Integrating research, education and extension for enhancing southern pine climate change mitigation and adaptation

Martin-reverse site visit questions

Question 1. Some additional details of the experimental design are needed. How many Tier 2 sites will there be? 20? And there appears that there will be 4 Tier 3 sites where factorial experiments will be established that will include rain reduction experiments. Will 4 sites give enough geographic coverage? What about the power? A recap of the different monitoring networks and the questions being addressed at each is needed.

The RFP required proposals to capitalize on existing monitoring networks in the region, and to develop and implement standard measurement methodologies on the network to monitor stores and fluxes of C, N and H_2O. Our network of existing southern conifer trials in the SE region is geographically and temporally very extensive, and our proposed monitoring network capitalizes on this breadth and depth. We have divided the network of existing trials into tiers to allow increasingly intensive measurements on subsets of the trials. Table 1 summarizes the characteristics of the three tiered monitoring network, including number of sites to be measured in each tier, treatments, measurements to be taken, and questions addressed in each tier.

Tier I will use the existing network of several thousand growth and yield cooperative (e.g., Shiver & Martin 2002, Russell *et al.* 2010) and U.S. Forest Service Forest Inventory and Analysis (FIA) permanent plots which blanket the region to provide extensive, spatially-explicit information on regional variability in productivity. A wide range of growth and yield trial series are available, some of which include management treatments such as planting density, thinning, fertilization, and weed control. Most of these plots have repeated tree inventory measurements over time and thus provide excellent information on spatial and temporal variability in tree productivity across the soil and climate factors in the region. It is unlikely that resources will permit the project to analyze the entire existing set of data from all trials, but we should be able to analyze hundreds of sites. While these sites will not provide direct information on all C and N pools, tree biomass dynamics (which will be derived from the inventory data and allometric relationships) dominate C and N flux relationships in most forest systems and so Tier I will be very informative given the number and distribution of sites. This Tier will have great utility for the development of improved growth and yield models (the standard for prediction of tree productivity under varying management regimes) and for verification and validation of simulation output from the biological models.

Tier II sites will be chosen from existing cooperative field studies and planted forest AmeriFlux installations (Noormets *et al.* 2010, Gonzalez-Benecke *et al.* 2010) which cover the full range of climate and soils in the region, and most of which include replicated silvicultural treatments. All of these trials have multiple historical tree inventory (typically survival, trees/acre, tree height and diameter) measurements; some have additional C and N budget measurements, as well. Tier II sites will be chosen to optimize variation in geography, soils, climate, stand age, and treatment (focusing on nutritional, competition control, and thinning or planting density treatments), as well as the strength of existing data for each trial. New, more intensive measurements on Tier II sites will enable standardized quantification of C and N pools and fluxes, including soil heterotrophic respiration, the key link between net primary production (NPP) and net ecosystem production (NEP). Included in the Tier II sites will be installations of a study currently being established by the Forest Nutrition Cooperative with support of the NSF Center for Advanced Forestry Systems that will use 15N to investigate the uptake efficiency and ecosystem fate of applied N fertilizer in loblolly pine plantations. A minimum of 20 loblolly pine stands across the South will be included in this study which will compare 15N labeled urea and three types of controlled release N fertilizers.

The number of Tier II sites was chosen after balancing budget constraints with the need for geographic, soils, age and treatment coverage. The region will be divided into four geographic "teams" to carry out Tier II (and Tier III) measurements: (1) TX A&M and Oklahoma State, (2) Auburn and Georgia, (3) Virginia Tech and NC State, and (4) Florida. While the actual number of sites measured within each group will depend on variations in distance to sites, age of studies, and other factors, we calculated that on average each team would be able to complete measurements on approximately 35 Tier II sites within their region over the five year period, for a total of 140 sites measured. Tier II is the heart of the monitoring network, representing a very ambitious and geographically diverse set of coordinated C and N pool and flux measurements. Carefully chosen ecophysiological parameters measured on a large fraction of the Tier II sites (maximum intercepted photosynthetically active radiation, estimates of "fertility rating," soil autotrophic and heterotrophic respiration) will enable us to parameterize key model inputs and characterize regional variation in important biological functions related to C and N cycling.

Data from the Tier I and Tier II sites will provide substantial information on climatic influences on productivity due to the wide geographic range and time span covered by the studies. However, climate change may produce combinations of conditions that have no analog in past climates. For this reason, we chose to situate the four **Tier III** sites across the full temperature and precipitation range of the species, and then to reduce precipitation by approximately 30%, which is at the extreme end of predictions for precipitation and/or soil moisture variation associated with climate change for the region. Because most planted pine forests are nutrient limited and nutrient management is widespread, it is important to examine the interaction of the precipitation treatment with an imposed nutritional gradient on this tier. While additional sites are often desirable, we think the proposed Tier III network represents the best balance of climatic variability with personnel and budget constraints. Intensive measurements of nutrient and carbon pool and flux and ecophysiological parameters will be undertaken on Tier III sites, enabling us to parameterize ecophysiological models for conditions likely outside the historical range of climatic variability encountered in the loblolly pine range, and therefore broadening the inference space for the models parameterized from these measurements.

Table 1. Overview of the three-tiered monitoring network.

Network Level	Number of Sites	Treatments	Measurements	Questions to be Addressed
Tier I	~ 500	Combinations of fertilization, competition control, planting density, thinning, stand age	Existing inventory data	How does tree productivity vary with climate, soils, stand development, and management factors? Verification and validation of growth and yield and carbon models.
Tier II	~ 140	Combinations of fertilization, competition control, planting density, thinning, stand age	Inventory, C & N pools, soil GHG fluxes and key ecophysiological model parameters on subset	How do above- and below-ground C and N pools and fluxes, as well as key ecophysiological modeling parameters, vary with climate, soils, stand development, and management factors? Parameterization, verification and validation of growth and yield and carbon models.
Tier III	4	Factorial combination of fertilization (control and “optimum”) and precipitation (rainfed and ~ 30% reduction)	Same as tier II, plus intensive C, N and H_2O ecophysiology	Same as tier II, plus extension of parameter space to climatic conditions likely not experienced within the historic loblolly pine range, and verification and validation of growth and yield, carbon, and water models.

Question 2: What about the lack of any N_2O measurements at any of the sites? There was concern among panel members that N_2O fluxes may not be simulated or otherwise accounted for. Why?

