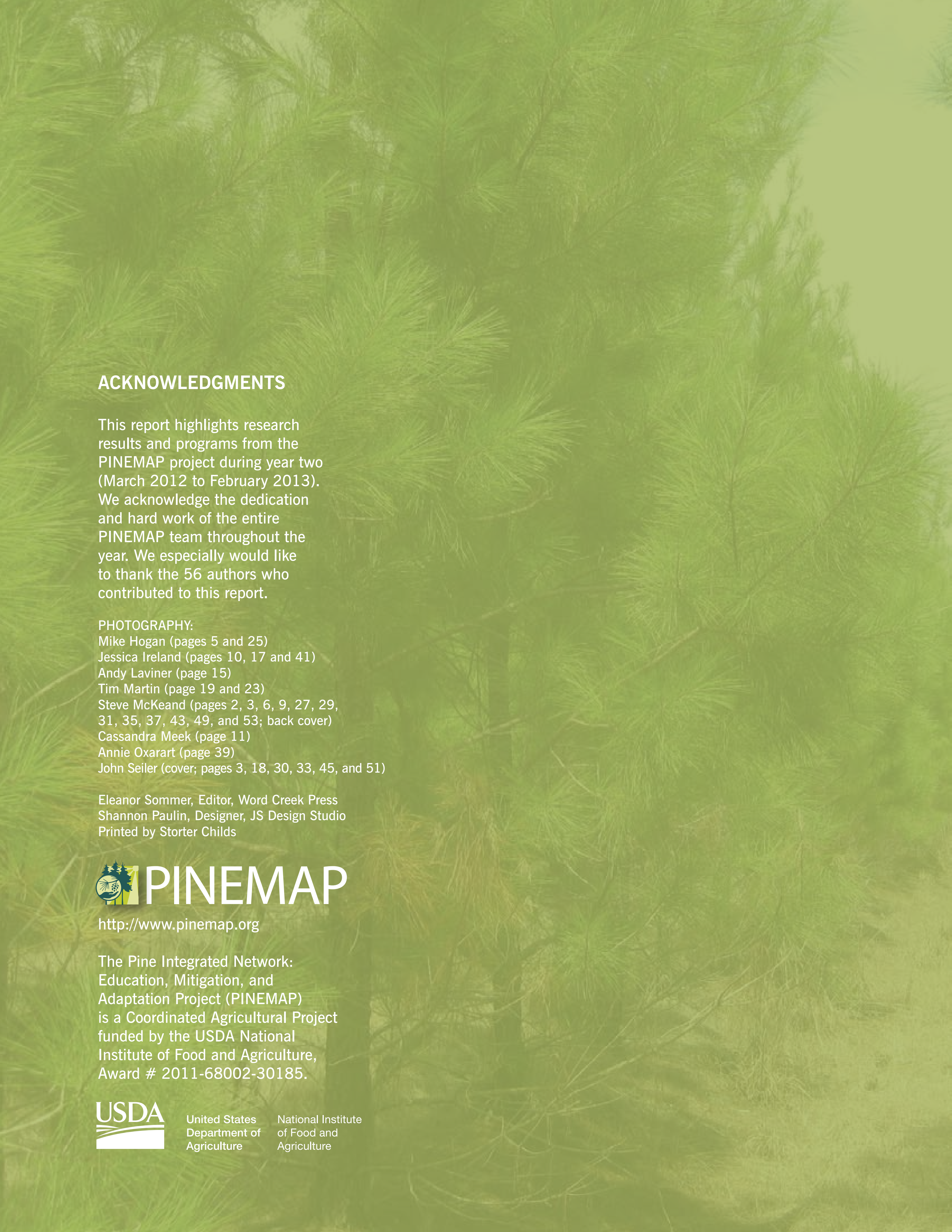
PINEMAP

Pine Integrated Network: Education, Mitigation, and Adaptation Project

Year 2 Annual Report | March 2012-February 2013

Mapping the future of southern pine management in a changing world



ACKNOWLEDGMENTS

This report highlights research results and programs from the PINEMAP project during year two (March 2012 to February 2013). We acknowledge the dedication and hard work of the entire PINEMAP team throughout the year. We especially would like to thank the 56 authors who contributed to this report.

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

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PINEMAP Year 2 Annual Report • March 2012-February 2013

Introduction

Welcome to the second Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP) annual report. PINEMAP is one of three Coordinated Agricultural Projects funded in 2011 by the United States Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA). PINEMAP focuses on the 20 million 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 United States (U.S.) citizens. 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 produce and disseminate the knowledge necessary to better manage planted southern pine forests in a changing world. 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. We hope this report conveys the breadth and depth of PINEMAP research and the clear connections to improved outcomes for our southern pine forests.

Outcome Theme Icons

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 over 120 forestry researchers, educators, Extension professionals, and students is building new networks and new infrastructure for cutting-edge, collaborative, 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

- 56 principal investigators
- 23 research/technical staff
- 7 postdoctoral research associates
- 38 graduate students

Team members are 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/networks include the following:

State climate offices and the multi-state Southeast Climate Consortium (SECC)
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 a local resource on climate.

Southern Regional Extension Forestry (SREF)
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 changing climate.

Project Learning Tree Network (PLT)
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 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). 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*
- *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*

USDA 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 conduct research as a part of PINEMAP.

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.

1. PINEMAP Monitoring Network

Establishment of a monitoring network to develop carbon, water, and nutrient storage and flux baselines and responses to climate and management was one of the primary requirements of the National Institute of Food and Agriculture (NIFA) grant that funds PINEMAP. The three-tiered monitoring network developed by PINEMAP leverages the enormous investments in cooperative research trials from the past several decades and creates an unprecedented resource for regional pine plantation research.

The Tier I "legacy" network (Figure 1.1) consists of hundreds of existing silviculture experiments and growth-and-yield plots that blanket the region and provide extensive, spatially explicit information on regional variability in productivity. The Tier II "active experiments" network (Figure 1.2) contains 127 existing silvicultural trials that cover the full range of climate and soils in the region on which detailed carbon (C) and nutrient balance will be measured. Finally, the Tier III "throughfall exclusion 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 are manipulated through fertilization and diversion of rain falling through the forest canopy (throughfall).

Data collected in the three-tiered monitoring network includes the following:

- Vegetation and soil sampling including leaf area, standing live and dead trees, understory vegetation, coarse and fine woody detritus, forest floor and soil organic matter, roots, and chemical and physical soil properties collected at various depths.
- Growth response data combined with carbon and nitrogen pool data to determine nitrogen use efficiency.

The PINEMAP monitoring network provides a wealth of data for model development and testing and improving understanding of how southern pine productivity responds to climate and soils both now and in the future.

Figure 1.1. Tier I legacy network.

Figure 1.2. Tier II active experiments network.

Figure 1.3. Tier III throughfall exclusion x fertilization network.

Data SIO, NOAA, U.S. Navy, NGA, GEBCO Image ©2012 TerraMetrics ©2012 Google
US Dept of State Geographer

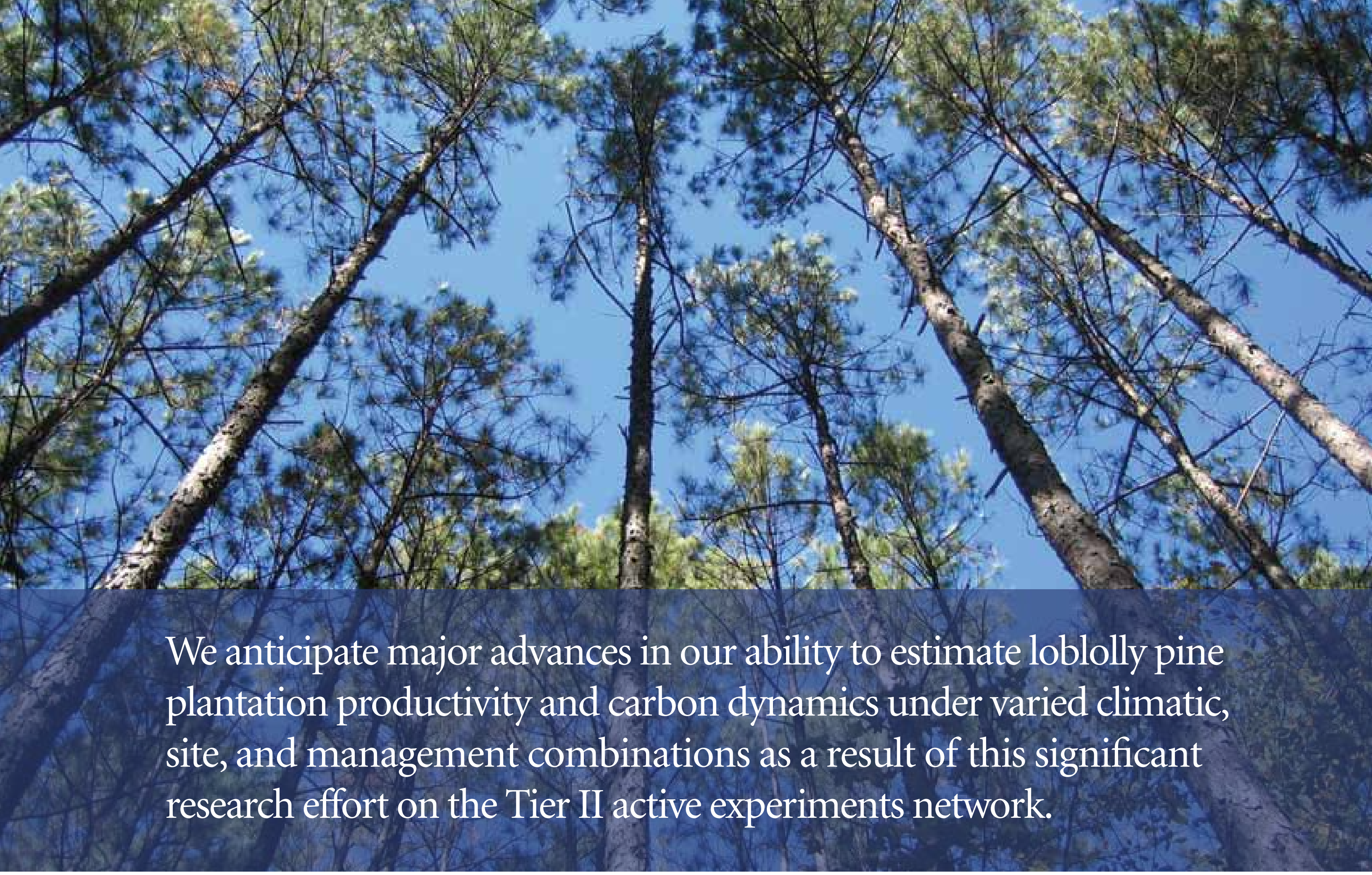
2. Refining Loblolly Pine Plantation Productivity and Carbon Estimation Using a Powerful Region-wide Network of Active Research Sites

Michael Kane

Professor • Warnell School of Forestry and Natural Resources, University of Georgia

Understanding pine productivity and associated carbon dynamics across a range of environmental conditions and silvicultural inputs is necessary to enable forest managers and policymakers to make informed decisions leading to productive, resilient forests that help mitigate climate change. As described on page 7, PINEMAP has implemented a three-tiered monitoring network to enhance the understanding of these dynamics. The objective of the Tier II active experiments network is to improve understanding of how above-ground and below-ground carbon and key relationships between ecological-physiological processes and carbon dynamics vary with climate, soil, stand condition, and management. The resulting data will be used to improve

Figure 2.1. An example of a Tier II site examining the effects of planting density on forest dynamics. The photo on the left shows a stand with 600 trees per acre, and the photo on the right shows a stand with 1,200 trees per acre. Photos by Evan Johnson.



We anticipate major advances in our ability to estimate loblolly pine plantation productivity and carbon dynamics under varied climatic, site, and management combinations as a result of this significant research effort on the Tier II active experiments network.

mathematical models for estimating plantation growth and yield and ecosystem carbon. These data will be especially important in the refinement of models that allow for productivity and carbon estimation for different climate, site, and management combinations. These models will be incorporated into decision support tools useful for land managers.

The Tier II active experiments network consists of 127 sites distributed throughout the Southeast (see Figure 1.2 on page 7). These sites were selected to represent the range of climate, geology, and soil conditions in the Southeast and span a range of plantation ages (5 to more than 25 years) covering a progression of stand development. At each site, a designed field study examines one or more silvicultural factors. Principal treatments represented in the network include planting density (Figure 2.1), thinning, fertilization, and competition control. There are a number of installations examining different genotypes planted in block plots in combination with different silvicultural treatments. The network also includes a regional series of plots examining effects and efficiencies of fertilization with various nitrogen fertilizers. These studies reflect ongoing priority research by forest biology, productivity, and biometrics university-corporate-governmental research cooperatives in the Southeast. PINEMAP is grateful to the research cooperatives and landowners for allowing access to these studies for this special sampling.

The Tier II active experiments network delivers data routinely collected by the cooperatives as well as data resulting from PINEMAP sampling. The cooperatives contribute site and tree measurement information. PINEMAP specific sampling on all or a subset of locations in this network includes a biomass and carbon inventory; soil sampling; tree canopy light interception measurements; wood core sampling used to determine water use efficiency; and assessments of soil carbon emissions, nitrous oxide emissions, and nitrogen uptake efficiency. This sampling effort and resulting data are the basis for a number of graduate student projects contributing to PINEMAP objectives. The locations of the network sites were finalized in June 2012, and sampling commenced shortly thereafter and will continue through 2015. PINEMAP researchers at Virginia Tech, University of Georgia, Auburn University, University of Florida, Oklahoma State University, and Texas A&M University conduct the field work and much of the related laboratory effort. A significant accomplishment in the past year was the standardization of sampling approaches and methods across the region. As of early March 2013, 28 locations have been sampled.

We anticipate major advances in our ability to estimate loblolly pine plantation productivity and carbon dynamics under varied climatic, site, and management combinations as a result of this significant research effort on the Tier II active experiments network.

3. Loblolly Pine Plantation Response to a Future Drier Climate: South-wide Study to Determine the Effects of Reduced Precipitation and Fertilization

Rod Will

Professor • Department of Natural Resource Ecology and Management, Oklahoma State University

Future climate scenarios indicate that the climate of the Southeast will likely be drier with an increased variability in frequency and intensity of precipitation events. As a result, fertilization of loblolly pine plantations may either help compensate for lower water availability or exacerbate the effects of drought due to greater leaf area and potential plant water use. To determine the effects of a drier climate and increased nutrient availability on loblolly pine plantation growth, canopy development, and physiology, PINEMAP installed the Tier III "throughfall exclusion x fertilization" network which is made up of four research sites situated at the edges of the native range of loblolly pine. The four sites, located in McCurtain County, Oklahoma; Taylor County, Florida; Taliaferro County, Georgia; and Buckingham County, Virginia, capture the current range-wide variability of climate, precipitation, and productivity (see Figure 1.3 on page 7). The research sites range in planting date from 2003 to 2008, are unthinned, and were planted with a mix of genetic sources appropriate for each region.

Initiated in 2012, treatments at all four Tier III sites consist of approximately 0.2 acre plots with four replications of a factorial experiment (Figure 3.1):

- Control: no treatment
- Fertilizer: fertilizer additions to achieve "optimum" nutrition
- Throughfall exclusion: panels installed in understory to divert 30% of throughfall off of the plot (Figures 3.2 and 3.3)
- Fertilizer + throughfall exclusion: combined fertilizer and throughfall exclusion treatment

Researchers at each Tier III site are measuring tree and stand growth, above and below ground carbon, changes in soil nutrient and water availability, whole-tree water use, leaf area development and canopy light capture, and soil carbon dioxide (CO_2) efflux (partitioned into autotrophic and heterotrophic components). To learn more about these research efforts, refer to the following articles:

- *Forest Carbon Sequestration: Big Changes Underfoot, page 12*
- *Understanding the Fate of Applied Fertilizer Nitrogen in Southern Plantation Forests to Address Economic and Environmental Issues, page 14*
- *Sap Flux Sensor Networks at Tier III Sites, page 16*

In addition, Tier III study sites serve as experimental platforms for additional research questions and topics unique to each region. The data from these study sites will allow us to understand how loblolly pine plantations grow and function under a drier climate scenario so that we can better predict growth, assess risk, and ultimately alter management to increase productivity and carbon sequestration.

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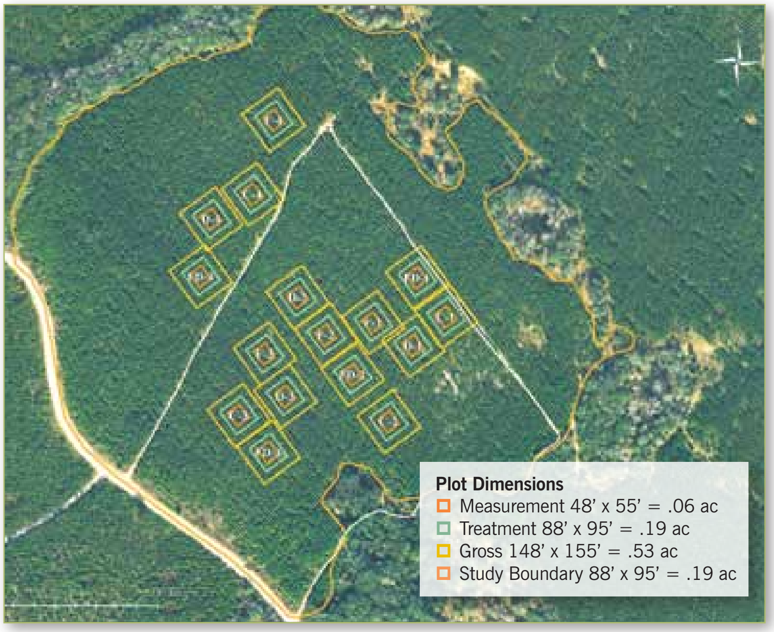


Figure 3.1. Site map and experimental design of the Florida Tier III site. The Florida Tier III Installation was established in April 2012 in a planted loblolly pine forest in Perry, FL. The study consists of a 2x2 factorial arrangement of treatments in a randomized complete block design with four replicates. The four treatments include control (C): no treatment; fertilizer (F): optimum fertilizer addition (200 lb/ac N, 25 lb/ac P, 50 lb/ac K, and a micronutrient blend based on 1 lb/ac B); rain throughfall exclusion (D): 30% throughfall captured and diverted from plot; and fertilizer + rain throughfall exclusion (FD): combined F and D treatments. Measurement plots consist of 45 trees (9 trees x 5 rows) and measure 48 x 55 ft. Each measurement plot is surrounded by a 20 ft treated buffer on all sides (treatment plot), followed by an additional 30 ft buffer around the treatment plot (gross plot).

Figure 3.2 (top). Throughfall exclusion structures at the Virginia Tier III site. Photo by Andy Laviner.

Figure 3.3 (bottom). The throughfall exclusion structures at the Oklahoma Tier III site are effective at collecting all kinds of precipitation. Photo by Cassandra Meek.

4. Forest Carbon Sequestration: Big Changes Underfoot

Brett Heim[1,4] • *Brian Strahm*[2,4] • *John Seiler*[3,4]

[1]*M.S. student* • [2]*Assistant Professor* • [3]*Alumni Distinguished Professor* • [4]*Department of Forest Resources and Environmental Conservation, Virginia Tech*

Figure 4.1. This picture shows a root exclusion core being excavated after a 90-day installation so that roots can be collected for analysis. Photo by Brett Heim.

Carbon (C) in terrestrial ecosystems is one of the main reservoirs in the global C cycle. Within these terrestrial ecosystems, soil C in the form of organic matter and plant biomass are the two largest pools of C. Further, the processes of photosynthesis and respiration that occur in these systems are the two largest fluxes of C globally. Given their size, even small changes in these pools and fluxes can significantly impact atmospheric CO_2 concentrations. Forest ecosystem management can influence global C dynamics by manipulating these pools and fluxes. Afforestation, in general, and forest management (silviculture), specifically, can increase terrestrial ecosystem C in soils and biomass. In the southern United States, intensive management of loblolly pine forests has resulted in appreciable increases in productivity since the widespread establishment of pine plantations in the 1950s. Understanding the interacting effects of management (e.g., fertilization) and climate variability (e.g., drought) will be critical in guiding the adaptation of these forest ecosystems for the mitigation of negative climate impacts.

To quantify the effects of management and climate change, a measure of C storage is necessary. One such measure that forest scientists use is net ecosystem productivity (NEP), a measure of the net C accumulated by an ecosystem. For a loblolly pine ecosystem, it represents the C captured by photosynthesis minus the losses due to plant and soil respiration. Unfortunately, a direct measurement of NEP is difficult over large geographic areas. Ecosystem C models have the capacity to predict NEP with one modification of their present configuration—there is a need to understand the relative contributions of soil heterotrophic, microbial respiration (R_H) and autotrophic, root respiration (R_A) to the overall belowground soil respiration (R_S). Present estimates suggest R_A and R_H are roughly evenly split, but deviations from this even split could have significant impacts on the estimates of C storage in managed forest ecosystems. In short, a higher proportion of R_H would result in lower measures of NEP; whereas, a lower proportion of R_H would indicate greater estimates of ecosystem C storage.

In order to partition R_S into its R_H and R_A components, R_S needs to be measured in a root free environment, and such conditions hardly exist in nature. On small scales, however, these conditions can be artificially created by severing the roots from their supply of plant carbohydrates (i.e., photosynthesis). Over time, the roots run out of carbohydrates for respiration

Figure 4.2. PINEMAP M.S. student Brett Heim uses a LI-COR 6200 to measure soil respiration underneath a throughfall exclusion structure at the Virginia Tier III site. Photo by John Seiler.

