lower prices for pine sawtimber lead to a land use change effect, reducing the incentive for private forest landowners to replant.

Though CO_2 fertilization does increase carbon stored in forests, a negative price impact works in opposition. Policies that increase demand for pine sawtimber could have three positive impacts: (1) higher pine sawtimber prices, encouraging greater private investment in planted forests, (2) lower pine pulpwood prices due to culls from sawtimber harvests, alleviating the extreme price pressure observed in Figure 8.4, and (3) more carbon stored in forests as a result of (1) and as a result of younger forests where prime growth phase syncs up with the increasing CO_2 fertilization trend.

Subregion	β_0 (Intercept)	β_1 (Age Class)	β_2 (Age Class)²	β_3 (Planting Year)
AL-NCtrl	-530.066	35.5482	-1.11552	0.247822
AL-North	-560.099	36.62347	-1.15857	0.262522
AL-SE	-490.121	35.68211	-1.12487	0.228112
AL-SW_N	-478.336	34.86674	-1.0888	0.222405
AL-SW_S	-525.145	32.92308	-0.99174	0.245977
AL-WCtrl	-507.851	34.49522	-1.06999	0.237004
AR-SW	-521.098	34.16982	-1.06003	0.243663
FL-Ctrl	-499.66	39.25084	-1.24117	0.233419
FL-NE	-537.299	37.51205	-1.1817	0.251475
FL-NW	-532.272	35.4133	-1.10143	0.249103
GA-Ctrl	-524.48	30.59843	-0.8741	0.246444
GA-NCtrl	-554.798	35.6817	-1.1158	0.259984
GA-North	-619	36.53884	-1.14938	0.291525
GA-SE	-558.976	31.20195	-0.89652	0.263411
GA-SW	-502.91	32.73339	-0.97958	0.235138
LA-NDelt	-422.329	33.97193	-1.08216	0.195779
LA-NW	-436.159	33.50539	-1.03755	0.202055
LA-SE	-504.102	36.13001	-1.13302	0.235188
LA-SW	-469.914	35.98298	-1.14233	0.218904
MS-Ctrl	-483.191	35.42034	-1.11515	0.224724
MS-North	-529.437	35.3201	-1.10875	0.247502
MS-South	-496.019	33.06876	-1.00172	0.231576
MS-SW	-476.105	36.10155	-1.143	0.221255
NC-NCP	-675.279	35.39278	-1.09895	0.319609
NC-Pdm	-633.997	31.16999	-0.9087	0.299967
NC-SCP	-629.766	34.43571	-1.04985	0.297054
SC-NCP	-597.998	32.71704	-0.96727	0.281978
SC-Pdm	-580.306	30.28267	-0.85548	0.274048
SC-SCP	-576.224	31.81921	-0.92549	0.271557
TX-NE	-486.458	27.19961	-0.7314	0.229412
TX-SE	-455.032	32.13193	-0.95335	0.212588
VA-CP	-718.463	32.62777	-0.96151	0.341224
VA-S_Pdm	-761.954	28.37408	-0.76376	0.363983

Table 8.1. Representative Input Table simulating CO_2 Fertilization Response for Climate Model bcc-csm1-1 under RCP Scenario 4.5.

[1]*Modified FIA survey units as described under "Spatial Conformity"*

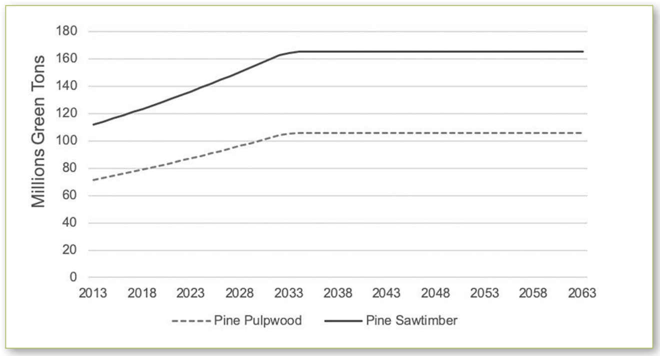


Figure 8.2. Demand scenarios in green tons for pine sawtimber (solid green) and pine pulpwood (dashed gray) for the *quantity demanded* and *fully economic scenarios.*

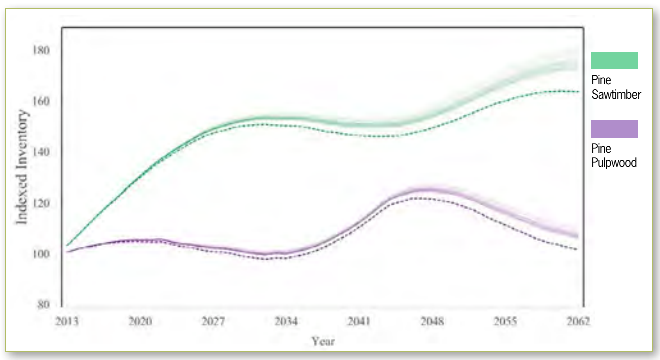


Figure 8.3. Figure 3. Indexed pine sawtimber and pine pulpwood inventory by climate scenario (20 climate models each for RCP scenarios 4.5 and 8.5) compared to the case without CO_2 fertilization (dashed line).

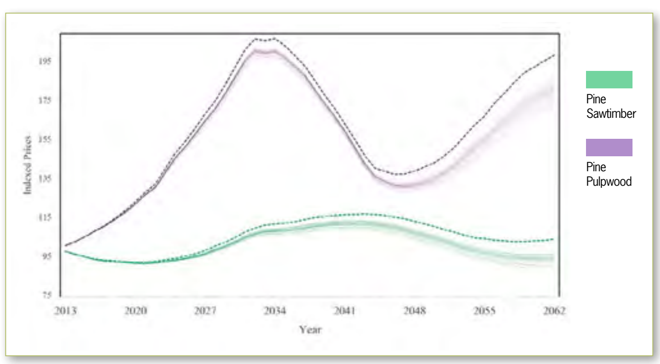


Figure 8.4. Indexed pine sawtimber and pine pulpwood inventory by climate scenario (20 climate models each for RCP scenarios 4.5 and 8.5) compared to the case without CO_2 fertilization (dashed line).

9. Improving Fertilizer Nitrogen Use Efficiency in Pine Plantations Across the Southeastern United States

Jay E. Raymond, Thomas R. Fox, Brian D. Strahm

Virginia Tech

Addition of nitrogen and phosphorus fertilizer is a major silvicultural approach to increasing planted pine productivity. Significant environmental and economic benefits can be derived by increasing the efficiency of fertilizer use through better identification of soils likely to respond to fertilizer, and the increased use of enhanced efficiency fertilizer products which minimize loss of nitrogen after application due to ammonia volatilization, denitrification, and leaching.

Because plants require high amounts of nitrogen (N) for the development of foliage and photosynthesis, plant growth is dependent on the amount of N available in the environment. Prior to 2006, most pine plantations across the Southeast US were fertilized during winter or early spring months with urea to minimize fertilizer nitrogen (N) losses caused by ammonia volatilization. A small percentage of the urea was treated with enhanced efficiency products in order to reduce N losses. Research over the past decade on a variety of these enhanced efficiency N containing fertilizer products has shown that these products do significantly reduce fertilizer N losses in pine plantations, which translates to an increase in the amount of fertilizer N available for plant uptake (Zerpa & Fox, 2011, Elliot and Fox, 2014; Werner, 2015, Raymond et al., 2016a). This research has directly led to the implementation over the past decade of treating urea with enhanced efficiency N containing fertilizer (EEF) products to reduce fertilizer N losses, with approximately 90% of urea applied currently treated with some form of EEF product.

Across the southeastern US, the productivity of many pine plantations is generally limited by low levels of both N and phosphorous (P). The low levels of N+P can usually be remedied through the application of N+P containing fertilizers. Research specific to the fertilization of loblolly pine plantations generally indicates positive growth responses for up to eight years following the application of 224 kg ha^{-1} N plus 30 kg ha^{-1} of P. This finding has led to the annual fertilization of more than 500,000 ha of pine plantations and has been an important driver of the improved productivity of these systems over time. Although fertilizer research in most pine plantations show positive responses to N+P fertilization, some sites failed to respond. Explanations to why certain pine plantations do not respond to N fertilization include the following: (1) improper site identification of nutrient availability; (2) nutrient imbalances created by N fertilization; and (3) N fertilizer loss translating to reduced N availability. Improving understanding of how fertilization N is partitioned in pine plantation ecosystems is important to the economic decisions and environmental stewardship of N fertilization and increasing the nitrogen use efficiency (NUE) of these ecosystems.

In the southeastern US, the Cooperative Research in Forest Fertilization (CRIFF) developed soil groupings that could be easily recognized in the field by land managers based on factors (e.g., moisture, soil type) that influenced growth (Jokela and Long, 2015). Identification of these soil categories has assisted land managers in predicting which pine plantations are likely to be responsive to N+P fertilization across the southeastern US. These CRIFF Soil Groups were developed for specific application in the southeastern Coastal Plain. Although they are effective for that region, they do not extrapolate well across the entire southeastern pine plantation region. Landowners in the southeastern Coastal Plain can continue to improve fertilizer use efficiency on their land base with the proper identification of CRIFF

Utilization of EEF products focusing on NH_3 volatilization in southeastern pine plantations can reduce fertilizer N loss and provide flexibility to apply N containing fertilizers at any time of the year to synchronize N fertilization to plant demand.

Soil Groups and their associated fertilizer recommendations as detailed in Jokela and Long (2015). Outside of the southeastern Coastal Plain, fertilizer NUE can be refined through the implementation of guidelines detailed in Carlson et al. (2014) and Albaugh et al. (2016). Site specific nutrient imbalances may also need to be remedied in cases where the application of N-only fertilizer has exacerbated problems. Recommendations for addressing this issue can be found in Vogel and Jokela (2011) and Carlson et al. (2014). The region-wide implementation of these management techniques will continue to improve the NUE of pine plantations across the southeastern US towards the stated goal of 15%.

Both the alignment of fertilizer prescriptions to improved soil type-associated guidelines and the use of enhanced EEFs can reduce losses and translate to an increase in N fertilizer retention in pine plantation ecosystems (Raymond et al.; 2016a, b). Granular urea has traditionally been the most commonly applied N fertilizer in forestry because of its high N content, ease of transport-storage-application, and hence low overall cost per pound of N applied. Unfortunately, N losses from urea fertilizer in pine plantations, primarily through ammonia (NH_3) volatilization, can exceed 50% under hot, humid, windy conditions. Though land managers have traditionally applied urea in winter or early spring to reduce the likelihood of these environmental conditions, they can occur at any time in the region. Additionally, fertilizer application during winter or early spring time periods may increase N losses via other pathways (denitrification or leaching) because of the low concurrent N uptake by pine trees.

Enhanced efficiency N containing fertilizer products can be formulated to reduce fertilizer N losses through any loss pathway. To improve plant N uptake and fertilization efficiency, EEFs that specifically reduce fertilizer N losses via the NH_3 volatilization pathway in the spring or summer can be applied to urea. Utilization of EEF products focusing on NH_3 volatilization in southeastern pine plantations can reduce fertilizer N loss and provide flexibility to apply N containing fertilizers at any time of the year to provide a more synchronous N fertilization to plant demand.

Enhanced efficiency fertilizers that reduce NH_3 volatilization can be divided into two broad categories. In the first, a chemical additive, such as N-(n-butyl) thiophosphoric triamide (NBPT) impregnates the urea granule which reduces urease activity, the enzyme in soil responsible for stimulating losses of ammonia from fertilizer N. Reducing urease activity allows the urea granule to dissolve and slowly move N into the soil, thus reducing NH_3 volatilization losses. A second EEF method is to coat urea granules with a physical barrier, as with a sulfur (S) or a polymer coating. This approach slows dissolution of the urea granule so that it is released to the environment in a more constant, gradual rate. This may reduce NH_3 volatilization losses and create release rates more synchronous with plant demand during the year. Recent research on both of these EEF methods in southeastern pine plantations has shown a 25-50% reduction in NH_3 volatilization using EEF products relative to urea (Figure 9.1, Raymond et al., 2016a). The reduction in NH_3 volatilization in these systems directly translated into a 20% increase in fertilizer N recovery from the system when using different EEF products compared to urea (Figure 9.2; Raymond et al, 2016b).

As an example, based on 2015 estimates from the Forest Productivity Cooperative, 474,120 acres were fertilized with N (urea) and P (DAP). Assuming that this area was operationally fertilized at the most common N application rate of 150 lb/ac, 77,303 tons of urea would have been applied to southeastern pine plantations. Assuming 90% of the southeastern pine plantation land-base was treated with some type of EEF product, this would translate to 425,000 acres of pine plantation fertilized with 69,572 tons of urea, or 32,003 tons of N, being treated with some form of EEF product. Using the results from Raymond et al. (2016a) shown in Figure 9.1, EEF products decrease volatilization

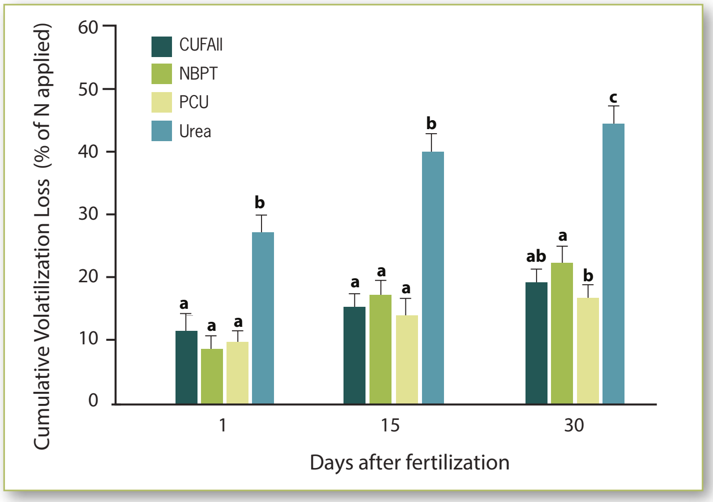


Figure 9.1 Cumulative mean volatilization loss from microcosms, expressed as a percent of loss of applied N fertilizer, for six mid-rotation loblolly pine plantations across the southern US after a spring+summer application of 15N (a stable isotope) enriched treatments (CUF, NBPT, PCU, urea). Different letters are significant differences at a=0.05, and error bars are the standard error of the mean. The N application rate used was 224 kg N ha-1.

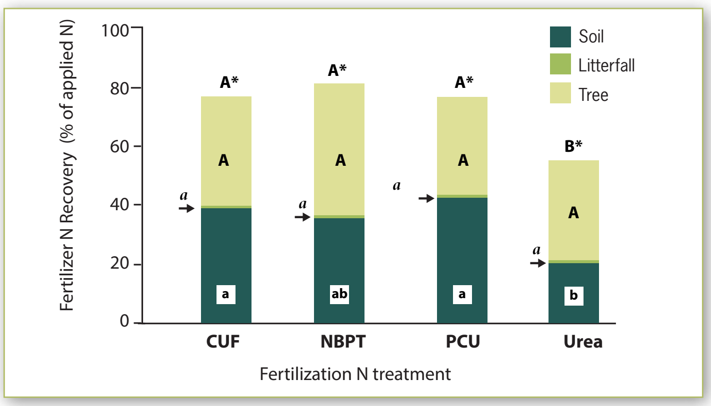


Figure 9.2. Cumulative fertilizer N recovery for pine plantation ecosystem, expressed as a percent of recovery of applied N fertlizer, for 10 mid-rotation loblolly pine plantations across the southern US after a spring+summer application of 15N enriched treatments (CUF, NBPT, PCU, urea). Different letters are significant differences at a=0.05, and error bars are the standard error of the mean. N application rate used was 224 kg N ha-1.

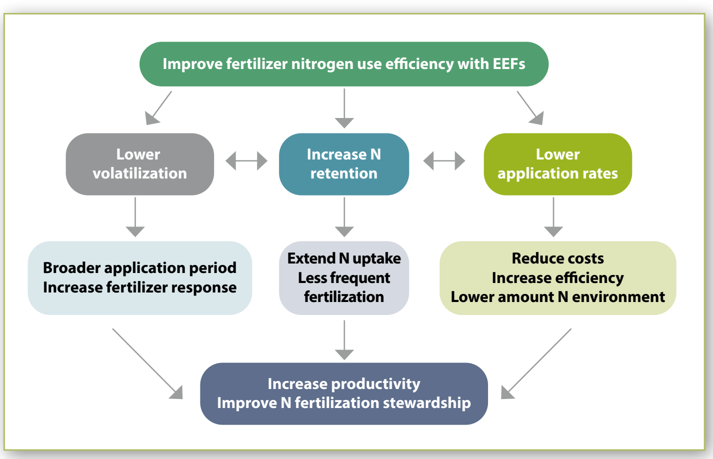


Figure 9.3. Management implications of improving nitrogen use efficiency in managed pine ecosystems with enhanced efficiency nitrogen containing fertilizers (EEFs).

by an average of 20% compared to urea. Because 90% of the area fertilized with urea was treated with an EEF product, only 6,400 tons of N would have volatilized from the urea treated with an EEF product compared to 12,801 tons of N from urea that was untreated. Additionally, because more fertilizer N remained in the ecosystem with EEF products (~80%) compared to untreated urea (~60%), fertilizer N uptake for the entire tree (foliage, stem, roots) averaged 40% for urea treated with EEF products compared to 30% for untreated urea. By treating urea with some form of EEF product, fertilizer N losses are reduced by a minimum of 20%. This reduction in fertilizer N loss from the ecosystem translates to an increase in fertilizer N uptake by crop trees of 10% in the first year after fertilization. By incorporating EEF technology during urea fertilization, N use efficiency can be increased by 15% in pine plantation ecosystems across the southeastern US. Additional improvements in the N use efficiency of these ecosystems using EEFs may also occur if the additional fertilizer N remaining in the system is available for plant uptake in the future. This continues to be an active area of research that is using stable isotopes (^{15}N) to trace the long-term fate of fertilizer N in pine plantation systems across the Southeast. The combination of these forest management techniques will continue to improve and refine fertilizer management in southeastern pine plantations in the future (Figure 9.3).

The improvement of fertilizer N use efficiency in southeastern pine plantation ecosystems continues to be a primary area of research for the forest products industry through the use of the forestry cooperatives that include the Forest Productivity Cooperative, Forest Biology Research Cooperative, and the Plantation Management Research Cooperative. Historically, these cooperatives have leveraged large quantities of private resources from the forest products industry to secure National Science Foundation (NSF) grants to achieve the PINEMAP objective of improving the N use efficiency of pine plantation ecosystems.

Future improvement in regional N use efficiency and increased flexibility to apply fertilizer N at any time to managed pine will come from:

- increases in the identification of fertilizer-responsive sites based on soil classification methods and implementation of appropriate intensive forest management; and
- increased use of enhanced efficiency N containing fertilizer products.

This research on EEF technology in pine plantation ecosystems in the southeastern US was conducted as a collaborative effort among PINEMAP, the Forest Productivity Cooperative and the Center of Advanced Forestry Systems (CAFS).

10. PINEMAP Markers for Climate-Smart Tree Improvement

Gary Peter[1], Carol Loopstra[2], Mengmeng Lu[2]

[1] University of Florida, [2] Texas A&M University

Advances in marker development and linkages to the loblolly pine genome developed in PINEMAP provide powerful tools for breeders that will enable more efficient and effective climate-smart tree improvement programs in the future.

Genetic improvement of loblolly pine began in the 1950s. This cooperative effort has produced 40–50% gains in volume yield compared to unimproved material. This improved genetic stock, together with advancements in silviculture, have increased yields 5–8 fold and cut rotation length in half. The genetic gains in stem volume are primarily due to improved growth rates, but are also associated with improved resistance to fusiform rust, a major fungal pathogen. Concurrent with these very valuable gains in volume, theoretical and practical advances have increased the efficiencies of every aspect of breeding, selection, testing, and deployment. These advances in efficiency have decreased the length of time needed to complete a cycle or generation of breeding from about 30 years in the first cycle to only 12–15 years as we enter the fourth cycle.

During the past 60 years, the climate over the loblolly pine natural range has warmed due to increased carbon dioxide (CO_2) levels in the atmosphere. While the increased CO_2 levels and warmer temperatures are predicted to boost loblolly pine growth and yields (See articles 2 and 3), it is also predicted that the patterns of abiotic disturbances (e.g., wind, drought, and flooding) as well as biotic pest and pathogen dynamics will change. Importantly, the changes in climate and weather are predicted to accelerate over the next 100 years. Therefore, it is critical to accelerate breeding and testing of more stress tolerant and disease resistant pines to ensure future productivity.

Recent advances in DNA sequencing and genotyping technologies have enabled the use of genetic markers to screen for desirable genotypes. In the PINEMAP project, we completed large scale genotyping of two gene discovery populations through two methods: Allele Discovery of Economic Pine Traits II (ADEPT2) (Cumbie et al. 2011)

For complex traits, association genetics is a powerful approach to discover genes.

Population	Protein Coding	Noncoding
ADEPT2	53%	47%
CCLONES	84%	16%

Table 10.1. Percentage of SNPs in protein coding and noncoding regions of the genome.

and Comparing Clonal Lines on Experimental Sites (CCLONES) (Baltunis, et al. 2006). This genotyping was enabled by the availability of a NIFA-funded genome sequence and assembly from loblolly pine (PineRefSeq - https://pinerefseq.faculty.ucdavis.edu/) (Neale et al. 2014). Eight-hundred ninety three individuals in CCLONES and 375 individuals in ADEPT2 were genotyped for single nucleotide polymorphisms (SNP) using exome capture sequencing (Table 10.1). For CCLONES, 63,000 biallelic SNPs were identified and genotyped (Quesada et al. 2019) and for ADEPT2 972,720 biallelic SNPs were genotyped (Lu et al. 2016).

The ADEPT2 and CCLONES populations were genotyped because many whole plant and molecular traits were available for analysis. Most traits of economic importance like growth, disease and pest resistance, and wood quality behave as complex traits with many genes affecting that desired phenotype. For complex traits, association genetics is a powerful approach to discover genes.

A significant constraint of traditional breeding is that not all genotypes can be tested in all environments. This shortcoming is magnified by the rapid change in climate. Thus, because individuals in the ADEPT2 population originate from many locations across the large natural range of loblolly pine, analyses were conducted with climatic variables. We identified a small subset of 375 SNPs whose variation was explained by climate alone with no effect from geography using the vegan R package. These SNPs may be useful for seed transfer decisions (Loopstra et al. 2019).

Taken together, the advances in marker development and linkages to the loblolly pine genome developed in PINEMAP provide powerful tools for breeders that will enable more efficient and effective climate-smart tree improvement programs in the future.

11. PINEMAP Educational Programs Benefit Middle School, High School, Undergraduate, and Graduate Students

Martha C. Monroe[1], John B. Kidd[2], Annie Oxarart[1], John R. Seiler[2]

[1]School of Forest Resources and Conservation, University of Florida, [2]Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University

The PINEMAP educational programs enabled the team to effectively reach educators and students who were not directly working on the project and offere current, science-based information about the relationship between climate and southern forests. These activities continue to prepare citizens to gain awareness, knowledge, and motiviation to engage in mitigation and adaption solutions to climate change.

PINEMAP supported two significant regional activities that engaged educators and students in learning about climate, forests, and forest management. In one activity, based at Virginia Polytechnic Institute and State University, 45 undergraduate fellows participated in four summer research programs and a distance course each following fall to build skills in communication and teaching. Fellows gave presentations in 116 classrooms to 7,423 middle school and high school students about climate, forests, and strategies to enhance system resilience. The 33 mentors (graduate students, post docs, and staff) in this program obtained experience critical to their personal and professional development as future forest resource managers and faculty members. In the second activity, a team based at the University of Florida produced an instructional module for middle and high school educators that reflected PINEMAP's research framework. More than 1,500 educators were trained to use this material with learners. This information will continue to be used to convey information, build systems thinking skills, and nurture hopefulness for solutions to climate change challenges. The evidence collected to demonstrate the effectiveness of these activities is summarized here and explained in more detail in the five articles that follow.

Undergraduate Fellowship Program

The PINEMAP Undergraduate Fellowship was developed to be an undergraduate research experience (URE) similar to National Science Foundation's Research Experiences for Undergraduates (REU) program. Three elements of the program make the PINEMAP fellowship a novel approach. First, because the program existed within the PINEMAP network of institutions, we offered an opportunity for a distributed URE where undergraduate participants traveled to a host university where mentors were located. Second, we encouraged and relied on graduate students instead of faculty members to mentor undergraduates. Third, the goal of public outreach was one of the greatest variations on URE. Students in the program participated in an online distance education course, "Effective Communication Skills," in the fall immediately following their summer research internships.

Extensive reach and building scientific capacity among minorities

This program was geographically far-reaching due to the network of PINEMAP institutions and partnerships with 1890s institutions. Undergraduates from universities across the eastern United States, California, Puerto Rico, and Quebec submitted applications for undergraduate fellowships. Students traveled to host institutions for their summer research, which offered many an opportunity to see cities and experience a new culture. After the summer experience, undergraduate fellows returned to their home institutions to teach younger students. As a result, the outreach to both undergraduate and secondary students expanded beyond our initial expectation of the southeastern US.