Several of the reviewers commented on the omission of N_2O measurements from our proposed work and felt that we would have a stronger proposal if N_2O were included in our analyses. We agree with the reviewers and now propose to measure both N_2O and CH_4 fluxes in the Tier II and Tier III installations along with the NH_3 and CO_2 emissions we originally proposed. This will enable us to conduct a more comprehensive evaluation of greenhouse gas fluxes from southern conifer ecosystems that is critically needed as part of a comprehensive lifecycle analysis (Cherubini *et al*. 2009; EPA 2009). One of the co-PIs (Dr. Strahm) recently obtained funding that will enable Virginia Tech to upgrade an existing gas chromatograph and optimize it for greenhouse gas analysis including N_2O and CH_4.

The omission of N_2O in the original proposal was a consequence of our focus on quantifying N fertilizer efficiency in southern conifer forest ecosystems, which is a key research question highlighted in the original RFP. Since the major loss mechanism following fertilization with urea in forest ecosystems is NH_3 volatilization, and relatively small quantities of N_2O are lost, N_2O loss will likely have little impact on N uptake efficiency of southern conifer plantations following fertilization. We thought it was important to address this priority as completely as possible, hence our focus on NH_3. However, even though N_2O accounts for only about 6% of anthropogenic greenhouse gas emissions, N_2O is a potent greenhouse gas. It is nearly 300 times more powerful in its greenhouse effect than is CO_2 (IPCC 2007). In addition, N_2O plays a role in ozone destruction. Therefore, we were remiss in failing to include N_2O in the original proposal and thank the reviewers for pointing out this deficiency.

Approximately one-third of the N_2O in the atmosphere originates in the soil. N_2O is a byproduct of two microbial driven N transformations in the soil. Nitrification is carried out by a group of soil nitrifying bacteria and is an aerobic process. Soil nitrifiers obtain energy from the conversion of ammonia into nitrate. During this process, a small amount of the ammonia is also converted to N_2O which is lost to the atmosphere (Castro *et al.* 1994, 1995; Basiliko *et al.* 2009). Fertilization of loblolly pine in the South with urea adds significant amounts of ammonia to forest soils which may stimulate the nitrification process and increase the potential for N_2O losses. The second pathway in soils that can result in N_2O losses is denitrification (Davidson *et al*. 1998). In anaerobic soils, denitrifiers utilize NO_3 as the terminal electron acceptor during the decomposition of soil organic matter. The majority of the NO_3 is converted to N_2 gas in this process, but small amounts of N_2O are also produced by denitrifiers. Nitrogen fertilization can increase production of N_2O in many sites. Recently, it has been questioned whether N_2O emissions are large enough in highly fertilized agricultural systems to offset C benefits of increased crop productivity (Crutzen *et al.* 2008). Unfortunately, much less is known about N_2O

in fertilized forest systems. Given these responses and uncertainties, we agree with the reviewers that it is critical that we measure the fluxes of N_2O.

Across the southern pine region, we expect the wide range of soil conditions to result in a variety of greenhouse gas emissions. In the anaerobic, low redox soils of the low lying regions, other greenhouse gases such as CH_4 may also be released to the atmosphere. Changes in CH_4 can also be important given high greenhouse warming potentials (GWP) of these gases. Relative to CO_2, CH_4 has a GWP of 62 over 20 years (about the length of a pine plantation rotation) and N_2O has a GWP of 275. Several of our Tier II sites and two of the Tier III sites will be located on poorly drained soils in the Coastal Plain. Similar to N_2O, CH_4 fluxes also tend to increase with soil moisture and following N fertilization (Megonigal 2004). In contrast, the well drained, upland forest soils such as those prevalent in many of our proposed Tier II and two of the Tier III sites are typically sinks for atmospheric CH_4 (Schlesinger, 1997, Price *et al.* 2003). Because the Tier II and III sites will be established on industrial field trials, most of which include N fertilization treatments, our monitoring network is uniquely suited to address these questions.

Proposed Approach

Three primary approaches are traditionally employed to quantify gas fluxes at the soil-atmosphere interface (Hutchinson and Livingston 2002): 1) estimates from diffusion theory combining measures of a diffusion coefficient of a gas with estimates of its concentration gradient based on Fick's law of diffusion, 2) micrometeorological techniques, like eddy-flux towers, which can integrate over larger spatial scales but can be prohibitively expensive to replicate across multiple sites, and 3) chamber methods where changes in gas concentrations can be measured by restricting the volume of air available for gas exchange. Chamber methods are ideal where discrete temporal and spatial observations are desired, and are adaptable to a wide variety of studies and sampling environments (Hutchinson and Livingston 2002). Further, they are relatively inexpensive, mechanically simple, yet powerful options to address the physical, chemical, and biological controls over soil-atmosphere gas flux (Holland *et al.* 1999). Chambers can be divided into two categories: static, or non-steady-state; and flow-through, or steady-state. Where the increased measurement sensitivity of very small fluxes is desired (*e.g.*, CO_2, N_2O, and CH_4), static chambers are optimal because they prevent gas diffusion into the atmosphere (Hutchinson and Livingston 2002). Where larger fluxes are to be measured at the same location for an extended period of time (*e.g.*, NH_3 volatilization following urea fertilization), flow-through chambers are ideal. Thus, for the measurement of soil-atmosphere GHG fluxes, we will deploy static chambers (Hutchinson and Livingston 2002) to evaluate N_2O and CH_4 fluxes at the Tier II and Tier III installations.

Static chambers will be manufactured in two parts: a permanent soil collar and a removable lid (Figs. 1 and 2). Both will be constructed to the specifications illustrated below and discussed in Hutchinson and Livingston (2002) and Holland *et al.* (1999). Soil collars will be installed at least one week prior to initial sampling to minimize disturbance effects from installation. On the day of sampling, the removable lid with silicone-filled rubber septa and vents to prevent pressure build up will be fitted onto collars. Samples of the headspace gases will be collected at 0, 15, 30, 45, and 60, and 120 min intervals using a gas-tight syringe and evacuated glass vial. Gas samples will be transported to Virginia Tech for analysis on a Shimadzu GC-2010 equipped with an electron capture detector (ECD), thermal conductivity detector (TCD) and flame ionization detector (FID). (Shimadzu Scientific Instruments, Columbia, MD).