Understanding the interacting effects of management (e.g., fertilization) and climate variability (e.g., drought) will be critical in guiding the adaptation of these forest ecosystems for the mitigation of negative climate impacts.

and R_A falls to zero. At this point, a measure of R_S is equal to R_H. Practically, this is achieved by driving a 10 cm wide core 35 cm into the ground to sever tree roots and waiting for the exhaustion of R_A (Figure 4.1). Then, comparing measures of R_S inside (now simply R_H) and outside ($R_S = R_H + R_A$), the core provides the information necessary to allow current ecosystem C models to more accurately predict NEP in order to determine if managed southern pine ecosystems can meet the objective of increased C storage.

During the 2012 field season, we tested this coring method at the PINEMAP Tier III site in Virginia. This nine-year-old loblolly pine stand is located in the Appomattox-Buckingham State Forest in the Piedmont region of Virginia. This location represents the northernmost range of climatic conditions where loblolly pine is intensively managed in the southeastern U.S. (see Figure 1.3 on page 7).

Respiration measurements were taken approximately every two weeks both adjacent to and on top of each root severing core to measure the decline in R_A over the course of a three month period (Figure 4.2). Soil temperature (at 10 cm) and moisture measurements (at 0 to 12 cm) were also taken adjacent to the collar during each measurement.

Respiration initially increased inside the cores due to the disturbance of installation. After a period of equilibration, however, the respiration inside the core began to decrease relative to outside the core before stabilizing after approximately 65 days (Figure 4.3). At the point of stabilization, the respiration measured inside the root severing cores was about 25% lower than respiration measured adjacent to the cores. This suggests that the assumed partitioning of R_S into equal proportions of R_H and R_A may underestimate the amount of C stored in these systems.

Based on these initial results, PINEMAP researchers will be deploying this method at the other Tier III installations as well as in a broader regional context at some of the Tier II sites to estimate loblolly pine NEP across the range of the species.

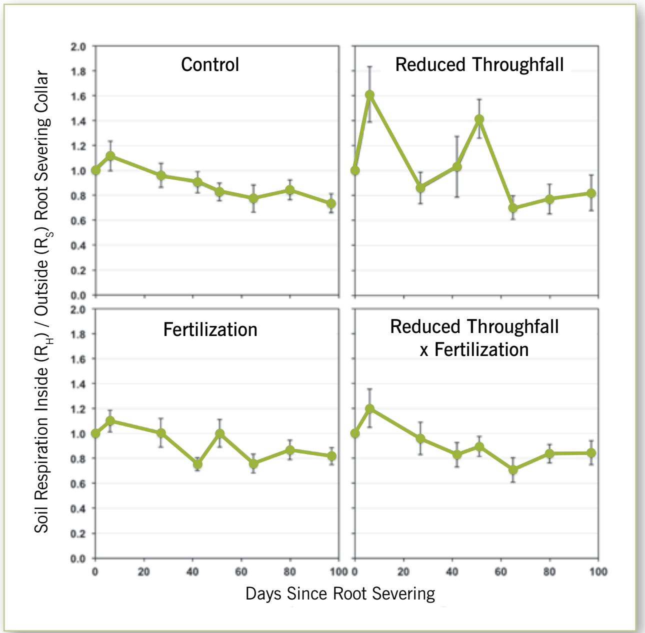


Figure 4.3. A time series showing the ratio of soil respiration measurements inside to soil respiration measurements outside root severing cores relative to time of core installation. Values below 1.0 indicate lower rates of soil respiration inside root severing cores. Once the response has stabilized (~65 days), the value is used to estimate the heterotrophic (R_H) contribution to total soil respiration (R_S).

5. Understanding the Fate of Applied Fertilizer Nitrogen in Southern Plantation Forests to Address Economic and Environmental Issues

Jay Raymond[1,4] • *Thomas Fox*[2,4] • *Brian Strahm*[3,4]

[1]*Ph.D. student* • [2]*Professor* • [3]*Assistant Professor* • [4]*Department of Forest Resources and Environmental Conservation, Virginia Tech*

Nitrogen (N) is a nutrient critical to the productivity of forests, but available N is often low in forests, which can severely limit growth. Consequently, for the last several decades, N containing fertilizers, generally in the form of urea, have been an integral management tool for plantation forestry in the southern United States to ameliorate these lower levels of plant available N. Nitrogen fertilization increases the growth rates of forest plantations, translating to increased economic benefits for landowners. Even so, the costs associated with fertilization have increased over the last decade, and future projections show a continued upward trend. Additionally, not all applied fertilizer N is incorporated into desired target crop trees. Depending on timing of application and climatic conditions, a large portion of the N derived from the fertilizer may be incorporated into other parts of the forest (e.g., understory competition, soils) or lost from the system due to gaseous transformations and movement into ground or surface water. These economic and environmental concerns are directing our research to achieve a better fundamental understanding of the fate of applied fertilizer N in southern forest plantations to improve nutrient management decisions.

To address these issues, our research uses fertilizers enriched or labeled with the stable isotope ^{15}N to track the fate of applied fertilizer N in plantation forests. Because only a small percentage of ^{15}N exists in the environment, enriching fertilizers with this isotope allows an accurate accounting of the movement of N derived from the fertilizers. The use of ^{15}N allows us to calculate how much and how quickly crop trees incorporate N applied from fertilizers. Additionally, because large N losses to the atmosphere can occur when using conventional fertilizers (urea), we are investigating whether enhanced efficiency fertilizers are able to reduce these gaseous losses. Enhanced efficiency fertilizers are treated with polymer coatings to slow the release of N to the soil solution, or with chemicals that inhibit urease (such as NBPT or CUF), a catalyzing enzyme of urea hydrolysis. We are also investigating the seasonal timing of fertilization, which is traditionally conducted in late winter or early spring when plant available N may be less limiting compared to summer months. Finally, we are examining how much fertilizer derived N is retained by understory competition.

To achieve these goals, in 2011 and 2012, 18 sites were established near existing research studies across the entire range of loblolly pine plantations in the southern United States (Figure 5.1). Five fertilizer treatments (a control with no fertilizer, urea, polymer coated urea, coated urea + NBPT [CUF + NBPT], and urea + NBPT) were applied at two different times (late winter and summer in 2011 and once in late winter in 2012) in 100 m^2 circular plots with similar characteristics. Five additional plots were installed at the Tier III sites in Virginia and Georgia to investigate the impact of retaining the understory vegetation. After fertilizer application,

Figure 5.1. Location of the ^{15}N sites across the southern United States and year of installation.

Economic and environmental concerns are directing our research to achieve a better fundamental understanding of the fate of applied fertilizer N in southern forest plantations to improve nutrient management decisions.

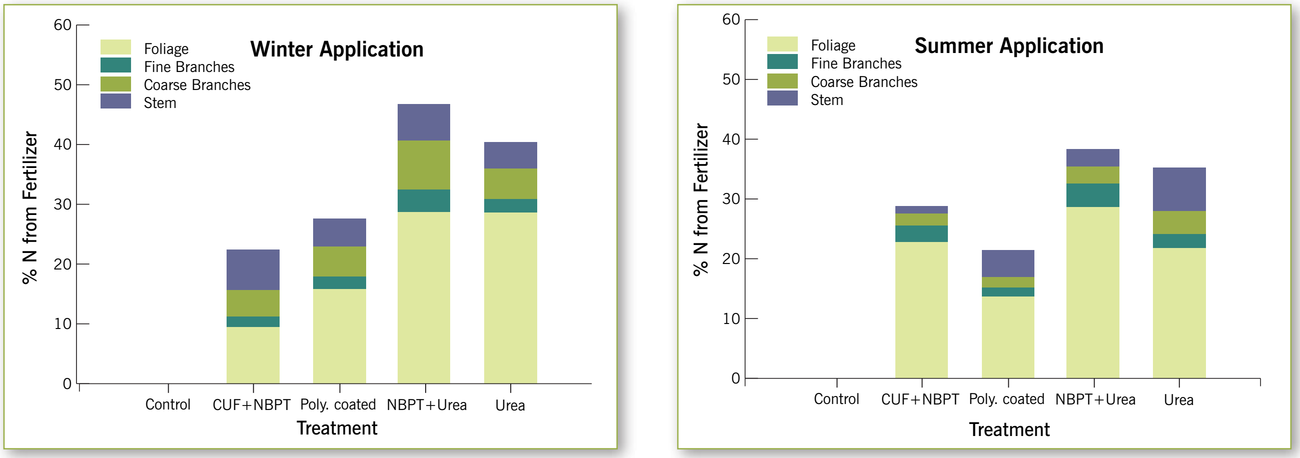


Figure 5.2. Graphs comparing the percentage of N (%N) attributed to fertilizer uptake from winter and summer ^{15}N fertilizer application at the Virginia ^{15}N site, located adjacent to the Virginia Tier III site. Both application periods indicate that foliage contains the largest levels of N attributed to the fertilizer for the above ground portion of the crop tree at this site.

measurements were taken to estimate gaseous and leaching losses of N. Foliar sampling was conducted every six weeks to estimate N uptake over the growing season. All components of the ecosystem were sampled at the end of the growing season to calculate the location of ^{15}N. Samples included the biomass of one tree to determine N uptake (foliage, fine branches, coarse branches, stems, and roots), understory competition (naturally regenerated trees, shrubs, vines, and herbaceous stratum), litter (separated by hardwood vs. softwood), forest floor, and mineral soil (at depths of 0-15 and 15-30 cm).

The preliminary results from one site near the Virginia Tier III study indicate that ^{15}N enriched fertilizers are being incorporated in the aboveground biomass of crop trees through the entire growing season, as evident by percent N uptake and foliar N concentrations. Pre-treatment foliar N concentration levels ranged from 1.08% to 1.10% for winter and summer plots. At biomass harvest, foliar levels of N increased, ranging from 1.40% to 1.55% for winter plots and 1.44% to 1.67% for summer plots. Winter fertilized plots had a larger percentage of N attributable to fertilizer when compared to summer, with the exception of coated urea + NBPT, which displayed an opposing trend. Preliminary recovery rates are highly variable between treatments, although the largest levels were observed in the foliage. Recovery of ^{15}N for above ground biomass was greatest in foliage for all treatments, followed by the stem from both summer and winter applications (Figure 5.2). Uptake of ^{15}N continued through the entire growing season. Initial calculations used values from each component of the single harvested crop tree and extrapolated to all trees within the plots. Future work will compare these values to allometric equations.

6: Sap Flux Sensor Networks at Tier III Sites

Eric J. Ward[1,4] • *Jean-Christophe Domec*[2,4] • *Asko Noormets*[3,4]

[1]*Postdoctoral Research Associate* • [2]*Research Assistant Professor* • [3]*Research Associate Professor* • [4]*Department of Forestry and Environmental Resources, North Carolina State University*

Water use and carbon uptake are intimately linked in plants, as both plant-atmosphere exchanges of water vapor and carbon dioxide (CO_2) occur through the stomata of leaves. Thus, insights about stomatal regulation of plant water use also inform us about carbon assimilation, productivity, and growth. Using a network of hundreds of sensors that measure water movement in the trunks of trees, or sap flux density, PINEMAP researchers can estimate how much water trees within each plot of the Tier III sites are using every half-hour. By comparing this water use to soil water content and atmospheric evaporative demand determined by vapor pressure deficit, we can estimate the conductance of canopy to water vapor (G_C), which is a measure of how tightly stomata are regulating water use and carbon uptake. Temporal change in G_C is a good indicator of plant responses to environmental variables. Here we describe how these measurements are being made and present some preliminary analyses of data collected at a Tier III site.

Figure 6.1. University of Florida M.S. student Maxwell Wightman drills a hole to insert thermal dissipation sensor probes into a tree at the Tier III site in Florida. Photo by Geoffrey Lokuta.

Methods

Sap flux density at each Tier III site is monitored by a network of thermal dissipation sensor probes (Figure 6.1).

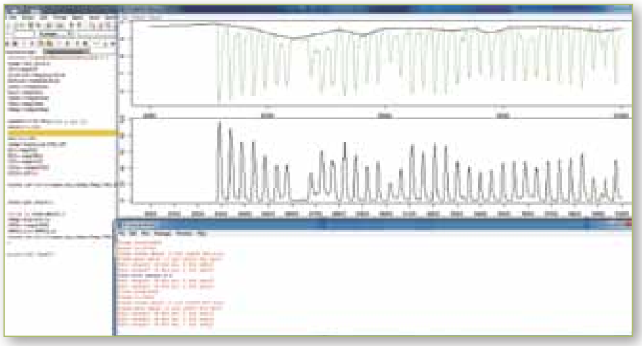
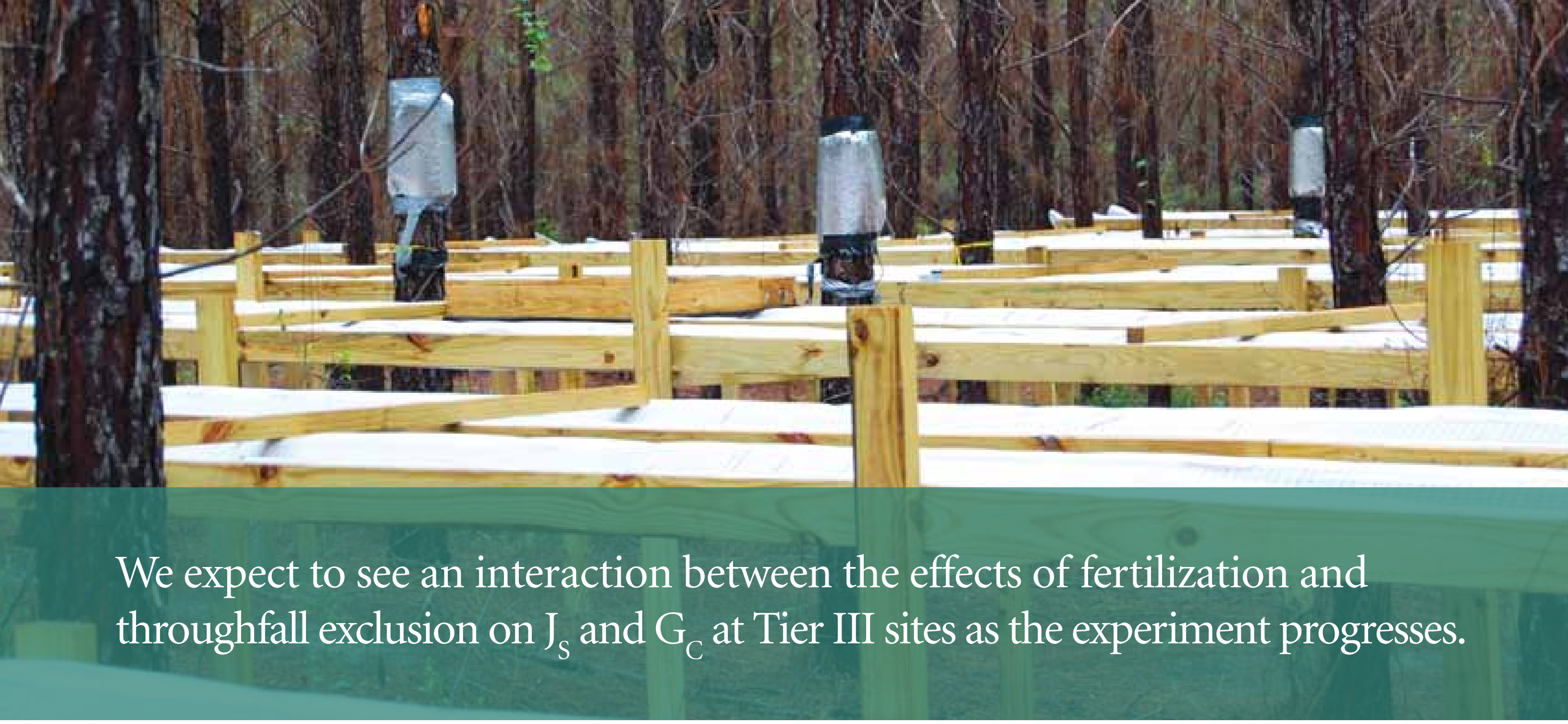


Figure 6.2. Screenshot of sap flux data quality control and processing program developed by PINEMAP researchers. The green line in the top panel shows raw data for a single sensor, and the black line shows the calibration calculated for the sensor based on environmental conditions. The resulting sap flux density in the bottom panel shows the daily rise and fall of water uptake for this tree over several weeks.

There are five such sensors per plot, for a total of 320 trees monitored across all four Tier III sites. Data from these sensors are measured every 60 seconds and averaged every 30 minutes. Additional data collected at a central location at each site includes air temperature, precipitation, relative humidity, and above- and below-canopy photosynthetically active radiation. In addition, a network of soil moisture probes records data for each plot every 30 minutes, with separate measurements below and between throughfall exclusion structures. All these data are collected daily by a central server at North Carolina State University using a cellular modem located at each Tier III site. All equipment is powered using photovoltaic solar panels.

Data quality control and processing have been standardized across PINEMAP sites using a program developed by PINEMAP researchers (Ward et al. in preparation; Figure 6.2) in the open source language R (R Foundation for Statistical Computing, Vienna, Austria). This program is being beta-tested by select research groups in the United States and Australia for eventual public distribution. Because sap flux probes require daily calibration based on predawn data subject to specific environmental thresholds (Oishi, Oren, and



We expect to see an interaction between the effects of fertilization and throughfall exclusion on J_S and G_C at Tier III sites as the experiment progresses.

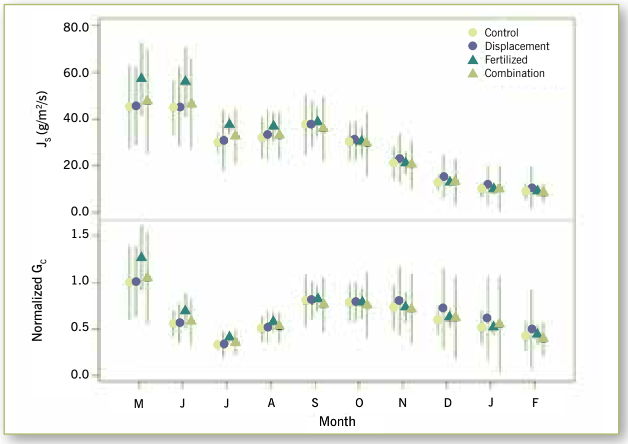


Figure 6.3. The top panel shows monthly daytime averaged sap flux density (J_S) measured in each treatment from May 2012 until February 2013. The bottom panel shows monthly daytime averaged canopy conductance (G_C) values estimated for each treatment, normalized by the maximum value observed in control treatment. Error bars represent 95% confidence interval, based on n=4 plots per treatment.

Stoy, 2008), standardization across sites is essential to ensure comparability of Tier III data.

For the preliminary results presented here, we gap-filled missing data from each sensor by regression against working sensors then calculated daytime averages for each plot. We assumed negligible differences between sapwood areas of treatments in calculating canopy conductance based on surveys of tree diameter. Such differences would be expected to be minimal at this early stage of the study and to increase in following years.

Early Results

Here we present preliminary results from the first nine months of data collection at the Tier III site in Buckingham County, Virginia, as monthly values of measured sap flux density (J_S) and estimated canopy conductance (G_C) for each treatment (Figure 6.3). While J_S directly represents the water use of trees on a sapwood area basis, G_C represents the integrated stomatal aperture of the leaves per unit ground area and corresponds to the limitation that stomatal regulation of water use imposes on carbon uptake. While J_S declines steadily from summer to winter due to falling temperatures and atmospheric evaporative demand, the lowest G_C values are found in July when the trees regulate their water use most tightly.

At this coarse temporal scale, the differences between treatments are minimal ($p > 0.10$ for all pairwise comparisons, Tukey's Honestly Significant Difference test). However, future analyses will employ hierarchical modeling techniques using a Bayesian state-space framework to quantify differences between half-hourly responses to light, atmospheric water demand, and soil moisture (Ward et al., 2013). The one notable feature about the data presented in Figure 6.3 is the tendency toward higher J_S and G_C in the fertilized treatment relative to the control in the summer months. It is likely that finer scale analyses will reveal a difference between the treatments' responses to environmental conditions underlying the monthly averages.

Fertilization is known to increase the leaf area of loblolly pine at many sites, but because loblolly is evergreen and needles live ~18 months, this difference may take multiple growing seasons to establish (McCarthy et al., 2007). The expected increase in leaf area following fertilization will result in higher J_S and G_C unless trees tighten their regulation of water use in future months. Thus, we expect to see an interaction between the effects of fertilization and throughfall exclusion on J_S and G_C at Tier III sites as the experiment progresses. As the amount of leaf area and the regulation of water both impact the capacity of trees for carbon assimilation, any such interaction would be expected to affect the growth of the trees as well. From the high-resolution data provided by Tier III sensor networks for hundreds of trees, we can make robust estimates of stomatal responses to environmental drivers. These responses represent a critical link between data and regional scale models of productivity, water use, and carbon sequestration, such as Water Supply Stress Index (WaSSI) (see *Regional Carbon Sequestration and Climate Change: It's All about Water*, page 24).

7. The 3-PG Model Produces Accurate Estimates of Loblolly Pine Growth

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Since the second harvest of naturally regenerated stands in the 1920s, productivity of loblolly pine has increased by 700% (Stanturf et al., 2003). These increases in productivity can be attributed to changes in silvicultural management regimes as well as genetic improvement. In the future, in addition to continued improvements in the silvicultural practices and further genetic selection, climate change may also change the productivity of loblolly pine stands (Wertin et al., 2010). For these reasons, a model that can accurately predict plantation productivity and also accommodate changes in environmental conditions and silvicultural treatments will be useful for both scientists and land managers. Physiological Principles Predicting Growth (3-PG) is a simple, process-based model that requires parameterization of relatively few physiological attributes and uses simple and readily available weather and site characteristics to produce predictions of stand growth. 3-PG has already been used with a number of tree species, climates, and site conditions throughout the world. Our long-term goal is to determine whether the 3-PG model can be used as a research tool to evaluate current and potential carbon sequestration in the region and to improve the model so that it will be a useful tool to evaluate management options for loblolly pine plantations.