Through partnership with the Commonwealth of Virginia's 1890 land-grant institution, Virginia State University, we recruited qualified students from 1890 and primarily minority institutions: 38% of all applications were from minority students. Thirty-seven percent of undergraduates admitted into the program were minorities. Of the nine minority students that completed the final, retrospective survey, two agreed and seven strongly agreed that this program increased their level of interest in attending graduate school. At least three are currently enrolled in a graduate program.

> "Thank you so much for providing this opportunity! This has got to be as great for your students as it is for mine. I cannot imagine giving a presentation like this when I was a sophomore in college!"

Three-quarters of the mentors were graduate students serving as primary mentors for undergraduate fellows. Other mentors were either experienced research staff or doctoral graduates in post-doctoral (post-doc) or tenure-track positions. Two represented institutions beyond the PINEMAP network, Indiana University of Pennsylvania and Virginia Commonwealth University. Mentors' post-summer written reflections on their experiences described the challenges and outcomes associated with mentoring undergraduate researchers. Mentors indicated the experiences were beneficial to the undergraduates and, in all but one case, to themselves. Further emphasizing the beneficial nature of this experience, six doctoral students were mentors in multiple years.

Addressing secondary students

Thirty-eight of 45 undergraduates participated in "Effective Communication Skills." The primary objective was to provide fellows with practical communication learning experiences to prepare them to teach public secondary school students near their home institutions. Each undergraduate developed an educational lesson targeting grade-level learning standards on a forest resources topic, such as the carbon cycle, soils, the water cycle, the role of fire in forest ecosystems, and forest management. Undergraduates were responsible for scheduling 10 visits with teachers in their communities to present hands-on science lessons. Our undergraduates visited 116 teachers' classrooms in 85 public secondary schools. The 340 presentations reached approximately 7,400 secondary school students who learned about the role and value of forests.

Teacher evaluations of students' presentations (including their relevance, structure, and engagement) were a large component (40%) of course grading. The evaluations were used to improve subsequent presentations and provided opportunities for teacher feedback. This feedback showed that students were appropriately prepared to deliver presentations that were relevant to learning objectives, according to an environmental science teacher in Virginia. This public school involvement had other and unexpected positive outcomes: One host teacher asked an undergraduate fellow to consider collaborating in the development of an environmental club at the school that would involve other interested local university students (e.g., undergraduates and graduate students) in developing presentations.

Southeastern Forests and Climate Change

A successful design

We also partnered with Project Learning Tree® (PLT), a national environmental education program, to develop a secondary module on climate change and forests (Southeastern Forests and Climate Change) that became part of the suite of curriculum materials disseminated by PLT coordinators across the region. We began the process by identifying module goals and activity objectives based on the research conducted within PINEMAP (Monroe, Oxarart, & Plate; 2013). By providing biology and environmental science teachers with supplemental activities that addressed current, critical research as well as curriculum objectives, we helped prepare the public to understand the types of findings PINEMAP researchers would

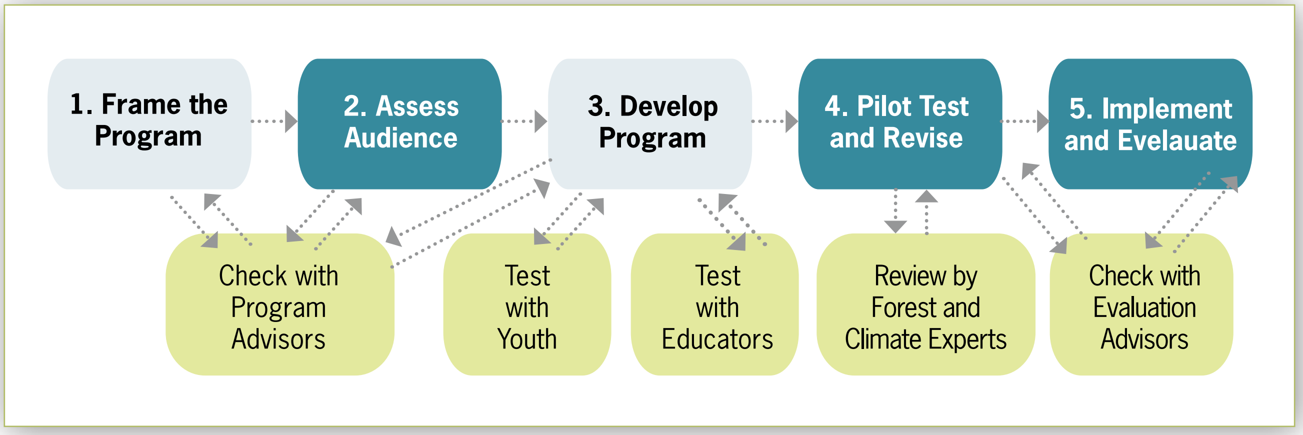


Figure 11.1. Program development (steps 1-5) involved 825 teachers and an additional 260 educators, students, and experts who engaged in specific opportunities to offer advice (blue and gray boxes).

report. This also enabled us to tap PINEMAP researchers to help design activities, review materials for accuracy, and provide supplemental videos. Forty-four PINEMAP faculty, post-docs, interns, and graduate students participated in the design and review of this module.

The module framework was also shaped by an assessment completed by more than 740 science teachers across the Southeast in 2012 who confirmed that the activities focused on climate change and local ecosystems would be engaging for students. Nearly all respondents (98%) conveyed the importance of critical thinking skills and connecting climate science to students' lives. The degree to which they were able to integrate activities across their curriculum or offer one- or two-week units depended on the specific science subject (Monroe, Oxarart, & Plate; 2013).

Tapping expertise

We collected feedback from practicing teachers at three points in the development process: the assessment, a pilot test of materials, and a summative evaluation (steps 2, 4, and 5 in Figure 11.1). We also developed advisory committees and actively sought input from educators participating in professional development programs and youth in science camps as we tested activities and evaluation tools. These opportunities (gray boxes in Figure 11.1) enabled us to answer key questions about activity design, relevance, and content accuracy; to revise materials to better meet teacher needs; and to obtain quotes from teachers who used the activities with students.

Iterative tests and basic research

We took advantage of several opportunities to test activities, collect feedback, and make revisions in the activity design or explanation. We organized a teacher symposium to introduce several activities and learned that more background on graphing and trigonometry was needed for science teachers to adequately guide their students through the activities. Two summer science camps enabled us to conduct experiments with parallel versions of several activities to determine that introducing the carbon cycle in the context of climate change helped youth learn more about carbon (Monroe, Hall, & Li; 2016). A survey of science educators helped us better understand their worldviews. We realized that although some science teachers do not think humans have contributed to global warming, all teachers agree that the topic of climate change is useful to convey the nature of science and make science relevant to learners (Kunkle & Monroe; 2018). The pilot test of draft materials led us to specific improvements, including a new activity to introduce a timeline of climate science research, adaptations for middle school learners, systems thinking discussion questions and supplemental activities, and better internal references to link activities into storylines and to background information.

Evidence of success

More than 5,000 copies of the 247-page instructional module have been distributed through workshops and conferences in 23 states to educators. Southeastern Forests and Climate Change is listed as a recommended resource for AP Environmental Science teachers by the College Board. In addition, more than 770 people are currently registered on the module website (www.sfrc.ufl.edu/extension/ee/climate). The materials are being widely used. For example, researchers in North Carolina have created a special program using this PINEMAP resource to train agriculture educators and explore cultural cognition, and educators in Taiwan have received funding to adapt this resource to their forests, climate projections, and curriculum. This resource is making a valuable contribution in science and agriculture classrooms around the globe.

Summary

These two projects enabled the PINEMAP team to effectively reach educators and students who were not directly working on the project and offer current, science-based information about the relationship between climate and southern forests. These activities continue to prepare citizens to gain awareness, knowledge, and motivation to engage in mitigation and adaptation solutions to climate change.

12. Impacts of a Four Year Undergraduate Research Experience in Forest Resources

John B. Kidd[1], John R. Seiler[1], and Shobha Sriharan[2]

[1] *Department of Forest Resources and Environmental Conservation, Virginia Polytechnic Institute and State University,* [2] *Department of Agriculture, Virginia State University*

The PINEMAP Undergraduate Fellowship Program engaged diverse undergraduate students in research, benefitting both them and their mentors through documented positive outcomes in personal, professional, and cognitive domains.

The PINEMAP Undergraduate Fellowship Program was a novel 12-week, full-time summer undergraduate research experience (URE) developed to provide undergraduate students from across the southeastern United States with the opportunity to conduct summer research with graduate students at PINEMAP institutions. Due to the PINEMAP network of land-grant universities, including several 1890s institutions, this program was able to recruit several minority undergraduates into its cohorts during 2011-2015. Beginning with a pilot program of six undergraduates at three universities in 2011, the program expanded over the next three years to include a total of 45 undergraduate students and 33 mentors at 10 universities (Figure 12.1). All PINEMAP disciplinary research groups were represented in the fellowship program, but the vast majority of fellowships were with the silviculture group. Goals of the program included engaging undergraduate students in natural resources research and providing graduate students with opportunities for assistance with research while gaining mentoring experience.

The completion rate for the summer part of the fellowship was 98%. Undergraduate participants were diverse: 53% of participants were female; and 37% were minorities and included African Americans (20%), Hispanic/Latino (11%), Asian/Pacific Islander (4%), and Native American (2%). We attribute this relatively high degree of minority participation to a partnership with the HBCU Virginia State University where work was done to recruit minority students each year. Most undergraduate research programs target upper class groups, and researchers recently suggested that URE programs should target other undergraduates (Russell et al., 2007). Undergraduate ranks in our program included mostly juniors (42%)

and sophomores (29%) with smaller numbers of freshmen (16%) and seniors (13%) at the time of their participation. This student distribution indicates that we successfully included students from groups not typically targeted by other URE programs, particularly in the natural resources discipline.

Over four years, the 33 mentors fell into the following categories: doctoral (PhD) candidates (49%); master of science candidates (24%); PhDs including experienced faculty researchers (12%) and postdoctoral associates (9%); and experienced research and Extension associates (6%). Nine mentors participated during multiple years, and half of all mentors were female (51%). The majority of mentorships were established as one graduate student mentor per undergraduate; however, a few of the mentorships were established with an undergraduate, graduate, and faculty and some included two graduate students.

Sixty percent of undergraduates completed pre- and post-summer surveys, which evaluated goals and attitudes toward research (1 = strongly disagree to 5 = strongly agree). We used paired t-tests to examine pretest and posttest scores for positive aspects of research, negative aspects of research, and usefulness of research. Students' self-reports indicated moderately to very positive attitudes toward science for each category. Students' attitudes toward the negative aspects of research and the usefulness of research did not change. However, undergraduates' attitudes toward the positive attributes of research significantly decreased from 4.1 to 3.9. The items in this factor included the statements, "I enjoy research," "I am interested in research," and "I am inclined to study the details of research." A decrease in attitudes toward positive attributes may suggest that undergraduates feel more upbeat about research or have unrealistic expectations before fully engaging in the practice of scientific research at an entry level position for a long period of time.

A retrospective survey was provided to all undergraduate student participants in May 2016. Respondents (62%) to the final survey evaluated the quality of life and quality of learning experience resulting from participation in the fellowship program as very good. All respondents indicated they would recommend the program to others, and all but one respondent indicated they would again make the decision to participate. Students reported greatest gains for items related to personal and professional outcomes, followed by graduate school and career preparation, general skills, career clarification, and application of knowledge and skills, and finally, understanding of science and research (Table 12.1). However, one student reported a decrease for some personal and professional survey items. Results suggest that participants gained greater insight into the work and effort involved in conducting scientific research, and this insight allowed them to clarify their interests in pursuing research as a career or changing trajectories within their chosen disciplines. Additionally, they valued the fellowship program as an opportunity to have a good summer job and to add a credential to their resumes for future employment. These results support previous research findings that the majority of undergraduate researchers experience greater gains across several outcome areas while a few individuals reported gains to a lesser degree (Lopatto, 2004).

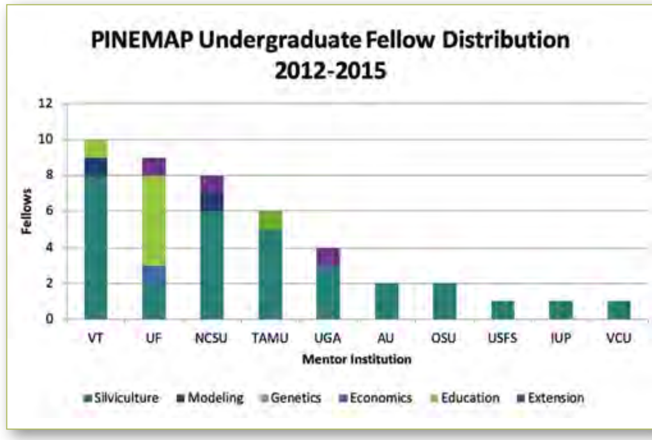


Figure 12.1. Distribution of undergraduate fellows among PINEMAP's collaborating institutions and disciplines from 2012-2015.

After each summer, we asked mentors to provide a brief written reflection on their experiences as mentors in the fellowship program. Of 272 coded statements, 18% referred to challenges of undergraduate research and 82% related to benefits of mentoring. Interpersonal statements (29%) included items related to general mentoring ability, mentoring skills, teaching skills, and communication skills. Professional outcomes (23%) included understanding of faculty work, development of advising and mentoring specifically related to career preparation, managerial skills, desire for future work with undergraduates, and organizational skill gains. The cognitive gains (22%) category included, but was not limited to, intellectual growth, a sense of undergraduates that informs teaching and mentoring, alterations of future mentoring strategies, and thinking differently. Instrumental gains (15%) were specifically related to work/ research productivity, research quality, satisfaction from undergraduate's outcomes, and improved qualifications. Socioemotional gains (11%) were related to confidence, enjoyment of work life, self-awareness, and responsibility for others. Five negative statements were related to effort involved in familiarizing students with the mentor's research or effort involved in dealing with challenges of mentoring undergraduates. All mentors that responded indicated a net benefit in their participation, even if the challenges associated with mentoring consumed time or if the mentor received no gains in research productivity.

We successfully met our goals of engaging diverse undergraduates with opportunities experiencing undergraduate research that were beneficial for their personal and professional development and of providing research assistance to PINEMAP mentors, which allowed them to grow as professionals. However, room for programmatic improvements was evident through the aforementioned negative outcomes from undergraduate survey responses and mentor statements indicating that participant needs or expectations may not have been met. These findings align with prior URE research that these programs are integral, worthwhile components of the scientific research pipeline in higher education.

This student distribution indicates that we successfully included students from groups not typically targeted by other URE programs, particularly in the natural resources discipline.

Organization Type	n	%
General skills	The feeling that your research experience was a good summer job	4.64
Career preparation	Exposure to new opportunities and/or experiences	4.50
Career preparation	Opportunities for networking with faculty, peers, and other scientists	4.36
Career clarification	Awareness of new fields of study	4.32
Confidence	Attention to detail related to work as a scientist	4.29
General skills	Technical skills related to laboratory and/or field work	4.25
Career preparation	Quality of your resume	4.22
Confidence	Confidence in your ability to conduct research	4.21
Confidence	Having a mentoring relationship with faculty	4.21
Confidence	General level of confidence	4.18

Table 12.1. Top 10 gains reported by undergraduate researchers participating in the PINEMAP Undergraduate Fellowship during 2012-2015. Outcomes from personal, professional, and cognitive domains reported in undergraduate research literature were included in the survey on a five-point rating where 1=decreased, 2=neutral, 3=slightly increased, 4=increased and 5= strongly increased.

13. Understanding, Measuring, and Cultivating Hope about Climate Change among High School Students

***Christine Li*[1] *and Martha Monroe*[2]**

[1] School of Natural Resources, University of Missouri, [2] School of Forest Resources and Conservation, University of Florida

Climate change is a complex, challenging topic and can be discouraging; however, results from our research with the *Southeastern Forests and Climate Change* module show that educational approaches can cultivate hope. This was achieved through real-world examples of scientists and forest managers who were working to understand, mitigate, and adapt to climate change, as well as through demonstrating how others can join them. Our study showed that these positive and informative activities may help nurture hope among high school students.

Climate change presents society with an enormous challenge, and at the same time, a great opportunity to engage students in learning about science and problem-solving. Carefully designed climate change education programs can facilitate increased knowledge about climate science and nurture hope to take actions. The development of the *Southeastern Forests and Climate Change* secondary module provided an opportunity to create a climate change educational resource that achieves three critical goals: (1) help learners understand the science of climate change in the context of forest management; (2) enhance skills in critical thinking, particularly about the process of science (NGSS, 2013); and (3) empower youth to actively engage in solutions to climate change (Selby & Kagawa, 2012). We designed a tool to measure hopefulness in order to assess the influence of these educational activities on students' willingness to engage in climate change.

Measuring Hope

To examine students' hope concerning climate change, we drew on the Hope Theory (Snyder, 2000) and the literature on self-efficacy (Bandura, 1977) to design an instrument to test whether or not willpower and "waypower" are applicable in this context. Willpower explains to what extent individuals believe that they are able to meet the life goals that they set for themselves; waypower is the extent to which they can think of ways to overcome a problem (Snyder, 2000). The instrument was revised three times. During Phase 1, we pilot tested the scale with 924 high school students across the Southeast and conducted an exploratory factor analysis to uncover the potential underlying factor structure. During Phase 2, we revised the scale and asked a panel of education and psychology experts to assess the extent to which willpower and waypower were being measured. During Phase 3, with 978 students from 28 secondary high schools across the region, we conducted a confirmatory factor analysis (CFA) to assess the extent to which the final model fits the data. CFA is a statistical procedure to test how well the survey items represent the constructs. Factor loading determines the degree to which each item affects the factor, with higher value meaning stronger affect. The final version, Climate Change Hope Scale (CCHS), contains 11 items (Table 13.1) (Li & Monroe, 2017). The study confirmed a three-factor solution with good model fit: (1) personal-sphere willpower and waypower, (2) collective-sphere willpower and waypower, and (3) lack of willpower and waypower.

"After the activity, they have started asking more involved questions about environment and climate change." — AN EDUCATOR FROM NORTH CAROLINA

	CCHS	
Factor 1: Personal-sphere will and way	**Factor loading**	**SE**
I am willing to take actions to help solve problems caused by climate change.	.759	.02
I know that there are things that I can do to help solve problems caused by climate change.	.683	.02
I know what to do to help solve problems caused by climate change.	.496	.03
Factor 2: Collective-sphere will and way		
If everyone works together, we can solve problems caused by climate change.	.827	.02
I believe that scientists will be able to find ways to solve problems caused by climate change.	.543	.03
I believe people will be able to solve problems caused by climate change.	.528	.03
I believe more people are willing to take actions to help solve problems caused by climate change.	.543	.03
Even when some people give up, I know there will be others who will continue to try to solve problems caused by climate change	.532	.03
Factor 3: Lack of will and way		
Climate change is beyond my control, so I won't even bother trying to solve problems caused by climate change.	.895	.02
The actions I can take are too small to help solve problems caused by climate change.a	.731	.02
Climate change is so complex we will not be able to solve problems that it causes.	.723	.02

Note: N = 946

Table 13.1. Factor parameter and standard errors for confirmatory factor analysis of CCHS

Cultivating Hope

To foster hopefulness regarding climate change, we used the following strategies in designing activities in *Southeastern Forests and Climate Change:* (1) built students' systems thinking skills in seeing connections, (2) applied climate information to a local context and demonstrating that others care about this issue, (3) introduced tools and projects that people were developing and using locally, and (4) provided strategies that students could continue to use to contribute to mitigation or adaptation. The summative evaluation of these activities provided an opportunity to explore to what extent hopefulness differed after participating in the five different activities and how did hopefulness change differently based on course, gender, grade level, or ethnicity.

We measured hopefulness before and after the program and observed a significant improvement. Our results also showed that increased hopefulness was not a function of gender, ethnicity, or grade level (Figures 13.1 and 13.2). No matter how hopeful students were initially, the activities increased their sense of hope regarding resolving climate change challenges.

Climate change is a complex, challenging topic and can be discouraging; however, results from our research with the *Southeastern Forests and Climate Change* module show that educational approaches can cultivate hope. This was achieved through real-world examples of scientists and forest managers who were working to understand, mitigate, and adapt to climate change, as well as through demonstrating how others can join them. Our study showed that these positive and informative activities may help nurture hope among high school students.

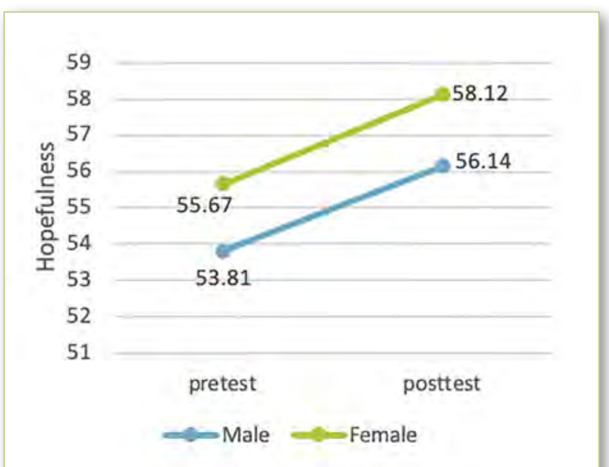


Figure 13.1. Comparison between male and female on hope score in summative evaluation.

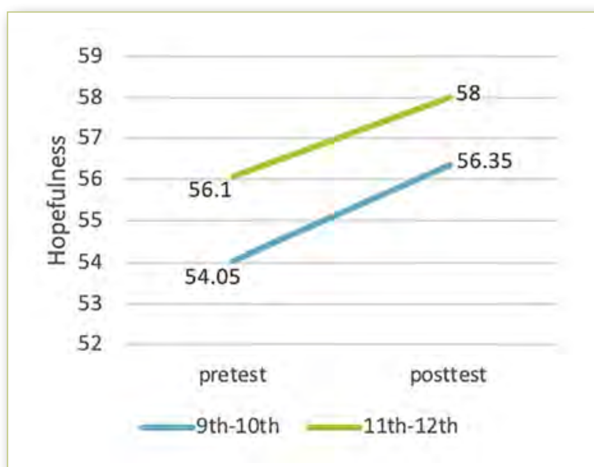


Figure 13.2. Comparison between younger and older students on hope score in summative evaluation.

14. Southeastern Forests and Climate Change: Environmental Education Module for Secondary Science Teachers

Annie Oxarart and Martha C. Monroe

School of Forest Resources and Conservation, University of Florida

The PINEMAP Southeastern Forests and Climate Change module was framed around the project's research activities. It assists educators in meeting several current education initiatives—Climate Change Education, STEM education (Science, Technology, Engineering, and Mathematics) and Education for Sustainability—by engaging learners in science, math, technology, economics, and environmental justice. Module activities build student skills in critical and systems thinking, as well as enhance group communication and collaboration, which are hallmarks of high quality education.

Southeastern Forests and Climate Change is an instructional module designed for middle school and high school science educators that is framed around PINEMAP's research activities (Table 14.1) and helps bridge the gap between understanding climate change and relating it to forestry and consumer choices. This collection of 14 activities helps biology, agriculture, and environmental science teachers focus on the interactions between climate and forests and the ways we can manage forests to adapt to and mitigate future change. The module has been well-received by educators throughout the Southeast.

Developed in partnership with Project Learning Tree® (PLT), the 247-page module is an interdisciplinary approach to climate change containing experiential activities, background information, step-by-step instructions, science-based perspectives, systems thinking connections, suggested modifications and enrichment adaptations, and correlations to national science standards. The accompanying module website (http://sfrc.ufl.edu/extension/ee/climate) not only offers a downloadable version of the module but also a wealth of supplementary resources including interactive activity descriptions, slide presentations, specialized systems thinking exercises, answer keys, videos of researchers explaining their work, and quotes from teachers who pilot tested the module providing encouraging words of wisdom for each activity. The website also includes tests of knowledge and web links for additional information to build teacher knowledge and skills. Nearly 200 people helped write and review activities, or participated in the advisory committee, content review, or formative and summative evaluations—which resulted in a high-quality product.

Training Educators and Facilitators

Using PLT's network of state coordinators, facilitators, and educators in the Southeast US, 94 people were trained at three regional "train the trainer" workshops held in North Carolina, Arkansas, and Florida in 2014 and 2015. These workshops introduced the module to facilitator teams from 12 states. Since then, more than 5,000 printed copies of the module have been distributed, and nearly 1,250 people have been trained to use the materials at 69 events that PLT coordinators or facilitators hosted. Minigrants provided to 11 southeastern states through the national PLT organization supported many of these workshops. While the majority of these events have taken place in the Southeast, 11 states outside of the region are also using the materials with minor modifications.

At the regional facilitator workshops, pre-post surveys show that participants' self-efficacy in teaching about climate change significantly increased. In turn, these trained facilitators used the same survey at 47 of their workshops and also showed that participants' had a significant increase in efficacy to teach about climate change. In fact, there was no significant difference between the two sets of post-workshop surveys. Because of the many differences between the facilitators, participants, and length of workshop (2 hours to 2 days), one might assume that the one constant, the module, is largely responsible for increasing educator confidence in teaching about climate change.