We propose a two-phased sampling design for N_2O and CH_4. We will measure N_2O and CH_4 fluxes quarterly at a subset of Tier II sites chosen to represent contrasting soil drainage, and containing contrasting N fertilization treatments. If site and treatment differences are not detected after a year of sampling, the Tier II sampling will be stopped. If differences are detected, we may increase temporal sampling intensity at the Tier II sites to better develop flux budgets for the two gases. At the four Tier III sites, samples will be collected bimonthly over three years within all treatment combinations at each site. We believe this intensity of temporal sampling will be sufficient to assess treatment differences and to approximate annual fluxes. Regression of time by concentration will be used to estimate flux. Gas flux mass will be determined through the application of the Ideal Gas Law,

$$C_m = (C_y \text{ x } M \text{ x } P)/(R \text{ x } T)$$

where:C_m = mass (μg) per unit volume of chamber (m^3), C_v = concentration of the trace gas (ppm), M = molecular weight of the species (μg/μmol), P = barometric pressure (atm), T = air temperature (K), R = universal gas constant. From there, the trace gas flux (*f*) will be calculated by:

$$f = V \text{ x } C_{rate} / A$$

where V = internal volume of the chamber, A = cross sectional area of soil covered by the chamber, and C_{rate} = change in C_m over the period in which the static chamber was closed, including only data recorded when trace gas fluxes appear linear, and not affected by differential pressure gradients.

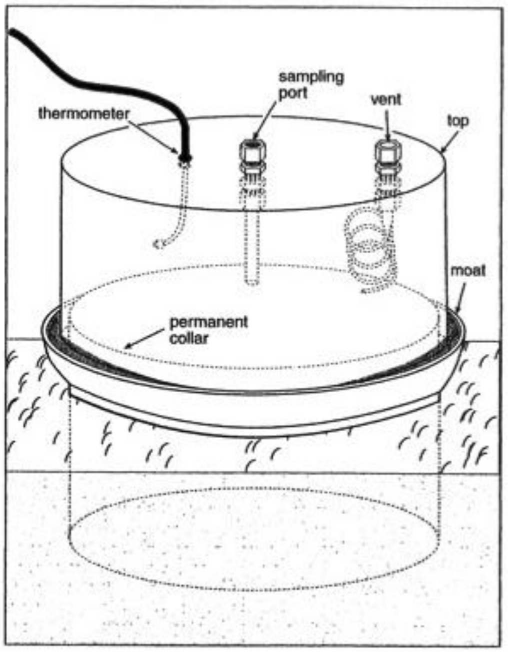

Figure 10.1. The recommended enclosure design including the vent, sampling port, thermometer, and moat for sealing the chamber to its permanent collar. Enclosure, permanent collar, and all fittings should be manufactured with inert materials: PVC, stainless steel, or aluminum. For measurement of reactive trace species, the enclosure can be lined with Teflon, but all materials should be tested to ensure that they do not adsorb, desorb, or otherwise react with the gas of interest. The moat of the permanent collar should be partially (and carefully) filled with water before placement of the enclosure. The water serves as a gas diffusion barrier, thus providing an effective seal. Vent dimensions and sampling port design are detailed in the text. Gastight fittings for the sample port are 1/4 inch Swagelock or Parker fittings. The enclosure can be tested in the laboratory by placing the enclosure in a shallow tray of water and testing for stable gas concentrations over time.

Figure 1 (Left). Schematic of a static chamber from Holland *et al.* (1999). **Figure 2 (Right).** A static chamber deployed in the field.

Question 3: There was much discussion among the panel about the LCA of regional forest management systems relative to various policy, climate and forest management scenarios. Some panel members felt the LCA should include the fate of wood and paper products. Also, the spatial resolution of the LCA was not clear, nor how the LCA would be parameterized. Please explain.

Life Cycle Assessment is a key component of our project and we agree with reviewers that clearer delineation of the boundaries is critical. In Aims 4 and 5, we will complete a comprehensive cradle to grave LCA accounting for carbon, nitrogen, water and energy footprints for producing forest products from planted loblolly and slash pine forests. In Aims 2 and 4, we will use this LCA together with biophysical and economic models for quantifying the impact of climate change and for comparing typical and alternative management scenarios on carbon sequestration and the effect on wood markets. In Aim 4, the results of the LCA will provide the basis for development of a bioeconomic model. In Aim 5, LCA will provide basic information for educators to use as they help youth compare products. Existing analyses may be used. The goal of this component is to help learners ask appropriate questions about products and understand the consequences of their purchases for carbon sequestration and climate.

LCA procedures are formalized in the ISO 14040 and 14044 environmental management standards and involve four phases: 1) goal and scope definition, 2) life cycle inventory (LCI) typically created in dedicated software such as GaBi or SimaPro that includes well accepted conversion factors, 3) life cycle impact assessment, and 4) interpretation that includes sensitivity and uncertainty analyses.

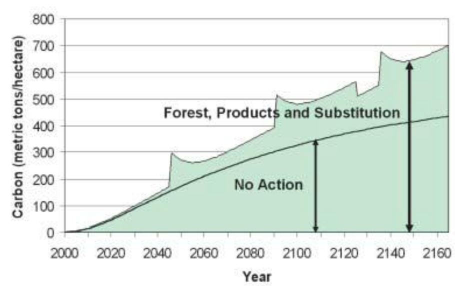

Figure 3: Comparison of carbon storage for natural unharvested forest and managed forests converted to building products. *http://www.corrim.org/pubs/articles/2006/OFRI_chapter07.pdf*

Life cycle assessments indicate that more carbon is stored when wood replaces concrete in construction of buildings than when the forest is not actively managed or harvested (Figure 3). Thus, our LCA will include the full Forest-Wood Chain. Within the boundary for the Forest-Wood Chain system there are three well recognized phases (adapted from Linder *et al.* 2010): 1) wood production (forest management), from stand regeneration to final harvest and transport to mills), 2) processing and manufacturing (mill conversion processes to transport and distribution of products); and 3) industry to consumer interactions, including type of product uses affecting product life-span. Our assessment needs to include all three phases in cradle to grave and cradle to cradle inventories to quantify the full carbon mitigation impacts of production forests and altered forest management.

We will focus on the main products produced from planted loblolly and slash pine forests. These include dimensional solidwood, plywood, oriented strand, medium density and particle board, as well as kraft linerboard used to make container board and fluff pulp. We are aware of the current interest in the potential of southern pine for bioenergy production, and will continue to monitor this area. If this appears to become a more important market, we will try to incorporate this into our research through collaboration.