Our first specific objective was to determine if 3-PG could accurately predict growth of loblolly pine (*Pinus taeda* L.) plantations across a range of sites in the Piedmont and Coastal Plain regions without having to adjust the physiological parameters in the model. We hypothesized that because (a) many physiological attributes of loblolly pine, including rates of net photosynthesis and carbon allocation, tend to be very similar across sites and (b) leaf area is highly responsive to fertility but less so to water and other environmental factors, a single physiological parameter set would be suitable for predicting growth across a range of loblolly pine plantations which differ in soil type and silvicultural treatments. The parameter set was obtained from a combination of published values in the literature and model calibrations developed from a single highly productive stand in the Coastal Plain region in Georgia. The calibrated model was evaluated using observed growth data obtained from seven plantations in Georgia, three in the Coastal Plain, and four in the Piedmont. Differences in potential productivity of each site were accounted for by changing only the value of the fertility rating and the soil type. The data for this evaluation was supplied by the

Our long-term goal is to determine whether the 3-PG model can be used as a research tool to evaluate current and potential carbon sequestration in the region and to improve the model so that it will be a useful tool to evaluate management options for loblolly pine plantations.

University of Georgia Plantation Management Research Cooperative from the sites used in the Consortium for Accelerated Pine Productivity Production Studies (Borders et al., 2004).

The model accurately estimated stem biomass and diameter growth at all sites (Figure 7.1). However, it did not accurately predict stand stocking density in most cases and tended to overestimate volume. Poor prediction of stand stocking can be attributed to density-independent mortality, which the model is unable to predict. The overestimated volume was due to an incorrect estimate of wood density. Despite these discrepancies in measured and modeled stand density and volume, it is our conclusion that, overall, the 3-PG model provided an accurate description of loblolly pine plantation growth and productivity in both the Piedmont and Coastal Plain regions using a single set of physiological parameters. This evaluation is now expanding with the use of growth data collected on a much wider range of sites, environmental conditions, and soil types across the loblolly pine range.

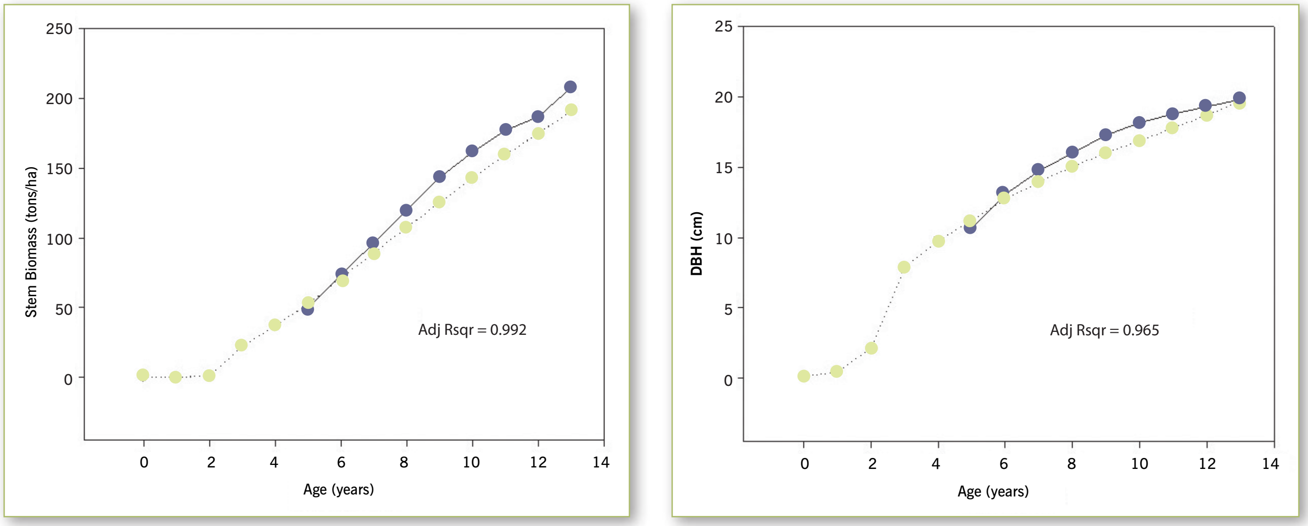

Figure 7.1. An example of the ability of the 3-PG model to predict loblolly pine plantation productivity. Yearly measurements of stem biomass and diameter at breast height (DBH) (blue circles) are compared to stem biomass and DBH predicted by the 3-PG model (yellow circles) for a plantation in the Piedmont region near Athens, Georgia.

8. Predicting Climate Change Effects on Loblolly Pine Productivity: An Evaluation of Various Modeling Approaches

Charles O. Sabatia[1,3] • *Harold E. Burkhart*[2,3]

[1]Postdoctoral Research Associate • [2]University Distinguished Professor • [3]Department of Forest Resources and Environmental Conservation, Virginia Tech

Accurately predicting loblolly pine growth and yield under different future climate scenarios requires stand models that incorporate climate, physiographic, and edaphic (biophysical) variables as predictors. In our research, we compared approaches for incorporating biophysical predictors in empirical growth and yield models for loblolly pine with a focus on height growth and site index.

Data and Methods

The Virginia Tech Forest Modeling Research Cooperative loblolly pine regionwide thinning studies (Figure 8.1) formed the basis of this research. Stand, soils, and climate data were compiled at each study location. Soils data were obtained from the United States Natural Resources Conservation Service Soil Survey Geographic (SSURGO) database using GIS data extraction techniques. Daily climate records for each location for the period 1980 to 2011 were obtained using the Oak Ridge National Laboratories' daily surface weather prediction models. The daily climate data were processed to provide seasonal and annual climate information such as summer precipitation and mean annual temperature. Overall, a total of 24 biophysical variables were available for use in modeling. Variable selection methods, including stepwise regression, factor analysis, and backward elimination in regression trees, were used to identify the most influential biophysical predictors.

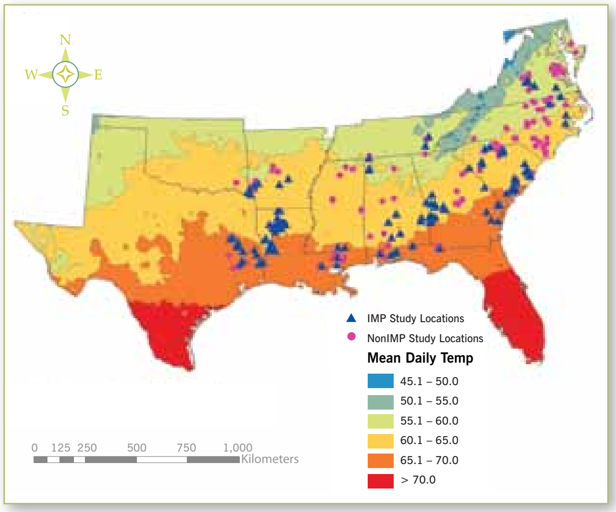

Figure 8.1. Plot locations of the Virginia Tech Forest Modeling Research Cooperative regionwide thinning studies superimposed on a map of the annual mean daily temperature across the study region.

Three approaches of modeling the effect of biophysical variables on loblolly pine growth and yield were investigated: (1) expressing parameters of height growth equations as functions of biophysical variables, (2) applying a nonparametric method (known as regression trees model) to predict site index from biophysical variables, and (3) using a parametric power and exponential function model to predict site index from biophysical predictors identified by factor analysis techniques.

Results

Expressing parameters of height growth equations as functions of biophysical variables did not result in satisfactory height growth models. Models fitted by this approach exhibited illogical parameter estimates for some of the biophysical predictors.

According to the nonparametric regression trees approach, seven biophysical predictors would be sufficient to accurately predict site index of intensively managed (IMP) loblolly pine stands while nine would be required for the non-intensively managed stands (non-IMP) (Figure 8.2). The seven predictors for IMP stands are growing season precipitation frequency, average growing season temperature, maximum January temperature, total summer precipitation, summer dryness index, August (late summer) precipitation, and January-July temperature differential. The nine predictors for non-IMP stands are growing season precipitation, growing season precipitation frequency, annual precipitation, summer precipitation, growing season dryness index, late summer precipitation, summer dryness index, soil depth (to 2 m maximum), and elevation. The resulting regression trees models had relatively high fit indices, 0.8649 and 0.8759 for IMP and non-IMP data respectively. The model mean square errors were 0.98 m and 0.87 m for IMP and non-IMP data respectively. However, the model appeared to overestimate site index for the least productive sites and underestimate it for the most productive ones. The biophysical variables-based models tended to shrink site index estimates towards the mean.

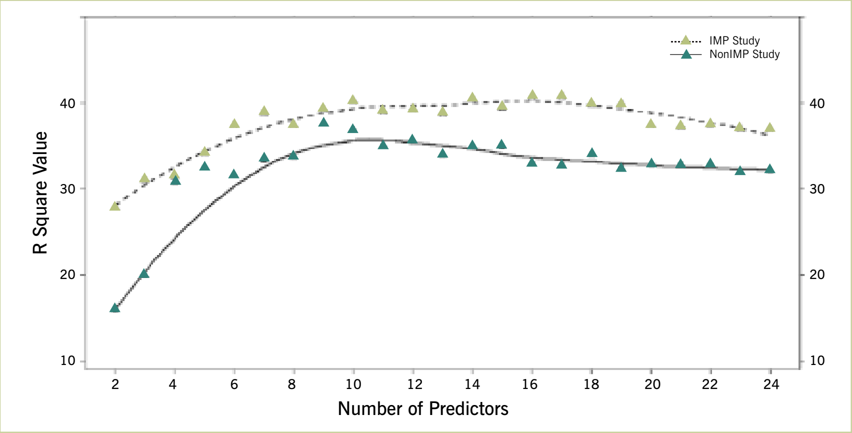

Figure 8.2. Trends in the R^2 value when number of biophysical predictors in the regression trees site index prediction model was increased, starting with the two most influential predictors. The R^2 value no longer changes significantly after seven predictors for the IMP study data and nine for the non-IMP study observations.

A Factor Analysis of the 24 biophysical variables showed that the location-to-location differences in the biophysical factors were due to four underlying factors, which were inferred to be some measure of (1) the quantity of heat, (2) precipitation, (3) drought intensity, and (4) soil water holding capacity. Annual growing-degree days, annual precipitation, growing season dryness index, and soil available water holding capacity were identified as the best representatives of the underlying factors. Incorporating these variables into a combined power exponential parametric equation resulted in a site index prediction model with fit index of 0.1805 for IMP data and 0.2331 for non-IMP data. Model root mean square error was 2.65m for IMP data and 2.11 for non-IMP data. The model parameter estimates were biologically logical in as far as the expected trends of the four underlying factors are concerned. However, the biophysical variables based-site-index model also exhibited shrinkage to the mean effect.

Conclusion

The nonparametric approach resulted in a closer fit to the data used for predicting forest productivity from biophysical variables. It is, however, difficult to provide a biological interpretation to the model. In addition, the model does not provide an explicit mathematical equation that could be more easily applied. The parametric approach resulted in a model with a poorer fit to the data but one that is biologically logical and contains an explicit mathematical function that can be applied. Both approaches for predicting site index of planted loblolly pine from biophysical factors showed similar trends in the residuals, with over predictions for low quality sites and under predications for high quality sites.

Piecing Together the Climate Data Puzzle

***Heather Dinon Aldridge*[1,3] • *Ryan Boyles*[2,3]** *[1]Applied Climatologist • [2]Director and State Climatologist • [3]State Climate Office of North Carolina*

There are vast amounts of climate datasets available online from various agencies, and although at first glance the datasets appear to be comparable, there are actually significant differences. Some data represent historical conditions over the past 50 or 100 years while other datasets aim to capture future conditions over the next 50 to 100 years. Other differences are due to factors such as the following:

- Dataset type, either point-based (e.g., weather stations) or gridded (e.g., radar data)
- Time scale of the observations (e.g., hourly, daily, monthly, or annual)
- Spatial resolution of gridded data (e.g., 5 km, 50 km, or 500 km)
- Period of record varying station by station with point data and dataset by dataset with gridded data
- Ability of global climate models to simulate certain features (e.g., some are better than others at capturing the seasonal cycle of temperature)

So which climate datasets have been recommended for PINEMAP? We provided historical and future climate data to the silviculture and ecophysiology and modeling teams to help them estimate potential productivity of loblolly pine in the Southeast United States. The following historical datasets were suggested:

- Point-based weather data (http://nc-climate.ncsu.edu/map/)
- Gridded Parameter-elevation Regressions on Independent Slopes Model (PRISM) data (http://www.prism.oregonstate.edu/)
- Gridded Idaho Experimental Program to Stimulate Competitive Research (EPSCoR) office dataset (combines PRISM and NASA North American Land Data Assimilation System) (http://webpages.uidaho.edu/jabatzoglou/DATA/griddedmetdata/METDATA/Gridded_Meteorological_Data.html)

The recommended dataset for future climate scenarios is the North American Regional Climate Change Assessment Program (NARCCAP) (http://www.narccap.ucar.edu/index.html).

These datasets were downloaded and formatted by the PINEMAP data management and modeling teams, extracted for the PINEMAP study region and for each location in the monitoring network, and made available to all PINEMAP researchers on a central website repository. This standardization of input data for the many PINEMAP modeling efforts is one example of the efforts in our project to integrate efforts across the region by building research infrastructure and standardizing methods.

9. Regional Remote Sensing to Estimate Forest Biophysical Parameters Including Thinning, Growth, and Stand-replacing Disturbances

Evan B. Brooks[1,4] • ***Valerie A. Thomas***[2,5] • ***Randolph H. Wynne***[3,5]

[1]*Ph.D. student* • [2]*Assistant Professor* • [3]*Professor* • [4]*Department of Statistics, Virginia Tech* • [5]*Department of Forest Resources and Environmental Conservation, Virginia Tech*

One of the aims of PINEMAP is to use models to assess alternative methods for managing forests on a broad scale. Many of these models can be driven by remote sensing data and products. Remote sensing data are typically used to ramp up the scale of models, taking isolated points in the field and producing regional maps conveying the larger pattern. In particular, Landsat data are ideally suited to this purpose, as they are free to download, cover over four decades of time for a sizable part of the Earth's surface, and have a sufficiently high resolution (30 m to a side) to show forest stand details. As a result, improvements in the information gleaned from Landsat data result in improvements to the models they drive. Innovations in Landsat data analysis can lead to the development of more effective models. Three such improvements and innovations are described here.

For a given location, one can obtain images at 16-day intervals. Depending on conditions at the time of sensing, these images may not provide relevant information for purposes of parameter estimation. Thus, a necessary first step is to fill out the Landsat time series. We did this with harmonic regression, producing curves that approximate conditions during the missing parts of the year (Figure 9.1). This works on a per-pixel basis, with each pixel treated independently of the others. By using a vegetation index as input data, the resulting harmonic curves reflected the phenology of the underlying land cover. Because harmonic regression is characterized by a set of coefficients, we could store only the coefficients for later use, generating the approximation easily as needed. This greatly reduced the storage requirements for producing a temporally detailed dataset, as we stored as few as 3 images to represent a year. We have used these curves to derive parameters such as start of season, minimum and maximum values, senescence, and more. Such variables could be grouped as parameter maps for model input.

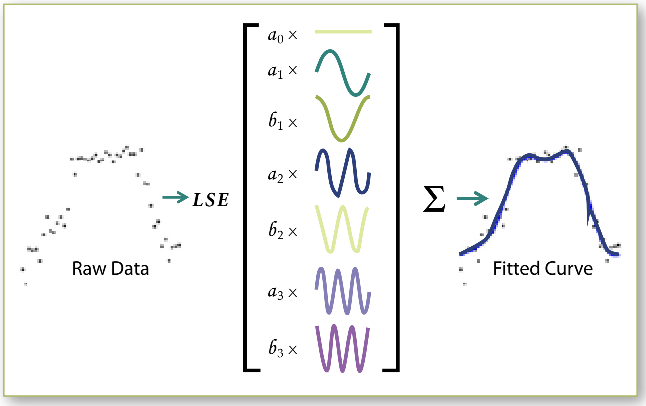

Figure 9.1. Concept of harmonic regression used to obtain continuous time series of information from discrete Landsat images.

These curves can be used to detect changes to the land surface at a very sensitive level, such as partial thinning of a stand. Since the residuals from the curves represent the manner in which our observations differ from the curve's model, subsequent patterns in the residuals can indicate changes to the original land cover. We tested this on a single Landsat scene on a timeframe from 2005 to 2011 using aerial photographs for most of the scene from 2009 and 2011 as validation data. Using the data from 2005 through 2008 as a training period, we generated harmonic curves for each pixel. We analyzed the 2009 to 2011 residuals from these curves with quality control charts. From the results, we were able to detect shifts in both the type and quality of land cover across the scene. We tested our method against known regions of thinning and showed it was capable of detecting not only subtle thins but also regions of regrowth (Figure 9.2). While being able to detect subtle changes with 30 m pixels is noteworthy, the most useful feature of the method is

While being able to detect subtle changes with 30 m pixels is noteworthy, the most useful feature of the method is that it easily incorporates new images as they arrive, without the need for significant reprocessing of the older data.

that it easily incorporates new images as they arrive, without the need for significant reprocessing of the older data. With such a tool in hand, one could, using only free Landsat data, monitor large regions for both growth and loss and be able to watch for spatial patterns in those changes, employing the resultant change maps as model inputs to update prior assumptions in models.

Another innovation with Landsat data is developing a proxy for site index. For a newly planted stand of a given species, conditions at the site (e.g., soil, hydrology, and topography) have a strong effect on that stand's growth rate. Typically, this is amalgamated into the location-based parameter of site index. However, Landsat data may be used to cheaply obtain a similar parameter over the region. By recording vegetation index data from a measured disturbance in an area over a few years, we can summarize the growth pattern of the area (Figure 9.3). By doing this for each pixel in a scene, we can group similar areas via cluster analysis. The resulting growth-based class map may be taken as a proxy of site index and used for model input in estimating parameters.

We will continue refining these methods and testing them across different parts of the region to ensure their robustness and utility. In particular, we will be focusing on developing rasters that can be used as model inputs, based on the techniques described above.

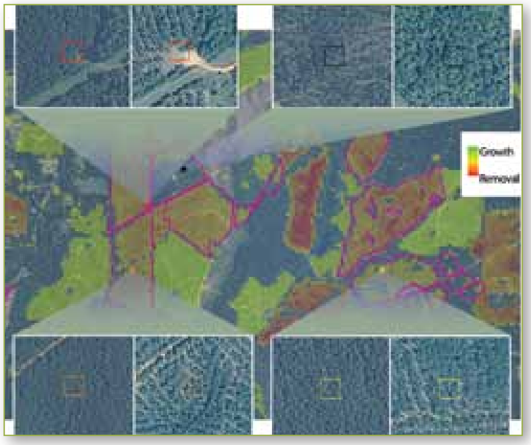

Figure 9.2 Control-chart based disturbances. From upper right, clockwise, insets show examples of negligible change (in this case, regrowth after an early thinning in the test period), light thinning, heavy thinning, and clear-cutting. The boxes are scaled to the size of Landsat pixels. Violet polygons are stands with known thinning histories from company records.

Figure 9.3 In this image, red shows change from disturbance over the 3 years following the capture of this image, and green/blue shows change in the 3 years after that. Disturbances were measured as the sharpest decrease in a running annual mean over a period of 27 years. Red regions are those that continued to decline, brown regions were not disturbed at all, blue regions grew back after an initial pause, and white regions grew back more rapidly.

10. Regional Carbon Sequestration and Climate Change: It's All about Water

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[1]Research Hydrologist • [2]Postdoctoral Research Hydrologist • [3]Ecologist/Team Leader • [4]Postdoctoral Research Associate • [5]Research Assistant Professor
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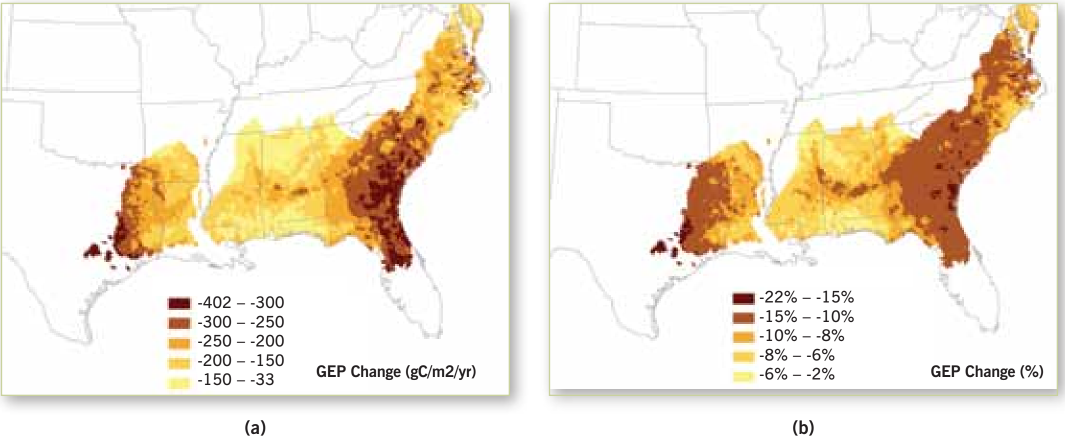
Forests need a lot of water to produce the goods (e.g., timber) and services (e.g., carbon sequestration and climate moderation) that benefit humans. Forests grow naturally in water-rich regions where precipitation is abundant or where groundwater is available, such as riparian areas in arid regions. For example, loblolly pine (*Pinus taeda* L.) forests are found in areas where mean annual precipitation normally exceeds 1,000 mm/yr (40 inches/yr). However, under climate change scenarios, water availability is projected to decrease and become more variable in the future, potentially impacting loblolly pine productivity. Extreme weather events such as heat waves and prolonged droughts are of particular concern for southern forests, which are not as well adapted to extreme soil water stress as their western counterparts.