Overall, the workshops included formal and nonformal educators, 67% of whom teach secondary audiences in grades 6 to 12 (n=623). Most of the classroom teachers who participated taught science courses such as biology, and environmental, Earth/space, or general sciences. A little more than half of the workshop participants reported not teaching about climate change prior to the workshop. After the workshop, the majority of participants were "very likely" to use the module in future work (67%), recommend the module to their colleagues (76%), and expand the coverage on climate change in their work (61%). Workshop evaluations suggest a number of workshop char-

"This curriculum is an excellent resource and provides educators tools to introduce discussions about climate change or dive into investigations." —TEACHER AND WORKSHOP PARTICIPANT

acteristics, such as providing a respectful learning atmosphere and providing information in an understandable way, increased participants' sense of efficacy and intent to use the materials (Table 14.2). In addition, workshop evaluations also suggest that the extensive website also supports the growing confidence in teaching about climate change. Educator comments suggest teachers believed they had acquired resources needed to teach about climate change:

- *I now have a jumping off point to look more closely at the issue through the resources in the guide.*
- *I can't wait to teach this module. I have become passionate about this topic in the past 2 days.*

Measuring Success

An online survey of all educators who have received the module, either through an educator workshop, the module website, or request, noted that over half (54%) used the materials with approximately 7,125 learners within the first year (n=379). For those who have not yet used the materials, more than half planned to use them in the future and were expected to reach an additional 4,800 students. Half of the respondents who had already used the materials were classroom teachers who used an average of two activities, mostly with 9th to 12th grade students. These teachers used the activities as a unit or part of a unit lasting less than one week (33%) or inserted into several units as relevant (28%). A third of respondents used the module with adults in nonformal settings, such as educator workshops or presentations, and 14% used the module with youth in nonformal settings such as day programs with schools and clubs or youth programs.

Respondents indicated that these activities helped them teach scientific concepts in a creative way, make science relevant, engage learners in developing evidence-based explanations, and use questions to engage learners (Table 14.3). Respondents also chose "agree" or "strongly agree" to indicate that learners were engaged in the activity, more knowledgeable about climate change, and more knowledgeable about climate impacts to forests. Additionally, respondents noted that learners gained systems thinking skills and critical thinking skills, and were more hopeful about human actions to address climate change. Most respondents used the interactive activity descriptions (70%) and narrated presentations or videos (61%) on the module website to prepare for some or all of the activities they used and indicated that they found these training resources "useful" or "very useful" (Figure 14.1).

Summary

Southeastern Forests and Climate Change assists educators in meeting several current education initiatives—Climate Change Education, STEM education (Science, Technology, Engineering, and Mathematics) and Education for Sustainability—by engaging learners in science, math, technology, economics, and environmental justice. Module activities build student skills in critical and systems thinking, as well as enhance group communication and collaboration, which are hallmarks of high quality education. Our data show that teachers are using the materials, and students are learning about managing forests in a changing climate and building skills they can use as engaged citizens of their communities.

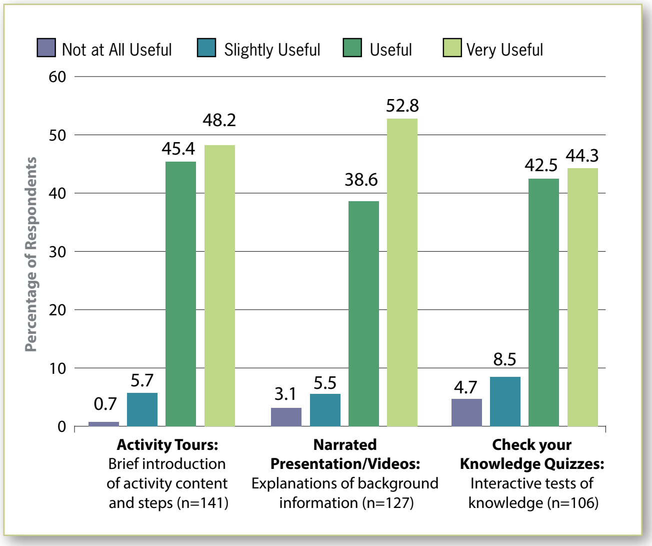


Figure 14.1. Usefulness of Online Teacher Tools

Section	Theme	Activity
1. Climate Change (CC) and Forests	Conveys that scientists currently understand observed changes in weather and climate are impacting forest ecosystems.	**1. Stepping through Climate Science –** Walk along a timeline of climate science and policy initiatives and explore connections between forests and climate. **2. Clearing the Air –** Explore common confusions about CC and role-play to discuss strategies to reduce greenhouse gas (GG) emissions. **3. Atlas of Change –** Use climate modeling to understand past changes and project future possibilities, and consider how forest ecosystems might change.
2. Forest Management and Adaptation	Forest managers can be encouraged to alter management practices to help create resilient forests that will survive climate challenges.	**4. The Changing Forests –** Review how scientists are monitoring forest changes and explore strategies to keep forests healthy. **5. Managing Forests for Change –** Develop and use a systems diagram to model forest management under future climate conditions. **6. Mapping Seed Sources –** Analyze data to determine the origin of the seeds and understand how variations in genotype create trees that may do better in new climatic conditions.
3. Carbon (C) Sequestration	Sequestering carbon in trees, soil, and wood products keeps it out of the atmosphere. Scientists are exploring if we can sequester more carbon in these pools.	**7. Carbon on the Move –** Become familiar with the carbon (C) cycle and pathways that increase and decrease atmospheric C. **8. Counting Carbon –** Measure trees near schools, calculate the amount of C stored in each, and compare the C sequestration potential for land-use types to estimated amount of C released by human activities.
4. Life Cycle Assessment (LCA)	Consumer choices can play a role in reducing and preventing The concept of externalities considers the environmental problems that can occur from the production, shipping, and disposal of various products.	**9. The Real Cost –** Learn about the externalities of consumer choices on the environment by doing a simulated shopping activity. **10. Adventures in Life Cycle Assessment –** Investigate LCA data for three types of outdoor dining furniture to determine which type would generate the lowest amount of GG. **11. Life Cycle Assessment Debate –** Debate four pairs of similar products to develop a set of questions about product life cycles that can help guide consumer choices.
5. Solutions for Change	Summarizes the concepts in this module. These can be adapted to reflect the activities that teachers selected. Students can be empowered with the knowledge and hope that all of us can help work toward healthy, sustainable forests and communities.	**12. The Carbon Puzzl**e – Use a series of facts to realize how forest plantations, wood products, and wood substitution can reduce atmospheric C, and then interpret a scientific graph. **13. Future of Our Forests –** Review information from the module in teams and share knowledge with an appropriate audience. **14. Starting a Climate Service-Learning Project** – Plan and complete an action project to mitigate climate change or help communities adapt to projected changes.

Table 14.1. Southeastern Forests and Climate Change Activities by Theme

To what extent did this workshop:	Mean[1]
Provide a respectful learning atmosphere	3.84
Present information that you could understand	3.74
Help you feel like part of a community of educators interested in teaching about climate change	3.59
Prepare you to use this PLT educational resource	3.58
Increase your confidence to teach about climate change	3.50
Prepare you to incorporate climate change into your work	3.48
Decrease confusion about this issue	3.47
Provide adequate time for reflection	3.30

[1]*Scale of 1 to 4, with 1 = not at all and 4 = very much, n=~732*

Table 14.2. Workshop Characteristics

To what extent did these activities support you in:	Mean[1]
Using questions to engage learners	3.55
Helping learners practice systems thinking skills	3.52
Engaging learners with discussions of ethics or environmental quality	3.52
Facilitating a meaningful discussion with learners who have a variety of perceptions	3.51
Using diagrams for representing scientific concepts	3.50
Helping learners interpret data	3.47
Discussing solutions to climate change challenges	3.46
Connecting science with current policy	3.44
Connecting consumer choices to sustainability	3.39

Table 14.3. Educator Objectives

15. Gauging the Effectiveness of the Southeastern Forests and Climate Change Module

Tracey Ritchie[1], Martha Monroe[1], Richard Plate[1], Annie Oxarart[1], and Christine Li[2]

[1] School of Forest Resources and Conservation, University of Florida, [2] School of Natural Resources, University of Missouri

Research with 32 teachers from 10 states showed that the Southeastern Forests and Climate change module was highly effective at helping students become more knowledgable about climate change and forests, and in gaining systems thinking skills. All of the teachers agreed or strongly agreed that they developed necessary skills to teach climate change.

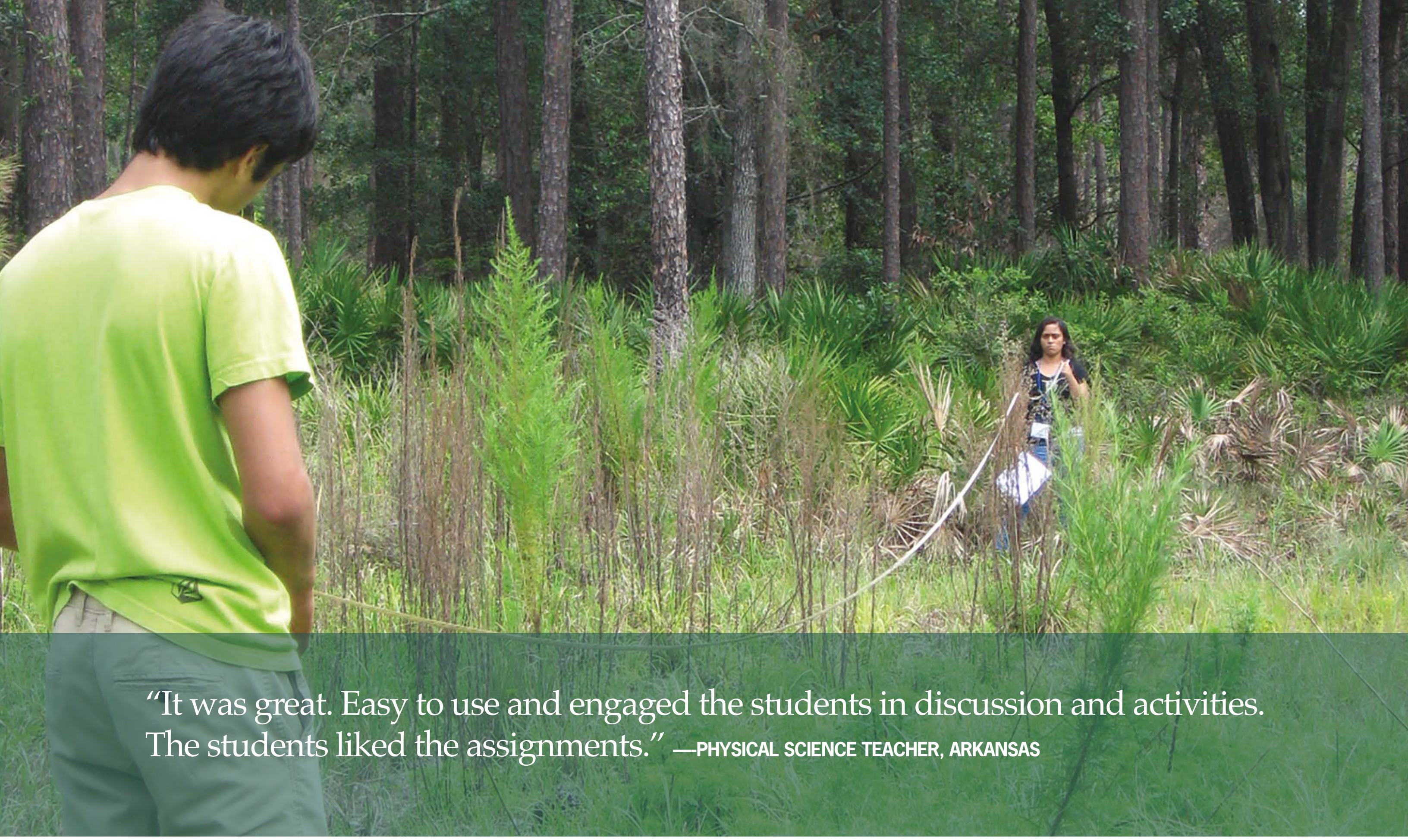
Teachers' comments about PINEMAP's *Southeastern Forests and Climate Change* secondary module and its impacts on students were overwhelmingly positive and evaluations showed an increase in respondents' abilities to teach about a complex topic. PINEMAP's education team created the comprehensive module through an extensive development and evaluation process. Through formative and summative evaluations, we assessed changes in students' knowledge as well as teachers' perceptions of how the activities worked in the classroom.

After initial development of the module, a formative evaluation was conducted in 2013. This resulted in module improvements such as creating an introductory activity, providing modifications to each activity that addressed diverse student abilities and time constraints, adding supplemental systems thinking exercises to the website, and clarifying teacher background sections and activity instructions. The summative evaluation, conducted in the spring of 2015, gauged the effectiveness of the revised product with a new set of teachers across the Southeast. The evaluation aimed to answer the following overarching questions:

- ✔ What are the teachers' perceptions of the secondary teaching module?
- ✔ What are the teachers' perceptions of the website and online training resources?
- ✔ To what degree did students meet the activity objectives?
- ✔ To what extent did these activities change the students' knowledge, skills, and attitudes?

In addition to these evaluation questions, we posed several research questions designed to assess student hope regarding climate change, student systems thinking abilities, and teacher efficacy when teaching about climate change.

The evaluation team selected 45 high school teachers to maximize variation in their location, limit subjects to relevant areas, and to increase class size from a pool of 160 interested teachers. Thirty-six teachers agreed to participate and received evaluation materials; 32 completed the process and received a stipend for participating. These 32 teachers came from 10 different states (AL, AR, FL, GA, LA, MS, NC, OK, SC, VA) and collectively taught over 1,500 students. The module was divided into three subject-based packages that each consisted of five activities (Figure 15.1). Packages were designed for biology courses (Package 1), agriculture and forestry topics



"It was great. Easy to use and engaged the students in discussion and activities. The students liked the assignments." —PHYSICAL SCIENCE TEACHER, ARKANSAS

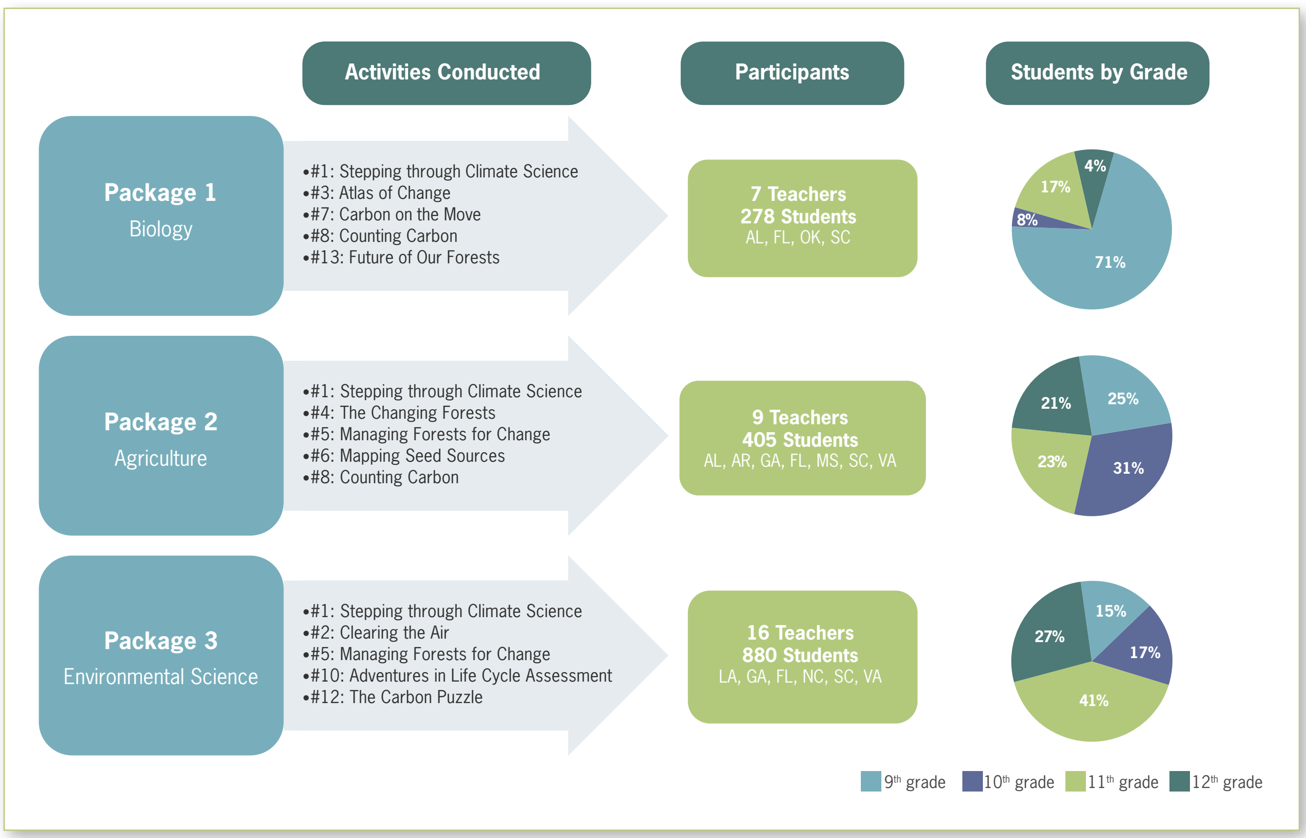


Figure 15.1. Summative Evaluation Breakdown

Concept	Prescore	Postscore	Difference	T value	p value	Increase in % of students who answered correctly
Package 1: Biology Classes (n=168)						
Forest management (6 items)	2.04	2.71	0.67	4.40	<0.001	54.8%
Carbon (3 items)	1.29	1.56	0.27	3.07	<0.002	39.3%
Climate (2 items)	0.91	1.07	0.15	1.91	<0.06	35.7%
Life cycle (1 item)	0.65	0.72	0.07	1.29	<0.2	21.4%
Package 3: Environmental Science Classes (n=627)						
Systems (7 items)	4.01	4.45	0.44	5.45	<0.001	49.0%
Carbon (2 items)	1.05	1.15	0.10	3.20	<0.005	21.7%
Climate (5 items)	2.77	3.23	0.46	6.96	<0.001	47.7%
Life cycle (3 items)	1.32	1.93	0.61	11.46	<0.001	52%

Table 15.1. High School Students' Knowledge Scores Before and After Instruction

(Package 2), and environmental science courses (Package 3). The evaluation process included the following steps:

- incorporating 5 activities into their lessons,
- providing feedback on each activity through an online survey,
- distributing and collecting parent consent forms,
- administering pre and post surveys to students, and
- completing a final online survey about their experience.

A separate knowledge test was developed for each package to cover topics in the five activities. Some questions from the formative evaluation were revised. Two parallel versions of the knowledge test (A and B) were used. Students also received a pre-post hope surveys (see article 2C). Package 3 included additional instruments for measuring systems thinking skills in students and involved twice as many teachers as the other two packages for this research. The tests and surveys were pilot tested with high school students and revised to ensure validity and reliability. All students took the pre-post tests and surveys, but only those with parent consent forms were used in the data analysis. In Package 1, a majority of the students were in 9th grade (71%) while Package 2 was more evenly distributed across all four grade levels. Package 3 was skewed toward 11th and 12th grade students. Teachers incorporated the five activities in different ways, either as a unit lasting one to two weeks (30%), a unit lasting more than two weeks (37%), or by inserting activities into several units throughout the semester as relevant (33%).

Student Learning

Student knowledge increased significantly from the pretest to posttest. Table 15.1 details the changes from Packages 1 and 3 by content theme. While overall students in Package 2 showed a significant increase from pretest to posttest ($t=4.83$, $p<0.01$), there was inconsistency among responses between forms A and B and therefore these data are not included. The research also showed significant increases in hope (see article 2C) and systems knowledge (see Table 15.1). Student interviews showed a basic level of systems thinking abilities. For example, students could describe systems relationships but still defaulted to simple, linear cause-effect relationships and often did not incorporate proper systems vocabulary. Systems thinking skill development was found to be highly dependent on a teacher's comfort and experience with systems thinking. Further research is being done to better understand how to increase teacher efficacy in systems thinking through professional development.

A second edition of the module, printed in October 2015, included revisions from suggestions obtained from the summative evaluation. The module website continues to be updated with new resources and suggested modifications from users. Module use has spread well beyond the Southeast and continues to grow (for more information see article 2D). The *Southeastern Forests and Climate Change* module serves a model curriculum resource that includes appropriate pedagogy, rigorous evaluation, and current content while providing engaging activities for teachers and students that can lead to impressive knowledge and skill gains.

Teachers' Perceptions

The majority of survey respondents indicated the module was "very supportive" in engaging students with applications of science (93%), engaging students in developing evidence-based explanations (86%), teaching scientific concepts in a creative way (83%), helping to practice systems thinking skills (80%), and addressing 21st century skills and knowledge (80%). When asked about their students' reactions to the activities, the majority of teachers agreed that students were more knowledgeable about climate change (91%), were more knowledgeable about climate impacts on forests (91%), and gained systems thinking skills (90%). Perhaps the most powerful finding from the summative survey was that 100% of the teachers chose "agree or "strongly agree" that they developed necessary skills to teach about climate change.

16. Practical Public Speaking: Integrating Community Outreach into an Undergraduate Forest Resources Communication Course

***John B. Kidd*[1]*, John R. Seiler*[1]*, and Shobha Sriharan*[2]**

[1] Department of Forest Resources and Environmental Conservation, Virginia Tech, [2] Department of Agriculture, Virginia State University

Over the course of the project, 38 PINEMAP Undergraduate Fellows from 8 states, Puerto Rico, and Quebec participated in an online course which prepared them to deliver experiential science lessons to over 7,000 middle and high school students. Fellows gained important science communication skills, and reported decreased anxiety about public speaking.

As a part of the PINEMAP Undergraduate Fellowship, participating undergraduate students built on their summer research experience with a fall semester course, "Effective Communication Skills." This online course emphasized communicating about natural resources topics to various audiences including public secondary school students and peer researchers. The course objectives included that students participate in community outreach, improve their communication skills, and learn skills for future work as graduate students and scientists.

The ability to communicate effectively to multiple audiences cannot be overstated and has long-lasting impacts for obtaining and succeeding in jobs. For natural resource graduates, whose work may revolve around translating and communicating complex scientific ideas for technical and lay audiences, it is even more important. This course falls in line with some recent adjustments in undergraduate curricula to support emphasis on society-ready students with high-quality communication skills (Sample et al., 2015; Bullard et al., 2014). The evaluation provided data on outcomes of students' formal communication to peer and lay audiences, which has typically received little attention in undergraduate research (UR) literature despite being a metric of positive student outcomes in UR.

Outreach to secondary school students was a defining component of the course. Each undergraduate presented a natural resources lesson to approximately 10 public secondary school classes near students' home institutions. Lessons included activities reinforcing important and relevant concepts related to forest resources, climate change, and PINEMAP research. For example, one presentation utilized a terrarium and infrared gas analyzer to show the process of photosynthesis decreasing atmospheric CO_2 and respiration increasing atmospheric CO_2. These projects allowed students to develop and practice skills for communicating science to a wide range of groups while providing important environmental education lessons meeting secondary school learning standards. In order to deliver a high quality environmental education lesson, students conducted many practice sessions to develop and refine them, before coordinating visits with nearby school teachers.

While communicating to lay audiences was an important part of this course, PINEMAP fellows also honed their skills communicating to technical audiences. They constructed scientific research presentations based on their summer work, including a written abstract, research poster, and narrated slide presentation (a slide presentation with recorded audio). Students submitted good quality drafts, received feedback for revisions, and submitted final versions for grades. After the first offering, we instituted a peer review activity for poster drafts to help students become familiar with giving and receiving feedback from peers.

Since 2012, 38 students over four cohorts completed the course and reached approximately 7,400 secondary school students (Table 16.1). Presentations were given in Virginia, Florida, North Carolina, Texas, Oklahoma, Kansas, Arizona, California, Puerto Rico, and Quebec. Classes varied from 5th to 12th grade in the following subject areas: biology, ecology, environmental science, and agriculture. Teacher responses to the program were very positive as indicated in comments on evaluations of students' presentations by host teachers.

We evaluated student and course outcomes through two measures: a pre-post format survey on students' public speaking anxiety (McCroskey, 1970) and an end-of-course evaluation. Students responding to both speaking anxiety surveys experienced a significant decrease in speaking apprehension (Figure 16.1). As evidenced by decreases in apprehension, this format of teaching practical public speaking and providing community engagement influenced students' attitudes and concerns about preparation and speaking to groups.

"If all college students were as prepared, articulate, and polished as [this student] was on his presentation topic, there would be a greater demand for these types of opportunities." **– 2015 HOST TEACHER.**

Student responses to the course were positive (Figure 16.2). Students agreed that assignments improved their creative thinking, oral communication, and written communication. Responses about the helpfulness of research communication assignments also suggested these tasks were beneficial. Students found more benefit in the abstract writing and research poster assignments than the narrated slide presentation. However, two students indicated that they did not think these assignments were helpful for their academic or career goals. Open-ended responses were overwhelmingly positive: One student remarked on the school presentations as a vehicle for academic and personal outcomes, "Public presentations to schools was a great experience and has improved my abilities and confidence in organizing and presenting a project." Another student said, "All of these assignments were very helpful to develop my scientific writing. I feel more prepared for my higher-level classes from this work."