In developing the LCA we will emphasize planted pine management. Members of our team have led the way in quantifying the carbon footprint for plantation grown loblolly (Markewitz 2006; Hubbard and Bowe 2008) and slash pine (Dwivedi *et al.* 2009; Gonzalez-Benecke *et al.* 2010) and we will expand on these efforts and build appropriate models in standard LCA software to link with available gate to gate conversion facility LCI. For comparison, LCA for other fiber/timber species in the United States (Harmon *et al.* 1996; White *et al.* 2001; Harmond and Marks 2002; Oneil *et al.* 2010; Puettmann *et al.* 2010) and other countries (Gundimeda 2001; Liski *et al.* 2001; Raimer *et al.* 2009; Linder *et al.* 2010; Palosou *et al.* 2010; Pingoud *et al.* 2001, 2010) are available from the literature. Well accepted models will be used to predict yields of roundwood for loblolly (Harrison and Borders 1996; Bailey and Fang. 2000) and slash (Pienaar *et al.*, 1996; Yin *et al.*, 1998; Logan 2005) pines. Harvested stems (from thinnings or clear-cuts) are categorized into three main product classes. Southern pine logs are merchandized based on stem diameter at 1.3 m height (DBH); sawtimber (> 10 in. DBH logs are sawn into lumber), chip-and-saw (> 6 and <10 in. logs are used to make small dimension sawn lumber and chips for use in papermaking) and pulpwood (<6 in. DBH logs used to make up pulp and paper). Merchantable volume, obtained from growth and yield modeling, will be transformed to biomass by multiplying by average specific gravity at a given age (Larson *et al.*, 2001; Peter *et al.* 2007; Gonzalez-Benecke *et al.* 2010).

The comprehensive LCA envisioned here is complex; fortunately, substantial progress in the field has already been made and many groups continue to make progress. Since 1996, the Consortium for Research on Renewable Industrial Materials (CORRIM) has completed many gate to gate, cradle to gate, and cradle to grave LCI for wood based materials (http://www.corrim.org/). For example in 2005 and 2010, CORRIM published special issues of Wood and Fiber Science that described the results of life cycle impacts of forest resource activities in the southeast (e.g., Pueltmann *et al.*, 2010) and life cycle inventories for gate to gate production of dimensional lumber (Milota et al, 2005), plywood, and oriented strand-board as well as cradle to gate LCI for medium density fiber and particle board, the major products manufactured from southern pine (CORRIM, Wood & Fiber Science volume 42 Sp. Issue and 37 Issue 3). In addition, CORRIM has reported life cycle assessments of the importance of stored carbon in residential buildings (Lippke *et al.*, 2010). CORRIM was recently funded from the USFS and DOE to conduct LCI and LCA for woody biomass conversion to biofuel (http://www.corrim.org/pubs/reports/annual/CORRIM_Annual_2010.pdf). In addition, AFRI is currently evaluating proposals for regional bioenergy centers. A requirement of all proposals is to complete LCA analyses for the feedstock and conversion processes being considered. If one of the proposals funded by this program includes southern pine, then we will work with this team related to biofuels. A LCA for the use of forest biomass in electrical production via co-firing with coal has been completed (Mann & Spath, 2001).

We propose to collaborate with CORRIM to leverage their existing gate to gate and gate to cradle models and LCI results for the southeastern US whenever possible. Members of CORRIM are also industrial members of the University-Industry Cooperatives and land grant universities collaborating on this proposal. CORRIM has used SimaPro for construction of their life cycle inventories and UF has a site license for SimaPro already. Where LCI are not available for specific products we will create our own using available industrial conversion efficiencies reported in peer-reviewed literature e.g., Peter *et al.* (2007).

All the product-types will be divided into different life span categories according to the classification proposed by Liski *et al.* (2001) and Gundimeda (2001) and adapted to loblolly and slash pine utilization patterns in the SE United States (Birdsey, 1996; Harmon *et al.*, 1996; Row and Phelps, 1991, 1996; Gonzalez-Benecke *et al.* 2010).

LCA interpretation requires an assessment of the LCI on specific parameters and quality of the data underlying them. Sensitivity analyses are done to assess the impact of varying inputs on output environmental values such as greenhouse gas emissions. Our sensitivity analyses will emphasize alternative forest management scenarios, harvesting and transportation and those processing parameters that are affected by the quality of the incoming pine biomass. Uncertainty analyses are done to assess the confidence of the LCI inventory results which are affected by errors in the data and variation in the efficiencies of processes. SimaPro facilitates uncertainty analyses by allowing users to set uncertainty for each parameters and performing Monte Carlo analysis.

Question 4: There was lack of clarity about how C sequestration in forestry plantation systems is defined, e.g. only below ground increases in carbon stocks or does it include above ground increases in wood stocks?

This project will consider two broad classes of forest system carbon pools: *in situ* and *ex situ*. *In situ* carbon includes all ecosystem carbon pools, including above- and belowground tree and understory plant biomass, above- and belowground detritus, and carbon in the mineral soil. The Aim 1 protocols described in the proposal are designed to quantify all of these *in situ* pools via direct measurement and allometry, following the international protocol for C accounting described by Law *et al.* (2008), modified for the relatively homogeneous structure of planted southern pine stands (Vogel *et al.* 2010). This protocol is in wide use by investigators in network-based research programs such as the AmeriFlux network and North American Carbon Program. Sampling will occur on previously-established inventory measurement plots for each site, which typically range from 0.01 to 0.10 ha, and will include replicate plots at each site. This protocol includes measurements of standing live and dead trees, understory vegetation, coarse and fine woody detritus, forest floor, and soil organic matter, roots, and chemical and physical properties collected at 0-5, 5-10, and 10-20 cm depths, then additional 20 cm depth intervals to 1 m, or as deep as possible.

Ex situ pools refer to carbon stored in forest products derived from harvested biomass. The biophysical modeling of Aim 2 is concerned primarily with sequestration of C *in situ*, while the Life Cycle Assessment of Aim 4 will include both *in situ* and *ex situ* pools, and will also account for C emissions associated with forest management and manufacturing processes (Markewitz 2006, Gonzalez-Benecke *et al. 2010*).