Studies have long documented that southern pine productivity is highly dependent on leaf area, light, and nutrient availability, and southern forests are the most productive in the nation due to plentiful rainfall and abundant sunlight. Water stress in some parts of the South occurs only periodically; therefore, water is a minor environmental control to southern pine productivity. However, projected drought frequency, duration, and severity are on the rise compared to the past decades. Thus, there is a possibility that water stress may become the top limiting factor for pine forests, especially in the western edge of the native range of loblolly pine where climate is in transition from humid to arid.

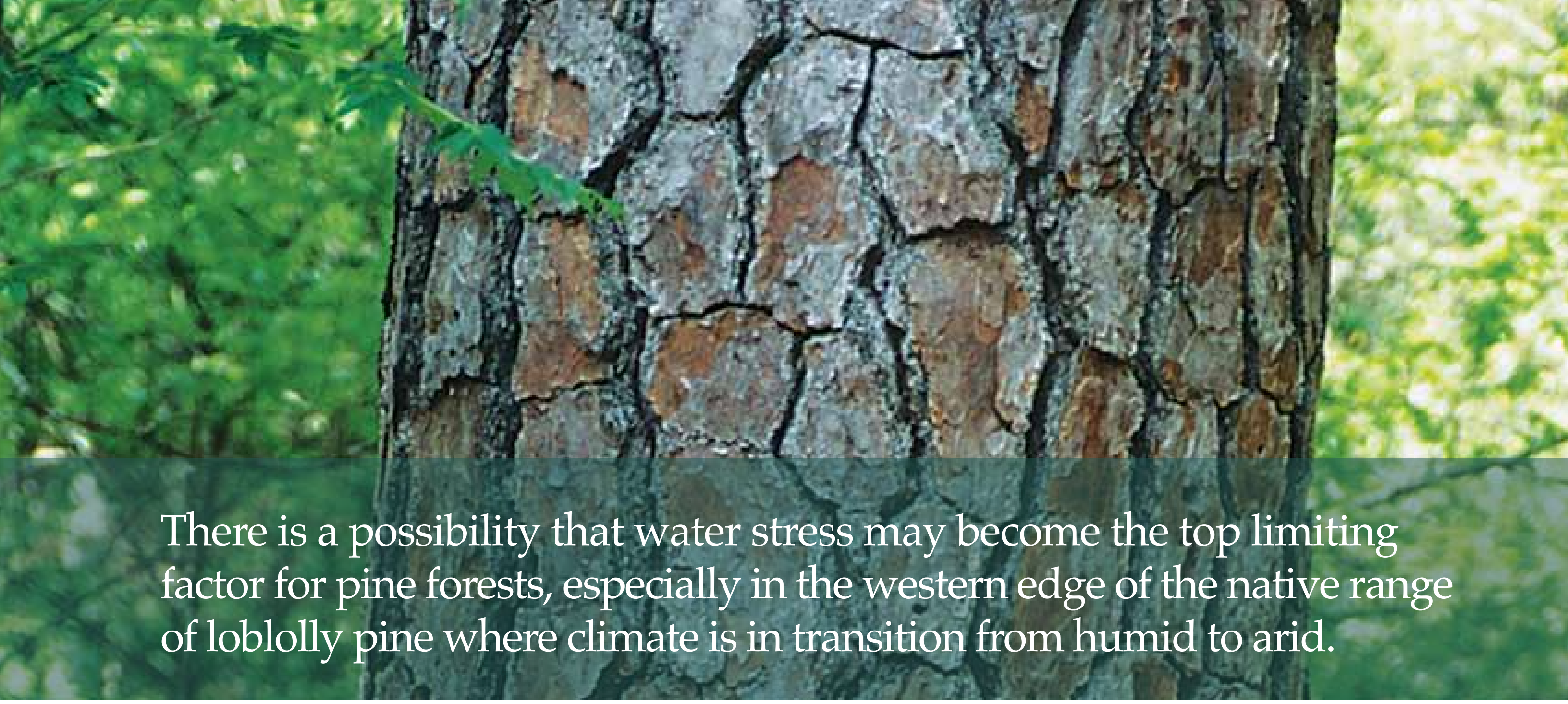
To understand the sensitivity of forest productivity to droughts, precipitation manipulation experiments and monitoring have been implemented at four Tier III sites across a climatic gradient in the loblolly pine range. These experiments provide a basis for understanding the expected response of these forests to lower precipitation. This research is limited to short-term studies on small sites and may not fully capture the spatial variability of climate, soil, and nutrient conditions across the entire loblolly pine domain. Regional scale models with interlinked carbon and water cycles have the capacity to simulate the sensitivity of forest productivity and water yield to multiple stressors over a large geographic region. Most importantly, a model can predict what will happen in the future to forests under different climate change and forest management scenarios.



(a)

(b)

Figure 10.1. WaSSI model simulated drought (30% rainfall reduction year round) impacts on annual gross ecosystem productivity (GEP) of watersheds covered by mid-rotation loblolly pine plantations (age 17) (a) absolute change and (b) relative change compared to historic climate.



There is a possibility that water stress may become the top limiting factor for pine forests, especially in the western edge of the native range of loblolly pine where climate is in transition from humid to arid.

Water-Centric Model : Linking Water and Carbon Cycles

We used the Water Supply Stress Index (WaSSI) model to identify "hot spot" watersheds that are most vulnerable to droughts in the loblolly pine range. At the spatial scale of a watershed, WaSSI simulates monthly evapotranspiration, stream flow, and carbon balances (i.e., gross ecosystem productivity [GEP], ecosystem respiration, and ecosystem net carbon exchange). The basic assumption of the WaSSI model is that water availability is the dominant driver of ecosystem productivity. Forest water use is driven by soil water availability, energy availability, and leaf area. Forest productivity is directly linked to evapotranspiration (ET) through the Water Use Efficiency (WUE) parameter that varies with stand age.

A series of hypothetical climate scenarios have been developed to study how droughts may affect GEP and water yield (Q) across the 9,283 watersheds in the study region. We modeled monthly forest water and carbon balances using 20 years (1990 to 2009) of historic climate data (PRISM database). We examined two levels of hypothetical precipitation reduction (15% and 30% reduction below latest 20 year means) and two stand ages (7 and 17 years) to represent climate impacts on GEP and Q for two stages of forest development.

Findings

Our simulations indicate that when precipitation is reduced by 30%, loblolly pine forest productivity (Figure 10.1) and water yield (Figure 10.2) is dramatically reduced compared to current conditions. The reduction can be as high as 400 g C/m^2/yr or 22% reduction from baseline (Regional mean= 200 ± 145 gC/m^2/yr or 10 ± 7%) and water yield is expected to decrease even more, 320 mm/yr or 65% reduction from baseline on average. Such a reduction is likely to transform many small perennial streams in certain forested watersheds in the drier regions to ephemeral water bodies (i.e., ceasing to flow during certain times of the year). A sensitivity test shows that a moderate reduction (15%) of rainfall may result in only marginal reduction in GEP (3.4± 6%), but still significant reduction in water yield, with regional average of 172 mm/yr or 35% reduction from current baseline. The preliminary results suggest that the effect of the two drought scenarios on the productivity of young stands (7 years old in our simulations) would be similar in magnitude for late-rotation stands (17 years old). Such simulations provide a predictive framework that can readily assimilate data from other PINEMAP research areas, such as transpiration and growth estimates from the Tier III sites.

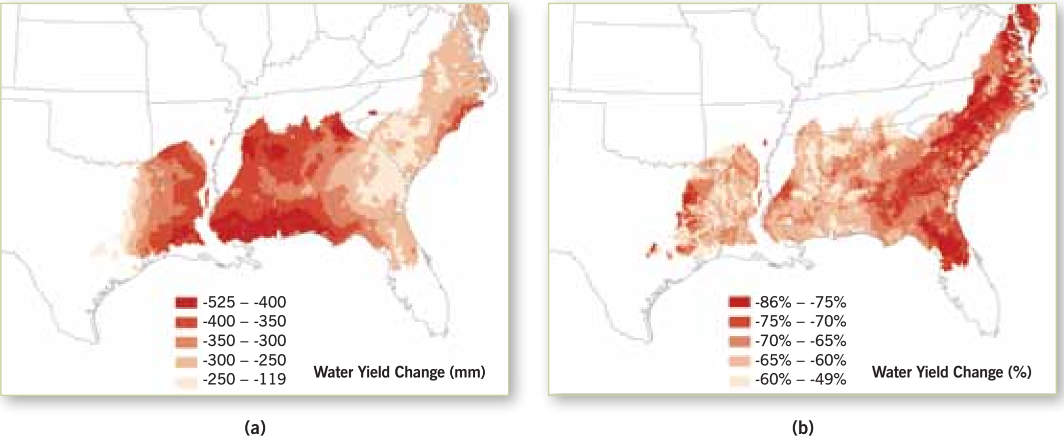


Figure 10.2. WaSSI model simulated drought (30% rainfall reduction year round) impacts on annual water yield of watersheds covered by mid-rotation loblolly pine plantations (age 17) (a) absolute change and (b) relative change compared to historic climate.

11. PINEMAP + PineRefSeq = Future Forests

Konstantin Krutovsky[1,7] • ***Tom Byram*** [2,8] • ***Ross Whetten***[3,9] • ***Nick Wheeler***[4,10]
David Neale[1,11] • ***Mengmeng Lu***[5,12] • ***Tomasz Koralewski***[6,12] • ***Carol Loopstra***[3,12]

[1]Professor • [2]Assistant Professor • [3]Associate Professor • [4]Affiliate Faculty • [5]Ph.D. student • [6]Postdoctoral Research Associate • [7]Department of Forest Genetics and Forest Tree Breeding, George-August-University of Göttingen; Department of Ecosystem Science and Management, Texas A&M University• [8]Department of Ecosystem Science and Management, Texas A&M University; Texas A&M Forest Service • [9]Department of Forestry and Environmental Resources, North Carolina State University • [10]College of Forestry, Oregon State University • [11]Department of Plant Sciences, University of California at Davis • [12]Department of Ecosystem Science and Management, Texas A&M University

The equation P = G + E + GxE describes the interactive effects of genotype (G) and environment (E) on an observed phenotype (P) and is one of the most powerful relationships in all of modern biology. Two USDA National Institute of Food and Agriculture funded projects are now working to elucidate the components of this model in unprecedented detail. The Pine Reference Sequences project (PineRefSeq) is attempting to develop the first complete genome sequence for loblolly pine (G) while PINEMAP investigates how the environment (E) interacts with individual trees and stands (GxE) to form the forest of the future (P).

The goal of the PineRefSeq project is to provide a complete genome sequence for an individual loblolly pine, which will enable future researchers to discover the nucleotide diversity in genes, promoter regions, and transcription factors. The ultimate aim is to provide an annotated list of genes describing function; regulation; and the place they occupy in biochemical pathways critical to growth, fitness, and adaptability. PINEMAP approaches the problem through the other components of the equation by examining how the environment influences phenotypes. Genetic variation is the critical point at which the two projects overlap, and the source of considerable project synergism.

Sequencing the loblolly pine (*Pinus taeda* L.) genome is far from trivial. At seven times the size of the human genome, it is one of the largest sequencing projects ever to be attempted (Figure 11.1). To further complicate matters, the pine genome is literally awash in repetitive DNA: gene families regulated in tissue specific ways, nonfunctional pseudogenes, highly repetitive structural sequences, and possibly millions of relics of genetic reorganization in the form of mobile genetic elements, such as transposons and retrotransposons (DNA sequences that can change their position within the genome). Despite these difficulties, the project has already had considerable success and recently released a draft sequence to the research community (see http://www.nifa.usda.gov/newsroom/news/2013news/01111_loblolly_genome.html).

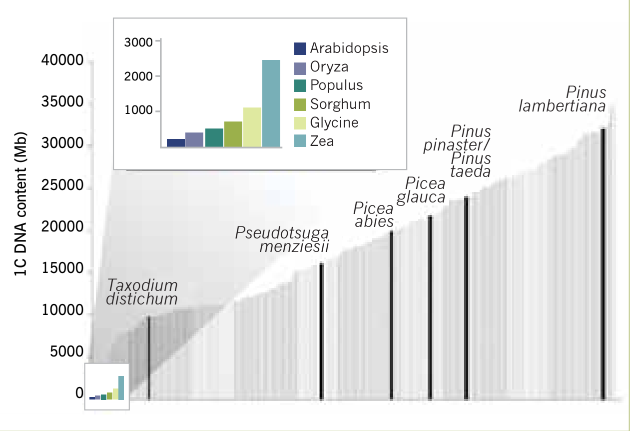


Figure 11.1. Relative genome size of several conifers compared to several species previously sequenced. Image credit: Modified from Daniel Peterson, Mississippi State University.

Meanwhile, PINEMAP is collecting measurements on phenotypes, environments, and genotypes with the goal of predicting the performance of future forests. PINEMAP researchers already are using the PineRefSeq sequence to

The way these two projects work together will be an iterative process, as PineRefSeq generates new sequences and proposes new putative functions and PINEMAP measures additional traits in novel environments.

verify and design platforms to acquire the most meaningful genotypes of the trees they are studying. Initially, this takes the form of (1) verifying genetic variation seen in existing databases from other projects, (2) designing platforms that will efficiently assay this variation, and (3) ensuring that all relevant parts of the genome are represented. The eventual goal is to identify functional differences, either in the structure of alternative forms (alleles) of important genes or in their regulation. The extensive database of interacting phenotypes and genotypes generated by the PINEMAP project will inform and validate the annotation process, including the assignment of function of the gene sequences developed by the PineRefSeq project.

Both the PineRefSeq and PINEMAP projects use the most modern genomic methods and similar next-generation sequencing (NGS) techniques. As a result, much of the sequence data generated by both projects will serve double duty. As an example, the first draft genome assembly (version 0.8 scaffolds generated by PineRefSeq) greatly helped the Texas A&M University genetics team map and cluster DNA sequence fragments consisting of several billion short nucleotide sequences generated in the PINEMAP project. These sequences were obtained from genomic DNA enriched for coding regions after hybridization with 647,634 oligonucleotide probes designed from 35,550 unigenes. By mapping the sequences to the draft genome assembly, from about 42,000 to 120,000 single nucleotide polymorphisms (SNPs) per sample were identified. These SNPs will be used further as highly informative genetic markers to study the association of genetic variation with the variation of adaptive traits and environmental variables. The PINEMAP project greatly benefits from the publicly shared Dendrome and TreeGenes databases that provide pine tree genomics data and bioinformatics tools to the forest genomics community currently maintained by the University of California Davis group of the PineRefSeq team.

In turn, data generated by the PINEMAP project can help improve and verify the PineRefSeq genome. Some of the SNPs or unigenes generated by PINEMAP have known locations on a high density linkage map and can be used as anchors for directing genome assembly in PineRefSeq project. Preliminary analysis indicates that some of the additional sequence fragments obtained by the Texas A&M University genetic team may span gaps between disjoint contigs (contiguous consensus DNA sequences assembled from shorter overlapping DNA segments) and scaffolds (ordered contigs separated by gaps where the exact DNA sequence is unknown) apparent in the early version 0.8 assembly. This will make an additional tool available to the PineRefSeq team to connect loose ends and improve the finished assembly. It may also be possible through a joint analysis of PineRefSeq and PINEMAP sequence data to infer important information on gene structure (e.g., exon and intron length and their junctions), something that neither project could easily do alone.

The way these two projects work together will be an iterative process, as PineRefSeq generates new sequences and proposes new putative functions and PINEMAP measures additional traits in novel environments. The outcome of this synergistic effort will be a better understood, more resilient, and more productive future forest.

12. Using Historical Progeny Tests to Optimize Pine Breeding and Deployment Strategies

Tom Byram[1,6] • *Tomasz Koralewski*[2,7] • *Gary Peter*[3,8] • *Jianxing Zhang*[4,8] • *Fikret Isik*[5,9] • *Alfredo Farjat*[4,9]

[1]*Assistant Professor* • [2]*Postdoctoral Research Associate* • [3]*Professor* • [4]*Ph.D. student* • [5]*Associate Professor* • [6]*Department of Ecosystem Science and Management, Texas A&M University; Texas A&M Forest Service* • [7]*Department of Ecosystem Science and Management, Texas A&M University*
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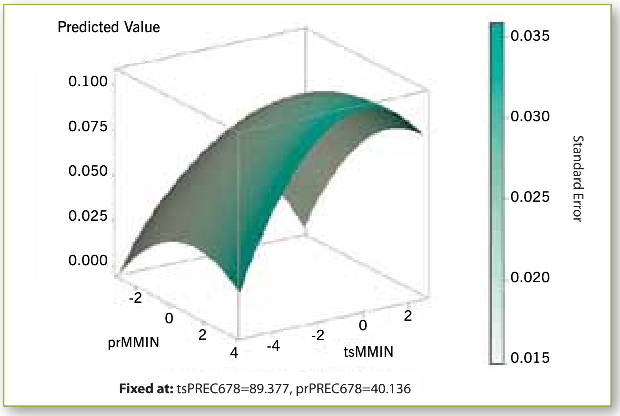
Foresters have long observed that populations of trees vary genetically across the landscape, showing signs of adaptation to local variation in soils and climate. Tree improvement specialists, seeking to take advantage of this adaptation, attempted to optimize assignments of seed sources (provenances) to planting zones (Wakeley, 1953). Early guidelines presumed that local seed would be best, but foresters quickly recognized that this was not always true. For example, southern pines expanded northward from the southern region they occupied during the last ice age, and their migration and adaptation sometimes lagged behind changing climates and expanding ranges. Trees also tend to be conservative in their growth habits, developing evolutionary survival strategies to respond to extremes in temperature and drought encountered over eons rather than to current conditions. Humans further complicate this picture by bringing their economic needs to bear and by changing the growing conditions through improved silviculture. All of these factors are important considerations as we attempt to understand how genetic variation can impact southern pine adaptation and mitigation in a changing climate.



Fixed at: tsPREC678=89.377, prPREC678=40.136

Figure 12.1. This graph shows 15-year volume performance by provenance from seed source trials located in the Western Gulf region of the southeastern United States. Seed sources are graphed from colder to warmer provenances for minimum winter temperature (prMMIN) against test sites graphed from colder to warmer minimum winter temperature (tsMMIN). Optimal performance follows the ridge indicating that local sources are best on the southern sites and more southern sources perform better when moved north up to changes of ~2° to 4° C and beyond. At more northern locations (i.e., tsMNIN = –4°C), performance of seeds from too far south declines.

To better understand the impact of seed movement, all of the southern tree improvement programs have established "common garden studies" with families from multiple seed sources established in plantings spanning a range of geographic conditions. The PINEMAP genetics team aims to use growth responses to historical weather patterns to predict how trees from different seed sources may grow under future climate conditions. Specifically, the goal is to provide landowners with insights about how their choices of seedlings may impact future productivity and give them the tools to mitigate environmental risks. The three southeastern tree improvement cooperatives are each working on separate data sets, but the approaches are similar. Weather at multiple test sites is used as a surrogate for a range of possible climates, while climate associated with seed sources reflects the conditions under which the trees evolved and for which they are expected to show local adaptation. Weather at the test site is then combined with climate at the seed source site to model and explain observed growth and survival performance in different deployment zones. Once optimal seed movement guidelines are established under current conditions, these models can be combined with future climate projections to predict performance under a range of possible climate patterns.

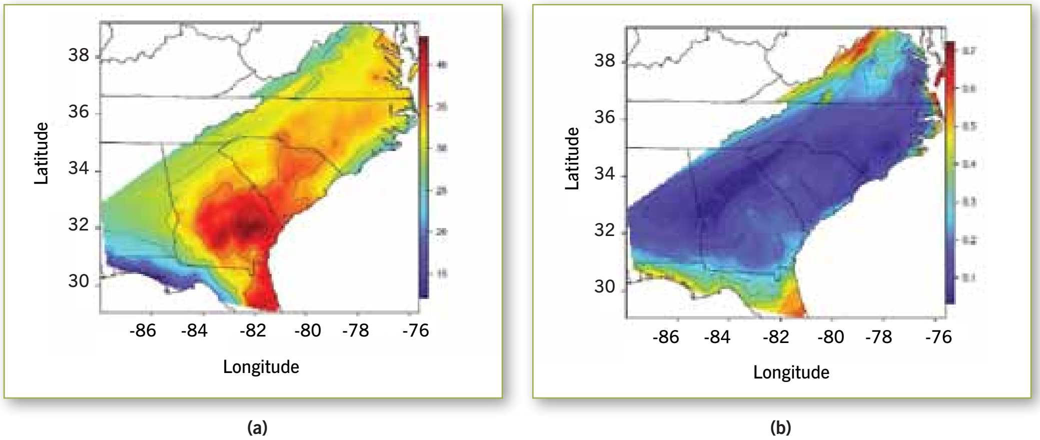
In the southeastern United States, climate varies gradually across the landscape from the coast to the interior highlands, from north to south and from east to west. The more maritime climates tend to have milder winters and wetter, more humid growing seasons. The more northern piedmont areas tend to have colder winters and drier summers. Loblolly pine is more or less contiguous across this region with few barriers to gene flow. Under these conditions, one would expect to see the evolution of gradual changes in adaptability with few, if any, populations exhibiting major differences from their nearest neighbors. Indeed, this is the case. The most frequently observed patterns in previous work (Schmidtling, 1994, 2001), as well as in current studies, are those that show variation with latitude or, more specifically, with weather variables that are often correlated with changes in latitude. While many factors probably affect performance of nonlocal seed sources

The implication is that sizeable gains in future loblolly pine productivity can be made through the application of better silvicultural methods, targeted seedling deployment supported by continued breeding and progeny testing, and the integration of the two efforts—exactly the goal of the PINEMAP project.

in complex ways, one of the most important is minimum winter temperature. Previous seed movement guidelines that recommended moving seed sources that evolved where winters were warmer to more continental environments seem to be validated. These trees have less conservative growth habits and will grow faster and be more productive than the local material. Moved too far north, however, growth and survival may be challenged. The old rule of thumb, which calls for limiting movement of southern pine to areas experiencing no more than a 5° F decrease in winter minimum temperatures, seems to be confirmed (Figure 12.1). Where this zone will be in the future depends on future warming trends and is likely to be even farther north than it is today.