Through course organization and activities, undergraduates were able to develop educational lessons beneficial to students they were teaching and to themselves. More than 7,000 students were reached through these activities and participating secondary school teachers indicated appreciation for this opportunity. Producing skilled scientific communicators is a critical component of an undergraduate natural resources program, and this innovative course design provided real-life opportunities to develop and evaluate education and communication skills valuable for interacting with peers and society.

	2012	2013	2014	2015	Total	Unique
Fellowships completed	5	12	10	11	38	-
Presentations delivered	53	107	81	99	340	-
Schools visited	14	25	24	32	95	85
Teachers visited	29	40	32	37	138	116
Students reached	1,060	2,629	1,518	2,216	7,423	-

Table 16.1. PINEMAP Fellowship outreach metrics resulting from student participation in the fall distance course, "Effective Communication Skills," for years 2012-2015.

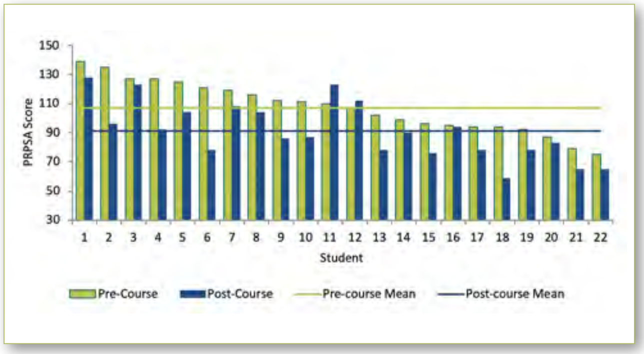


Figure 16.1. Self-report pre-post-course undergraduate scores on the Personal Report of Public Speaking Anxiety scale (McCroskey 1970) for students participating in the PINEMAP Undergraduate Fellowship fall distance education course for years 2012-2015. Lower scores indicate lower anxiety.

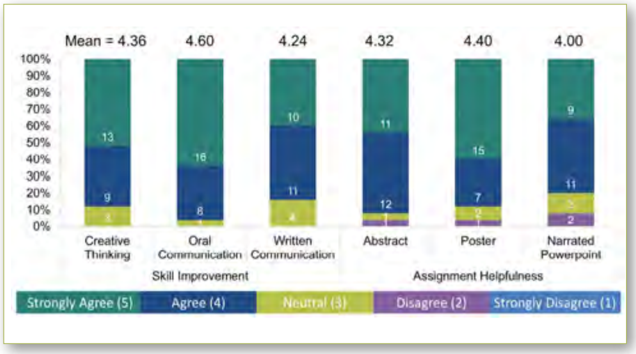


Figure 16.2. End of course evaluations (n = 25) for years 2012-2015 suggest that students improved creative thinking, oral communication, and written communication skills, and that the research communication assignments were helpful.

17. Three Years and Three Tiers: Education and Outreach in the PINEMAP Undergraduate Fellowship Program

John B. Kidd and John R. Seiler

Virginia Tech

The PINEMAP Undergraduate Fellowship Program engaged the public through fellow presentations to local, public secondary school teachers and students as they learned about forest resource science and climate issues. The program also built capacity for greater integration across geographical and disciplinary boundaries as undergraduate fellows worked with graduate students, staff, and principal investigators who may share similar and/or diverse interests within climate and forest science.

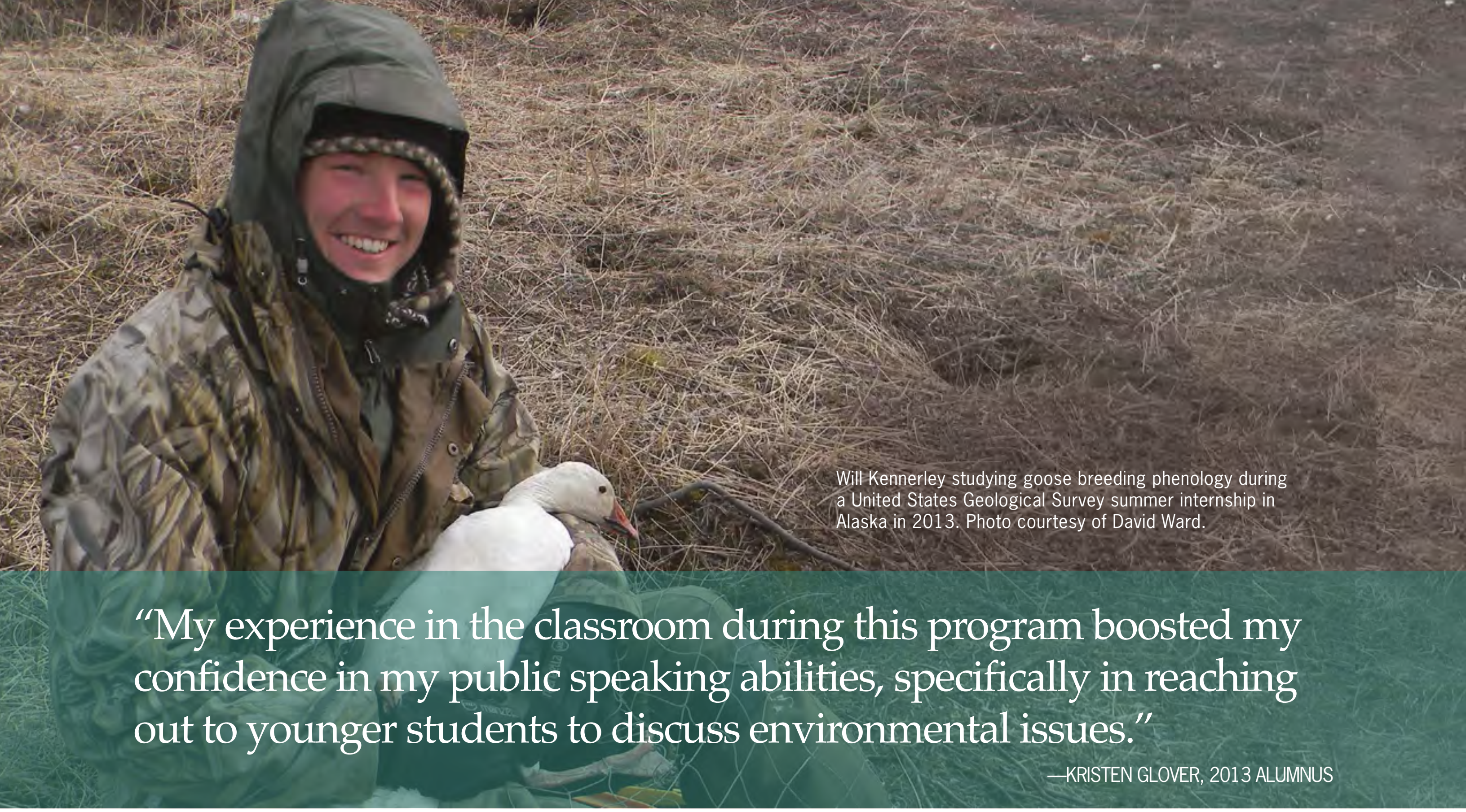
Outreach programs are critical to making research available and relevant to society. The PINEMAP Undergraduate Fellowship Program was a highly integrative education and outreach component of the PINEMAP project that brought together graduate students, undergraduate students, public secondary school teachers, and public secondary school students. This integration offered the potential for each participant to be exposed to a variety of research interests, skill sets, and learning experiences. Undergraduates from across the southeastern United States and Puerto Rico were hired as wage employees of Virginia Tech, earning up to $7,000 for work in the summer and fall terms. These undergraduate fellows were paired with graduate student researchers at PINEMAP's collaborating universities (Figure 17.1). The program included an intensive, distributed (students hosted at different sites) summer research internship followed by a distance-delivered education course in the fall. In this course, undergraduate fellows learned science communication skills, developed lessons on natural resources and climate change issues, and presented those lessons to public secondary school students. In the summer and fall terms of 2012, 2013, and 2014, a total of 26 fellows delivered 233 presentations to 5,043 secondary school students (Table 17.1).

Will Kennerley, a 2012 undergraduate fellow, prepares root samples for incubation during his PINEMAP fellowship. Photo courtesy of John Seiler.

Three undergraduate cohorts completed the fellowship since the program's initial offering in 2012. Thirty fellows were part of the program, and twenty-six successfully completed it. The majority of fellows were recruited as sophomores or juniors. Many of these students also participated in other research internships. Of the eight fellows who graduated, five are presently working and three are now graduate students pursuing master degrees.

The fellowship's two components offered complementary gains to students. Alumni regarded the research internship as a critical learning experience that taught content and procedural knowledge applicable to subsequent coursework and provided a foundation for obtaining and performing professional work in natural resources disciplines. Interacting with experienced researchers, professionals, and graduate students also offered undergraduates a positive, confidence-building experience. For instance, Rudy Rutemiller, a 2013 alumnus, remarked, "The summer of research itself taught me how to interact with true professionals, and to not be afraid to ask questions and really learn."

The fellowship also gave undergraduate students a deeper understanding of the personal investments in and the broader impacts of professional research. The fall distance learning course provided undergraduates with useful communication tools, including instruction in how to develop and present educational lessons targeted toward public audiences, as well as the preparation of scientific research abstracts and posters. Additionally, undergraduate students developed confidence and experience in public speaking, as Kristen Glover, a 2013 alumnus, noted, "My experience in the



Will Kennerley studying goose breeding phenology during a United States Geological Survey summer internship in Alaska in 2013. Photo courtesy of David Ward.

> "My experience in the classroom during this program boosted my confidence in my public speaking abilities, specifically in reaching out to younger students to discuss environmental issues."
>
> —KRISTEN GLOVER, 2013 ALUMNUS

classroom during this program boosted my confidence in my public speaking abilities, specifically in reaching out to younger students to discuss environmental issues."

Public school teachers also valued the program and commented on its positive and engaging experiences for their classes: "Thank you so much for providing this opportunity! This has got to be as great for your students as it is for mine. I cannot imagine giving a presentation like this when I was a sophomore in college!" wrote an environmental science teacher at Twin Springs High School, Nickelsville, Virginia. Teachers saw the program as providing valuable lessons for students that "fit perfectly" within the curricular units, thanks to the training the fellows received on state science standards. This observation also extended to the program's broader relevance, as a teacher at Robious Middle School in Midlothian, Virginia, wrote, "Connection to current research & global issues = more please!" This work in the public schools also had unexpected positive outcomes: one of the host teachers asked an undergraduate fellow to consider collaborating in the development of an environmental club at the school that would involve other interested local university students (e.g., undergraduates and graduate students) in giving presentations.

The fellowship program concluded in 2015 after offering the same opportunities to a fourth and final participant cohort. From graduate student mentors to undergraduate fellows to secondary school teachers and students, the PINEMAP fellowship made impacts in the areas of research and education. This program was an important outreach component of the overall project as it conveyed the relevance and value of southeastern forest resources and climate. The program's positive influence was visible and has a high likelihood of persisting for years to come.

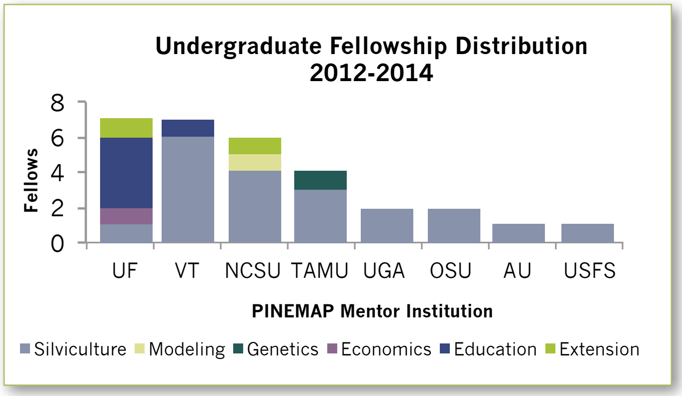


Figure 17.1. Distribution of undergraduate fellows among PINEMAP's collaborating institutions and disciplines from 2012–2014.

Outreach metric	2012	2013	2014	TOTAL
Fellowships completed	5	12	9	26
Presentations delivered	54	107	72	233
Schools visited	14	25	23	62
Teachers visited	29	40	28	97
Students reached	1060	2629	1354	5043

Table 17.1. Individuals reached through the PINEMAP. Undergraduate Fellowship Program as of February 2015.

18. Non-industrial Private Landowner Attitudes, Perceptions, and Willingness to Participate in Carbon Offset Programs in the Southeastern United States

Donald Grebner

Mississippi State University

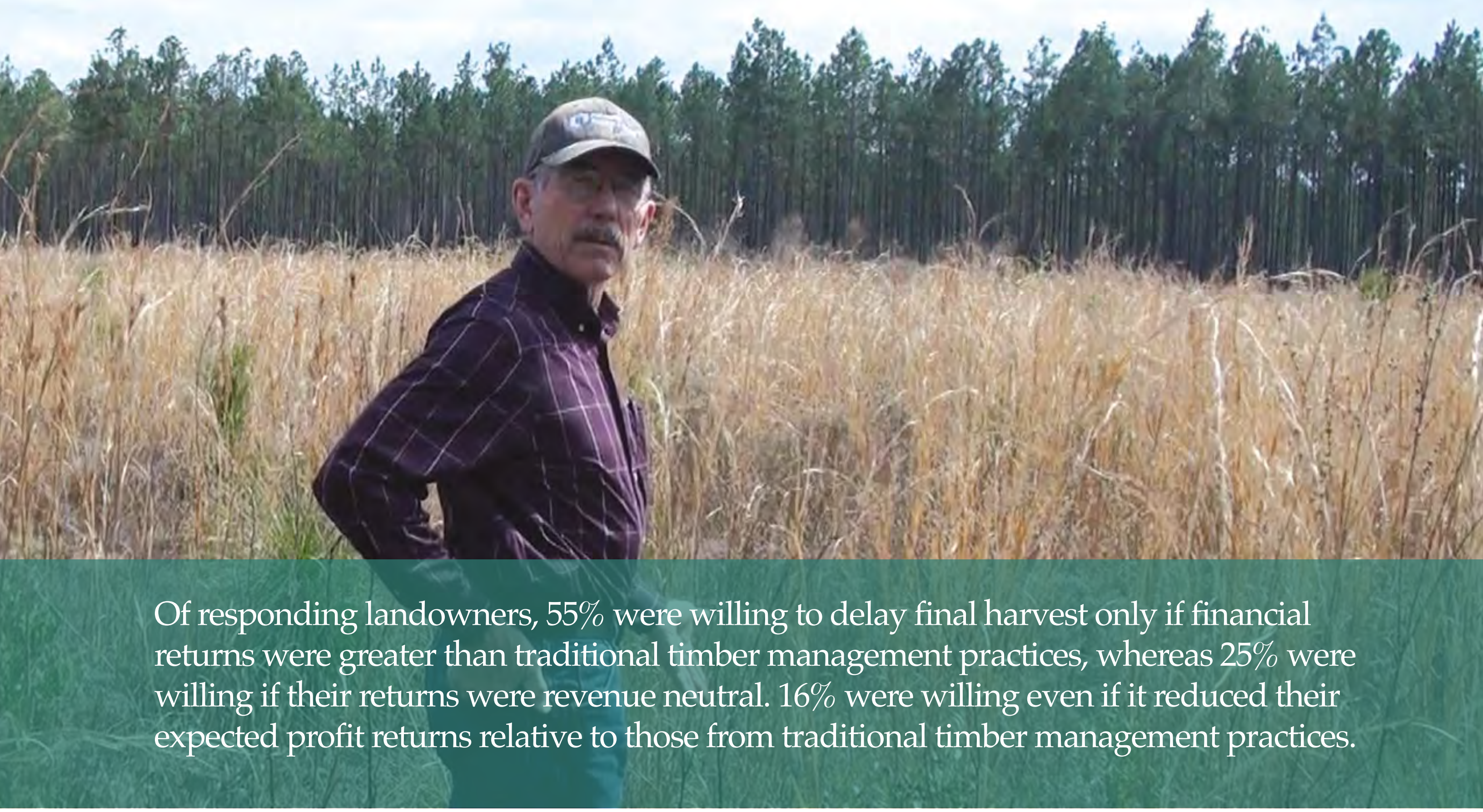
Non-industrial private forest (NIPF) landowners own 58% of southern forestland, and are much more diverse than industrial forest landowners. Studies of NIPF landowners in the region showed that they are largely willing to participate in carbon mitigation or offset programs, but that their willingness depends on program attributes, primarily those related to contract length and financial returns.

Most forested land in the southern United States is privately owned. Non-industrial private (NIPF) landowners, who own 58% of southern forest land overall, have motivations and desires which differ from industrial private forest landowners, so policies and programs that are focused on southern forests need to consider this audience. Motives of NIPF landowners can vary widely depending on their personal levels of household income, size of their ownerships, locations, forest types, access to markets, and exiting inventories, as well as a host of socio-economic factors. Industrial forest landowners are less variable, as they are generally profit maximizers with some constraints due to their organizational structures. Within the PINEMAP project, two studies were conducted to evaluate the behavior of NIPF landowners at the state and regional levels to understand their perceptions of climate change and willingness to participate in carbon offset programs. Study results indicated that NIPF landowners were largely willing to participate in carbon mitigation or carbon offsets programs, but that willingness was dependent on program attributes. Information from this study will inform development of climate mitigation policies and programs for forestry targeted toward NIPF landowners.

Climate change and the consequences for our economy as well as the environment will have an incredible impact on our society for many generations to come. Though there are many contributors to the emission of greenhouse gasses into the atmosphere, there are also many potential mitigation strategies that could be employed to combat this growing problem. Strategies to mitigate greenhouse gases for the forest sector include reduction in deforestation, increased afforestation, reforestation, effective forest management regimes that promote increased growth and longer rotations, and the production of cellulose-based products with longer shelf lives. Estimating the amount of carbon sequestered from these strategies is relatively straightforward. However, targeting policy based programs at the national, regional, or state level to private landowners with diverse motives and future plans is challenging.

We conducted two studies to understand NIPF landowner beliefs and behaviors. The first focused specifically on NIPF landowners in Florida as an example to understand landowner behavior regarding carbon offsets (Soto et al., 2016). A second regional study focused on NIPF landowner beliefs towards climate change and carbon sequestration programs across the following southeastern states with significant acreages in pine: Alabama, Arkansas, Georgia, Florida, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Texas, and Virginia (Khanal et al. 2016a). Surveys for the regional study were mailed to 5,000 forest landowners, yielding 735 completed surveys. Based on survey results, landowners were grouped into three broad climate change belief clusters defined as neutral (47%), skeptical (35%), and supportive (18%). A majority of southern NIPF landowners believe their forests are either not at risk or only moderately at risk of losses due to natural causes (e.g., wildfire or pest damage), however, 18% do believe that their forests are at risk to losses from natural causes. These landowners overwhelmingly expect no change in average timber yield from climate change impacts. In contrast, 22% of the supportive group expect a timber yield decline of at least 5% or more due to climate change.

NIPF landowners were also asked about their willingness to implement a carbon sequestration strategy, such as delaying the final harvest of their pine forest (Khanal et al., 2016b). Of the



Of responding landowners, 55% were willing to delay final harvest only if financial returns were greater than traditional timber management practices, whereas 25% were willing if their returns were revenue neutral. 16% were willing even if it reduced their expected profit returns relative to those from traditional timber management practices.

landowners who responded, 55% were willing to delay final harvest only if their financial returns were greater than traditional timber management practices, whereas 25% were willing to do so if their returns were revenue neutral. It is important to note that 16% were willing to do so even if it reduced expected profits from traditional timber management practices.

Landowner characteristics were found to be important factors affecting the willingness to delay harvest. Those who had recreational goals as primary land management objectives were most likely to agree to delay final harvest. However, when certain landowners were asked to participate in a program with requirements such as having a management plan or undergoing frequent verification, they tended to be less willing to participate in potential carbon sequestration programs. Given that few landowners had forest management plans, this hesitance may signal an aversion to incurring additional costs associated with participating in a carbon sequestration program unless the added benefits are substantial. Interestingly, a preexisting plan to harvest did not influence a landowner's decision whether to delay harvest for carbon sequestration purposes, suggesting that landowners are open to changing their harvest decisions if market conditions, including incentive payments, are favorable.

The goal of the Florida example study was to discern institutional preferences and barriers to landowner participation in carbon offset programs. This survey evaluated potential program attributes such as contract length, penalty for early withdrawal, type of risk tool, and demographic and institutional trust; and was sent to participants in the Florida Stewardship Program. Results indicated that NIPF landowner participation in carbon offset programs depended upon program payments. Specifically, NIPF landowners in Florida would need approximately $13.11 per acre per year to switch from a 40-year carbon offset contract to one that required a 100-year commitment. These same landowners would have to be willing to give up $27.90 per acre per year to shorten their contract to only 10 years. Results indicate that carbon offset programs offering at least $20 to $30 per-acre-per-year could greatly improve program enrollment, which is broadly consistent with the literature on landowner incentive payments.

This coordinated research effort within the PINEMAP project generated key findings at both state and regional scales regarding NIPF landowner attitudes, perceptions, and willingness to participate in carbon offsets programs. We now have a better understanding of what beliefs NIPF landowners hold across the region and characteristics that can be used to effectively predict their perspectives. From a regional perspective, we know that there are a large number of NIPF landowners who are willing to implement carbon sequestration practices as a climate change mitigation strategy if sufficient financial compensation is provided. Regional conclusions were supported by state-level analysis in Florida, which suggests that landowners will agree to longer carbon offset contracts if provided sufficient compensation. However, a small subset of landowners would also be willing to forgo some profit to participate in carbon sequestration programs. Critically, this depends on their primary forest management objective, which can vary significantly for this diverse group for forest landowners. Importantly, information generated by these studies can be used to inform effective and robust policies and programs to encourage forest landowners to adopt management practices that increase carbon sequestration.

19. Climate Change and Economic Impacts on Southern Pines

Damian C. Adams[1], Andres Susaeta[1], Jim Gan[3], Puneet Dwivedi[2], Jose R. Soto[1], and Doug Carter[1]

[1] School of Forest Resources & Conservation, University of Florida , [2] Warnell School of Forestry & Natural Resources, University of Georgia,
[3] Department of Ecosystem Science & Management, Texas A&M University

PINEMAP's economics research program quantified a range of risks and opportunities for plantation management associated with future climate. While future climate is likely to create risks associated with disturbance and provision of ecosystem services, a number of potential policy and management approaches exist for mitigating these risks, and ensuring the continued provision of wood and ecosystem services from planted pine forests in the future.

The impacts of climate change on southern plantation forestry in the United States depend heavily on assumptions about climate, pine productivity, disturbance risk, landowner adaptation efforts, and the value of ecosystem services. Using stand-level simulation models developed during the PINEMAP project, we simulated the effects of a range of feasible changes to forestry productivity and disturbance risk from climate change, and the associated economic impacts (Susaeta et al.; 2014a, 2014b). We found that forest land value was sensitive to assumed changes in forest productivity, with economic losses occurring with losses in productivity. Forest land values were also projected to decline following an increase in disturbance risk for all assumed levels of plantation productivity (i.e., -20% to +20% change), suggesting that even with productivity gains, the net effects of climate change (CC) on plantation pines are likely to be negative due to increases in disturbance risk. However, adoption of more resilient species (slash pine vs. loblolly) and density levels (low versus high) as CC adaptation strategies were found to offset much of the losses but would also result in less sequestered carbon (C). Similar results were found with a more refined model that focused specifically on wildfire disturbance risk from CC (Susaeta et al., 2016c). With changes to policy and market availability for C sequestration payments, the economic motive for adopting these adaptation strategies could be muted or even reversed.

Payments for other forest-based ecosystem services may also affect adaptation strategy adoption. We simulated the economic impacts of CC on plantation loblolly stand profitability when assuming payments for both C sequestration and forest biodiversity and found that altered climatic conditions would have a moderately strong, positive impact on stand profitability (productivity +42.8% and +45.6% with moderate and high levels of precipitation and temperature increases, respectively; Susaeta et al., 2016b). Similar analyses for natural loblolly pine forests found a small negative net impact on plot efficiency in providing timber, C sequestration, and biodiversity (Susaeta et al. 2016a). We also simulated the impacts of tree density on water yield under alternative climate scenarios, and associated economic impacts with water payments (Susaeta et al., 2016d). We found a notable tradeoff between water yield and both wood products and C sequestration--higher water yield is associated with lower tree biomass. Even at forest water prices much lower than the typical costs of water supply improvement strategies (e.g., infrastructure improvements, graywater reuse, and efficient fixtures), we found that water payments to forest landowners are economically feasible and could more than offset expected timber-related losses to landowners. Additional payments for water yield would further encourage landowner adoption of CC adaptation and management strategies that result in less tree biomass and C sequestered, or that have decreased disturbance risks. Another important consideration by landowners and policymakers is the role of novel tree pests that may thrive under changing climatic conditions and affect disturbance risk and thus landowners' use of adaptation strategies (Susaeta et al. 2016e).