The standard measurement of C sequestration *in situ* is Net Ecosystem Production (NEP, Randerson *et al.* 2002), which is defined (disregarding typically small fluxes such as leaching of dissolved organic carbon and lateral transfers of C – Lovett *et al.* 2006) as:

$$NEP = GPP - R_a - R_h$$

where GPP is gross primary production, the total carbon fixed by plant photosynthesis, and R_a and R_h are autotrophic and heterotrophic respiration, respectively. This reduces to:

$$NEP = NPP - R_h$$

since net primary production (NPP) is defined as GPP less autotrophic respiration. Net Primary Production will be quantified by the inventory measurements and allometry in the Tier II and Tier III networks, while heterotrophic respiration in the soil (the primary source of heterotrophic respiration in plantation systems, Maier and Kress 2000) will be quantified with the gas exchange / root exclusion approach described in the proposal. As described in Aim 3, carbon data collected in the Tier II and Tier III sites will be used to parameterize the stand-scale model

3-PG (which simulates, among other parameters, NPP), and the stand-to-regional scale model CASA Express (which simulates, among other parameters, NEP).

Question 5: It was not clear whether changes in pests and pest ranges would be considered, an obvious gap for a single species forest system. Please respond.

In the proposed research, changes in pests and pest ranges are being considered in three ways.

Aim 2 proposes to conduct regional scaling modeling with changes in southern pine beetle (SPB) distribution (see response to Question 7 for more details).

Aim 4 proposes to conduct landowner level and regional scale modeling of SPB and fire to compare risks of status quo and altered management on timber value and C mitigation. This research will reveal the impact of climate change on the risk of disturbance due to fire and SPB outbreaks and the contribution of adapting management to improve C mitigation on wood supply.

At the regional scale, variations in forest and climate conditions, disturbance occurrence and severity, and human interventions along the climate gradient in the South provide rich information for modeling climate change impacts and adaptations. We will employ panel data modeling to establish the relationships between the risk of forest fire or SPB infestations and explanatory variables including mean and extreme temperatures, precipitation, forest stand structure and conditions, site quality, forest management practices, and other factors. Historical data on forest fires, SPB infestations, and climate along with forest stand information drawn from the Forestry Inventory and Analysis database (US Forest Service Southern Research Station, 2010 FIA Data Center, Forest Inventory and Analysis, Knoxville, TN) will be used in modeling. The regression models will be estimated with and without the inclusion of adaptation activities including stand density control, tree species mix and improvements, and salvage harvest. The models will reveal (a) the impact of climate change on the risk of disturbances and (b) the contributions of adaptations to mitigating the risk under climate change. The risk estimates will further be converted into economic losses in terms of timber and carbon values based on timber and carbon prices and projected future forest areas in the South under climate change. The findings will provide insights into the impact and costs (damage) of the disturbances under climate change and the role of adaptations in mitigating the impact, guiding the development and deployment of forestry adaptation strategies.

Aim 3 proposes to identify alleles in genes that control resistance to fusiform rust, pitch canker and southern pine beetle. Identification of genes and/or tightly linked markers for resistance can then be used to accelerate breeding as well as screen the current generation of germplasm that is being deployed for the presence of resistance genes. Loblolly pine trees with higher rates of oleoresin flow are more resistant to southern pine beetle (SPB) (Knebel *et al.* 2008). The diterpenes present in oleoresin are effective antifungal compounds. Mono and diterpene contents in oleoresin are under genetic control (Squillace *et al.* 1980). Recently we have shown in clonal loblolly pine studies that oleoresin flow is also under genetic control (Westbrook, Zhang, Peter, Davis unpublished). Thus, mapping genes for oleoresin flow and composition will provide insight into the mechanisms of SPB resistance, one of the most important insect pests on southern pine.

We did not propose to directly assess changes in pests and pest ranges in the CAP, in part because the standard grant competition solicited proposals for this kind of research. Consequently, a subset of co-PIs submitted a proposal "Rapid Breeding and Disease Management for Climate Adaptation in Southern Pines." In this standard grant proposal, Objective 3 proposed to develop spatially explicit models to forecast shifts in pathogen and insect distributions as functions of climate change scenarios by conducting comprehensive risk modeling leading to updated range maps for fusiform rust and southern pine beetle, the two most important diseases for loblolly and slash pine. If this complementary standard grant is funded then these data would become available for use by the whole CAP research team. If this proposal is not funded then we will work with existing functions and models relating pathogen and insect dynamics to climate factors (see response to Question 7 for more details).

Question 6: The focus is exclusively on loblolly pine. Is there potential for other cropping systems in case climate change results in severe disease or insect pressure that reduces the viability of this single species system? This gets to the sustainability issue.

The RFA was for southern conifer production forests. In the proposal loblolly pine (*Pinus taeda*) was emphasized due to the widespread planting of this species across the region, occupying ~ 80% of the pine estate. The majority of the rest of the pine estate is planted slash pine (*Pinus elliottii* var. *elliottii*). Thus, loblolly and slash pine account for >98% of the planted pine forests in the region. More recently, interest in planting longleaf pine (*Pinus palustris*) has grown, but much of this is for restoration and not for wood production. Shortleaf (*Pinus echinata*) is the other main southern pine with a broad natural range similar to loblolly (Figure 4). Shortleaf is not planted for commercial production due to its slow early growth. In addition to these major species, some minor species are also planted, notably sand pine (*Pinus clausa*) in FL, Virginia pine (*Pinus virginiana*) in the northern most part of the southeast region.

Although Aims 1, 2 and 4 emphasized loblolly pine, similar work will also be completed with slash pine. Slash pine accounts for about 20% of the pine estate and our knowledge of its biology is close to that of loblolly pine with the exception of DNA sequence information, where virtually none is available for slash pine. In Aim 3 we will develop seed deployment models for loblolly and slash pine based on provenance and performance data from the advanced generations in the tree improvement cooperatives. We will also develop seed deployment models for longleaf and shortleaf with data from the Southern Pine Seed Source Study (Schmidtling, 2001). To the extent possible selections of longleaf pine tested in the tree improvement cooperatives will also be used.

Slash pine can grow on wet sites because of its ability to make aerenchyma tissue in its roots, whereas loblolly pine does not survive on sites with long periods of standing water. Consequently, slash pine is planted on flatwood sites in LA, FL, and GA that are too wet for loblolly pine. Slash pine is also planted on nutrient poor sites where it will often grow better under low fertilizer input systems than other southern pine species. Compared with loblolly, slash pine growth is not as responsive to fertilization and the timing of thinning is more critical due to the slower rate at which crowns grow and respond to release in this species. In general, slash pine is considered less susceptible to tip moth and southern pine beetle than loblolly, but even healthy trees are colonized during outbreaks (Table 2).