Another weather factor with distinct geographic trends is precipitation. This is evident in both seasonal averages and in year-to-year fluctuations and is likely to be especially important on the western edge of the loblolly pine range where low rainfall is generally considered to be largely responsible for the species' limits. While summer precipitation certainly plays a major role in determining site productivity, it is less clear how much effect it has on determining seed source adaptability. Some of the reasons may be related to study design and the difficulties inherent in using progeny tests to study climate change. One challenge is that each tree improvement cooperative is working with a subset of the loblolly pine population, and none of the common garden trials have a range-wide sampling of seed sources. Perhaps a more significant problem is that all of the current test sites used for modeling were planted within the range of conditions generally recognized as suitable for supporting productive stands. Furthermore, early growth and productivity as measured in these tests does not necessarily reflect long term adaptability.

These modeling efforts provide robust support for current and future seed deployment guidelines at the provenance level. For example, a preliminary prediction model for height growth of loblolly pine based on historical progeny test data and climatic variables can be used to develop deployment decisions to mitigate climate change for plantation forestry (Figure 12.2). These modeling efforts also point out the limitations of this simplified approach to predicting productivity. By using only climate variables as input, the impacts of site specific conditions such as soil quality and silvicultural practices that contribute substantially to forest productivity are ignored. Likewise, using only the climate at the seed source to represent a common evolutionary background fails to factor in gains that can be made from taking advantage of the considerable tree-to-tree genetic variation. The implication is that sizeable gains in future loblolly pine productivity can be made through the application of better silvicultural methods, targeted seedling deployment supported by continued breeding and progeny testing, and the integration of the two efforts—exactly the goal of the PINEMAP project.



(a)

(b)

Figure 12.2. (a) Ordinary least squares (OLS) model predictions for height (HT) at age 8 years using loblolly pine local seeds for an hypothetical future scenario with 5% decrease in precipitation, 2% increase in maximum temperature, and 2 degree increase in minimum temperatures. (b) Standard error of OLS predictions of tree height.

13. Comparing Genotyping Technologies for Efficiency and Cost-effectiveness

Ross Whetten[1,4] • Konstantin Krutovsky[2,5] • Jason Holliday[3,6]

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One of the objectives of the genetics team in the initial phase of the PINEMAP project is to compare different methods of obtaining molecular marker genotypes for hundreds to thousands of individual trees (Figure 13.1). These markers will then be analyzed, together with phenotypic data and breeding records from the cooperative breeding programs, to test the hypothesis that genetic variation for resilience to climate variation exists in southern pine breeding programs. Previous results suggest that many trees in the breeding program show good adaptability across a range of site conditions. However, confirmation and extension of those results will be important in guiding the efforts of pine breeding programs in the southeastern United States to mitigate the risk that climate change will have dramatic impacts on pine plantation productivity.

Two general methods for detecting genetic variation have been compared. One method, hybrid-capture sequencing, uses synthetic "bait" sequences to capture fragments of genomic DNA that correspond to genes of interest for sequencing. This approach requires a significant investment to synthesize the bait molecules and, therefore, has a higher cost per individual sample analyzed, but is expected to yield more information about genetic variation in expressed genes. The other method is restriction-enzyme-based, and uses the fact that genes tend to have lower levels of DNA methylation than repetitive elements or non-expressed DNA sequences. This tendency can be used to enrich for sequences in or near genes, without requiring custom synthesis of DNA. This method has a much lower cost per individual at present, but may yield information that is less narrowly focused on the coding sequences of expressed genes. Pilot experiments have been conducted for both methods: hybrid-capture at Texas A&M University (under the supervision of Konstantin Krutovsky) and restriction-enzyme-based methods at North Carolina State University (Ross Whetten) and Virginia Tech (Jason Holliday).

The hybrid-capture used a pool of almost 647,634 custom-synthesized oligonucleotide hybridization probes ("bait" sequences) to capture DNA fragments of interest and resulted in detection of 42,000 to 120,000 single-nucleotide polymorphisms (SNPs) per sample. The "bait" sequences were designed based on DNA sequences of about 35,550 putative genes identified by previous projects. The frequency of SNPs discovered is about one SNP per 340 base pairs (bp) of DNA sequence, which is consistent with previous reports of genetic variation in loblolly pine (*Pinus taeda* L.).

It seems likely that hybrid-capture methods will be better suited to experiments focused on variation in expressed genes, while the restriction-enzyme-based method will be better suited to low-cost, high-throughput analysis of genome-wide variation.

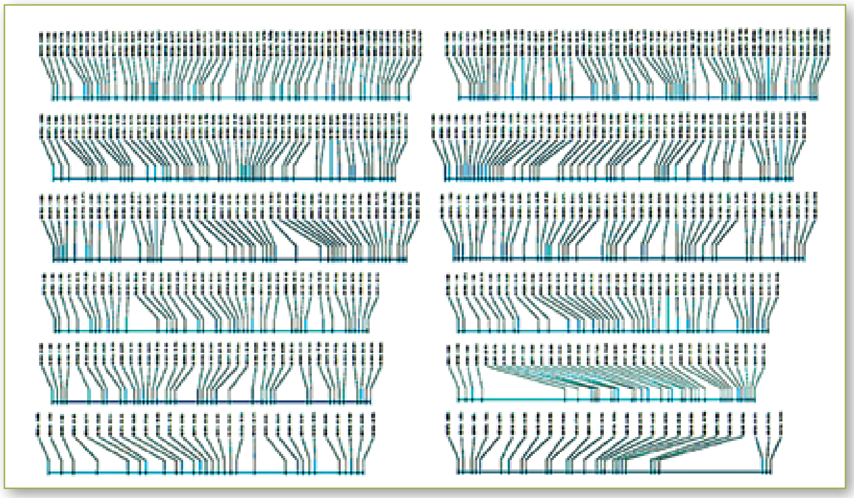

Figure 13.1. This image shows a preliminary high-density genetic linkage map of single nucleotide polymorphism (SNP) markers, with 12 groups that presumably correspond to the 12 loblolly pine chromosomes.

The North Carolina State experiment used DNA samples from a parent tree and 90 offspring of that parent, to allow testing the value of observed DNA sequence variants as genetic markers, and the Virginia Tech experiment used DNA samples of the same parent tree and 7 offspring. The methods used in these two experiments were slightly different; one used two restriction enzymes to fragment DNA, while the other used a single restriction enzyme combined with random breakage of DNA molecules. The two-enzyme method gave better results, so that will be the approach used in future experiments of this type.

One key question for application of these genotyping technologies will be whether a single technology is suited for all the experiments envisioned as part of the PINEMAP genetics component, or if different technologies will be better for different experiments. The cost difference between the hybrid-capture and the restriction-enzyme-based methods is significant at this point, although further optimization of the methods used may reduce that difference in the next year. It seems likely that hybrid-capture methods will be better suited to experiments focused on variation in expressed genes, while the restriction-enzyme-based method will be better suited to low-cost, high-throughput analysis of genome-wide variation.

In summary, preliminary results comparing genotyping technologies show that cost-effective high-throughput genotyping of pine breeding populations is feasible at a cost of about $30 per individual tree for the restriction-enzyme-based methods. Hybrid-capture sequencing may provide more information about coding sequences of expressed genes, which could be an important asset for detecting genetic variation that underlies phenotypic variation in adaptive traits in loblolly pine. The PINEMAP project includes several different genetics experiments based on different populations, and both the restriction-enzyme-based and hybrid-capture sequencing methods are likely to find application in achieving the project objectives.

14. The Impact of Forest Biomass-based Bioenergy Development on Climate Change Mitigation Opportunities

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Pulpwood is increasingly being used for wood pellet production in the United States (U.S.). This trend is expected to continue in the future, as international, federal, and state governments are promoting policies that encourage use of forest biomass for production of energy products including electricity. Diversion of pulpwood for bioenergy development will affect net carbon sequestered in wood products and wood and paper present in landfills but will bring additional carbon savings in the form of avoided carbon emissions due to substitution of carbon intensive grid electricity. This study analyzes changes in net carbon sequestered in wood products and wood present in landfills due to the use of pulpwood and logging residues for electricity generation relative to their current usage. We incorporate the effects of avoided fossil fuel carbon emissions to better ascertain the overall carbon savings associated with the utilization of pulpwood for bioenergy development. This analysis focuses on the carbon implications of a shift in pulpwood utilization and does not consider the economic, wood supply, or policy ramifications of such a change.

Methods

The unit of analysis is one hectare (ha) of slash pine *(Pinus elliottii)* plantation located in the southern U.S. with harvest age varying from 6 to 50 years. We simulated carbon dynamics for 300 years starting from the first harvest year for each harvest age. We performed life-cycle assessments to estimate total carbon savings for four cases (Table 14.1) under two scenarios of forest management for biomass production (intensive and non-intensive). All carbon flows were considered starting with forest management and continuing through decay of wood and paper products in landfills including net carbon emissions avoided due to grid electricity substitution. Carbon emissions related to plantation management were allocated to different timber products based on their mass percentage at a given harvest age. An assumption was made that wood waste produced while manufacturing a given wood product would be consumed within the facility itself for heating needs. Non biogenic carbon emissions resulting from burning of wood waste at manufacturing facilities, wood pellets at power plants, and logging residues in forest fields were also considered. Exponential decay functions were used to model carbon present in wood products and carbon emissions from landfills. Figure 14.1 shows the systemic boundary used for the ENE-LR case, and appropriate changes were made to system boundaries while modeling other selected cases.

Case name	Sawtimber	Chip-n-saw	Pulpwood	Logging residues
LEFT-LR	Lumber	OSB	Paper	Left on the ground
BURN-LR	Lumber	OSB	Paper	Burn on the ground
ENE-LR	Lumber	OSB	Paper	Electricity generation
ENE-LR&PW	Lumber	OSB	Electricity generation	Electricity generation

Table 14.1. Cases for quantifying carbon sequestered in long-term wood products and wood and paper present in landfills.

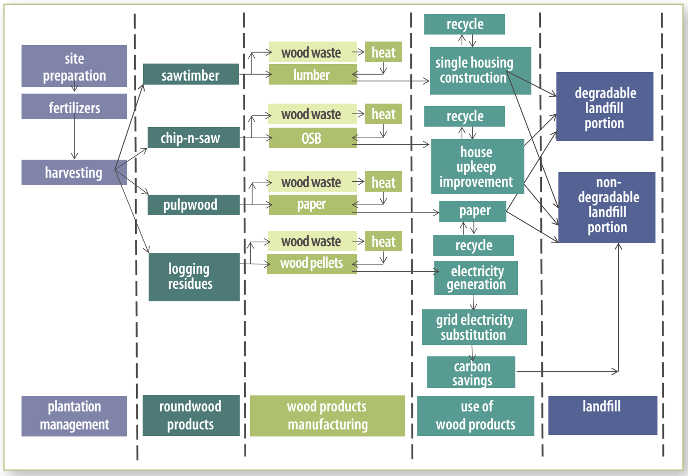


Figure 14.1. System boundary for the case ENE-LR.

Results

Figure 14.2 shows total carbon savings trajectories in wood products and wood and paper present in landfills

Diversion of pulpwood for bioenergy development will affect net carbon sequestered in wood products and wood and paper present in landfills but will bring additional carbon savings in the form of avoided carbon emissions due to substitution of carbon intensive grid electricity.

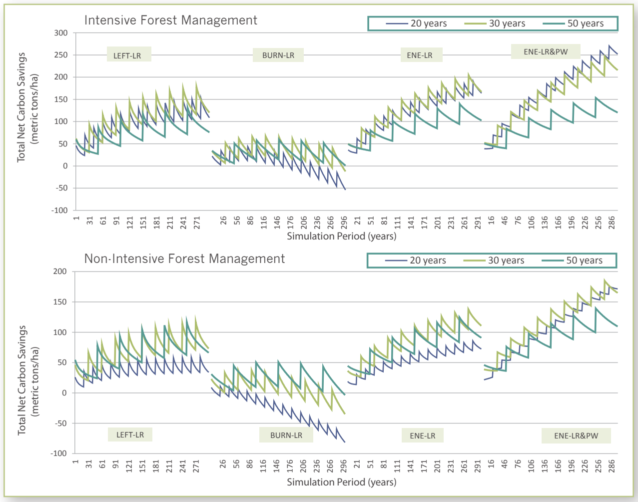


Figure 14.2. Distribution of total carbon savings in metric tons/ha (y axis) for selected cases at different harvest ages over a simulation period (x axis).

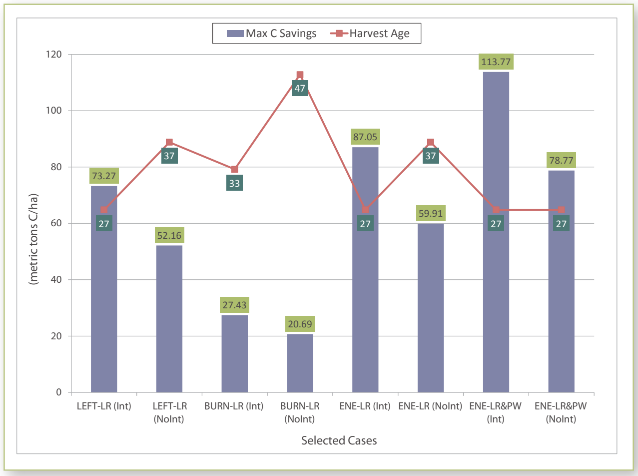


Figure 14.3. Maximum value of carbon savings and corresponding harvest age for selected cases.

for each case under different harvest ages and for both forest management scenarios. These trajectories account for all carbon flows including net carbon sequestered in wood products and wood and paper present in landfills and avoided carbon emissions due to grid electricity substitution. Net carbon sequestered (positive values) or emitted (negative values) is always higher under intensive forest management relative to non-intensive forest management due to higher availability of biomass. We also found that harvest age plays an important role in determining total carbon savings for the various scenarios. The average annual net carbon emissions avoided due to displacement of grid electricity plays a critical role in determining total carbon savings, especially at younger harvest ages, across the 300 year simulation.

Figure 14.3 shows maximum total carbon saved under both forest management scenarios along with corresponding harvest age. When the logging residues or logging residues plus pulpwood are used for electrical power (ENE-LR and ENE-LR&PW), the maximum carbon sequestered is greater than the current (LEFT-LR and BURN-LR). Utilization of pulpwood along with logging residues for bioenergy production decreases net carbon sequestered in wood products and wood and paper present in landfills relative to when only logging residues are utilized for bioenergy production. However, this loss in sequestered carbon is well compensated by avoided carbon emissions due to grid electricity substitution.

Conclusions

Our results suggest that the use of logging residues and pulpwood for bioenergy development helps in saving more carbon long-term relative to when either logging residues are left on field to decay or burned on site. However, caution should be exercised in selecting a suitable baseline while promoting use of logging residues or pulpwood as a feedstock for bioenergy development, in general, or electricity generation, in particular, to ensure long term carbon benefits from forest biomass based bioenergy development.

15. Pine Plantations in the Southern Forest Economy: Market, Land Use, and Carbon Consequences of Increased Supply

Robert Abt[1,3] • ***Karen Abt***[2,4]

[1]Professor • [2]Research Economist • [3]Department of Forestry and Environmental Resources, North Carolina State University • [4]USDA Forest Service Southern Research Station

PINEMAP is an ambitious project to integrate and synthesize our genetic and silvicultural knowledge of southern pines to enhance carbon sequestration. The primary goal is to advance and deploy the science of improved fertilizer efficiency and genetic improvement to grow more profitable and resilient forests which store more carbon. The increased carbon gains come from both the intensive (productivity) and extensive (increased area) margin. While contributing 60% of pine removals and over 40% of total removals in the South, pine plantations occupy only 25% of private timberland. Since this privately owned resource is in a region where land use fluctuates between forest and agriculture, the net carbon outcome will depend on complex interactions between technology, markets, and policies across agriculture and forestry sectors.

There are a few important interactions that may determine the ultimate carbon outcomes associated with future pine plantation management. The focus here is on the market consequences of growth increases in the pine plantations. Given the disproportionate market impacts relative to their role in the landscape, price impacts from plantation supply can influence land use and dampen net carbon gains. This is a type of market "leakage" is a key factor in carbon accounting. (Murray et al., 2002). These effects are modeled using the Sub-Regional Timber Supply (SRTS) model (Abt et al., 2012). The SRTS is a market simulation framework based on empirical data where supply is shifted by tracking product inventories. The inventory, growth, and removal starting point for these runs was based on 2011 U.S. Forest Service Forest Inventory Analysis (FIA) data.

This is a preliminary first-order analysis that uses historical relationships and focuses only on forest carbon. This analysis will be enriched and expanded as PINEMAP progresses. New information will (1) alter the base case as climate change impacts on existing plantations is better understood, (2) provide better estimates of fluxes within and between forest carbon pools, and (3) incorporate linkage to models of product carbon outcomes beyond the forest. Here, the emphasis is on the sensitivity of forest carbon outcomes to markets and policies that influence the economic viability of southern working forests.

A key characteristic of southern timber markets is price responsiveness of forest product supply and demand. Both supply and demand tend to be price inelastic (Pattanyak et al., 2002). This means that an increase in demand or supply has a bigger price effect than harvest effect. Other things equal, an increase in pine supply will lower prices more than it increases harvest. To capture agriculture-forest dynamics, SRTS is linked to an updated, reduced-from version of Hardie et al. (2000). These results are not forecasts; the model is simply used as a tool to characterize the relative importance of different factors on carbon outcomes.

The first example focuses on carbon outcomes from supply increases for the Alabama, Florida, Georgia region published in

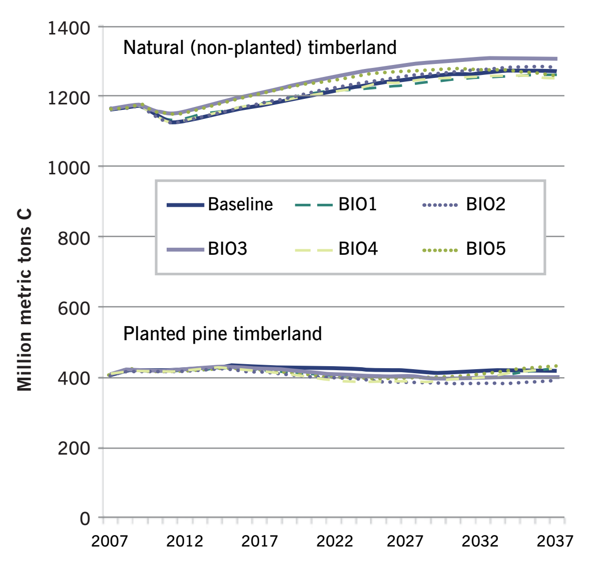
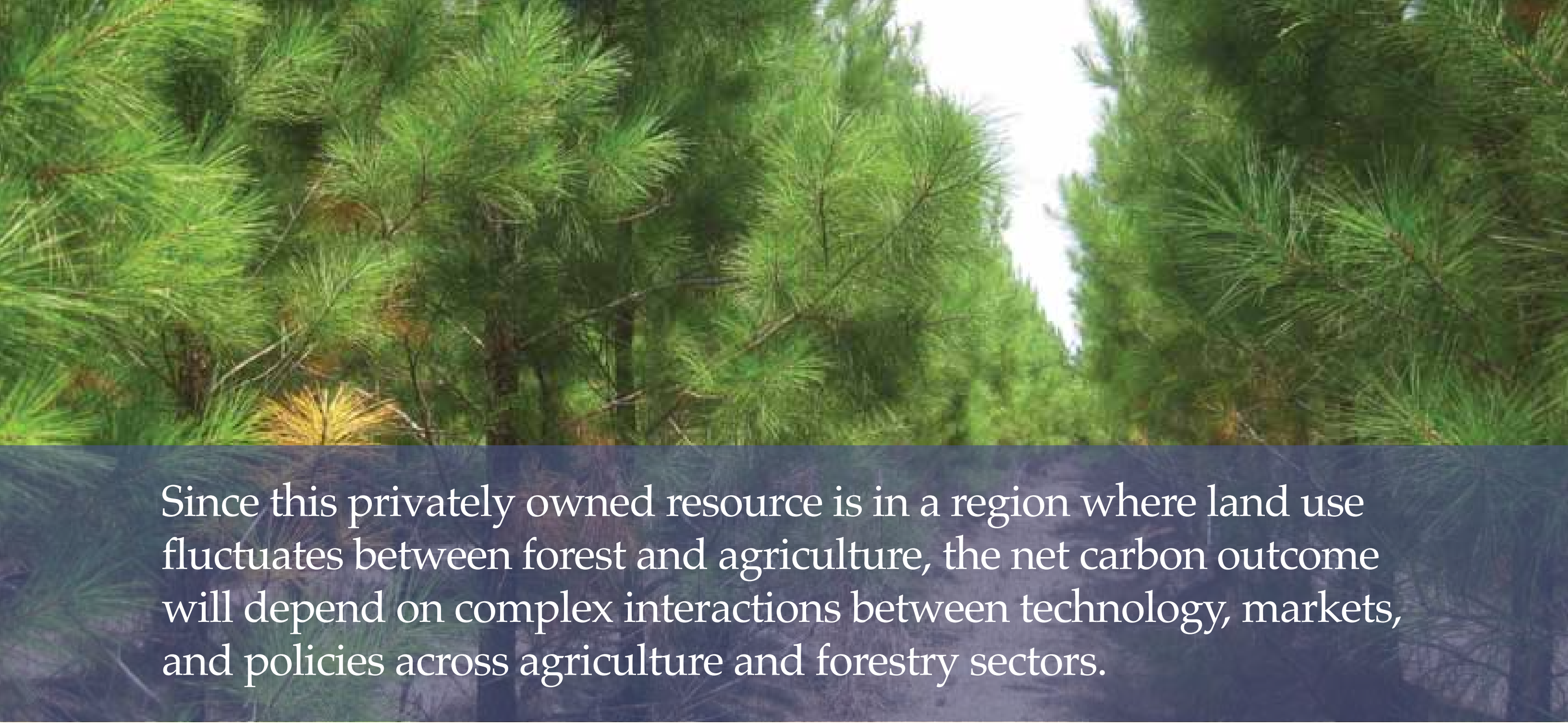


Figure 15.1. Carbon outcomes from enhanced supply scenarios in Alabama, Florida, and Georgia.