Forest land values were also projected to decline following an increase in disturbance risk for all assumed levels of plantation productivity (i.e., -20% to +20% change), suggesting that even with productivity gains, the net effects of CC on plantation pines are likely to be negative due to increases in disturbance risk.

20. Disturbance Risk to Southern Pine Forests from Wildfires and Pests: Estimation, Impact and Response

Jim Gan[1], Damian Adams[2], and Andres Susaeta[2]

[1] Department of Ecosystem Science and Management, Texas A&M University, [2] School of Forest Resources and Conservation, University of Florida

Changing climate is likely to alter patterns of disturbance associated with wildfire and native and exotic insects. The PINEMAP economics team developed novel modeling and analysis approaches to better quantify these risks, and to assess potential risk mitigation approaches. A range of mitigation actions are likely economically feasible, including increased monitoring for invasive pests at ports, adjusting rotation ages, salvage harvesting, and purchase of wildfire insurance.

Climate change is expected to significantly affect growing conditions for forests and the risk of disturbances in the Southeast United States (US). For instance, elevated temperatures may exacerbate droughts that would potentially increase the risk of wildfire (Bedel et al., 2013) and southern pine beetles (SPB) (*Dendroctonus frontalis* Zimmermann) (Gan, 2004) and leave trees highly vulnerable to damage by other insects and pathogens, further reducing forest productivity (Chmura et al., 2011). The projected increase of these disturbances likely will affect the resilience and sustainability of forests in general and the future investment in forestry and current optimal forest management in particular. The dynamic nature of future natural hazards given expected changing climatic conditions is an essential component of the complex decision-making process for forest landowners (Yousefpour et al., 2012).

Risk estimation

The PINEMAP team estimated the risk of wildfire and SPB under several future climate scenarios. The approach included two steps. First, using historical data we established the statistical relationships among the risk, climatic conditions and other pertinent variables. Second, we projected the future disturbance risk using the statistical relationships and the future climate conditions projected by global climate models (GCMs).

Results indicate the impact of the projected climate change on wildfire and SPB risk would vary spatially and temporally as well as with the projected climate, although the risk in general would increase in the Southeast US. (An et al., 2014 and 2015; Gan et al., 2014a). Projected climate change scenarios above are more likely to increase the frequency rather than magnitude of SPB outbreaks. The models projected the highest increase in wildfire risk for the western part of the Southeast (Texas, Oklahoma, Louisiana, and Mississippi), followed by Florida and Kentucky. In general, increases in temperature elevate wildfire and SPB risk, while a rise in precipitation reduces those risks. Increases in spring, summer, and winter temperatures are particularly associated with increases in both wildfire and SPB risk. Salvage timber harvest would be helpful in containing SPB risk.

Impact

Traditional models for forest valuation under fire risk assume that timber volumes, risk of wildfires, stumpage values, and costs are constant between timber crops. As part of PINEMAP, we developed a generalized model in which these parameters are likely to vary between timber crops, thus improving projections of impacts of climate-mediated disturbance risk on harvesting decisions across successive timber crops (Susaeta et al., 2016a). We assumed that for each timber crop, a landowner would have to replant regardless of the disturbance event (stand harvest or salvage due to fire arrival), and in each instance would face different levels of stumpage prices and forest growth, regeneration costs, discount rates, wildfire risk, and salvageable portions of the stand. Thus, the optimal harvest age is also expected to fluctuate from timber crop to timber crop. Using this model, we assessed the impact of two particularly important factors that may drive harvest decisions in terms of a natural disaster such as fires—risk and salvageable portion—on optimal harvesting decisions.

Comparative static analysis results showed that fire risk and salvageable portion have countervailing impacts on the optimal harvest decision. Risk varies as trees age, with current risk and future risk of wildfires defined separately. According to our results, increases in the

Our findings suggest that the economic gains associated with improvements to current preventative measures are very large (around $4.6 billion dollars), and would greatly outweigh the cost of programs that reduce the expected arrival of exotic ambrosia beetles.

current risk of wildfire-related losses shorten the predicted optimal harvest age. Higher future risks, however, would have the opposite impact – lengthening the optimal rotation. With increasing trends in fire risk and consequently low profitability of future timber crops, the optimal harvest age is expected to be longer in current timber crops than would be when predicted by a traditional model. We also find that decreases in the current salvageable portion would shorten the harvest age, suggesting that disturbances that cause more extreme damage would lead landowners to harvest sooner. The generalized model can be a valuable supportive tool for designing cost-effective policies and programs to mitigate the negative economic effects of wildfires; for example, developing timber stands with more fire-resistant forest species that yield higher economic returns (e.g., longleaf pine).

We also assessed the role of trade-based introduction of a novel bark-boring beetle species to the southern US, leveraging PINEMAP and USDA-APHIS (Animal and Plant Health Inspection Service) funding. It is expected that we will see a growth in trade of wood products from Asia directly to the Southeast US, leading to increased risk of a novel, invasive bark beetle. In 2002, the redbay ambrosia beetle (*Xyleborus glabratus* Eichhoff) arrived from Asia and quickly spread as far south as the Everglades in Florida. This beetle is a vector of the deadly laurel wilt fungus (*Raffaella lauricola* T.C. Harr.), which has caused more than 90 percent tree mortality of redbay trees and significant losses in avocado (*Persea spp.*) in Florida. Additionally, this fungus threatens swampbay (*Persea palustris*) in the coastal planes of Georgia, Florida, Alabama, Mississippi, South Carolina, and North Carolina (Spiegel & Leege, 2013). There are approximately 3,600 species of ambrosia beetles in Asia, including many that are specific to pines, but it is not yet known whether there is a threat to southern pines analogous to laurel wilt (Bateman et al., 2014). The most damaging species (*Xyleborus glabratus*) is a host specialist on pines. Should one such species prove to be a pest specialized on southern pines, its introduction would have serious economic, social, and ecological consequences and could threaten southern forests that support a multibillion-dollar timber products industry.

To better understand this threat, we employed a forest stand-level simulation model that predicted the economic impacts of a hypothetical invasion of a yet unknown ambrosia beetle X on the value of forestland and the optimal forest management of loblolly pine stands (Susaeta et al., 2016b). Our results indicate that an increase in the enforcement of international phytosanitary standards for preventing the establishment of ambrosia beetle X, even with very low effectiveness (as low as 30% arrival reduction) would protect economic revenue (by $791 ha^{-1}) and increase optimal harvest age (by 1.2 years). Our findings suggest that the economic gains associated with improvements to current preventative measures are very large (around $4.6 billion dollars), and would greatly outweigh the cost of programs that reduce the expected arrival of exotic ambrosia beetles.

Response

There are several adaptation options that can be adopted by forestland owners in the region to mitigate the negative impacts of elevated wildfire and SPB risk future projected climate change scenarios in the Southeast US. Following are three examples: (1) adjusting rotation age according to the risk seems is a viable option (Susaeta et al., 2016a and 2016b); (2) salvage harvesting of SPB-killed trees can reduce the spread of the risk (An et al., 2014); and (3) purchasing wildfire insurance can alleviate the economic loss to the landowner if a fire occurs (Gan et al., 2014b). Additionally, other wildfire protection measures such as fuel reduction treatments and fire line establishment are also feasible (Gan et al., 2015). However, these options have not been widely used by forestland owners in the region partly because of costs, unfamiliarity of the risk and available programs, and the requirement for joint action of neighboring landowners to prevent from the spillover of the risk, among other reasons (Gan et al., 2014b and 2015). This indicates that additional outreach and assistance efforts are needed to encourage landowners to explore and better adapt methods to future wildfire and SPB risk that is projected to result from climate change.

21. Socio-ecological and Economic Considerations for Incentivizing Forest C Sequestration

Damian C. Adams[1], Jose R. Soto[1], and Francisco J. Escobedo[2]

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Incentives to landowners to sequester additional carbon generally have positive impacts on landowners (due to increased income) and on society (due to increased climate change mitigation). However, changes in forest management can affect not only forest landowners, but also local economies and communities of people that rely on forests. This research characterized the demographics of people living near high carbon forests, and produced information useful for designing more effective and socially appropriate mitigation programs.

Given the low cost of using forests to offset greenhouse gas emissions relative to other feasible means (Stavins, 1999), it is likely that forests will be enlisted in the effort to mitigate the effects of climate change. For example, the United States Environmental Protection Agency (US EPA) has a stated goal to reduce total carbon dioxide (CO_2) emissions from US power plants by 32% of 2005 levels, and signaled that offsets from forestry could be included in state plans to meet emissions targets. In the southern US, which is dominated by privately owned forestland (e.g., 71% of forestland in Florida is privately held), substantial changes to forest carbon (C) storage would likely rely on payments for forest C sequestration. These payments would be needed to generate increases in C storage. Without such payments, CC-related disturbance risks could cause landowners to adopt adaptation strategies that lead to *lower* C storage (see summary on climate change and economic impacts on southern pines (Article 16 in this volume).

We know that incentivizing forest C sequestration affects landowner management decisions, which affects forest-based market (e.g., timber) and nonmarket (e.g., biodiversity) ecosystem services. The net economic effects of this on forest landowners and society are driven by assumptions about future climate, pine productivity, land management, disturbance risk, and the availability of mechanisms to allow landowners capture the value of forest-based ecosystem services. There are inherent tradeoffs (e.g., water yield and C sequestration) and synergies (e.g., timber and C sequestration) associated with forest-based ecosystem services that policymakers and landowners should consider. The ability of different forests to sequester carbon is heterogeneous across the landscape so related impacts will differ spatially.

Changes in forest management can affect not only forest structure and ecosystem services, but local economies and communities of people that rely on forests (e.g., sawmill workers, hunters, and truck drivers). These distributional effects relate to social goals formalized in US decision making. Environmental justice and equity considerations are part of federal regulatory impact analysis – a type of benefit-costs analysis that must accompany significant changes to federal rules, like the EPA's Clean Power Plan.

To better understand the potential distributional impacts associated with payments for forest C sequestration, we modeled the relationship between C stocks and the characteristics of forests and surrounding communities (Soto et al., 2016). We selected Florida as an example case for the analysis since it is likely to rely heavily on forests to address CC policy goals. Florida has a high proportion of forest land cover (approximately 50% forested), has experienced rapid population growth that has constrained natural resource availability (mostly water), is particularly vulnerable to CC effects due to sea level rise, and would need to reduce its power plant CO_2 emissions by 26% under the 2014 EPA Clean Power Plan rule.

We analyzed 902 forest plots and US Census data from 2009-2011 to characterize the demographics of people and communities near high carbon storage forests in Florida, focusing on socioecological factors (e.g., population age, income, education, stand size, tenure, forest type) and estimates of existing forest carbon stocks. Both multiple linear regression and quantile regression (QR) analyses were conducted, and results indicated several demographic

Our findings … signal the need for a more nuanced approach to considering the net impacts of policies that lead to increased forest C sequestration.

and ecological factors that correlated with forest C stocks. Importantly, quantile regression allowed the identification of distributional effects of the variables that were masked by the multiple linear regression approach.

Several ecological variables were good predictors of C storage and had theoretically expected signs, but QR identified important distributional effects. Basal area, stand size, stand age, and site quality exhibited positive effects that increased in strength towards the upper end of the C stock distribution. For basal area, the positive effect only held for the upper portion of the C distribution, but its effect increased at a significantly faster rate than other ecological variables. Likewise, silvicultural treatments were found to be important drivers of C stocks, but only for some points of the C stock distribution.

Statistically significant demographic variables included education (with effects strongest at the upper end of the C stock distribution; proportion with graduate degrees positively related for C stock percentiles above 30th, and proportion with no formal education negatively related for C stocks below 50th and above 70th percentiles); age (positive relationship between C stocks and proportion aged 22-39); income (generally negative relationship between C stocks and higher income levels); ethnicity (C stocks mostly falling with increasing proportions of Hispanic and African-America residents); land tenure (C stocks increased with proportion of owner occupied forestland, but with negative effects below the 60th percentile); and location (urban was weakly positively related to C stocks) (see Table 21.1). Our findings are consistent with other studies that have assessed the influence of both ecological and social variables on forest cover and associated ecosystem services, such as C storage. However, unlike previous studies, our use of quantile regression provided details on the differing relationships that these variables have on forest C stocks along the low-to-high C stock gradient (see Figure 21.1).

Broadly speaking, payments for forest C sequestration are believed to have positive impacts on forest landowners, due to added income, and on society, given the benefits associated with CC mitigation. Our findings do not suggest otherwise, but they do signal the need for a more nuanced approach to considering the net impacts of policies that lead to increased forest C sequestration. These results can be used to inform a more nuanced understanding and perhaps lead to more effective and socially appropriate policies and programs that can target areas with high C stocks while also considering the broader social implications of these efforts such as rural poverty and environmental justice.

Factors of Influence	Estimate	Robust Std. Error	t Ratio	Prob > |t|	Rank Order of Effect
Basal*	0.46	0.03	15.05	0.00*	16
Pine forests[0,1]	-0.48	2.23	-0.21	0.83	14
Ownership[0,1]	1.27	2.87	0.44	0.66	5
Site quality*	4.35	1.41	3.07	0.00*	3
Stand size*	4.65	1.49	3.13	0.00*	2
Silvicultural[0,1]	0.88	3.53	0.25	0.80	8
Disturbance[0,1]	2.83	4.81	0.59	0.56	4
Stand age*	0.47	0.06	7.83	<0.00*	15
Hispanic*	-0.50	0.16	-3.18	0.00*	12
African-Americans**	-0.16	0.09	-1.73	0.08**	20
Whites	Omitted				n/a
No formal education	-0.61	0.57	-1.08	0.28	10
Primary school	0.59	0.83	0.72	0.47	11
Secondary school	-0.10	0.55	-0.18	0.86	23
High School	Omitted				n/a
Bachelor's degree	0.30	0.26	1.16	0.25	19
Graduate degree*	1.02	0.51	1.98	0.05*	6
Owner occupied	0.14	0.10	1.41	0.16	22
Urban	0.06	0.04	1.27	0.20	25
Under 21	Omitted				n/a
22-39*	0.35	0.16	2.14	0.03*	18
40-64	0.15	0.20	0.77	0.44	21
65 and greater*	-0.45	0.19	-2.37	0.02*	17
Under $25K	Omitted				n/a
$25K-49K	0.01	0.20	0.03	0.98	26
$50K-99K*	-0.69	0.23	-3.08	0.00*	9
$100K-199K**	-0.50	0.29	-1.70	0.09**	13
Above $200K**	-0.91	0.55	-1.67	0.09**	7
County*	-0.09	0.03	-2.86	0.00*	24
Intercept	-16.59	17.98	-0.92	0.36	1
Prob > F	<0.00				
Number of observations	902				
R-Square statistic	0.59				

Table 21.1 Influences on Forest Carbon Storage.

*Note: Table from Soto et al. (2016). Pine: 0 Predominantly Pine and 1 Otherwise; Silvicultural treatment: 0 untreated and 1 treated; Ownership: 0 public and 1 private; Disturbance: 0 undisturbed, 1 disturbed; Site quality = 1, 2, 3, 4, 5, 6 and 7 (See Table 1 for descriptions); * Effect of factor of influence statistically significant at value of α = 0.05; ** Effect of factor of influence statistically significant at value of α = 0.10; Prob > F is the p-value associated with the F-statistic.*

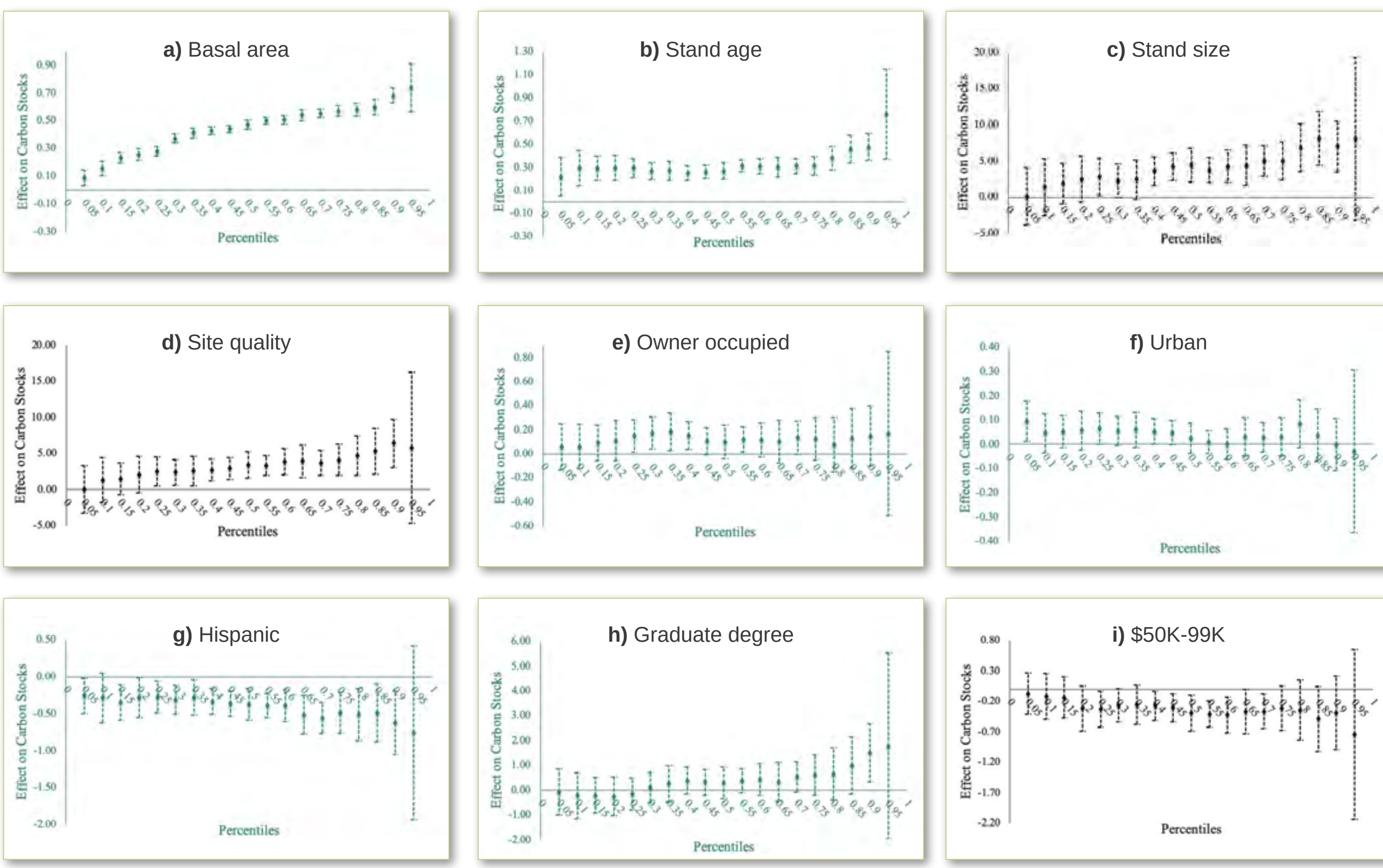


Figure 21.1. Quantile regression estimates of socioecological and economic determinants of Florida carbon stocks (from Soto et al., 2016).

Note: Confidence intervals denoted by a long dash at end of the dashed vertical lines.

22. Data Driven Outreach: PINEMAP Products, Terminology and Programming

Mark Megalos[1] and Leslie Boby[2]

[1] Extension Forestry Specialist, North Carolina State University, [2] Extension Associate, Southern Regional Extension Forestry

Extension specialists were involved with PINEMAP research from the start, and conducted important social science research to better understand the project's intended stakeholders and audiences. This research provided data that were used to develop of more effective, focused Extension programming.

The interdisciplinary focus of PINEMAP placed Extension specialists in the forefront of research design and data gathering. Since PINEMAP goals include influencing management practices, it was necessary to understand the perceptions and information needs of forestry stakeholders. The involvement of the Extension team from the beginning of PINEMAP allowed for a crucial assessment of information needs from the professional foresters, resource managers, corporate and large forest managers who were survey respondents. This unprecedented cross-sector needs and interest scoping informed educational publications, program design, implementation, and delivery. Involving Extension throughout the project has allowed stakeholder needs to inform and guide the unprecedented interdisciplinary research into the intersections of climate, genetics, physiology, modeling, and economic science. This article summarizes the results and impacts of the social science research conducted by Extension principal investigators, staff, graduate research assistants, and collaborating academics.

Tasked with developing outreach and training materials for the region's pine managers, the Extension team worked with the education team to gather "baseline" knowledge on attitudes of climate change and demographics of Extension agents across the Southern region. Similar observations as well as beliefs and needs surveys of professional foresters, agency contacts, and research cooperative members were used to further inform the development of the materials. The following survey responses helped to prioritize our outreach efforts and education material development for these audiences:

TOP FIVE CORPORATE RESEARCH NEEDS	
Research Need	**% Cooperative Foresters ranking it as important or very important**
Planting genotypes that are tolerant of drought, insects, and/or disease	75 %
Breeding for enhanced yield	72 %
Silvicultural techniques to promote forest productivity and increase stand vigor (i.e., partial cutting or thinning) to lower the susceptibility to insect attack or disease outbreaks	72 %
Species and/or genotype selection	68 %
Fertilization to enhance forest growth	67%
TOP FIVE STATE AGENCY AND EXTENSION / RESEARCH NEEDS	
Informational/Research Need	**% Agency Foresters ranking it as important or very important**
Silvicultural techniques to promote forest productivity and increase stand vigor (i.e., partial cutting or thinning) to lower the susceptibility to insect attack or disease outbreaks	86%
Control of undesirable plant species that will become more competitive in a changed climate	73%
Managing forest insects and diseases	73%
Planting genotypes that are tolerant of drought, insects, and/or disease	65%
Breeding for enhanced yield	60%

Foresters who accept climate change are significantly more likely than non-accepters to have observed climate evidence locally (*seeing CC*), feel concern about forestry impacts (*connecting to CC*), and agree that different management will be required to address climate change (*adapting to CC*).

RESEARCH Driven Outreach: Assessing Needs/Attitude to Target Professionals

Our results indicate a close relationship between foresters' climate change (CC) attitudes and perceptions and their management responses (Figure 23.2). Foresters who accept climate change are significantly more likely than non-accepters to have observed climate evidence locally (*seeing CC*), feel concern about forestry impacts (*connecting to CC*), and agree that different management will be required to address climate change (*adapting to CC*). Logically, foresters who accept human causality are more likely to consider adaptation strategies to climate change in their management decisions. However, those who do not accept human causality can be reached directly with

Figure 22.1. Concerns of 2013 Southeastern Forest Professionals (where color and size of font reflect concern level); graphic from Boby, Hubbard & Khan (2014).

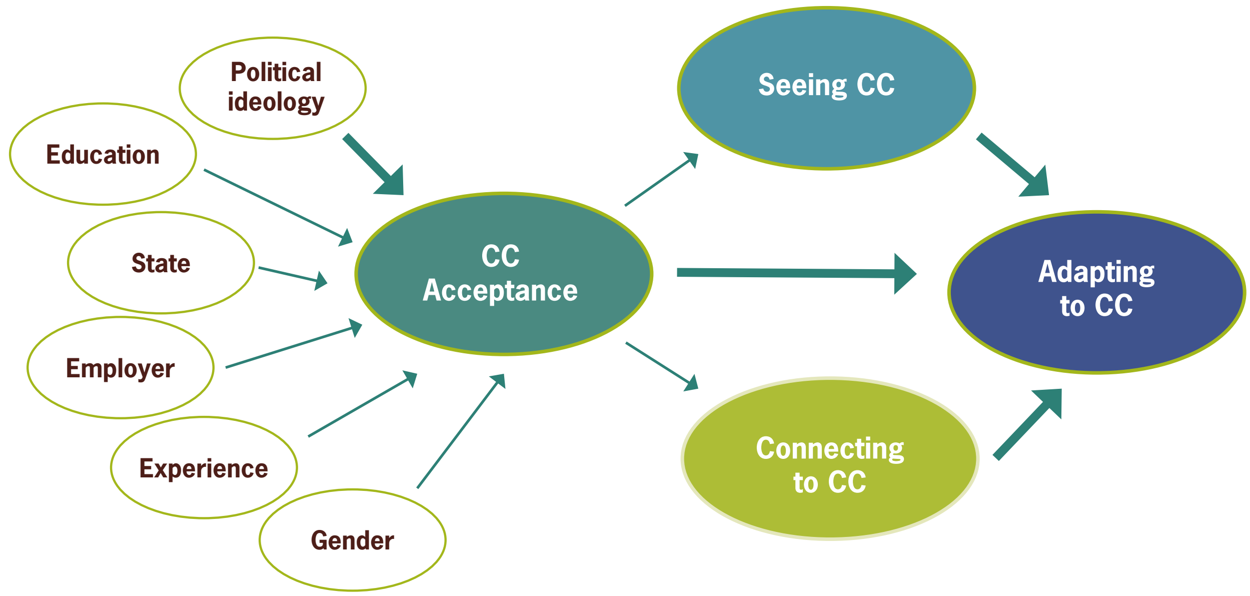


Figure 22.2. Summarized relationships between demographic charecteristics, climate change attitudes, personal perceptions, and adaptive management responses for Southeast forestry professionals. Note: bold arrows indicate relationships that remain significant in single-variable analysis; standard arrows indicate relationships that are only significant in single-variable analysis.

an adaptation message if they connect or have concerns about risks to forestry profits (health, disease, invasive species, fire), and to a lesser extent if they have seen extreme weather (such as droughts and seasonal flooding). Our research (Morris et al, 2016) indicates that tapping into forest health concerns in order to foster adaptation strategies was the most broadly successful approach to connecting to the professional audience as a whole, yielding the largest effect on adaptation intention. Therefore, educational programming focused on connecting should prove most effective.