The Western Gulf Tree Improvement Cooperative and Cooperative Forest Genetics Research Program are genetically improving slash pine. Slash pine genetic improvement is the main activity of the CFGRP and they are in its 4th cycle of breeding and selection, the same as loblolly pine in the NCSU Tree Improvement Program and WGTIC. Compared with unimproved loblolly pine, unimproved slash pine is more susceptible to fusiform rust and pitch canker. Consequently, improving rust resistance has been a major focus for the breeding effort and 3rd

generation slash pine selections are now highly resistant to fusiform rust. Slash pine is planted outside of its natural range on wet sites in LA. With increasing temperatures, the possibility exists to plant more slash pine on sites where loblolly would typically be planted; however, the native range of slash pine is significantly more restricted than loblolly pine (Figure 3). The yield of slash pine tends to be lower than loblolly pine, particularly with more intensive fertilizer regimes. Thus, slash pine is an excellent alternative to loblolly in the southern part of its range.

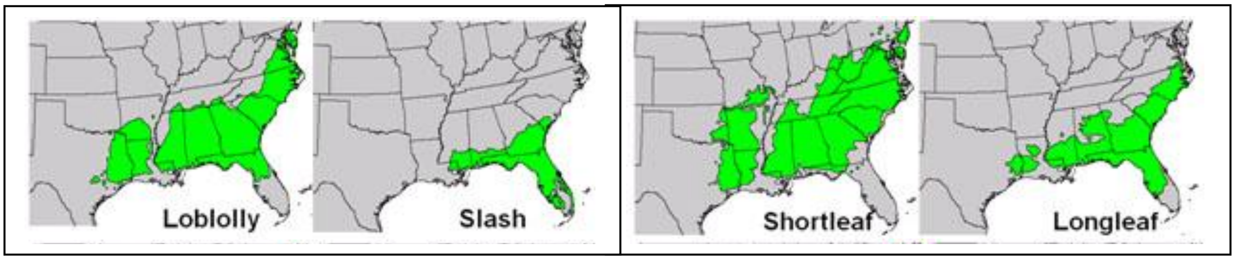

Figure 4. The natural ranges for the four main southern pine species

Longleaf pine accounts for <2% of the pine estate. Longleaf pine has a broad range more similar to loblolly pine. Longleaf typically grows on drier sandhill sites than loblolly or slash pine. However, our knowledge of planted longleaf pine is significantly more limited due in part to its having a prolonged grass stage, an important adaptation to fire dominated ecosystems. Recently, silvicultural techniques to accelerate release of longleaf seedlings from the grass stage have been successful and more acres are being planted with containerized longleaf seedlings. These plantings are typically for ecological restoration rather than wood production. Nurseries are selling seedlings with wild selections of longleaf tested by the Tree Improvement Cooperatives. Thus, tree improvement cooperatives have experience with longleaf pine reproduction. However, contrary to "common" knowledge, planted longleaf pine grown with fertilization to speed progression through the grass stage and to promote growth are susceptible to fusiform rust, in fact more so than the latest generations of loblolly and slash pine. Longleaf pine resistance to southern pine beetle is fairly good due to the relatively high oleoresin flow typical of this species. Longleaf has potential for wider planting, especially now that silvicultural treatments can accelerate early growth past the grass stage. There is a small base of first generation tested material but further genetic improvement will need to overcome the episodic flowering characteristic of this species.

A small subset of CAP co-PIs (L. Samuelson, K. Johnsen, T. Martin) have recently been awarded five years of funding from the Department of Defense to measure carbon pools in longleaf pine forests and develop models for carbon sequestration (http://www.clpe.org/NEWCLPE/researchnew.html). This information will be available to the CAP for comparison with loblolly and slash pine, and to use in regional simulations to examine tradeoffs associated with species deployment alternatives.

Table 2. Comparison of the Biology and Management and Genetic Improvement Status of the Four Main Commercial Southern Conifer Species

Species	% of Planted Forestland in SE	Growth Rate	Status of Genetic Improve-ment	Status of Silviculture	Disease & Pest Tolerance	Drought & Fire Resistance
Loblolly	80	Highest rate of early growth, most responsive to fertilization	3rd cycle nearing production; 4th cycle of breeding & testing underway	Advanced – regionwide trials for nutrition, stand density, competition control…	Strong rust resistance, moderate SPB resistance	Moderate to high drought tolerance, especially western provenances
Slash	18	Early growth rate second to loblolly, not as responsive to fertilizer	3rd cycle nearing production; 4th cycle of breeding & testing underway	Advanced – rangewide trials for nutrition, stand density, competition control…	Moderate to strong rust resistance, better SPB resistance relative to loblolly & shortleaf,	Moderate drought tolerance,
Longleaf	<2	Early growth significantly less than loblolly & slash, responsive to fertilization	1st cycle in production; no active breeding	Early stage – competition control to rapidly pass through grass stage, most intolerant to competition	Weak to moderate rust resistance, good SPB resistance compared with loblolly & shortleaf	High drought and fire tolerance
Shortleaf	negligible	Slowest early growth rate of all 4 spp	none	Minimal	Strong rust resistance, Weakest resistance to SPB of all 4 spp.	High drought tolerance, Better fire resistance than loblolly & slash

In conclusion, the extensive range, substantial plasticity, widespread planting and responsiveness to changes in silviculture, advanced generations of germplasm and genomic resources make loblolly pine the best model tree species to contribute substantial short-term gains in adaptability and mitigation emphasized in the RFA.

Reviewers are concerned about the apparent paucity of discussion regarding the role of management practices in controlling climate change related changes in risk to fire and pests.

We fully agree with the reviewers that management practices are crucial to minimizing risk to fire and pests. Common widespread practices that forest managers currently use to protect pine plantations against pests and fungal diseases include : 1) promoting tree vigor through herbaceous and woody competition control, nutrient management and stand density control, 2) planting stock with improved genetic resistance, 3) delayed planting after site preparation, for pales weevil, 4) spraying approved insecticides and fungicides in very limited situations and 5) rapid removal of infected trees. In addition, prescribed fire is another alternative, but the large forest plantation owners typically don't practice this because of liability exposure.