Since this privately owned resource is in a region where land use fluctuates between forest and agriculture, the net carbon outcome will depend on complex interactions between technology, markets, and policies across agriculture and forestry sectors.

Abt et al. 2012. In Figure 15.1, the carbon outcomes of several supply scenarios are shown. The baseline scenario reflects the impact of the recession and a recovery over time with additional demand for small roundwood due to bioenergy demand. Scenarios BIO3, BIO4, and BIO5 reflect the same demand but different combinations of supply responses. Scenario BIO3 shows the impact of increased timberland due to higher prices; this includes increased area of plantations and less loss of natural forest to agriculture. Scenario BIO4 shows an intensive management (plantation growth) response, and scenario BIO5 shows the combined effect of both area and growth response. Note that growth increases in scenarios BIO4 and BIO5, allowing forest carbon in pine plantations to end higher than the baseline even with increased bioenergy harvest. However, only scenario BIO3, which reduces the loss of timberland to agriculture, leaves the non-planted resource at a higher carbon level than the baseline. The increased plantation growth rates in scenarios BIO4 and BIO5 lower wood prices, leading to a small increase in natural timberland loss. This loss, however, more than offsets the carbon gains on plantations.

Figures 15.2 and 15.3 show the carbon outcomes in the South for planted pine carbon and total forest carbon, respectively, under three longer run scenarios: (1) no demand increase, (2) .5% per year demand increase for all products, and (3) .5% per year demand increase and a doubling of growth rates on plantations by the 100-year projection. Since the start of the recession in 2009, the constant demand scenario is a future with low prices and accelerated timberland loss, especially in plantations, after 2040. Carbon increases in natural stands due to decreased harvest, but, eventually, the loss of timberland to urbanization and agriculture leads to loss of carbon in the forest. Higher demand leads to higher prices and less loss of timberland, which more than offsets the carbon loss due to increased harvest. Growing plantations faster increases their carbon stock but lowers prices leading to accelerated loss of timberland which more than offsets the gain in carbon due to faster growth.

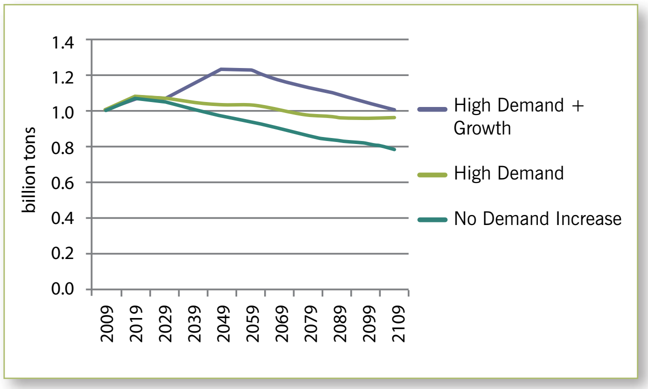


Figure 15.2. Plantation carbon outcomes with enhanced plantation growth.

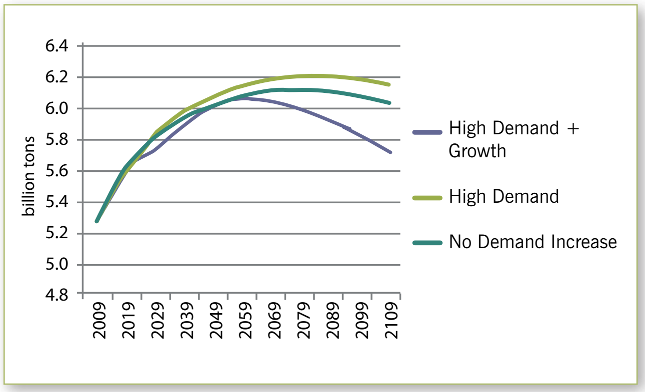


Figure 15.3. Total forest carbon outcomes with enhanced plantation growth.

These results emphasize the importance of context as PINEMAP moves forward. Eventually, our contributions to carbon management in stands, forests, and rural landscapes will be one component of a dynamic, complex policy- and market-driven economy. This perspective should enhance our ability for better outreach and more effective advocacy for science-based policy options. A clear implication of these results is that policies which affect retention of working forests could dominate even significant improvements in carbon sequestration on pine plantations.

16. A Generalized Carbon Sequestration and Hurricane Risk Model to Determine the Optimal Harvest Age in Southern Pine Plantations

Andres Susaeta[1,4] • **Douglas Carter**[2,4] • **Sun Joseph Chang**[2,5] • **Damian Adams**[3,4]

[1]Postdoctoral Research Associate • [2]Professor • [3]Assistant Professor • [4]School of Forest Resources and Conservation, University of Florida
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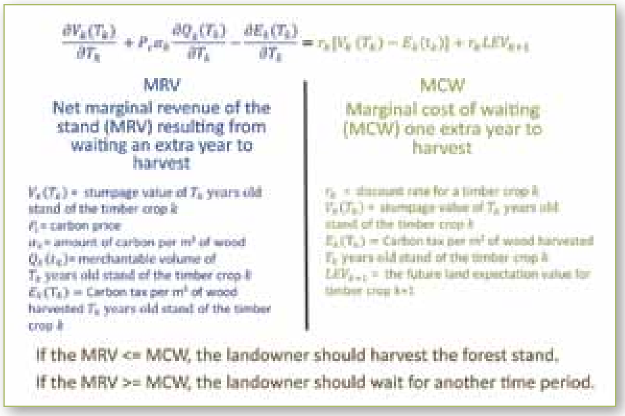
The Faustmann model (1849) was developed to aid land owners and land managers in determining the optimal rotation age that maximizes the net present value of forest-related cash flows. A major limitation of the model is its deterministic nature. Carbon sequestration and risk related to natural hazards such as hurricanes, wildfires, flooding, pest outbreaks, ice storms, and droughts are important for forest management, yet the Faustmann model fails to incorporate all these factors. Reed (1984) adapted the Faustmann model to explicitly incorporate risk from natural hazards. His model assesses the effect of catastrophic event risk on optimal timber harvesting and profitability of a forest stand embedded within a Faustmann framework.

In 1995, van Kooten et al. proposed a now widely used carbon sequestration model in which both carbon sequestration and timber benefits are simultaneously incorporated in a forest management model. In this model, a forest landowner is periodically paid a subsidy for carbon uptake in the trees and taxed when carbon is released due to harvesting or decay.

One of the limitations of the Reed and the van Kooten et al. models is that the salient parameters of each model are assumed to be constant from timber crop to timber crop. For example, in the van Kooten et al. model, carbon prices and amount of carbon in timber volume are assumed to be constant; in the Reed model, the probability of risk of catastrophic events and salvageable portion of the forest stand are assumed to be constant.

In reality, these parameters are highly variable and uncertain, therefore increasing the risk of rotation age decisions. Trees with better wood properties may increase the proportion of carbon in wood and total carbon uptake, and landowners might plant different species of pine with varying wood properties between rotations. In addition, age, biological, and ecological conditions of the forest stand may influence the probability of a natural hazard and the possibility of salvage operations.

In this study, we develop a generalized version of the van Kooten et al. (GVK) and Reed (GR) models in which the optimal harvest age is not restricted to these limitations.



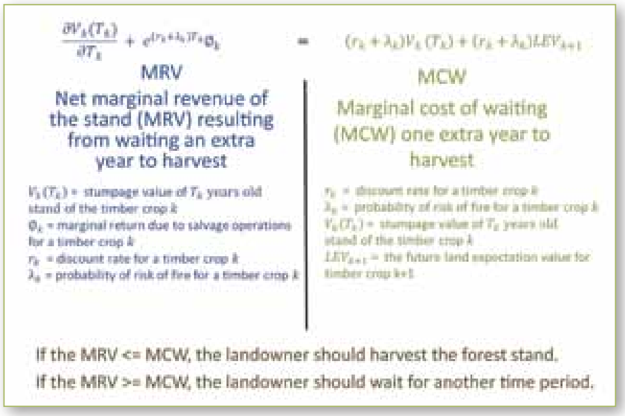
$$\frac{\partial V_k(T_k)}{\partial T_k} + P_c\alpha_k\frac{\partial Q_k(T_k)}{\partial T_k} - \frac{\partial E_k(T_k)}{\partial T_k} = r_k[V_k(T_k) - E_k(t_k)] + r_k LEV_{k+1}$$

$V_k(T_k)$ = stumpage value of T_k years old stand of the timber crop k
P_c = carbon price
α_k = amount of carbon per m³ of wood
$Q_k(t_k)$ = merchantable volume of T_k years old stand of the timber crop k
$E_k(T_k)$ = Carbon tax per m³ of wood harvested T_k years old stand of the timber crop k

r_k = discount rate for a timber crop k
$V_k(T_k)$ = stumpage value of T_k years old stand of the timber crop k
$E_k(T_k)$ = Carbon tax per m³ of wood harvested T_k years old stand of the timber crop k
LEV_{k+1} = the future land expectation value for timber crop k+1

If the MRV <= MCW, the landowner should harvest the forest stand.
If the MRV >= MCW, the landowner should wait for another time period.

Figure 16.1. The generalized version of the Van Kooten et al. (GVK) model and its key relationships.



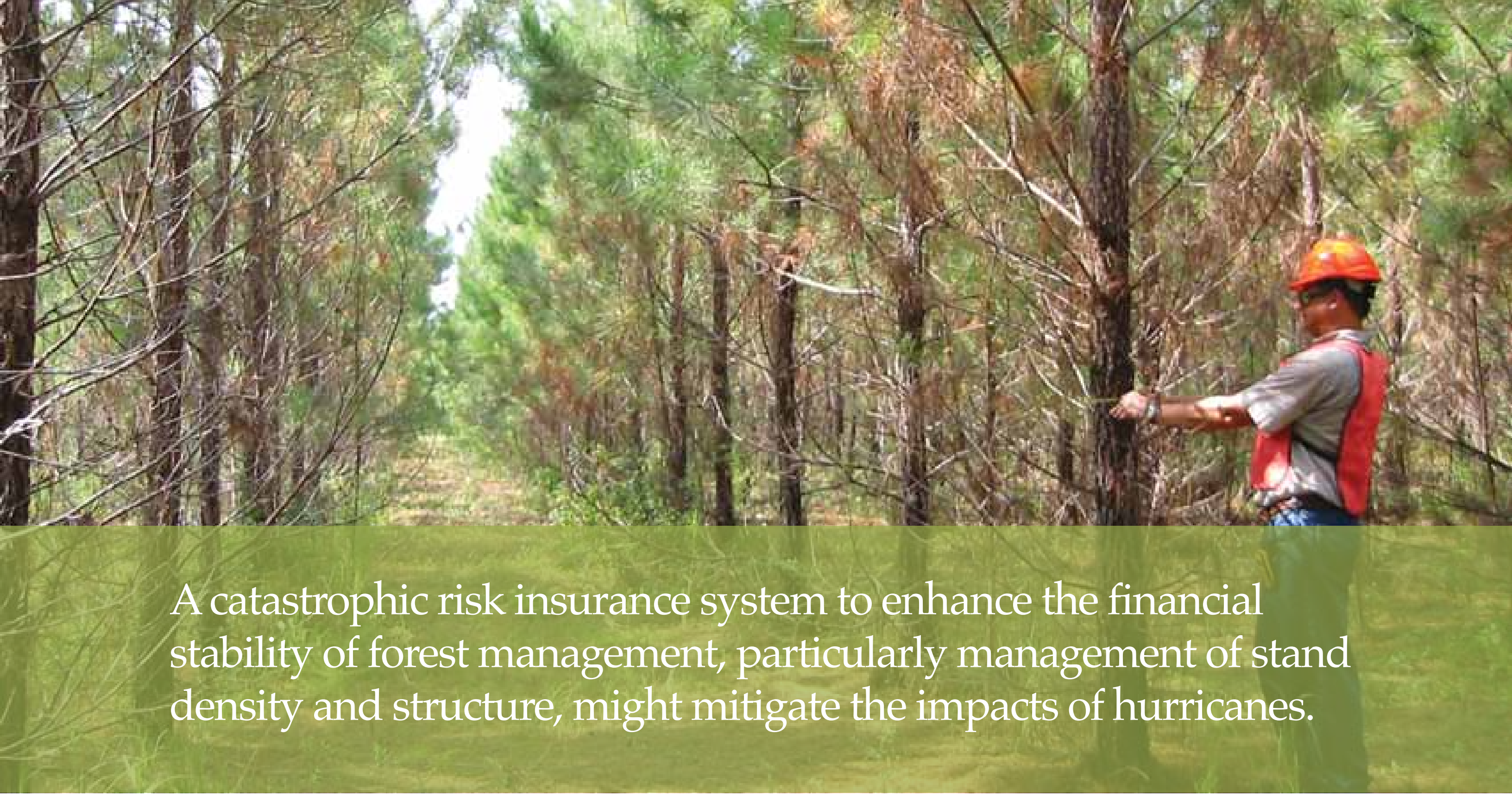
$$\frac{\partial V_k(T_k)}{\partial T_k} + e^{(r_k+\lambda_k)T_k}\emptyset_k = (r_k+\lambda_k)V_k(T_k) + (r_k+\lambda_k)LEV_{k+1}$$

$V_k(T_k)$ = stumpage value of T_k years old stand of the timber crop k
$\emptyset_k$ = marginal return due to salvage operations for a timber crop k
r_k = discount rate for a timber crop k
λ_k = probability of risk of fire for a timber crop k

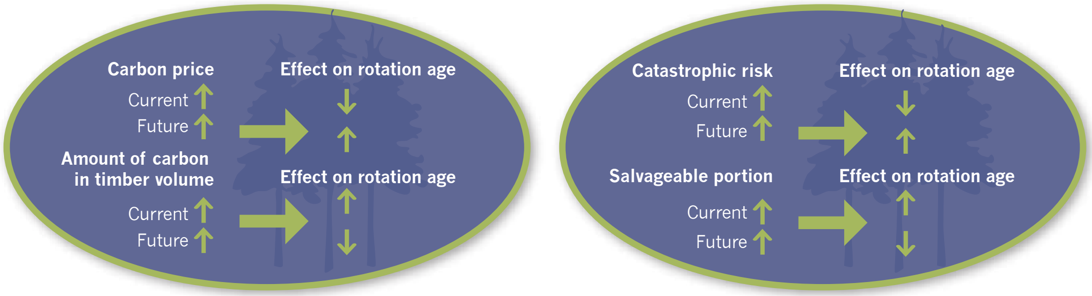
r_k = discount rate for a timber crop k
λ_k = probability of risk of fire for a timber crop k
$V_k(T_k)$ = stumpage value of T_k years old stand of the timber crop k
LEV_{k+1} = the future land expectation value for timber crop k+1

If the MRV <= MCW, the landowner should harvest the forest stand.
If the MRV >= MCW, the landowner should wait for another time period.

Figure 16.2. The generalized version of the Reed (GR) model and its key relationships.



A catastrophic risk insurance system to enhance the financial stability of forest management, particularly management of stand density and structure, might mitigate the impacts of hurricanes.



(a)

(b)

Figure 16.3. (a) Impacts of current and future increases in parameters of generalized van Kooten et al. (GVK) model on the optimal harvest age. (b) Impacts of current and future increases in parameters of generalized Reed (GR) model on the optimal harvest age.

Key relationships

Figures 16.1 and 16.2 show, respectively, the key relationships of the generalized van Kooten et al. (GVK) model and the generalized Reed (GR) model.

In both figures, the left side of the equation represents the net marginal revenue of the stand (MRV) by waiting one extra year to harvest. In Figure 16.1, it includes marginal earnings due to growth in stumpage value, carbon uptake, and marginal carbon emission taxes. In Figure 16.2, it includes earnings due to the growth in stumpage value and the marginal return due to salvage.

In both figures, the right side of the equation represents the marginal cost of waiting (MCW) one extra year to harvest. In Figure 16.1, it includes the cost of holding the stand value while accounting for the carbon emitted into the atmosphere and the cost of holding the land. In Figure 16.2, it represents the cost of holding the stand value and the land. In both figures, these equations stipulate a rule regarding harvesting: the optimal harvest age is reached when both sides of the equation are equal. Thus, if the MRV $\leq$ MCW, the landowner should harvest the forest stand. If the MRV > MCW, the landowner should wait for another time period.

Implications of different parameters on the optimal harvest age

Increases in current carbon prices and larger amounts of carbon in timber volume would extend the optimal harvest age (Figure 16.3a). Higher future carbon prices and larger amounts of carbon in timber volume would shorten the optimal harvest age. The GVK model indicates that as longer harvest ages result from increased current carbon prices, the supply of sequestered carbon would also increase. The formulation of policies that ensure a dynamic carbon market would incentivize forest landowners to lengthen the current harvest age and produce longer-lived forest products.

On the other hand, increases in the current risk of hurricane-related losses would shorten the predicted optimal harvest age (Figure 16.3b). Higher future risks, however, would have the opposite impact. Increases in current salvageable portions would lengthen the harvest age, while higher future salvageable portions would reduce the harvest age. The GR model indicates that, regardless of the timing of the natural hazard, profitability of forestlands would be negatively impacted. A catastrophic risk insurance system to enhance the financial stability of forest management, particularly management of stand density and structure, might mitigate the impacts of hurricanes.

17. Creating Educational Materials to Teach Youth about Forests and Climate

Martha Monroe[1,3] • **Annie Oxarart**[2,3]

[1]Professor and Extension Specialist • [2]PLT-PINEMAP Education Coordinator • [3]School of Forest Resources and Conservation, University of Florida

PINEMAP's integrative research is the focus of a new secondary module for middle and high school science teachers. The module was developed through a partnership with Project Learning Tree® (PLT), a national environmental education program, and contains 13 engaging activities that will be pilot tested in classrooms throughout the Southeast United States in fall 2013. The activities are designed to introduce students to the important relationship between southeastern forests and climate change, echoing every dimension of PINEMAP's research. This module will provide youth with the knowledge and skills to understand forest mitigation and adaptation strategies.

To guide the development of the module, we conducted an audience assessment of secondary science teachers in the Southeast (Monroe, Oxarart, and Plate, in press). Of those who responded (n=746), 77% already cover climate change; however, they do so in different ways depending on which courses they teach (Table 17.1). A large majority (82%) of the respondents are interested in continuing to cover climate change in future courses. To meet their needs, our lessons were designed to incorporate the following educational goals (percent of respondents indicating particular goals):

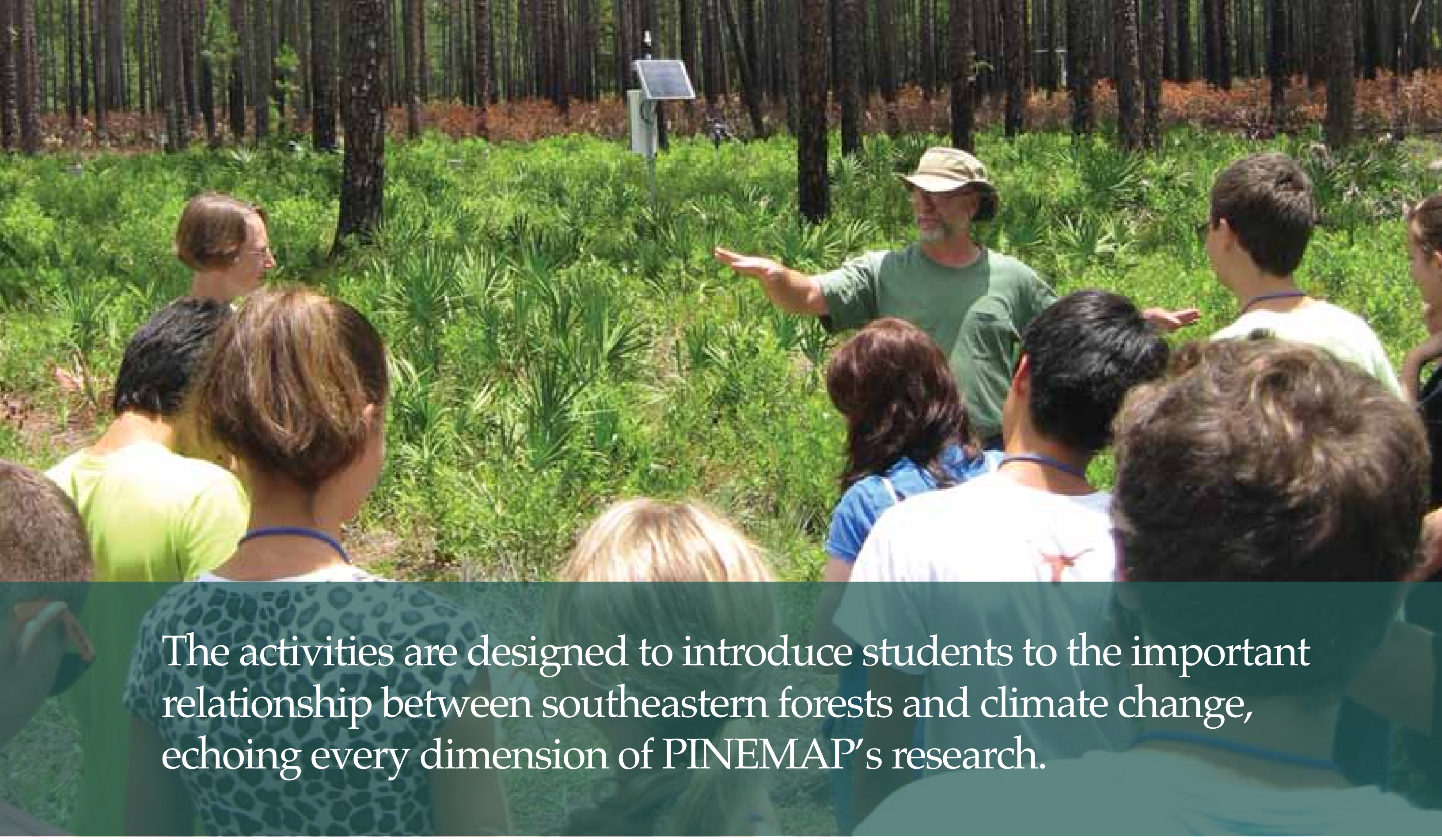
- Connect science to students' everyday lives (98%)
- Emphasize critical thinking (98%)
- Develop data analysis skills (94%)
- Emphasize choices that affect sustainability (92%)
- Emphasize systems thinking (92%)

Recognizing the importance of helping students understand what they can do, 85% of respondents are willing to include information about life cycle analysis to show how consumers can affect carbon sequestration.