Framing Extension's Climate Change Outreach to Landowners

The outreach opportunities provided by the PINEMAP resources will be helpful for addressing uncertain weather and climate change. As clients inquire about causes of drought, extreme weather events, and pest outbreaks, Extension can address adaptation responses directly. The problem-solving focus developed to use with Extension clients offers the opportunity to initiate critical conversations about future uncertainty, extreme weather, risk management, and economic concerns. Extension can highlight and advance management actions that maximize resource health, productivity, and resilience in changing climate. In turn, agents can tailor outreach to clients' needs and climate change attitudes, providing information on resilience and climate science as appropriate. We suggest that framing the science based on concern (*connect*) maximizes the likelihood that clients will accept Extension recommendations—ensuring "appropriate information is disseminated and applied for best results" (James, Estwick, & Bryant, 2014).

Implications

To communicate effectively with foresters in the Southeast region, we recommend climate change educators refrain from overemphasizing climate change and capitalize instead on the *connect* pathway to most efficiently motivate adaptive management. Extension can help foresters *connect* to climate change by illustrating the relevant impacts of climate change on forestry and demonstrating the appropriate silvicultural management responses. Climate change programming can promote adaptation without focusing on anthropogenic climate change through emphasis on minimizing risk, planning for uncertainty, and managing for resilience to local climate impacts. These outreach insights have the potential to move the Southeast forestry community toward resilience in the face of climate change.

In order to effectively empower clients to solve problems, Extension must consider its audience. As climate change becomes more evident in the Southeast and awareness correspondingly grows, state Extension Services can build on pioneering programs to clearly address climate change. For doubtful audiences, Extension agents can still discuss climate change symptoms and capitalize on opportunities for meaningful dialogue about future uncertainty. As interest arises, Extension can deliver current climate science information and embrace grassroots momentum toward local adaptation solutions. Following a client-tailored model, Extension can help people with differing climate change views successfully adapt their management strategies based on their unique needs and aspirations.

23. Minority Landowners and Climate Change Workshops

Joshua Idassi[1], Gwendolyn Boyd[2], and Leslie Boby[3]

[1] North Carolina Agricultural and Technology State University, [2] Alcorn State University, [3] University of Georgia

Small and minority landowners often encounter challenges beyond sound forest management planning and risk management due to historic issues surrounding heirs' property and limited trust and access to cost-sharing programs, management assistance, and tax incentives. To older, minority landowners better understand their forest management options, the PINEMAP Extension team held a series of workshops covering topics including fire potential, timber taxes, timber sales, heirs' property,longleaf and conservation options and trends and financial assistance programs.

The PINEMAP Extension team and other collaborators (universities, state and federal agencies, and not for profit organizations) organized four successful workshops targeting small scale and socially disadvantaged female farmers and woodland owners in four states. These workshops were held in Huntsville, AL, Wilmington, NC, Myrtle Beach, SC, Nacogdoches, TX, and had more than 100 attendees who learned about climate change and its likely effects on their forestlands.

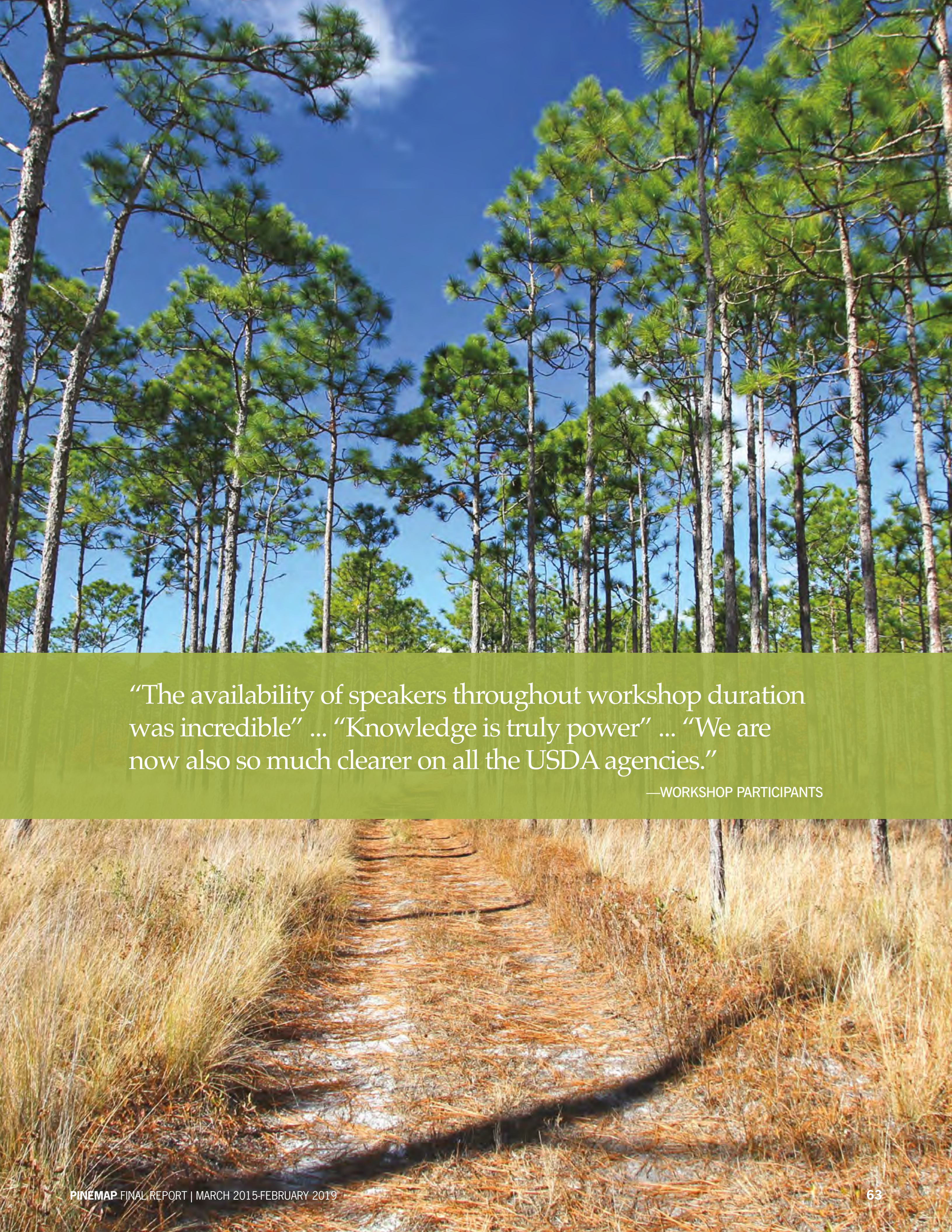
The topics included fire potential, timber taxes, timber sales, heirs' property, longleaf and conservation options and trends and financial assistance programs. Fire potential, because it is projected to increase globally through combinations of increases in temperature, increases in atmospheric CO_2, and changes in precipitation patterns (Liu 2010), was a topical thread through the workshops. Sessions were offered on forest management, understanding environmental stressors, climate change, and prescribed forest fire.

All of the landowners who attended indicated in evaluations that they were very satisfied with the relevance of information provided, presentation quality of instructors, and the overall quality of information presented. Nearly all of the participants (96-100%) felt that the sessions: (1) Forest land Management and Environmental Stressors, (2) Forest Fires: Economic, Cultural and Ecological benefits of prescribed burning, (3) Basic tax information, (4) Timber sales and Timber Price trends, and (5) Available USDA Financial Assistance Programs were valuable.

Sessions also focused on other needs of the target audience, specifically, understanding and mitigating legal risks in sustainable management of forestlands. Small and minority landowners often encounter challenges beyond sound forest management planning and risk management due to historic issues surrounding heirs' property and limited trust and access to cost-sharing programs, management assistance, and tax incentives. Knowledge and access to competent legal counsel was provided by partner entities to add value to workshop content and offerings. The workshops connected landowners to legal resources and government cost-sharing programs, some of which also offer direct prescribed burning assistance.

Beyond the typical classroom sessions on a variety of forest management issues, the workshops included field trips to demonstrate concepts learned during the classroom presentations, including prescribed fire as a land management tool. Nearly all participants (95%) thought the field trips were very valuable. For many of the participants, the hands-on experiences provided new and novel information about ways to manage and maintain their loblolly pine forestlands. For example, in Nacogdoches, TX, the prescribed forest fire training exercise was conducted by the Texas Forest Service in collaboration with a private forest landowner; and the NC and SC workshops also highlighted prescribed fire and management benefits during field trips.

About three quarters of workshop participants were 50 years old and above, 16% were between 40 and 50 years, and fewer than 10% were between 30 and 40 years of age. Sixty-eight percent of participants had owned lands for 4 to 40 years, while the remaining 32% indicated that their land has been in family possession for between 70 and 216 years. Nearly all the participants (96%) indicated that their expectations for the workshops were met.



"The availability of speakers throughout workshop duration was incredible" ... "Knowledge is truly power" ... "We are now also so much clearer on all the USDA agencies."

—WORKSHOP PARTICIPANTS

24. Team Science and the DSS Development Process

Heather Dinon Aldridge and Corey Davis

State Climate Office of North Carolina, North Carolina State University

The PINEMAP Decision Support System is a comprehensive deliverable for the project, combining the latest forestry research and future climate projections into a web based tool. The development of the system involved iterative inputs and guidance from PINEMAP stakeholders, climatologists, and forest scientists.

The PINEMAP Decision Support System (DSS) was developed over the past six-year funding period (2011-2017) through an iterative process. The DSS is a comprehensive deliverable for the PINEMAP project, combining the latest forestry research and future climate projections into a set of web-based tools. The system provides forest managers with a way to see what environmental conditions they can expect for both the short- and long-term future, and to help them understand how future conditions might influence the management decisions that they make today. Each of the climate scientists and forestry researchers on the PINEMAP team brought their distinct knowledge of existing data, models, and visualizations in order to develop DDS. Combining this data and scientific expertise into a usable website for a wide range of end users has been both a challenge and a rewarding learning process. Most scientists don't typically work on such large, interdisciplinary projects, so learning how to achieve team science has been an integral part of the DSS development process.

The DSS was designed primarily for professional foresters to provide guidance about how climate affects loblolly pine trees in terms of environmental risks, suitability of conditions for growth, and ecosystem services such as carbon sequestration. Work on the DSS encouraged a unique mindset among team members, reorienting focus onto synthetic goals and deliverables instead of purely individual research. This shift to looking at merging research outputs across multiple universities and subdisciplines epitomized PINEMAP's team science.

The first step in building the DSS was to determine how users would interact with it. While the climate scientists were chiefly responsible for creating the tool, their lack of forestry experience meant that they needed interpreters and input from others more experienced with the effective delivery of climate information to foresters. Initially, the DSS was conceptualized as location-specific or stand-based, where users coming to the page would choose a single location to see information such as climate characteristics for that site. This was the recommended framework for retrieving information because most forestry and climate data originates from a specific location, such as a weather station or a forest research plot.

PINEMAP members noted that because stand-based guidance was already accessible in tools provided by the forestry industrial cooperatives, the DSS as planned likely would not provide additional insight. Therefore, we reimagined the DSS design with a regional focus. As development took place, it became clear that additional, routine feedback from the PINEMAP team would be extremely important to create the most valuable, meaningful tools for end users. Thus, we established an iterative development process that included multiple ways to evaluate the effectiveness and usability of the DSS. This included expert guidance, beta testing, geocognition research via eye tracking, and internal review with Extension professionals and the broader PINEMAP team.

The first set of DSS tools used historical and projected climate data to visualize climate-based risks and opportunities for foresters. One such tool, initially branded as Seedling Deployment tool but renamed Cold-Tolerant Markets for Nurseries tool, was based on the research of US Department of Agriculture (USDA) geneticist Ron Schmidtling, who suggested seedlings could be moved to locations with annual extreme minimum temperatures up to 5°F colder than the source locations without appreciably increasing the risk of cold damage (Schmidtling, 2001).

While future minimum temperature projections were straightforward to produce, the mechanism for how to create a usable tool was not clear. Gary Peter, a PINEMAP team member

While the original DSS concept seemed clear, as we moved through it, we learned that each step included multiple decision points and choices—so the process was frequently one or two steps forward and one step back.

and professor of Forest Genomics and Cell Biology at the University of Florida, contributed expert guidance on presentation and interpretation. Peter suggested a way to display this information as shaded isotherms, or bands of equal temperature, showing the future migration of seedling deployment ranges, along with providing an option to see the 5-degree range for a given future time period highlighting regions for safe seedling deployment or recruitment (see Figures 24.1 and 24.2).

As this tool was developed (along with several others, e.g., tools showing the occurrence of extreme cold temperatures, summertime temperatures, and summertime precipitation), additional feedback was received through two rounds of beta testing. Participants included PINEMAP Extension team members, a small subcommittee of researchers, and professional foresters from industrial cooperatives.

The beta testers independently reviewed the DSS and answered questions about their experiences and the usability of the tools, including the clarity of wording, colors, and tool features, such as the time series plots. Several weeks later, small groups of two to four beta testers each met with DSS developers by phone to discuss their experiences in more detail. Suggested changes were incorporated by the developers.

A final step in the DSS evaluation process used an eye tracking study conducted by North Carolina State University Geocognition Lab researchers at the 2016 Appalachian Society of American Foresters Meeting. In this study, 31 participants ranging from undergraduate students to public- and private-sector forestry professionals worked through scenarios using different DSS tools. As they interacted with the DSS and answered questions based on the tools, their pupil movements were tracked using passive eye tracking sensors.

The results from this eye tracking study informed several key improvements to the DSS, including the need to better highlight how users could select a location, view map overlays, and find tooltips and other embedded help. Based on this study and other feedback from PINEMAP team members, the Seedling Deployment tools were rebranded as Dynamic Hardiness Zones, and the tools were re-worked to place a greater emphasis on the 5-degree ranges.

While primarily developed for a forestry audience, the PINEMAP DSS is a multifaceted tool that can be leveraged by nonforestry groups for their decision-making processes. As an example, the Florida Fish and Wildlife Conservation Commission (FWC) is incorporating DSS outputs—mainly changes in precipitation and temperature—into a climate adaptation plan, which is part of FWC's management planning efforts in Florida's gulf coast region. Also, PINEMAP DSS maps and time series plots have been used within the USDA's Southeast Regional Climate Hub *Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies* publication.

Overall, in addition to providing a useful tool for foresters and others, the DSS has served as an integration vehicle during its development, facilitating team science among PINEMAP researchers. The PINEMAP project presented an opportunity to link the research being done by all PIs and institutions within a comprehensive deliverable product: the PINEMAP DSS. The DSS created a platform for integrating the team-wide science and building internal capacity to share results and ideas.

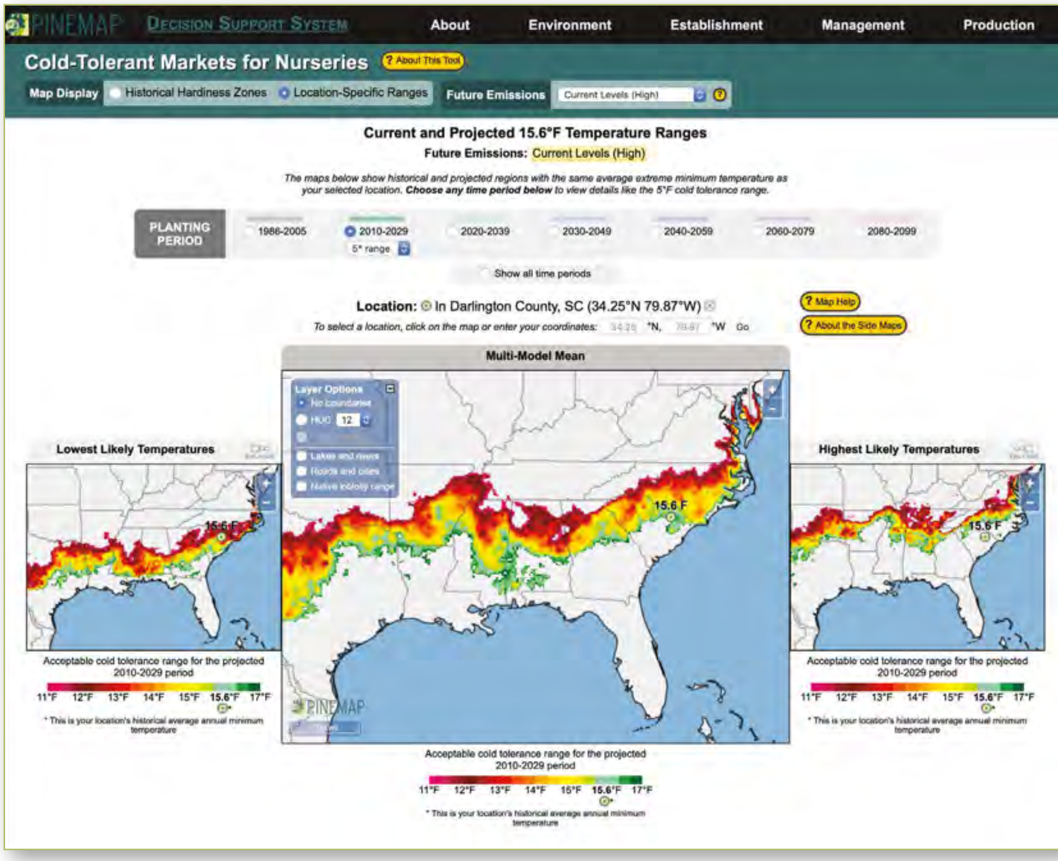


Figure 24.1. Screenshot of the Cold-Tolerant Markets for Nurseries tool (formerly known as the Seedling Deployment tool), with 5-degree range of shaded isotherms, or bands of equal temperature, that highlight the future migration of seedling deployment ranges for 2010-2029.

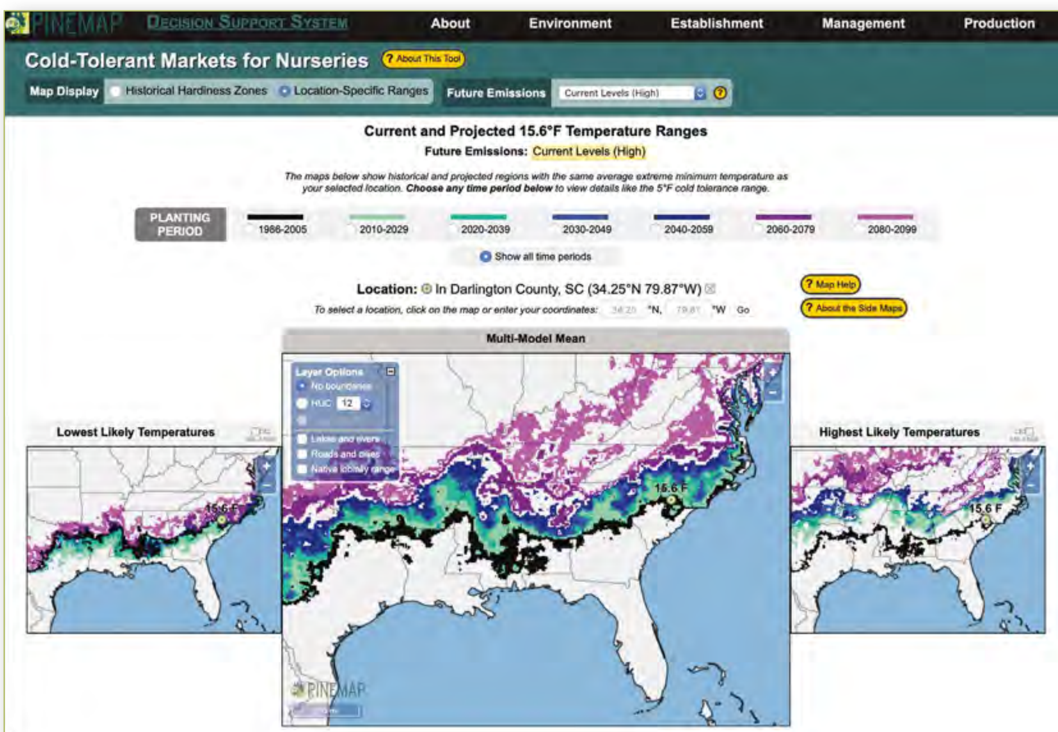


Figure 24.2. Screenshot of the Cold-Tolerant Markets for Nurseries tool (formerly known as the Seedling Deployment tool), with shaded isotherms, or bands of equal temperature, highlighting the future migration of seedling deployment ranges for all future time periods (with 5-degree range turned off).

25. Projecting the Future of Your Pine Forest: DSS Components and Deliverables

***Heather Dinon Aldridge*[1, 3]*, Corey Davis*[1, 4]*, and Leslie Boby,*[2, 5]**

[1] *State Climate Office of North Carolina,* [2] *Southern Regional Extension Forestry*

The PINEMAP Decision Support System presents complex, spatially explicit information on historical and future climate and forest science research in an easy-to-use interface. Menu sections on Environment, Establishment, Production, and Management display PINEMAP climate data and science outputs in a novel three-panel map format that allows users to understand the full spread of projections.

The PINEMAP Decision Support System (DSS), one of the key deliverables of the six-year PINEMAP project, is a platform that connects interdisciplinary research and data in order to develop and deliver tools relevant to forestry management decisions. The PINEMAP DSS is an efficient way to provide professional foresters with specific recommendations based on the latest forestry research and climate projections.

The DSS was developed with input from project scientists, but also with considerable contributions from forestry stakeholders who provided feedback on flow, function, and design through beta testing sessions. The DSS menu structure is organized around four categories of tools: Environment, Establishment, Management, and Production (Figure 25.1). The tools correspond to decision-making points across a forest stand's lifetime.

DSS tools on the **Environment** menu relate to climate-based risks and opportunities, such as the occurrence of minimum temperatures below various thresholds; average summertime temperature and precipitation; and Summer Dryness Index, a ratio of summer growing degree days to summer precipitation developed specifically for loblolly pine trees in their native range. These future climate projections were also used to create two tools related to seedling deployment and recruitment, which are on the **Establishment** menu.

Regional ecological modeling outputs related to forestry productivity and water supply are integrated as tools in the DSS. Available outputs include gross and net primary productivity, above ground wood carbon, and water yield. These variables arel be housed on the **Management** and **Production** menus.

The science behind the models is complex, but the interface has been designed to allow users to begin by selecting one of the four categories and access the corresponding tools. Once a tool is selected, a map is shown where users can either select a point on the map or enter the latitude and longitude of the target area.

EXAMPLES OF QUESTIONS THAT CAN BE ANSWERED BY THE DSS:

1. On average, what will the coldest minimum temperature be in the future so from what location should I source my seedlings?
2. Will it be drier in the future and should I thin more aggressively because of that?
3. How will future climate affect production at my location?

Through our interactions and partnerships with forestry stakeholders, the DSS has become a new, innovative strategy for encouraging climate thinking for forestry decisions.