Controlling damage from pest and fungal attack in southern pine plantations is challenging due to the large size of trees, decades long rotation length and the modest per acre value of the crop at harvest. Together these factors limit approaches that may typically be used in agriculture such as rotating crops and applications of agrichemicals. For example, in forestry operations the spraying of fungicides is limited to the nursery and insecticides principally to seed orchards. During the rotation the primary management practices are thinning and fertilization to maintain tree vigor. In general stands are managed proactively to promote growth of the stand throughout the rotation because of the economic incentive, thinning helps control SPB infestation and damage. The regional simulations in Aim 2 and Aim 4 will include assessment of management scenarios intended to reduce the risk of damage from fire and pests. Additional detail about disturbance scenario modeling can be found in the response to Question 7.

Question 7: Ostensibly, the experimental manipulations may help with decisions to improve economic efficiency but don't mimic conditions such as extreme temperature or precipitation patterns. The model simulations claim to analyze disturbance scenarios, but no examples of the scenarios are provided. Please provide detail.

While alterations in timing and duration of droughts or extreme temperatures are predicted to be an element of changing climate, simulating these factors in forestry field experiments is extremely difficult and beyond the scope of this project. While a number of studies (most or all carried out by co-PIs on this proposal) have examined the effects of increased precipitation (irrigation) on planted pine (Albaugh *et al.* 2004, Allen *et al.* 2005, Samuelson *et al.* 2008, Gonzalez-Benecke and Martin 2010), no large field studies, to our knowledge, have applied throughfall exclusion treatments to planted pine in the SE U.S. While they will not provide direct data on the effects of altered timing or duration of droughts, the reduced precipitation treatments in the Tier III sites will provide unprecedented information about the response of loblolly pine to reduced soil moisture under a range of silvicultural and geographic conditions.

Disturbance from insects, wildfire, and hurricanes cause significant damage to forest resources each year in the U.S. Climate change may impact the frequency and severity of some natural disturbances. Simulations predict that the frequency of severe hurricanes will increase, while the frequency of less severe storms will decline. Decreased rainfall regimes, if coupled with increased temperature, would likely result in increased frequency and possibly intensity of wildfires (Twilley *et al.* 2001; Sugimura *et al.* 2008; Bowman *et al.* 2009). The research we proposed primarily dealt with climate change effects on disturbances through the model simulations in Aim 2 and 4, and through genetic research in Aim 3.

Fire is the most important disturbance shaping southeastern forests. In many cases, the frequency and intensity of fire is the primary determinant of ecosystem composition and structure (Myers and Ewel 1990). Changes in wildfire frequency would likely impact the distribution of ecosystem types on the landscape. Carbon sequestration would be affected by altered wildfire frequency or intensity in two ways. First, increased wildfire frequency, regardless of intensity, almost invariably decreases rates of carbon sequestration through direct combustion of biomass carbon (Tilman *et al.* 2000; Fellows and Goulden 2008). Second, more frequent stand-replacing wildfires will skew the age distribution of forests on the landscape downward, which will alter carbon sequestration since very young stands in the region tend to be carbon sources (Clark *et al.* 2004; Binford *et al.* 2006).

Hurricanes can create massive forest disturbance, with resulting dramatic reductions in carbon sequestration (Xiao *et al.* 2008) due to decreased leaf area and structural damage (Powell *et al.* 2006). Similar to fire disturbance, the "resetting" of forest succession by hurricane disturbance can also have significant impact rates of carbon sequestration.

Insect population and outbreak patterns are affected by climate. Interactions of insects with climate can be quite complex, since climate will affect, sometimes independently, three different factors that influence outbreak dynamics: (1) the population dynamics of the pest; (2) the physiological resistance of the host species; and (3) the population dynamics of antagonistic organisms like mites and fungi (Ayres and Lombardero 2000, Hofstetter *et al.* 2007). For the purposes of this project, existing information on climate effects on pest populations and outbreaks (such as Ungerer *et al.* 1999) will be used, in combination with climate projections, to simulate altered pest outbreak dynamics.

Aim 2: The altered precipitation and temperature regimes predicted for the region may increase the frequency and/or intensity of forest wildfires. We will assess the effects of these changes on forest carbon dynamics in the region, and will evaluate mitigation approaches under altered climate scenarios. Climate forecasts will be used to drive the Florida State University Center for Ocean-Atmospheric Prediction Studies wildland fire model and other appropriate wildland fire risk models to generate fire probabilities under the altered climate scenarios. A probabilistic approach will be used to assess the changes in forest age class distribution in the region caused by altered frequency of stand-replacing fires. The age class distribution data will be used to model forest carbon sequestration using both existing (Binford *et al.* 2006, Gonzalez-Benecke *et al.* 2010) and new carbon models developed over the course of the project. Management approaches such as prescribed fire, thinning, and fuels reduction treatments will be assessed using spatially explicit tools such as the Southern Fire Risk Assessment System (http://www.southernwildfirerisk.com/), which will generate altered wildfire probabilities, which will in turn be used to generate additional age class distribution maps. Forest carbon sequestration will again be estimated for the alternative management scenarios, but with new carbon model runs which account for the effects of prescribed fire on understory and forest floor carbon pools.

The population dynamics of the most important native southern pine insect pest, the southern pine beetle (*Dendroctonus frontalis*), are affected in part by temperature regimes, with minimum winter temperature serving as a good predictor of population dynamics and outbreak potential (Ungerer *et al.* 1999, Figure 5).