Method for Covering Climate Change	Courses
Informal discussions	Agriculture, chemistry, and physical science
Planned lessons < 1 week	Biology (regular and AP), earth science, integrated science, marine science
Planned lessons > 1 week	Environmental science (regular and AP), ecology, environmental issues

Table 17.1. Methods for covering climate change in secondary science courses.

Regarding teaching strategies, over 85% of respondents believe it is appropriate or very appropriate to explain scientific uncertainty, present rationale for how people interpret climate change differently, discuss advantages and disadvantages of climate-related policies, and discuss the history of climate change science. Respondents disagreed on one teaching strategy—presenting all perspectives as valid—with 36% viewing this strategy as inappropriate and 41% as appropriate. This divide may be the result of two interpretations of the question. While political solutions have multiple perspectives, each with potentially valid concerns, climate science has only one. Making this distinction clear is an important feature of our materials. Many open-ended comments focused on addressing multiple perspectives about climate change through the lens of science. Survey respondents are interested in teaching about climate change and southern forests, especially if the lessons connect science to students' lives with critical-thinking and data-analysis skills. Recognizing that climate change is a controversial issue, many



The activities are designed to introduce students to the important relationship between southeastern forests and climate change, echoing every dimension of PINEMAP's research.

of these educators see this topic as an opportunity to explore the nature of science with their students.

The basic concepts that underpin PINEMAP's research agenda form the framework of the module: tree growth, genetics, forest change models, forest management, and life cycle assessment. The module is divided into five sections, with activities in each section connecting to an overarching theme (Table 17.2). Working with PINEMAP faculty and partners enabled us to develop activities that engage students in following Web quests, analyzing data sets, and measuring forest carbon storage. Some activities were tested with students to learn which of two competing versions did a better job of teaching the main themes (see *Improving Climate Change Education Strategies*, page 40).

In addition to integrating PINEMAP research topics into one product, the process of developing the secondary module has built strong and productive relationships between educators, researchers, and other experts—creating a network of interested parties that includes internal and external collaborators. The writing team included graduate and undergraduate students, faculty, staff, and a postdoctoral associate. We also tapped experts for data, suggestions, and assistance, including the State Climate Office of North Carolina, USDA Forest Service, National Renewable Energy Laboratory, and Consortium for Research on Renewable Industrial Materials (CORRIM).Undergraduate and graduate students taking an environmental education course helped develop and test early versions of module activities and the needs assessment.

All activities were reviewed by an Education Advisory Committee during bimonthly conference calls where activity objectives, concepts, and procedures were discussed, critiqued, and altered. Twenty-four educators served on the committee, representing a broad range of climate, forestry, education, curriculum development, and training expertise. In addition, several activities formed the basis of discussion for an educator professional development activity, the North American Association for Environmental Education (NAAEE) Climate Change Professional Learning Group. Finally, the activities were sent to PINEMAP researchers and external experts for content review in preparation for the development of a teacher training workshop and the formative evaluation. Through all of these interactions, more than 80 people—mostly from the Southeast, but some located in other regions—have been connected to the development of these materials, enhancing the partnership between educators and forest/climate researchers.

Section	Theme
1. Climate Change and Forests	Projected climate changes will likely affect forest ecosystems.
2. Forest Management and Adaptation	Forests can be managed to thrive in a changing climate.
3. Carbon Sequestration	Forests can be managed to reduce atmospheric greenhouse gases and to prevent greenhouse gas emissions.
4. Life Cycle Assessment	Consumer choices can play a role in reducing and preventing carbon emissions.
5. Solutions for Change	Working toward healthy, sustainable forests and communities.

Table 17.2. PLT secondary module themes.

18. Improving Climate Change Education Strategies

Stephanie Hall[1,3] • **Martha Monroe**[2,3]

[1]M.S. student • [2]Professor and Extension Specialist • [3]School of Forest Resources and Conservation, University of Florida

Climate change is a global issue that requires knowledgeable citizens who are able to make informed decisions about mitigation and adaptation activities. Currently, neither adults nor teens are well informed on this issue, suggesting the need for a stronger education effort. However, some teachers may avoid climate change because they are unsure of how to approach a controversial issue. Also, some students enter the classroom with misconceptions and attitudes about climate change that are influenced by sources outside the classroom. Using activities drafted for the Project Learning Tree secondary module (see *Creating Educational Materials to Teach Youth about Forests and Climate*, page 38), the following research questions were investigated:

1. To what extent are student attitudes about climate change influenced by their perception of their parents' opinions of climate change?
2. How does integrating carbon cycle lessons with climate change affect student interest and knowledge about carbon?
3. Is a role play or discussion more effective for encouraging students to respectfully discuss a variety of opinions about climate change?

Methods

Data were collected at two summer science programs organized by the University of Florida's Center for Precollegiate Education and Training: Science Quest (SQ) and Student Science Training Program (SSTP).

Figure 18.1. Science Quest week one students measuring carbon in the forest. Photo by Jessica Ireland.

Figure 18.2. Science Quest week two students moving through the carbon cycle. Photo by Annie Oxarart.

Science Quest

Participants were 47 rising high school sophomores in two offerings of a week-long program. Students in each program engaged in a half-day educational experience about forest carbon. The week one group (SQ1) learned about carbon cycles in the context of climate change (Figure 18.1). The week two group (SQ2) participated in the same activities, but climate change was not mentioned until after the posttest (Figure 18.2). Group interviews were conducted after completing the activities to explore students' attitudes about the lesson (Table 18.1).

Student Science Training Program (SSTP)

Participants were 42 rising high school juniors and seniors in a seven-week research program. All students took a pretest that measured their climate change knowledge and attitudes as well as their perception of their parents' attitudes. Students attended a one-hour lecture introducing climate change science and why people hold different perspectives about this issue. Four days later, all students took a posttest on their climate change knowledge and attitudes. Students were split into small groups. Half of the groups participated in a role play with different climate change perspectives in which they were asked to generate three solutions to climate change that everyone could agree on. The other groups participated in a discussion in which they had to agree on three climate change solutions they felt would be practical given that people in their community hold many different perspectives (the same perspectives as presented in the role play). Students also completed a questionnaire about the lesson.

In the interviews, students explained that linking carbon cycle activities with climate change makes the topic more interesting and relevant, even for students who are less concerned about climate change.

Results

Students' Climate Change Attitudes

A forward stepwise regression was conducted to predict student attitudes about climate change. There was a strong R^2 value for SQ2 and SSTP; the most significant term was perception of parents' climate change attitudes. SQ1 had a weak R^2 value and the most significant term was students' political views. This implies that students come into the classroom already holding opinions about climate change that are partially influenced by outside factors, such as perception of parents' attitude and the political party they favor.

Student Knowledge Gain and Interest

In the SQ1 group, students scored significantly higher ($p<0.05$) on the posttest than the pretest. The pretest and posttest scores were not significantly different for SQ2. There was no significant difference between the week 1 and 2 pretests or posttests. Embedding the carbon cycle lesson in the context of climate change appears to have significantly increased student knowledge about the carbon cycle, although this conclusion would be stronger if there were a significant difference between the posttest scores. In the interviews, students explained that linking carbon cycle activities with climate change makes the topic more interesting and relevant, even for students who are less concerned about climate change.

SQ1 group- Carbon cycle activities in the context of climate change (n=23)	SQ2 group- Carbon cycle activities not in the context of climate change (n=24)
• Pretest on carbon cycle knowledge • Activities – Students move through the carbon cycle as a carbon atom and discuss human impacts on the carbon cycle – Students measure carbon in a tree, calculate their state's sequestration rate, and compare to emissions rate • Posttest • Interviews	• Pretest on carbon cycle knowledge • Activities – Students move through the carbon cycle as a carbon atom – Students measure carbon in a tree and calculate carbon in the forest • Posttest • Discussion of human impacts on the carbon cycle, state's sequestration rate compared to emissions rate • Interviews

Table 18.1. Students' attitudes about the lesson in the SQ1 group and SQ2 group.

Role Play and Group Discussion

Students engaging in the role play activity made more frequent mentions of other perspectives but also had a greater frequency of disrespectful comments than students engaging in the discussion activity. Changing the role play to emphasize respect or adding a moderator could make the conversation more respectful. This modified role play offers a potential strategy for teachers to approach the controversy while not confusing students about the science of climate change.

Discussion

Climate change is typically covered in earth science classes, but it can also enhance the biology curriculum by providing an interesting framework for learning about topics such as the carbon cycle. Students come into the classroom with knowledge and attitudes influenced by outside sources, however, which could affect learning. Activities should be designed to offer teachers guidance to approach the types of situations they are likely to face and to facilitate interesting and engaging activities with students.

19. PINEMAP Distance Graduate Course: Engaging Graduate Students in Interdisciplinary Dialogue and Thinking

Jessica Ireland[1,3] • ***Martha Monroe***[2,3]

[1]*PINEMAP Project Coordinator* • [2]*Professor and Extension Specialist* • [3]*School of Forest Resources and Conservation, University of Florida*

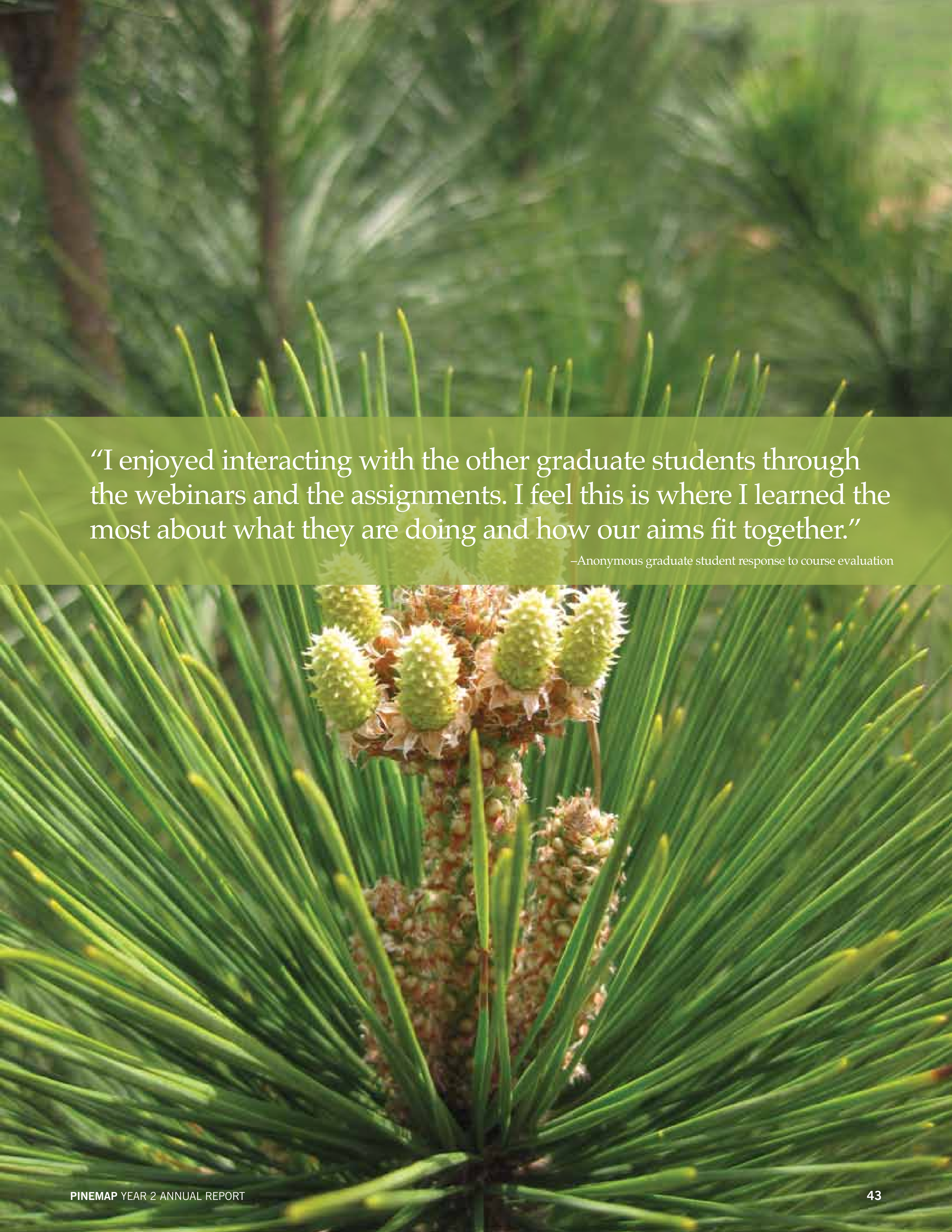
As part of the education outcomes of PINEMAP, an online graduate course was conducted during the spring 2012 and 2013 semesters with the goals of:

- engaging graduate students in exploring climate change mitigation and adaptation issues in southern pine forests and
- building capacity for integration among research disciplines and between research and education/Extension.

Twenty-two students (16 Ph.D. and 6 M.S.) from 8 southeastern universities participated in the spring 2012 course, and a team of 15 faculty members assisted with instruction and assignment coordination. Students registered for one or two credits of independent study or special topics at their home institution and were assigned final grades by their faculty advisor. Throughout the semester, students participated in live webinars covering topics including impact of climate change on forest ecosystems, climate model projections in the southern United States, southern forest futures, carbon scoring and policy, Extension programming, challenges to communicating about climate, decision support systems, and interdisciplinary research. In addition, students completed related readings and participated in online discussion. Students also completed two group assignments during the course, a research-focused assignment and an interdisciplinary outreach assignment.

Results from an evaluation conducted at the conclusion of the spring 2012 offering indicated that the course facilitated learning about climate change (mean of 3.55 on a 4 point scale) and climate change mitigation and adaptation in southern pine forests (mean of 3.10 on a 4 point scale) and also instilled a better understanding of integration among PINEMAP research activities (mean of 3.45 on a 4 point scale) and research and Extension (mean of 3.55 on a 4 point scale). Students indicated that they enjoyed interacting, collaborating, communicating with, and getting to know other graduate students and found that the course offered a great deal of useful information.

Students and faculty alike overwhelmingly agreed that the course should be offered again in spring 2013. Based on feedback from the evaluation, we revised the course structure for spring 2013. Some of the major changes included revising one of the group assignments to be an individual research assignment on interdisciplinary research, better defining the grading structure with rubrics, reducing the amount of weekly readings, restructuring the lectures to be an introduction to each topic rather than an in-depth exploration of a specific area, making the online discussion required, and better engaging faculty in the online discussion. Nineteen students from eight universities participated in the spring 2013 course, and anecdotal feedback suggested the revisions have helped students engage to a greater extent and develop a stronger foundation in all of the interrelated topics.



> "I enjoyed interacting with the other graduate students through the webinars and the assignments. I feel this is where I learned the most about what they are doing and how our aims fit together."
>
> –Anonymous graduate student response to course evaluation

20. A Different Kind of Research Experience for Undergraduates: The PINEMAP Undergraduate Fellowship Program

John B. Kidd[1,3] • *John R. Seiler*[2,3]

[1]*PINEMAP Intern Program Coordinator* • [2]*Alumni Distinguished Professor* • [3]*Department of Forest Resources and Environmental Conservation, Virginia Tech*

The PINEMAP Undergraduate Fellowship Program has a unique twist on the traditional research experience for undergraduates (REU) in that each of the undergraduates accepted into the program is paired with a PINEMAP graduate student mentor and participates in a distance course following completion of the 12-week, full-time summer internship. Undergraduates from across the southeastern United States are hired as wage employees of Virginia Tech, earning up to $7,000, and are paired with graduate student researchers at one of PINEMAP's collaborating universities (Figure 20.1). This distributed fellowship affords most undergraduate fellows the opportunity to experience working in a setting outside their home universities. Additionally, the program vertically integrates undergraduates, graduate students, and faculty with the potential for each participant to be exposed to a variety of research interests, skillsets, and learning experiences. Undergraduates then take gained knowledge and skills back to their universities as they continue their degree programs. This capacity to train undergraduates as researchers and educate them on climate change and forest resources issues addresses PINEMAP's education and training goals.

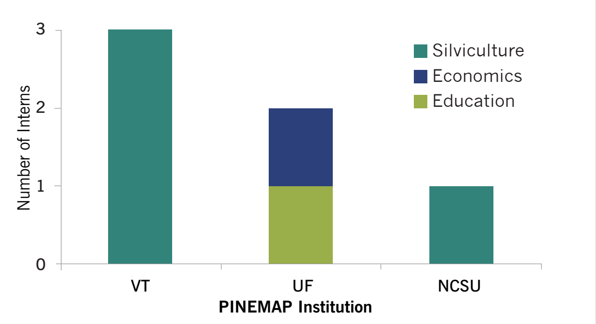


Figure 20.1. Distribution of 2012 undergraduate fellows among PINEMAP's collaborating institutions and disciplines.

Figure 20.2. Paul Decker, a 2012 undergraduate fellow from Virginia Tech, helps test a Project Learning Tree secondary module activity on southern pine forests and climate change at a Science Quest summer field day at Austin Cary Forest Learning Center near Gainesville, FL. Photo by Martha Monroe.

Undergraduate fellows in the 2012 pilot year had learning experiences that were practical and philosophical. Fellows performed technical work on their mentors' projects and learned not just the 'how' but also the 'why' behind the research. Many fellows were also able to help with other research projects as opportunities presented themselves.

> "I realized how much I learned about SO many things. I learned many new skills and techniques…over the course of the summer, I did everything from tree-coring, to stream-monitoring, to root-scanning, and of course LI-COR use [a LI-COR infrared gas analyzer measures carbon dioxide flux rates]"
>
> —Will Kinnerley, 2012 PINEMAP Fellow

Students became appreciably more capable of performing their duties over the summer. Being able to interact and have discussions with a graduate mentor also prompted undergraduates to consider their career paths in thoughtful ways. This exposure to the depth of a single project and the breadth of research within lab groups and departments gave undergraduates an appreciation for rigorous research that they may not have experienced through a traditional undergraduate education.

For example, Will Kennerley worked with M.S. candidate Brett Heim at Virginia Tech and reflected on his experience:

> *"I realized how much I learned about SO many things. I learned many new skills and techniques; after all, over the course of the summer I did everything from tree-coring, to stream-monitoring, to root-scanning, and of course LI-COR use [a LI-COR infrared gas analyzer measures carbon dioxide flux rates]. I learned how graduate school works and what it's like to be a grad student, which was especially valuable knowledge since I know that I'll hopefully be in Brett's position in just a couple of years."*

Paul Decker, an undergraduate fellow paired with M.S. candidate Stephanie Hall at the University of Florida, worked on the development and pilot testing of activities for a Project Learning Tree secondary module on climate change and southern forests (Figure 20.2).

Graduate students remarked that they experienced growth as a mentor, particularly since this was the first time some of them had interacted with undergraduates in this type of relationship. When asked about their experiences, some of them reflected on the intricacies of directing undergraduates in specific research practices as well as in general work activities and communication. Wen Lin, a first-year Ph.D. student at North Carolina State University at the time, shared her reflection on the overall experience and noted that she had to revise her approach to directing her upcoming-sophomore assistant, Rebecca, over the fellowship:

> *"The most important lesson I learned from this internship is how to communicate effectively with undergraduates. At first I communicated with the intern as I did with professors or graduate students. . . . As time went by, I learned to articulate a task, giving clear and specific description of background and goals, and have found that requiring timely [progress] reports was the best way to get updates and provide help."*

Part of this communication gap was due to varying degrees of knowledge, but it was also due to Rebecca's broader transition from a young adult to adult. Another mentor, Stephanie, was grateful for having someone to "share the workload" and for the experience of being a graduate student working with an undergraduate considering an advanced degree.

Based on reviews of the pilot year, additional emphasis is being placed on the identified strengths of the program, and we are also making revisions to improve targeted areas of the program. Specifically, participants in the 2013 program can expect more opportunities for a shared cohort experience and integration into PINEMAP research. We look forward to reporting on the program's second year as we expand to include 12 fellows and 12 mentors in 2013.