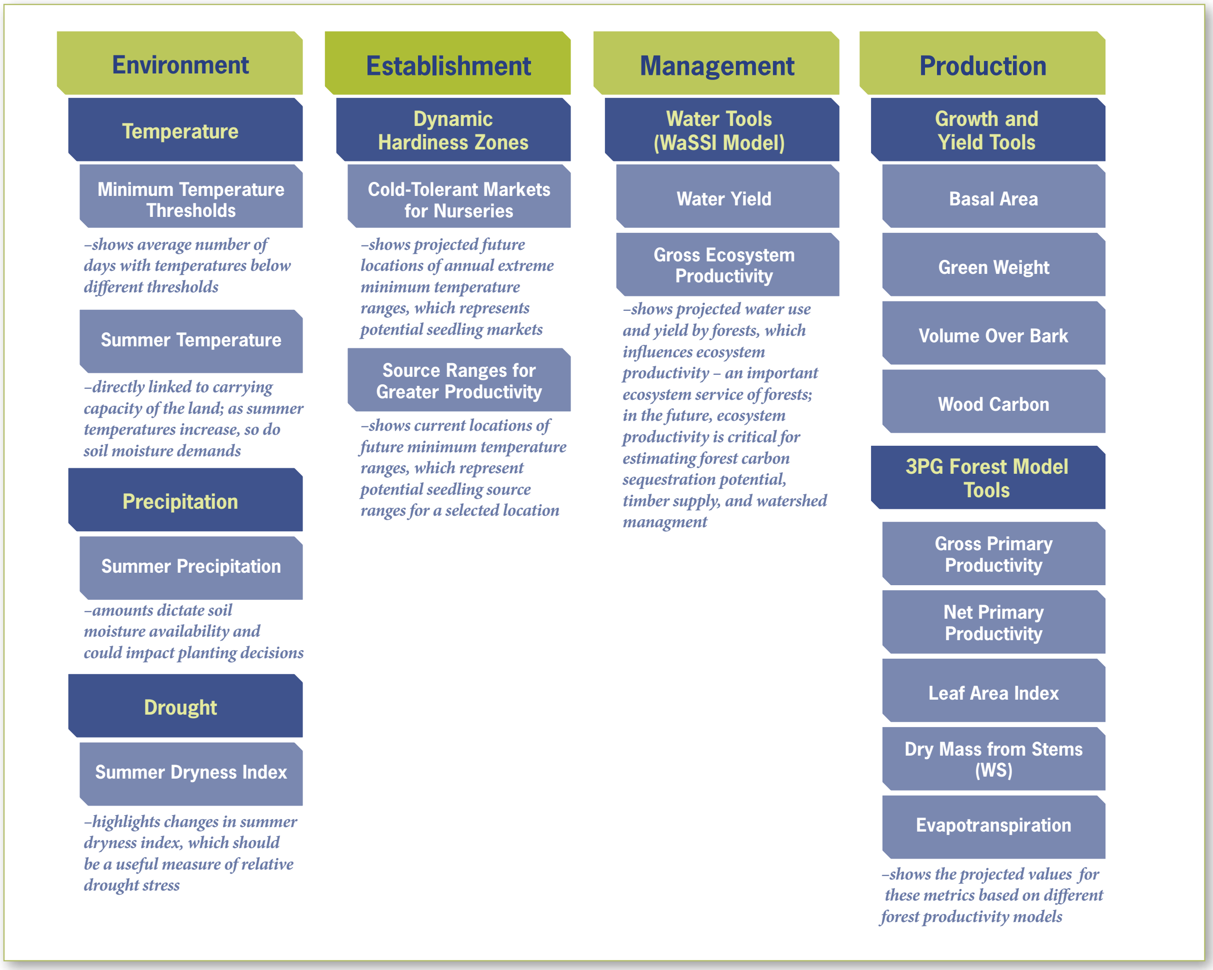


Figure 25.1. List of DSS menu categories and the corresponding tools.

After the tools are selected, users can then explore historical observed conditions (averaged from 1986-2005), or future projections and averages (historical observed + projected change). When selecting conditions for the future, there is a choice between two different emissions scenarios: "business-as-usual" (no reductions from current greenhouse gas emission trajectories) or "reduced emissions." Users can also choose what time period in the future they would like to explore by selecting from multiple 20-year time slices through the end of the century (i.e., 2020-2039, 2040-2059). Once an emissions scenario and time slice are chosen, data are visualized both spatially and temporally within the DSS interface to provide meaningful and understandable data. The DSS features an innovative three-map layout to convey the full range of possibilities (Figure 25.2). The center DSS map represents the multimodel mean of 20 downscaled global climate models while the left and right maps depict values two standard deviations above and below the multimodel mean. The three maps are displayed side-by-side in order for all three future outputs to be shown next to each other. Visualizing this spread allows decision makers to be better informed about the possible future changes that may affect loblolly stands.

Beneath the three maps, most DSS tools feature a time series plot that summarizes both historical conditions and future projections for the location of interest. For each future time period, the spread of likely outcomes is shown as gray bars on the plot, with both future emissions scenarios depicted (Figure 25.3). This allows users to envision the spread of possible future outcomes, rather than just a single possibility.

Becoming familiar with all of the tools and features in the DSS can be intimidating for first-time users, so background information is provided to guide users throughout the product. Tooltips are embedded throughout the interface to highlight and explain important features and concepts. An interactive Frequently Asked Questions page is also available to clarify individual concepts and provide more detailed information about the data contained in the DSS.

The DSS was launched in December 2015 and has received positive reviews. Several workshops since then have incorporated the DSS data and concepts, and further changes and additions have been made to the interface based on user responses. The DSS has become a cornerstone of PINEMAP's outreach platform, providing a mechanism to interact directly with stakeholders and speed up the research-to-end-user pipeline. Since the design is flexible, the DSS can continue to evolve as new information and tools continue to be developed. Through our interactions and partnerships with forestry stakeholders, the DSS has become a new, innovative strategy for encouraging climate thinking for forestry decisions.

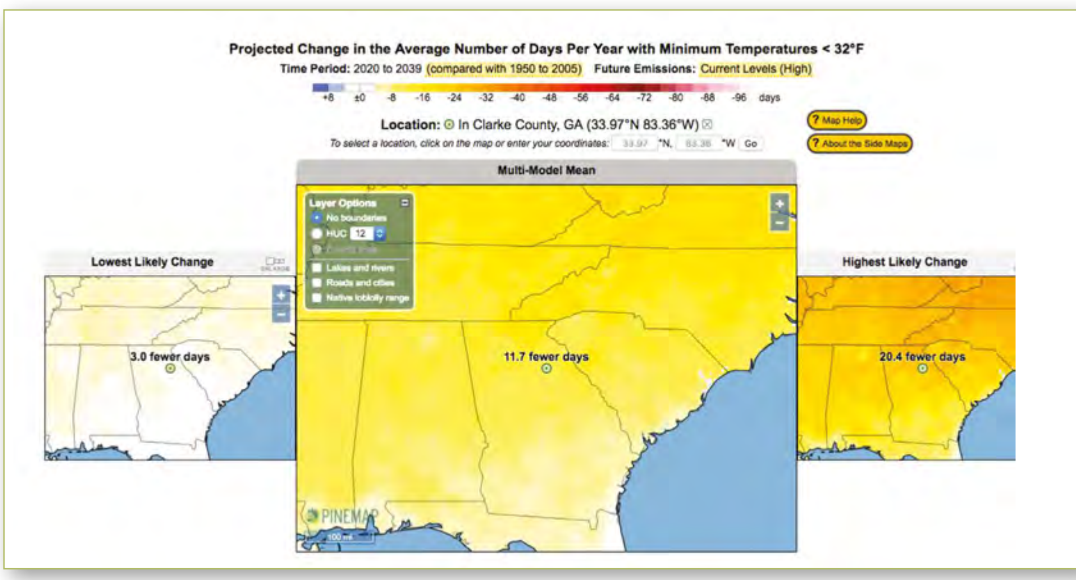


Figure 25.2. Screenshot of the DSS innovative three-map layout that helps convey the range of future possibilities.

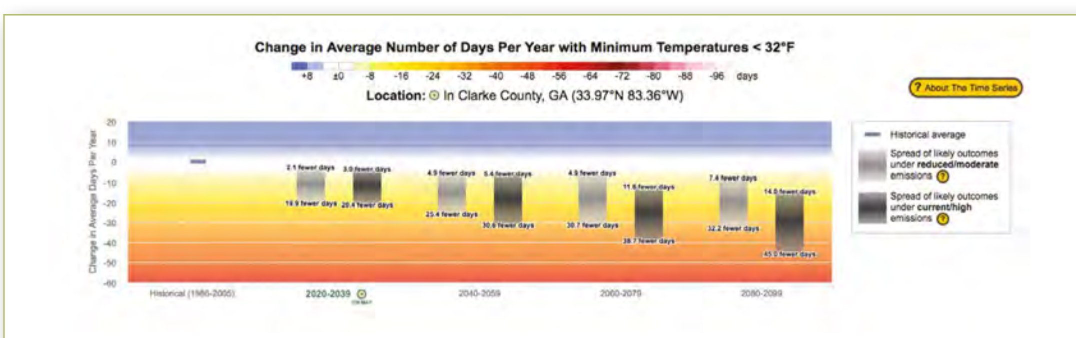


Figure 25.3. Screenshot of the DSS time series plot that summarizes both historical conditions and future projections for the location of interest and helps convey the full and likely range of possibilities and uncertainty.

26. Unveiling the PINEMAP Decision Support System

Leslie Boby[1], Mark Megalos[2], Heather Aldridge[2,3], and Corey Davis[2, 3]

[1] Southern Regional Extension Forestry, [2] North Carolina State University, [3] State Climate Office of North Carolina

To assure widespread dissemination of research results to stakeholders, the PINEMAP Decision Support Sytem was introduced to diverse stakeholders at professional workshops, conferences, and meetings throughout the region.

After several years of fine-tuning, the PINEMAP Decision Support System (DSS) became fully operational in 2016, allowing users to explore forestry management options under different future climate projections. It is available to foresters, landowners, and the general public. The successful creation of the PINEMAP DSS is a result of all diverse and knowledgeable team members who contributed to its creation. Testing and improvement on early versions started with the internal PINEMAP team followed by Forest Research Cooperative members and foresters. “Conscious involvement by the intended users made all the difference,” said Heather Dinon Aldridge, the DSS chief architect. “We targeted end users in the development process in order to make a better product.” Test versions were presented at workshops and feedback was incorporated into successive versions.

The DSS, though built to function intuitively, is a complex tool and its intricacies can be challenging to explain and understand. While one part of the PINEMAP team worked specifically on DSS development, others on the Extension and education teams helped test the concepts and provide guidance. There have been numerous presentations at formal venues to foresters through the Society of American Foresters (SAF) meetings (county chapters, the southeastern chapter, and the national meeting). Presentations have also been given at meetings for Extension foresters and Agriculture and Natural Resource Extension agents from the major land grant universities and 1890s institutions. Both audiences were receptive to the tool, and asked questions and provided feedback that helped in fine-tuning the product. PINEMAP team member Martha Monroe successfully used the DSS in a training exercise at a “Women Owning Woodland Workshop” in Arkansas. Although most attendees at this meeting were in their 50s or 60s and not experienced computer users, the evaluations indicated that participants felt they were successfully able to use the tool following the training session.

One of the serendipitous aspects of the DSS development was the user research. Heather Dinon Aldridge and Corey Davis partnered with Karen McNeal, Lindsay Maudlin, and Rachel Atkins from the Geocognition lab at NCSU to perform an eye-tracking study using the DSS. At the Appalachian SAF meeting, interested attendees were asked to explore the DSS while special equipment tracked the movement of their pupils. This allowed the researchers to determine which parts of the tool were most useful. Results from this research showed that most users viewed text on a web-page in an “F” pattern, meaning that they spend the most time reading text that appears highest on the page or at the beginning of a new paragraph. Based on this feedback, the DSS information was adjusted to place the most relevant information at the top and left hand side of the page to best communicate it to the users.

DSS outreach and training continues as the PINEMAP Extension team presents at conferences and meetings. Presentations have bolstered strong interest and increased use of the tool over time. As awareness grows, so does the user base. While the PINEMAP project funding has ended, the PINEMAP DSS will live on, providing public access to important research results for stakeholder decision making.

"Conscious involvement by the intended users made all the difference. We targeted [them] in the development process in order to make a better product."

—HEATHER DINON ALDRIDGE, THE DSS CHIEF ARCHITECT. "

27. PINEMAP's Forest Resiliency Guides: Translating Research to Action

Leslie Boby[1], Eric Taylor[2], and Mark Megalos[3]

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Managing forests for resilience is the central approach for dealing with a changing and uncertain future. The PINEMAP forest resilience guidbook was created in response to stakeholder needs for information on silvicultural approaches for mitigating risk. The guide includes sections on establishment, tending of young and mature stands, harvesting, and tending to neglected stands, and includes information focused on the three important subregions of the Western Gulf, Coastal Plain, and Piedmont.

Packaging and delivering information from researchers to stakeholders requires careful thought. Sharing small pieces of information may not always allow forest landowners and foresters to see the whole picture. In order to see past the individual "trees" of research, the PINEMAP Extension team, with input and assistance from PINEMAP researchers and others, has been hard at work on a comprehensive "forest" of research insights—the Forest Resiliency Guide. Each section is tailored to specific local conditions and captures key resilient actions. Organized by key action stages in a sustainable forest life cycle, the step-by-step manual fosters enlightened risk-reducing forest management activities from seedling to harvest. The guides will initially be distributed as regional Extension publications. Plans are underway to further localize recommendations for state-level versions in collaboration with Extension agents and state forestry agencies. Because the audience for this manual ranges from landowners who may just be learning that forests need to be actively managed to experienced landowners or consulting foresters who are ready for the latest innovations, we carefully assembled information that is both accessible for those starting out but that contains details and advanced methods to assist those more experienced.

Five Sections by Stand Age

1) New Pine Establishment (0-5 years)
2 Tending to Young Stands (5-12 years)
3) Tending to Mature Stands (>12 years)
4) Harvesting for Sustainability, and
5) Tending to Neglected Stands (no management, high-graded, or overly mature)

Section Setup

Each section stands alone and provides an overview with an introduction, philosophy for management, desired end results, a preparation checklist, and an "activities" checklist with detailed instructions for management.

Three Subregional Guides

1) Western Gulf
2) Coastal Plains
3) Piedmont

Because southern pine forests cover a great deal of geographical diversity with unique challenges, three regional versions of the guidebook will be developed.

The Forest Resiliency Guide's purpose is to provide information needed to adapt forest management approaches and plant improved tree varieties to increase forest resilience and sustainability under variable climates. The guide is the right mechanism for delivering insights from PINEMAP research to family forest landowners, foresters, and other practitioners.

Loblolly pine plantation management has been fine-tuned by a half century of successful research and the experience of the eight university—industry forest research cooperatives across the South. The guide leverages research information from decades-long studies and translates that knowledge base directly to the owners of the resource in the form of

The PINEMAP forest resiliency guide is the right mechanism for delivering insights from PINEMAP research to family forest landowners, foresters, and other practitioners.

actionable guidelines. The project team distilled research-based information into the "nuggets" of information most useful to enable informed decision making of consulting foresters or forest landowners. The PINEMAP project has been instrumental in allowing us to deliver the forest research cooperatives' cutting-edge research in a publically accessible manner for the first time. The three regional guides provide the latest innovations from PINEMAP research, and recommend forest management tailored to specific land and landowner characteristics.

Though these guides are not a substitute for professional forestry guidance and a forest management plan, they can serve as a base from which professional guidance can allow for custom advice and effective implementation. As such, we hope that the guides will become a tool for consulting foresters to help walk their clients through the detailed decision points and actions needed to manage forests well and to protect and bolster investments. Information packaged in this way also assists Extension agents learn about cutting edge forest management techniques in order to provide adaptation tips for clients.

The risk-reduction and forest health resilience context that frames the guides makes them a unique resource among available Extension forest management publications. The straightforward simplicity of step-by-step checklists for supporting target densities clarifies the best path to management of their plantations. Focusing on key forest life stages highlights the proper timing of management and monitoring actions for landowners, providing both simplification and critical sequence information. The guides' timeline reaches beyond initial establishment considerations to stand maturity and includes recommendations for thinning timing, fertilization, and competition control. Since significant investments are involved, the harvesting section includes recommendations on how to protect and maximize landowner profits.

As part of PINEMAP, we developed a needs assessment for southern foresters and members of the cooperatives to determine tools and resources for forest management and climate change. Results showed that 61% of foresters think climate change is occurring but they differ in what they think is its cause (Boby et al., 2016); 40% of foresters think that forest management strategies will need moderate or significant changes to respond to threats from climate change, and 25% think slight changes to management are needed. Though concerns were expressed, only a third of the respondents felt they were somewhat or moderately knowledgeable about silvicultural strategies to mitigate these threats and reduce risk of loss. Seventy-three percent were interested in learning more about mitigation strategies (73%). Based on these results and to capture multiple audiences, the Extension team has focused on messaging towards increasing forest resiliency and risk reduction. The information contained in these guides will help to reduce existing known risks, but will also include information from PINEMAP research that specifically addresses ways to make forest stands resilient in a changing climate. More concerned foresters will likely be more motivated to take action. Therefore, including information that enhances resiliency for these “early adopters” is an important component of the guides.

The guide will be available soon in both printed and digital form. In discussions with Extension forester colleagues across the south, the concept has been well-received, and the book will be adaptable for state-specific needs. As with all research, new information is constantly coming to light, and we hope to include any updates in the digital version as they become available. Finally, since this guide cannot capture all of the information needed, there will be an extensive reference list and links to the PINEMAP Decision Support System tool and other online tools to help with decision making for forestry management. Following this culmination of the PINEMAP project, the Extension team will remain poised to deliver results and updates to end users efficiently and effectively.

Three sample pages from the handbook:

28. Forest Research Cooperatives and PINEMAP: Motivating Change to Reduce Risk through Actionable Information

Leslie Boby

Southern Regional Extension Forestry

Forest Research Cooperatives were the primary conduit for PINEMAP's interaction with corporate forest landowners. This two-way communication occured through needs assessment, regular cooperative meetings, and a formal corporate rollout workshop.

Forest research cooperatives have been around for more than 50 years and have tackled many challenges for improving loblolly pine productivity and management over that time, but a changing climate is an even more complex challenge. Loblolly pine research in the South has been the beneficiary of decades-long public-private partnerships between forest industry and university researchers. These forest research cooperatives (FRCs) have furthered loblolly pine growth, yield, genetics, and management 100 fold since they first began. PINEMAP's researchers include many of the university members of these cooperatives, and therefore, they've brought expertise and even data to PINEMAP's efforts toward creating an even better platform for data collection, research, and analysis. The research cooperatives are typically driven by research questions that directly affect forest management in all capacities; however, research to moderate the effects of climate change on pine plantations and/or to absorb more carbon as a sink have been less of a priority. Therefore, one of the interesting aspects and responsibilities of the PINEMAP project was to motivate corporate stakeholders (forest industry cooperative members) to begin to think about potential climate change effects on the industry by providing more concrete actionable information regarding what might be done to respond to opportunities or mitigate risk. One of PINEMAP's main responsibilities has been to use experiments and models to better define what the opportunities and risks of climate change may be and to help cooperative members talk and expand the knowledge about how they might respond.

Extension to forest industry and landowners has been a key end goal of PINEMAP, and we made a concerted effort toward the beginning of the project to assess corporate stakeholders' needs and interests regarding climate change and the future in general. This survey was very helpful in refining how we approached these issues. One of the

FOREST RESEARCH COOPERATIVES

- Cooperative Forest Genetics Research Program
- Cooperative Tree Improvement Program
- Forest Biology Research Cooperative
- Forest Modeling Research Cooperative
- Forest Productivity Cooperative
- Plantation Management Research Cooperative
- Southern Forest Resource Assessment Consortium
- Western Gulf Forest Tree Improvement Program

One of PINEMAP's main responsibilities has been to use experiments and models to better define what the opportunities and risks of climate change may be and to help cooperative members talk and expand the knowledge about how they might respond.

mechanisms used to reach corporate stakeholders was through FRC partnerships and PINEMAP contacts through advisory board meetings. At these meetings, PINEMAP researchers shared the latest highlights from project research along with detailed graduate student projects that had particular interest for the cooperatives. Additionally, several coops made time to give their members tours of PINEMAP Tier III experimental sites. Many cooperatives also provided beneficial feedback to PINEMAP, and updates and presentations to those groups resulted in discussions and valuable suggestions for PINEMAP research. FRCs shared their data with PINEMAP; for example, the Forest Modeling Research Cooperative (FMRC) shared data from two region-wide datasets consisting of permanent growth plots with long-term repeated measurement data. These data, coupled with funding from the PINEMAP project, facilitated analyses and qualitative modeling that was essential to meeting PINEMAP goals and objectives.

Additionally, the engagement of a small group of corporate stakeholders in beta testing of PINEMAP Decision Support System modules was critical and helped make the modules much more relevant and useful for stakeholders.

Finally, the coop rollout meeting in Athens in May 2017 provided an excellent opportunity to convey the full scope of what PINEMAP has accomplished, and to help stakeholders understand what tools and resources are available to help them use this information to improve forestry management for resiliency and productivity.

References

Abatzoglou, JT, & TJ Brown (2012). A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology, 32*(5), pp. 772-780.

Abt, RC, FW Cubbage, and KL Abt (2009). Projecting southern timber supply for multiple products by subregion. *Forest Products Journal* 59(7-8) 7-16.

An, H, J Gan & K Clifton (2014). *Impact of climate conditions and adaptation on southern pine beetle infestations.* Poster presented at the Annual PINEMAP Project Meeting, Athens, GA.

An, H, J Gan & S Cho (2015). Assessing climate change impacts on wildfire risk in the United States. *Forests* 6, 3197-3211.

Baltunis, BS, DA Huber, TL White, B Goldfarb & HE Stelzer (2006). Genetic analysis of early field growth of the loblolly pine clones and seedlings from the same full-sib families. *Canadian Journal of Forest Research* 37: 195-205.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191-215.

Bateman, CC, J Hulcr, A Black, & W Bo (2014). Protecting American pine forests: an assessment of potentially invasive beetle-fungus pathogens in Asia. In: Gandhi, K, & J Hulcr (Eds.), *56th Annual Southern Forest Insect Work Conference*. Charleston, SC, p. 47.

Bedel, A, T Mote & SL Goodrick (2013). Climate change and associated fire potential for the southeastern united states in the 21. *International Journal of Wildland Fire* 22: 1034–1043.

Boby, L, W Hubbard, & H Cole (2013). *Climate change perceptions of southern foresters: Preliminary survey results*. PINEMAP Research Summary. Retrieved from http://www.pinemap.org/ publications/research-summaries/extension/CC_Perceptions_of_Southern_Foresters.pdf

Boby, L, WG Hubbard & S Khan (2014). Climate Change Attitudes of Southern Forestry Professionals. Pinemap Extension Factsheet. http://www.pinemap.org/publications/fact-sheets/CC_Attitudes_Southern_Foresters.pdf

Bracho, R., J.G.Vogel, R.E.Will, A.Noormets, L.J.Samuelson, E.J.Jokela, C.A.Gonzalez-Benecke, S.A.Gezan, D.Markewitz, J.R.Seiler, B.D.Strahm, R.O.Teskey, T.R.Fox, M.B.Kane, M.A.Laviner, K.M.McElligot, J.Yang, W.Lin, C.R.Meek, J.Cucinella, M.K.Akers, and T.A.Martin. 2018. Carbon accumulation in loblolly pine plantations is increased by fertilization across a soil moisture availability gradient. Forest Ecology and Management 424:39-52.

Bullard, SH, PS Williams, T Coble, DW Coble, R Darville & L Rogers (2014). Producing "society-ready" foresters: A research-based process to revise the bachelor of science in forestry curriculum at Stephen F. Austin State University. Journal of Forestry, 112(4): 354-360. doi: 10.5849/jof.13-098.

Burkhart, HE, EB Brooks, H Dinon-Aldridge, CO Sabatia, N Gyawali, RH Wynne & VA Thomas (2018). Regional simulations of loblolly pine productivity with CO_2 enrichment and changing climate scenarios. *Forest Science*, 64(4), pp. 349-357.

Caldwell P, C Muldoon , C Ford-Miniat, E Cohen, S Krieger, G Sun, S McNulty & PV Bolstad (2014). Quantifying the role of National Forest system lands in providing surface drinking water supply for the Southern United States., Gen. Tech. Rep. SRS-197. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. pp: 135.

Chmura, DJ, P Anderson, G Howe, C Harrington, J Halofsky, D Peterson, D Shaw, & J St. Clair (2011). Forest responses to climate change in the northwestern United States: ecophysiological foundations for adaptive management. Forest Ecology and Management 261, 1121–42.

Clarke, LE, JA Edmonds, HD Jacoby, HM Pitcher, JM Reilly & RG Richels (2007). Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Synthesis and Assessment Product 2.1a. U.S. Climate Change Science Program and Subcommittee on Global Change Research.

Cumbie, WP, A Eckert, J Wegrzyn, R Whetten, D Neale & B Goldfarb (2011). Association genetics of carbon isotope discrimination, height and foliar nitrogen in a natural population of *Pinus taeda* L. *Heredity* 107: 105-114.

Gan, J (2004). Risk and damage of southern pine beetle outbreaks under global climate change. Forest Ecology and Management 191, 61-71.

Gan, J, H An & K Clifton (2014). Climate change impact on southern pine beetle infestations. Presented at the 2014 Society of American Foresters Convention. Salt Lake City, UT.

Gan, J, A Jarrett & C Johnson Gaither (2014). Wildfire risk adaptation: Propensity of forestland owners to purchase wildfire insurance in the southern United States. Canadian Journal of Forest Research 44, 1376-1382.

Gan, J, A Jarrett & C Johnson Gaither (2015). Landowner response to wildfire risk: Adaptation, mitigation or doing nothing. Journal of Environmental Management 159, 186-191.

Gonzalez-Benecke, CA, RO Teskey, H Dinon-Aldridge & TA Martin (2017). *Pinus taeda* forest growth predictions in the 21st century vary with site mean annual temperature and site quality. *Global Change Biology* 23, 4689–4705 (2017).

Gonzalez-Benecke, CA, RO Teskey, H Dinon-Aldridge & TA Martin (2017). *Pinus taeda* forest growth predictions in the 21st century vary with site mean annual temperature and site quality. *Global Change Biology* 32:772-717.

Gonzalez-Benecke, CA., RO Teskey, TA Martin, EJ Jokela, TR Fox, MB Kane & A Noormets (2016). Regional validation and improved parameterization of the 3-PG model for *Pinus taeda* stands. *Forest Ecology and Management* 361:237-256

Gyawali, N & HE Burkhart (2015). General response functions to silvicultural treatments in loblolly pine plantations. *Canadian Journal of Forest Research, 45*(3), pp. 252-265.

Henley, J (2006). HUC12: watershed boundary dataset for 12-digit hydrologic units. *US Geological Survey, Reston, VA.*

James, AA, NM Estwick & A Bryant (2014). Climate change impacts on agriculture and their effective communication by Extension agents. *Journal of Extension* [On-line], 52(1) Article 1COM2. Available at: http://www.joe.org/joe/2014february/comm2.php

References

Keenan TF, DY Hollinger, G Bohrer, D Dragoni, JW Munger, HP Schmid & AD Richardson (2013). Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. Nature, 499: 324-327. doi: 10.1038/nature12291.

Khanal, PN, DL Grebner, IA Munn, SC Grado, RK Grala, JE Henderson & M Measells (2016). Non-industrial private forest landowner beliefs toward climate change and carbon sequestration in the Southern US. *Journal of Forestry*, 114(5): 524-531.

Khanal, PN, DL Grebner, IA Munn, SC Grado, RK Grala & JE Henderson (2016). Evaluating non-industrial private forest landowner willingness to manage for forest carbon sequestration in the southern United States. *Forest Policy and Economics* 75: 112-119.

Kunkle, KA & MC Monroe (2018). Cultural cognition and climate change education in the U.S.: why consensus in not enough. *Environmental Education Research*, doi: 10.1080/13504622.2018.1465893

Landsberg, J & P Sands (2011). *Physiological ecology of forest production: Principles, processes and models*. Burlington, MA: Academic Press Elsevier.

Landsberg, JJ & RH Waring (1997). A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest Ecology and Management* (95) 209-228.

Li, CJ & MC Monroe (2017). Development and validation of the climate change hope scale for high school students. *Environ and Behavior*. 1-19. doi: 10.1080/103504622.2017.1367916

Loopstra et al (2019). Personal communication.

Lopatto, D (2004). Survey of Undergraduate Research Experiences (SURE): First findings. *Cell Biology Education*, 3(4), 270-277.

Lu, M, KV Krutovsky, CD Nelson, TE Koralewski, TD Byram & CA Loopstra (2016). Exome genotyping, linkage disequilibrium and population structure in loblolly pine (*Pinus taeda* L.) *BMC Genomics* 17:730

Mccarthy HR, R Oren, AC Finzi, DS Ellsworth, HS Kim, KH Johnsen & B Millar (2007). Temporal dynamics and spatial variability in the enhancement of canopy leaf area under elevated atmospheric CO_2. *Global Change Biology* 13: 2479-2497. DOI: 10.1111/j.1365-2486.2007.01455.x.

McCroskey, J C (1970). Measures of communication-bound anxiety. Speech Monographs, 37: 269-277.

McElligott, KM, JR Seiler & BD Strahm (2016). Partitioning soil respiration across four age classes of loblolly pine (*Pinus taeda* L.) on the Virginia Piedmont. *Forest Ecology & Management* 378:173-180.

McNulty SG, JM Vose & WT Swank (1996). Loblolly pine hydrology and productivity across the southern United States. *Forest Ecology & Management* 86: 241-251. doi: 10.1016/S0378-1127(96)03744-9.

Meihshausen, M, SJ Smith, K Calvin, JS Daniel, MLT Kainuma, J-F Lamarque, K Matusmoto, SA MOntzka, SCB Raper, K Riahi, A Thomson, GJM Velders & DPP van Vuuren (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change* 109: 213-241.

Monroe, MC, S Hall & CJ Li (2016). Can climate change enhance biology lessons? A quasi-experiment. *Applied Environmental Education and Communication* 15(2): 125-137.

Monroe, M & A Oxarart (2015). *Southeastern forests and climate change*: A Project Learning Tree secondary environmental education module, Second edition. Gainesville: University of Florida. http://sfrc.ufl.edu/extension/ee/climate/wp-content/uploads/Module_Final.pdf

Monroe, MC, A Oxarart & R Plate (2013). A role for environmental education in climate change for secondary science educators. *Applied Environmental Education and Communication* 12(1): 4-18.

Morris, H (2014). 2013 Climate change attitudes of southeast forestry professionals: Implications for outreach. M.S. Natural Resources, North Carolina State University. NCSU Libraries Institutional Repository. Retrieved from http://www.lib.ncsu.edu/resolver/1840.16/9225

Morris, HLC, MA Megalos, WG Hubbard & LA Boby (2016). Climate Change Attitudes of Southern Forestry Professionals: Outreach Implications. *Journal of Forestry* 114(5): 532-540.

Neale, DB, JL Wegryzn, KA Stevens, AV Zimin, D Puiu, MW Crepeau, C Cardeno, M Koriabine, et al. (2014). Decoding the massive genome of loblolly pine using haploid DNA and novel assembly strategies. *Genome Biology* 15(3): R59.

Next Generation Science Standards (NGSS). (2013). *The Next Generation Science Standards*. Retrieved March 15, 2013 from http://www.nextgenscience.org/next-generation-science-standards

PINEMAP. 2017. *PINEMAP*. June 27. http://www.pinemap.org/.

Pruski, LA, SL Blanco, RA Riggs, KK Grimes, CW Fordtran, GM Barbola, JE Cornell & MJ Lichtenstein (2013). Construct Validation of the Self-Efficacy Teaching and Knowledge Instrument for Science Teachers-Revised (SETAKIST-R): Lessons Learned. *Journal of Science Teacher Education* 24 (7): 1133–1156.

Quesada et al. (2019). Personal communication.

Riahi, K, A Grübler & N Nakicenovic (2007). Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological Forecasting & Social Change* 74: 887–935.

Russell, SH, MP Hancock & J McCullough, J (2007). The pipeline: benefits of undergraduate research experiences. *Science*, 316(4), 548-549.

Sabatia, CO & HE Burkhart (2014). Predicting site index of plantation loblolly pine from biophysical variables. *Forest Ecology and Management* 326: 142-156.

Sample, VA, RP Bixler, MH McDonough, SH Bullard & MM Snieckus (2015). The promise and performance of forestry education in the United States: Results of a survey of forestry employers, graduates, and educators. *Journal of Forestry* 113. http://dx.doi.org/10.5849/jof.14-122.

Schmidtling, RC 2001. *Southern pine seed sources*. USDA, Forest Service, Southern Research Sta. Gen. Tech. Rep. SRS-44.

Selby, D & F Kagawa (2012). *Education and climate change: Living and learning in interesting times*. London: Routledge.

Service, U.S.N.R.C. (1995). *Soil Survey Geographic (SSURGO) Data Base: Data Use Information*: National Cartography and GIS Center.

Snyder, CR (Ed.) (2000). *Handbook of hope: Theory, measures, and applications*. San Diego, CA: Academic Press.

Soto, JS, DC Adams & FJ Escobedo (2016). Landowner attitudes and willingness to accept compensation from forest carbon offsets: Application of best-worst choice modeling in Florida USA. Forest Policy and Economics, 63: 35-42.

Soto, JS, FJ Escobedo, DC Adams & J Blanco (2016). A Distributional Analysis of the Socio-Ecological and Economic Determinants of Forest Carbon Stocks. *Environmental Science & Policy* 60: 28-37.

Spiegel, K.S., Leege, L.M., 2013. Impacts of laurel wilt disease on redbay (Persea borbonia (L.) Spreng.) population structure and forest communities in the coastal plain of Georgia, USA. Biological Invasions 15, 2467-2487.

Stavins R. N., 1999. The cost of carbon sequestration: A reveled-preference approach. *The American Economic Review* 89: 994–1009.

Sun G, Caldwell P, Noormets A, McNulty SG, Cohen E, Myers JM, Domec JC, Treasure E, Mu QZ, Xiao JF, John R, Chen JQ. 2011. Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model. J Geophys Res-Biogeo, 116. Doi 10.1029/2010jg001573.

Sun G, McNulty SG, Myers JAM, Cohen EC. 2008. Impacts of Multiple Stresses on Water Demand and Supply Across the Southeastern United States. J Am Water Resour As, 44: 1441-1457. DOI: DOI 10.1111/j.1752-1688.2008.00250.x.

Sun G, Noormets A, Gavazzi MJ, McNulty SG, Chen J, Domec JC, King JS, Amatya DM, Skaggs RW. 2010. Energy and water balance of two contrasting loblolly pine plantations on the lower coastal plain of North Carolina, USA. Forest Ecol Manag, 259: 1299-1310. DOI: DOI 10.1016/j.foreco.2009.09.016.

Susaeta A., Carter, D., Adams, D. 2014a. Impacts of climate change on economics of forestry and mitigation strategies in the Southern United States. *Journal of Agricultural and Applied Economics* 46(2): 257-272.

Susaeta A., Carter, D., Adams, D. 2014b. Sustainability of forest management under changing climatic conditions in the southern United States: adaptation strategies, economic rents and carbon sequestration. *Journal of Environmental Management* 139: 80-87.

Susaeta, A., Carter, D., Chang, S.J., Adams, D., 2016a. A generalized Reed model with application to wildfire risk in even-aged Southern United States pine plantations. Forest policy and Economics 67, 60-69.

Susaeta, A., Adams, D., Carter, D., Dwivedi, P. 2016a. Climate change and ecosystem services output efficiency in southern natural loblolly pine forests. *Environmental Management* 58: 417-430.

Susaeta A., Adams, D., Carter, D., Gonzalez-Benecke, C., Dwivedi, P. 2016b. Technical, allocative, and total profit efficiency of loblolly pine forests under changing climatic conditions. *Forest Policy and Economics* 72: 106-114.

Susaeta A., Carter, D., Chang, SJ., Adams, D. 2016c. A generalized Reed model with application to wildfire risk in even-aged Southern United States pine plantations. *Forest Policy and Economics* 67: 60-69.

Susaeta A, Soto J, Adams D, Allen D. 2016. Economic Sustainability of Payments for Water Yield in Slash Pine Plantations in Florida. Water-Sui, 8: 382.

Susaeta A., Soto, J., Adams, D., Allen, D. 2016d. Economic sustainability of payments for water yield in slash pine plantations in Florida. *Water* 8: 382-398.

Susaeta, A., Soto, J., Adams, D., Hulcr, J. 2016e. Pre-invasion economic assessment of ambrosia beetle X on loblolly pine forests in the Southeastern United States. *Journal of Environmental Management* 183(3): 875-881.

Susaeta, A., Soto, J., Adams, D., Hulcr, J., 2016b. Pre-invasion economic assessment of invasive species prevention: A putative ambrosia beetle in Southeastern loblolly pine forests. Journal of environmental Management 183(3): 871-881.

Templeton, B.S., J.R. Seiler, J.A. Peterson, and M. Tyree. 2015. Environmental and stand management influences on soil CO_2 efflux across the range of loblolly pine. For. Ecol and Manag. 355:15-23.

Thomas, R.Q., A. Jersild, E. Brooks, V.A. Thomas, and R.H. Wynne. 2018. A mid-century ecological forecast with partitioned uncertainty predicts increases in loblolly pine forest productivity. *Ecological Applications*. 28(6): 1503-1519.

Thomas, R.Q., E.B. Brooks, A. L. Jersild, E. J. Ward, R. H. Wynne, T. J. Albaugh, H. Dinon-Aldridge, H. E. Burkhart, J. C. Domec, T. R. Fox, C. A. Gonzalez-Benecke, T. A. Martin, A. Noormets, D. A. Sampson, and R. O. Teskey. 2017. Leveraging 35 years of *Pinus taeda* research in the southeastern US to constrain forest carbon cycle predictions: regional data assimilation using ecosystem experiments. *Biogeosciences* 14:3525-3547

Thomas, R.Q., A.L. Jersild, E. B. Brooks, V. A. Thomas, and R. H. Wynne. 2018. A mid-century ecological forecast with partitioned uncertainty predicts increases in loblolly pine forest productivity. *Ecological Applications* 28(6): 1503-1519.

Virginia Polytechnic Institute and State University, prepared by E. B. Brooks. (10-13-16). 3-PG Outputs for SRTS - County. unpublished raw data

Vose JM, Peterson D, Patel-Weynand T. 2012. Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector. In: General Technical Report PNW-GTR-870, U.S. Forest Service, Pacific Northwest Research Station.

Westfall, J. A., & Amateis, R. L. (2003). 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), pp. 279-284.

Yousefpour, R., Bredahl Jacobsen, J., Thorsen, B.J., Meilby, H., Hanewinkel, M., Oehler, K.,

2012. A review of decision-making approaches to handle uncertainty and risk in adaptive forest management under climate change. Annals of Forest Science 69, 1–15.

Appendix A: PINEMAP Team Members

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- **Andres Susaeta,** School of Forest Resources and Conservation, University of Florida
- **Eric J. Ward,** Department of Forestry and Environmental Resources, North Carolina State University

PINEMAP GRADUATE STUDENTS

Name	Institution	Advisor(s)	Degree	Thesis / Dissertation Title / Topic
Benjamin Ahlswede	Virginia Tech	Quinn Thomas	M.S.	Biophysical Climate Effects of Sub-biomes within the Temperate Forest; Implications for Plantation Forestry and Urban Expansion in the Southeast United States
Mukhtar Ahmed	University of Florida	Francisco Escobedo	M.S.	Remote Sensing and Ecosystem Service Tradeoffs
Hyunjin An	Texas A&M University	Jianbang Gan	Ph.D.	Impact of Climate Change Extremes and Adaptation on Southern Pine Beetle Infestation
Casey Ausmus	Oklahoma State University	Thomas Hennessey	M.S.	Partitioning and Quantifying Autotrophic and Heterotrophic Components of Soil Respiration in a Loblolly Pine Plantation Influenced by Nutrient and Water Availability
Bruce Barros Souza	University of Georgia	Robert Teskey	M.S.	Estimating Transpiration in Loblolly Pine *(Pinus taeda)* Plantations Using the 3-PG Model
Stan Bartkowiak	Auburn University	Lisa Samuelson	M.S.	Fertilization Effects on Water Use of 8-year-old Loblolly Pine *(Pinus taeda* L.) Vary with Throughfall Treatment
Rajesh Bawa	Virginia Tech	Jason Holliday	Ph.D.	Association and Evolutionary Genetics of Loblolly Pine
Robert Brown	University of Georgia	Daniel Markewitz	M.S.	Seasonal Proportions of Heterotropic Soil Respiration in Southern Loblolly Pine Plantations
Rachel Burnett	North Carolina State University	Mark Megalos	M.S.	Climate Predictors of Wildfire Size in North Carolina, 1979-2006: A Quantile Regression Approach
Zach Clark	University of Georgia	Mike Kane	M.S.	Effects of Site, Planting Density, Cultural Intensity, and Site Preparation on the Growth and Development of Non-planted Vegetation in Loblolly Pine Plantations
Joe Clark	Auburn University	Lisa Samuelson	M.S.	Physiology and Growth of a 6-year-old Loblolly Pine (*Pinus taeda* L.) Plantation in Response to Rainfall Exclusion and Fertilization Treatments
Margaret Clifford	University of Florida	Martha Monroe	M.S.	Motivating Extension Agents with Reasonable Training and Opportunities
Ernest Dixon IV	North Carolina State University	Robert C. Abt	M.F.	Continuous-time Continuous Stochastic Process Models of Pine Stumpage Prices and Plantation Returns in the Southeast US
Yuan Fang	North Carolina State University	Jose Stape	Ph.D.	Modeling Carbon Dynamics of Two Loblolly Pine Plantations in the Piedmont Region
Alfredo Farjat	North Carolina State University	Ross Whetten and Fikret Isik	Ph.D.	Modeling Climate Change Effects on the Growth of Loblolly Pine; Prediction of Genetic Merit in a Clonal Population of Loblolly Pine
Anslei Foster	North Carolina A&T University	Joshua Idassi	M.S.	Growth of Pleurotus Ostreatus Fungus on Degraded Canola Plant Material Substrate and the Rate of Measurement on the Release of Glucose
Carla Gann	University of Georgia	Daniel Markewitz	M.S.	Surface Efflux of N_20 and CH_4 within *Pinus taeda* L. Plantations in the Piedmont and Lower Coastal Plain of the Southeast United States
Ranjith Gopalakrishnan	Virginia Tech	Randolph Wynne and Valerie Thomas	Ph.D.	Effective Characterization of Fuel Load and its Impact on Future Fire Regimes in Managed Loblolly Pine Plantations of Southeast USA
Nabin Gyawali	Virginia Tech	Harold Burkhart	Ph.D	Modeling General Response to Silvicultural Treatments in Loblolly Pine Stands
Stephanie Hall	University of Florida	Martha Monroe	M.S.	Addressing Climate Change through Biology Concepts: Insights for Educators
John Hastings	North Carolina State University	Mark Megalos	M.S.	Beta Testing DSS, Climate Term Glossary, GIS Model to Identify Genetically Significant Populations.
Brett Heim	Virginia Tech	John Seiler and Brian Strahm	M.S.	Partitioning Soil Respiration in Response to Drought and Fertilization in Loblolly Pine: Laboratory and Field Approaches
Miles Ingwers	University of Georgia	Robert Teskey	Ph.D.	Ecophysiological Responses of Loblolly Pine to Water Deficits
Omkar Joshi	Mississippi State University	Donald Grebner	Ph.D.	Woody Biomass and Bioenergy Opportunities in Mississippi
Puskar Khanal	MSU	Donald Grebner	Ph.D.	Nonindustrial Private Forest Landowners Willingness to Sequester Forest Carbon in the Southern United States
John Kidd	Virginia Tech	John Seiler	Ph.D.	A Systematic Review of Existing Natural Resources Research Experiences for Undergraduates Programs and Evaluation of the PINEMAP Undergraduate Fellowship Program
Shelby Krantz	University of Florida	Martha Monroe	M.S.	Message Framing to Affect Forest Landowners' Intention to Adapt to Climate Change
Melissa Kreye	University of Florida	Damian Adams	Ph.D.	Valuing Forest Conservation Programs to Protect Water Quality
Kristen Kunkle	University of Florida	Martha Monroe	M.S.	Integrating Climate Change Education in the Classroom: Applying a Motivated Reasoning Framework to Mitigate Cultural Conflict
Andy Laviner	Virginia Tech	Thomas Fox	Ph.D.	Water Use and Nitrogen Cycling in Loblolly Pine Plantations Under Reduced Water Availability
Jie (Christine) Li	University of Florida	Martha Monroe	Ph.D.	Effective Climate Change Education: Factors affecting Students' Learning and Teachers' Hope and Self-Efficacy
Wen Lin	North Carolina State University	Asko Noormets and J.C. Domec	Ph.D.	Drought Sensitivity of Plant Carbon Exchange and Allocation in Loblolly Pine
Mengmeng (Miranda) Lu	Texas A&M University	Carol Loopstra and Konstantin Krutovsky	Ph.D.	Association of Exome Variation with Potential Adaptation to Climate Change in Loblolly Pine *(Pinus taeda* L.)

Name	Institution	Advisor(s)	Degree	Thesis / Dissertation Title / Topic
Cody Luedtke	University of Georgia	Robert Teskey	M.S.	Carbon Dioxide Fluxes and Nonstructural Carbohydrates in Seedlings as Influenced by Heat, Drought, and Low Light
Adam Maggard	Oklahoma State University	Rodney Will	Ph.D.	Implications of Potential Climate Change on Loblolly Pine (*Pinus taeda* L.) and the Interaction Between Fertilizer and Drought; Drought and Carbon Stress Mortality in Loblolly Pine (*Pinus taeda* L.)
Kristin McElligott	Virginia Tech	John Seiler and Brian Strahm	Ph.D.	Environmental Drivers of Soil and Forest Floor Respiration as Influenced by Age and Management in Loblolly Pine Stands
Teri Medsker	Oklahoma State University	Duncan Wilson	M.S.	The Effect of Soil Moisture on Nutrient Dynamics and Productivity of Loblolly Pine Plantations
April Meeks	North Carolina State University	Jose Stape	M.S.	Characterization and Assessment of Competing Vegetation in Mid-rotation Loblolly Pine Stands at Hofmann Forest, NC
Marco Minor	Texas A&M University	Jason Vogel	M.S.	Relationship Between Decomposition and Soil CO_2 Efflux under Different Management Regimes
Percy Montecinos	Virginia Tech	Tom Fox	M.F.	Impact of Fertilization and Weed Control on Growth of Loblolly, Shortleaf, White and Virginia Pine
Hilary Morris (Cole)	North Carolina State University	Mark Megalos	M.S.	2013 Climate Change Attitudes of Southeast Forestry Professionals: Implications for Outreach
Lara Nichols	Virginia Tech	Tom Fox and Brian Strahm	M.S.	Relationships among Soil Properties and Soil CO_2 Efflux in a Loblolly Pine-Switchgrass Intercropped System
Charles Pell	Auburn University	Lisa Samuelson	M.S.	Long-term Interactive Effects of Throughfall Rain Exclusion and Fertilization on Physiology of Loblolly Pine (*Pinus taeda* L.)
Ji (Jill) Qi	University of Georgia	Daniel Markewitz	Ph.D.	Drying-Rewetting Cycles: Impacts on Deep Soil Carbon and Hydrology
Jay Raymond	Virginia Tech	Thomas Fox	Ph.D.	Use of N^{15} Labeled Nitrogen Fertilizer to Evaluate Uptake Efficiency and Environmental Fate of Urea and Enhanced Efficiency Fertilizers in Forest Plantations
Tracey Ritchie	University of Florida	Martha Monroe	Ph.D.	Assessing Strategies for Teaching Systems Thinking in Secondary Science
C. Wade Ross	University of Florida	Sabine Grunwald	Ph.D.	Simulating Terrestrial Ecosystem Dynamics Across the Southeastern U.S.
Ed Russell	Virginia Tech	John Seiler	Ph.D.	Fertilizer and Throughfall Reduction on Water Relations and Drought Tolerance of Loblolly Pine
Jose Soto	University of Florida	Damian Adams	Ph.D.	Estimating the Supply of Forest Carbon Offsets: A Comparison of Best-Worst and Discrete Choice Valuation Methods
Beth Stein	Virginia Tech	V. Thomas	Ph.D.	Applications of Imaging Spectroscopy in Forest Ecosystems at Multiple Scales
Santosh Subedi	Virginia Tech	Thomas Fox	Ph.D.	Fertility Rating Assessment in the 3-PG Model
Praveen Subedi	University of Florida	Eric Jokela	Ph.D.	Inter-rotational Effects of Fertilization and Weed Control Treatments on the Productivity and Soil Nutrient Availability in Juvenile Loblolly Pine Plantations
Ram Thapa	Virginia Tech	Harold Burkhart	Ph.D.	Modeling Mortality of Loblolly Pine (*Pinus taeda* L.) Plantations
Laura Townsend	North Carolina State University	Ross Whetten	M.S.	Identifying Genetic Variation in Site Adaptability in Loblolly Pine (*Pinus taeda* L.)
Mohamad Traboulsi	University of Florida	Damian Adams	M.S.	Assessing the Economic Value of Forest Water Yield in Florida: A Production Function Approach
Aaron Vuola	North Carolina State University	Mark Megalos	M.S.	North Carolina Cooperative Extension Perceptions and the Six Americas of Climate Change
Ying (Maggie) Wang	University of Georgia	Robert Teskey	Ph.D.	Predicting Loblolly Pine Growth Under the Climate Change Conditions in the Southeastern Region with a Set of Validated Physiological Parameters
Amy Werner	Virginia Tech	Tom Fox	M.S.	Nitrogen Release, Tree Uptake and Ecosystem Retention in a Mid-Rotation Loblolly Pine Plantation Following Fertilization with ^{15}N Enriched Enhanced Efficiency Fertilizers
Jared Westbrook	University of Florida	John Davis	Ph.D.	Discovering Genes and Predicting Phenotype for Improved Bark Beetle Resistance in Loblolly Pine
Maxwell Wightman	University of Florida	Timothy Martin	M.S.	Loblolly Pine (*Pinus taeda*) Water Relations in Response to Fertilization and Throughfall Exclusion
Elizabeth Wilson	Texas A&M University	Jason West and Jason Vogel	M.S.	The Effects of Water Stress on Variability in Mesophyll Conductance of Loblolly Pine (*Pinus taeda* L.) Leaves
Marco Yanez	Virginia Tech	Tom Fox and John Seiler	Ph.D.	Management Intensity Effects on Growth and Physiological Responses of Loblolly Pine Varieties and Families Growing in the Virginia Piedmont and North Carolina Coastal Plain of the United States
Jinyan Yang	University of Georgia	Robert Teskey	Ph.D.	Effects of Throughfall Exclusion and Fertilization on Soil CO_2 Efflux and its Components in a Loblolly Pine (*Pinus taeda*) Plantation
Lu Zhai	Texas A&M University	Jason Vogel	M.S.	Finding Ideotypes by Examining Interactions among Silvicultural Intensity, Genotype, and Environment for Full-Sib Loblolly Pine Families
Jianxing Zhang	University of Florida	Gary Peter	Ph.D.	Integrating Climate and Genetic Effects of Loblolly Pine by Universal Response Functions
Yang Zhang	Texas A&M University	Jason West and Jason Vogel	Ph.D.	Effect of Climate Change and Forest Management on Carbon and Nitrogen Dynamics of Woody Debris in Southern U.S. Loblolly Pine Forests

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USDA United States Department of Agriculture
National Institute of Food and Agriculture