21. Undergraduates Using Climate and Forest Ecosystem Issues to Engage Public Secondary School Students

John B. Kidd[1,3] • ***John R. Seiler***[2,3]

[1]PINEMAP Intern Program Coordinator • [2]Alumni Distinguished Professor • [3]Department of Forest Resources and Environmental Conservation, Virginia Tech

The PINEMAP Undergraduate Fellowship Program was developed to meet student education and training goals within PINEMAP's education team. The fellowship program is both innovative and integrative, combining a summer undergraduate research experience with a fall distance course. Undergraduate students from across the southeastern United States apply to become fellows and are paired with a graduate student mentor from a PINEMAP institution. The mentor supervises the undergraduate throughout a 12-week paid summer fellowship, and fellows experienced the range of activities involved in rigorous scientific PINEMAP research. At the end of the summer fellowship, fellows return to their home universities for fall courses and participate in a distance course, *Effective Communication Skills*. This course is an avenue for fellows to educate secondary students near their universities about PINEMAP's goals and research.

Effective Communication Skills is a three-credit, letter-graded, distance education course co-taught by Virginia Tech faculty. Students receive credit by registering for independent study hours through their universities' academic advisors. The course is conducted synchronously over the Internet using web conferencing software and meets formally for one hour each week during the fall. Students also complete assignments outside of class as their schedules allow.

The course has two major components, and both are related to research that fellows conduct during their summer internship. First, the course covers various interpersonal written, oral, and nonverbal communication skills. Students learn about these skills through multimedia, readings, and self-reflection, and then put these skills to use when developing and practicing presentations to be given in middle and high school classrooms later in the semester. Additionally, students communicate scientific research through writing an abstract and creating scientific poster and PowerPoint® presentations based on their summer research.

Students who participated in the 2012 pilot program found these assignments to be not just another graded project but insight for the types of communication that graduate students and scientists use. A student wrote in the course evaluation:

> *"These assignments were great because they are a good practice for graduate school. Both the internship and these assignments in the fall helped me to gain an insight as to what graduate school is all about."*

The second, and perhaps most important, component of the course is the outreach component: students deliver their presentations to secondary public school audiences. These presentations target primarily middle and high school science classes, but 4-H or scouting groups are also potential audience groups.

While developing presentations, students identified standards of learning (SOL) from their states' educational guidelines for the targeted grade level and subject. Paul Decker, a fellow majoring in natural resources conservation at Virginia Tech, responded:

> *"The class presentations are sounding more exciting as we go further into planning our outlines and finding the SOLs that we want to discuss."*

After selecting a target SOL, students developed an outline for a hands-on presentation that incorporated

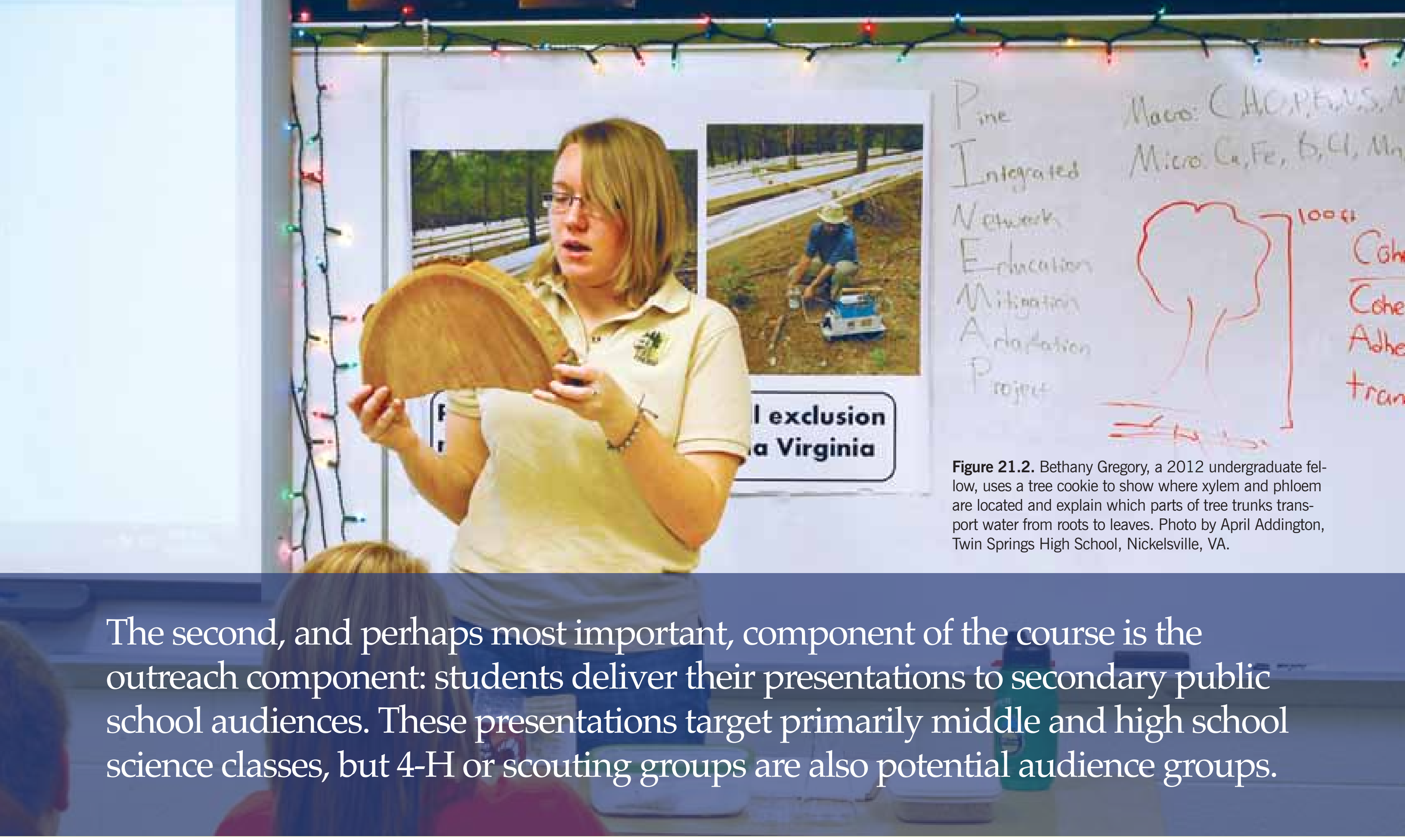


Figure 21.2. Bethany Gregory, a 2012 undergraduate fellow, uses a tree cookie to show where xylem and phloem are located and explain which parts of tree trunks transport water from roots to leaves. Photo by April Addington, Twin Springs High School, Nickelsville, VA.

> The second, and perhaps most important, component of the course is the outreach component: students deliver their presentations to secondary public school audiences. These presentations target primarily middle and high school science classes, but 4-H or scouting groups are also potential audience groups.

their personal research interests, climate change issues, and forest resources. This outline became the backbone for a 50-minute lesson on each student's chosen topic and included activities to help secondary students understand the complex concepts. For example, Will Kennerley utilized a terrarium and a CO_2 gas analyzer to show the process of photosynthesis decreasing atmospheric CO_2 and respiration increasing atmospheric CO_2 (Figure 21.1). Bethany Gregory, a fellow from Virginia Tech, gave a presentation titled, "Where's the Water?" to 15 different groups of biology, agriculture, and ecology students (Figure 21.2). Each presentation relayed PINEMAP's goals to manage southern forests for increased resilience and sustainability under changing climates. All presentations touched on practices that students could use to help mitigate climate change or natural resource degradation. Fellows coordinated with teachers to schedule visits to local middle and high schools. In the first pilot year, 54 presentations were delivered to 1,060 public school students from 16 different schools (Table 21.1). These numbers have the capacity to dramatically increase as the program grows over the next two years.

Figure 21.1. Will Kennerley (far right), a 2012 undergraduate fellow, demonstrates how forests can impact atmospheric CO_2 levels to a high school biology class in Southwest Virginia. Photo by April Addington, Twin Springs High School, Nickelsville, VA.

Outreach metric	Number
Fellowships completed	5
Presentations delivered	54
Schools visited	16
Teachers visited	29
Students reached	1,060

Table 21.1. Individuals reached through the 2012 PINEMAP Undergraduate Fellowship Program.

The *Effective Communication Skills* course proved to be a useful tool for teaching undergraduates skills related to science communication and education while also engaging students in educating secondary school students about climate change and forest ecosystems. The course also laid the foundation for fellows to pursue graduate studies and future careers in natural resource disciplines.

22. Tell Us What You Really Think: Survey of Professional Foresters in the South to Study Perceptions and Continuing Education Needs

***William G. Hubbard*[1,3] • *Leslie Boby*[2,3]**

[1]Southern Regional Extension Forester • [2]Extension Associate • [3]Southern Regional Extension Forestry

A critical component of PINEMAP's success will be the change in knowledge, behavior, and, ultimately, adoption of new practices and techniques by forest resource professionals in the southern pine region. Because many of these professionals work directly with private landowners, they are an excellent resource to work with to deliver new information and technology to the private landowner audience. Extension works closely with these professionals, who may work as consultants, state forestry agency county foresters, or forest industry or environmental organization representatives, in addition to other roles. The PINEMAP Extension team has created a south-wide database of over 7,000 forest resource professionals. The state-by-state listings of professional foresters were obtained through collaborative agreements with various organizations and associations as well as information that was publicly available on the Internet. This database will only be used to for social science research such as needs assessments, stakeholder analyses, information dissemination, and program evaluation.

In the winter of 2013, the database was used to conduct a comprehensive survey of forest resource professionals' perceptions of, experiences with, and continuing education preferences in the areas of climate science, catastrophic weather, and resilient forest management strategies. The results, to be tabulated and analyzed later in 2013, will provide Extension educators an idea of the concerns that professional foresters have with regard to climate change and catastrophic weather events. The results will also be useful for designing continuing education courses on adapting to and mitigating for climate and weather related impacts on pine plantations in the South.

The survey used Likert scale responses and open-ended questions to enable participants to reflect on and rate their levels of agreement with statements regarding climate and weather changes they may have experienced in their lifetime (see Figure 22.1 for an example of survey questions). They may have witnessed, for example, longer, hotter summers or they may have noticed a greater frequency in or severity of floods, drought, or insect and disease damage. Survey participants were also given the opportunity to rate their concern regarding the current and potential severity of climate change and catastrophic weather. These two areas highlight an interesting research question regarding potential differences between what might be witnessed on the ground versus concern for how severe a situation might be. They may, for example, witness hotter, drier summers but not necessarily think it is cause for concern.

In addition to gathering information on observations and perspectives, analysis of survey results will provide educators with valuable information regarding general level of knowledge and interest in learning more about climate science, climate change, climate/weather related tools and technologies, and forest resiliency strategies. Several questions gauged confidence in using existing climate and weather tools in forest management. Survey participants were also offered an opportunity to rate their personal preferences for both the topics and type of professional development offered; they were asked to rate their interest in learning more about general climate and science education, climate and weather models, decision support systems, economics, and other topics. They were also asked to rate their preferred venue for learning, including traditional face-to-face workshops, meetings, and

> “I would like to see more information on timing of silviculture herbicide applications and seedling planting times as related to prevailing weather patterns.” —anonymous response to PINEMAP professional foresters survey

Internet-based methods such as asynchronous e-learning and webinars. Finally, survey participants were asked if they would like to continue to be involved with the PINEMAP project, and if they would like to continue to receive information regarding southern forest management.

The results of this survey will be provided to PINEMAP researchers, Extension specialists, and continuing education coordinators who can analyze the data using various parameters. Data can be filtered by state, education level, age, years since graduation, gender, job description, and even political affiliation. Extension educators, continuing education professionals, and others can use this information to develop educational programs for professional foresters to promote resilience and sustainability of southern pine plantations.

Sample questions from the PINEMAP Professional Foresters Survey

1. Please indicate your level of agreement with the following statement: “In my lifetime, I have noticed a change in the climate (longer, hotter summers; warmer, drier winters; cooler, moister summers; earlier, drier, springs, etc.).
2. To what extent do you feel concerned about the long term impacts on our forests from the following weather and climate related factors?
3. Do you use any tools to assist with “climate smart” forest management (such as long-term climate models, recent updates to the plant hardiness zone map, the U.S. Drought Monitor, the Keech-Byram index, etc.?)
4. The following are some conditions that U.S. farmers and forest owners/managers have experienced over the past few years. To what extent have you or your clients witnessed any of these in the past several years.
    - Greater frequency and/or severity of flooding
    - Longer dry periods and/or drought conditions
    - Greater frequency of or more severe occurrences of insect damage
    - Greater frequency of or more severe occurrences of disease damage
    - Greater frequency or more sever occurrences of invasive plant infestations
    - More frequent and/or extreme rainfall events
    - Increased soil erosion
    - Increased frequency of or more severe fire events
    - Warmer winters
    - Cooler winters
    - Hotter summers
    - Cooler summers
    - Drier planting season
    - Wetter planting season
    - Change in length of growing season
    - Increase in frequency of extreme weather events (tornadoes, hurricanes, ice storms, etc.).
    - Other (please specify and provide how frequently you see this)

Figure 22.1. Sample questions from the PINEMAP professional foresters survey initiated in January 2013.

23. PINEMAP Decision Support System: What Is It and What Can It Do for You?

***Heather Dinon Aldridge*[1,3] • *Ryan Boyles*[2,3]**

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Forest managers often need more information to help with decision making. To meet that need, a website is under development that will answer questions related to planted pine management in a changing environment. The PINEMAP Decision Support System (DSS) is a new tool being designed by PINEMAP researchers and Extension specialists that will offer a collection of web-based tools and educational materials to assist professional foresters, Extension agents, and landowners with decision making regarding land management practices while reducing risk factors such as pests, disease, and climate change. These web-based tools will integrate science and data from modeling studies to produce results that can help professionals and clients make informed decisions. In particular, management recommendations for new and existing stands will include ways to

- improve forest health and resiliency;
- utilize nitrogen and other fertilizer inputs more efficiently;
- maximize carbon sequestration; and
- understand potential future climate scenarios.

PINEMAP researchers are working to address these topics as well as investigating genetic, economic, climatic, and silvicultural factors, such as

- the best genetic varieties to plant for drought resistance;
- site specific density management guidelines for optimal growth;
- recommended management practices to reduce vulnerability to southern pine beetle outbreaks; and
- optimal fertilizer usage to reduce unnecessary nitrogen and other elements in the atmosphere and environment.

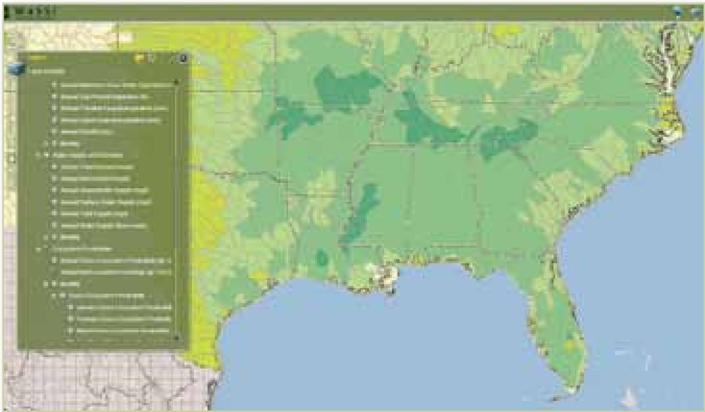

Figure 23.1. Example output from the WaSSI model, courtesy of the USDA Forest Service Southern Research Station and Eastern Forest Environmental Threat Assessment Center (http://www.forestthreats.org/research/tools/WaSSI).

How do you build a DSS?

In short, lots of communication and collaboration. Since we are essentially starting from scratch on this DSS project, we can build it the way we want, which has its advantages, but that also makes it a challenge. The DSS is an integration vehicle for PINEMAP, with each project team (including researchers, educators, and Extension professionals) actively contributing to the final product. Researchers are providing data or tools for the DSS, such as

- throughfall exclusion measurements at Tier III sites;
- carbon sequestration projections from the Water Supply and Stress Index (WaSSI) Ecosystem Services Model (Figure 23.1);

The PINEMAP Decision Support System (DSS) is a new tool being designed by PINEMAP researchers and Extension specialists that will offer a collection of web-based tools and educational materials to assist professional foresters, Extension agents, and landowners with decision making regarding land management practices while reducing risk to factors such as pests, disease, and climate change.

- updated deployment guidelines using a uniform response function; and
- information about ecosystem services including carbon, timber, and understory diversity.

Using expert knowledge of our target audiences, the Extension team is developing the layout and design for the PINEMAP DSS.

An effective DSS is often built using an iterative process of interaction between stakeholders and scientists. This iterative process has been successful with an agricultural DSS developed and released in 2010 by the Southeast Climate Consortium (SECC) (AgroClimate, http://agroclimate.org/). For example, map-based and time series tools on AgroClimate (Figure 23.2) are available to farmers and Extension agents to assist them in decision-making processes during planting or harvest. Recently, the SECC transitioned their DSS to an open source version called Open AgroClimate. The PINEMAP DSS framework will be similar to that of Open AgroClimate.

What are some of the challenges?

In order to get the DSS structure in place, there are multiple elements to consider related to both PINEMAP researchers and our stakeholders. The framework must be flexible enough to accommodate the following scenarios:

- Tools that exist, are in development, or are not yet built.
- Researchers with computer programming skills ranging from low to high.
- Datasets that are gridded (climate model output) and have point data (e.g., Tier research site data).
- Data that are pre-generated (usually from sophisticated models that take a long time to run) and data that are run in the background as a user clicks a button (usually from less complex models that can run quickly).
- Data/tools that comply with data use agreements.

The DSS layout and design must also consider needs of the target audience by considering the following:

- What are their levels of sophistication?
- What decisions are they trying to make?
- Is the design/layout intuitive to them?
- Do they find the information and tools useful?

These questions can be answered by interacting directly with landowners, Extension agents, and professional foresters who use the DSS. This interaction, which will occur during the training workshops, is extremely crucial to the success of the DSS as an integration vehicle for PINEMAP.

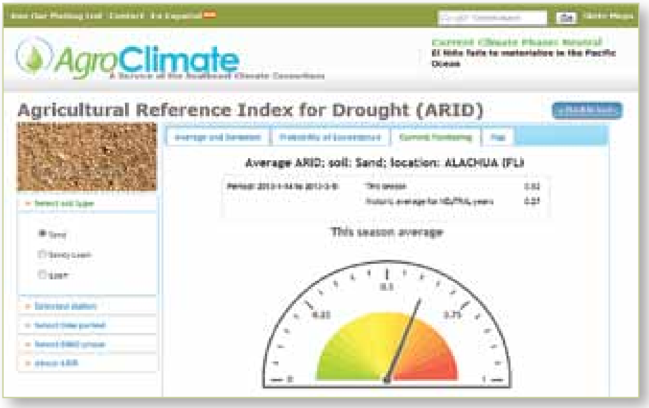

Figure 23.2. Agricultural Reference Index for Drought tool in the AgroClimate DSS, courtesy of the SECC (http://agroclimate.org/tools/ARID/).

24. Building Partnerships to Manage Forest Threats

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A key aspect of the PINEMAP project is building relationships and leveraging strengths. PINEMAP was designed to bring together research, education, and outreach to develop and disseminate the information necessary to increase forest resilience and sustainability under variable climates. One aspect of the PINEMAP Extension team's efforts is to produce educational publications to create new awareness of forest threats from climate change. It was natural that the Extension team saw unique value in the work of the U.S. Forest Service's Eastern Forest Environmental Threats Center (EFETAC). PINEMAP is partnering with the center to rewrite the EFETAC state-oriented factsheet, which succinctly reviews forest threats and associated management solutions for North Carolina, to apply to the region covered by PINEMAP.

> A southern region forest threats fact sheet *(Southern Region: Forest Threats and Management Options for Healthy Forests)* is being developed. The new product is crafted with a focus on PINEMAP priorities and adaptation to current and emergent forest threats.

The foundation of our collaboration with EFETAC is the Template for Assessing Climate Change Impacts and Management Options (TACCIMO). TACCIMO is a web information interface and database that facilitates the integration of climate change science and natural resources peer-reviewed science. TACCIMO provides a user-friendly literature search of thousands of papers on climate projections and resource planning and management options. TACCIMO was initially developed for national forest planners, but it is now available for public consumption. With an eye toward expanding the reach of TACCIMO, our EFETAC partners jumped at the chance to share their product with a growing PINEMAP audience.

After several conference calls and in-person meetings, a plan was created to develop a southern region forest threats fact sheet *(Southern Region: Forest Threats and Management Options for Healthy Forests)*. The new product is crafted with a focus on PINEMAP priorities and adaptation to current and emergent forest threats. Increased risks from insects, diseases, drought, and invasive species form the backbone of the fact sheet within a focus on *actions* that foresters and landowners can implement to reduce risk.

TACCIMO staff originally developed a general fact sheet on forest threats for the North Carolina region, and then in collaboration with PINEMAP Extension staff, created the second fact sheet for the southern region. Although the southern region encompasses numerous forest types, the new fact sheet captures the primary forest types and threats. This fact sheet has been peer-reviewed and will soon be available for distribution.

We have already begun to create additional publications that explore individual forest threats (e.g., insects, fire, and invasive species) as well as suggested management techniques to adapt to or mitigate these threats. The PINEMAP Extension team is in the process of creating connections with other support organizations and ultimately to provide information to foresters, forest landowners, and others associated with forest management so that they can implement "climate-smart" land management and, in the process, increase forest resilience under climate variability.

PINEMAP integrates research, extension, and education to enable southern pine landowners to manage forests to increase carbon sequestration; increase efficiency of nitrogen and other fertilizer inputs; and adapt forest management approaches to increase forest resilience and sustainability under variable climates.

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USDA United States Department of Agriculture

National Institute of Food and Agriculture