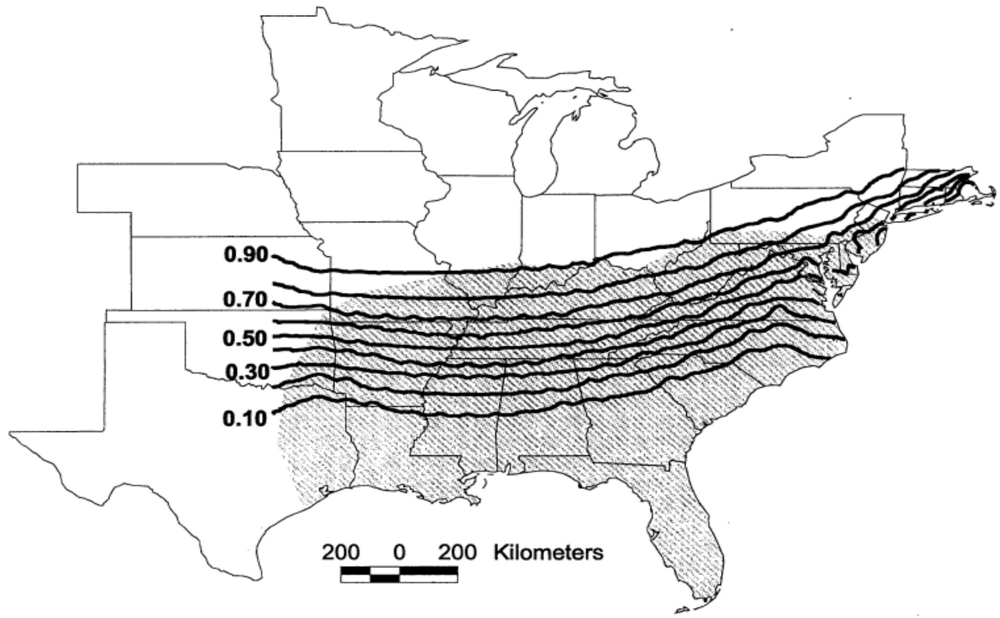

Figure 5. Annual probability of reaching the lower lethal temperature for *Dendroctonus frontalis*. Maximum reported *D. frontalis* distribution is shaded. (Ungerer *et al.* 1999).

We will use relationships such as those reported in Ungerer *et al.* (1999), in combination with future climate scenarios, to simulate potential changes in southern pine beetle population dynamics and outbreak potential. The carbon balance effects of these changes can then be simulated using carbon models given simulated tree mortality rates from outbreaks. Similar approaches will be taken to simulate the effects of altered hurricane frequency or severity.

Aim 3: We will develop new seed deployment guidelines by relating provenance and progeny trial growth data with climatic variables. These analyses may also be valuable in predicting the susceptibility of germplasm to biotic stress associated with altered temperatures and precipitation. In general, trees that are not growing are more susceptible to SPB attack.

Aim 4: At the regional scale, variations in forest and climate conditions, disturbance occurrence and severity, and human interventions along the climate gradient in the South provide rich information for modeling climate change impacts and adaptations. We will employ panel data modeling to establish the relationships between the risk of forest fire or SPB infestations and explanatory variables including mean and extreme temperatures, precipitation, forest stand structure and conditions, site quality, forest management practices, and other factors. Historical data on forest fires, SPB infestations, and climate along with forest stand information drawn from the Forestry Inventory and Analysis database (Southern Research Station, 2010 FIA Data Center, Forest Inventory and Analysis, Knoxville, TN) changes in pest and pest ranges coming from climate modeling results from Aim 2 described above. The regression models will be estimated with and without the inclusion of adaptation activities including stand density control, tree species mix and improvements, and salvage harvest. The models will reveal (a) the impact of climate change on the risk of disturbances and (b) the contributions of adaptations to mitigating the risk under climate change. The risk estimates will further be converted into economic losses in terms of timber and carbon values based on timber and carbon prices and projected future forest areas in the South under climate change. The findings will provide insights into the impact and costs (damage) of the disturbances under climate change and the role of adaptations in mitigating the impact, guiding the development and deployment of forestry adaptation strategies.

Question 8: There is a major emphasis on analyzing the genetics of breeding and natural populations to discover alleles in genes that control important adaptation and mitigation traits to climate change. Can much progress be made on this front in a 5-year period?

In the next 5 years, we are well positioned to discover many alleles in genes controlling productivity, growth response to nitrogen fertilization and adaptive traits using association and linkage mapping approaches. Through previously funded NSF Plant Genome ADEPT2 and the AFRI CTGN projects, we have used association genetics to test for significant associations between ~4800 SNPs in 4400 genes and traits in multiple loblolly pine breeding populations, including ADEPT2 and CCLONES -two of the three populations proposed to be studied in this proposal. This research has demonstrated the feasibility of this approach and identified significant SNPs associated with growth, fusiform rust and pitch canker resistance, water relations, anatomical, chemical, and mechanical wood property phenotypes in loblolly pine. In Aim 3, we proposed to work with 3 populations all of which already have been established in field trials. Two of these populations are 9 years of age and we have excellent phenotype data from these trials (Table 3). To complement existing phenotype data, we propose to collect oleoresin flow and chemical composition, cold tolerance, additional growth and water relations phenotype data to conduct association mapping with our existing SNP genotype information as well as add new genotype data to be collected. The ADEPT2 population was established in the field this past year and growth and adaptation phenotypes will be measured throughout the project time period.

Table 3. Overview of Populations for Allele Discovery

Name	Genetic Structure	Field Tests	Age (Yr)	Available Phenotypes	Available Genotypes
ADEPT2	435 unrelated parents from across south	3 sites (GA, FL, TX) with clonally propagated rooted cuttings	1	2 yr nursery bed growth, foliar ^{13}C & N, mRNA levels of ~200 transcripts, foliar metabolome, pitch canker resistance	77 SSR; 4800 SNPs
CCLONES	62 full sib families from 31 parents from the Lower Gulf Elite Pop.	6 sites (GA, FL) with rooted cuttings & seedlings	8	Annual growth, height growth phenology, crown dimensions, foliar ^{13}C, wood anatomical, chemical and mechanical properties, fusiform rust and pitch canker resistance	77 SSR, 4200 SNPs
PSSSS	140 unrelated mother trees crossed with the same 40 father pollen mix; 20 mother trees from each of 7 regions east of MS river	17 sites (AL, GA, FL, NC, TN, SC, VA) with seedlings	14-16	Growth years 4 & 8	none

Our main barrier for discovering more alleles in key genes is the availability of a genome sequence and high throughput genotyping data from our populations. The 2011 AFRI Bioenergy RFA requested proposals to sequence the loblolly pine genome. Successful completion of a draft genome will greatly enable our goal to discover all of the key alleles in important genes controlling productivity and adaptive traits. We expect a draft genome sequence to become available during the second year of this project. Here we propose to dramatically improve the SNP coverage in our 3 study populations by high throughput next generation sequencing. Discovering alleles in genes associated with productivity and adaptive traits will enable rapid screening of germplasm in breeding and deployment populations that will help guide deployment and assist with applied breeding. As all three southern pine tree breeding programs and their constituent member organizations are part of this CAP, useful tools in the form of genetic markers, etc. will be rapidly adopted. Furthermore, since these programs supply 100 percent of the improved planting stock for the southeast, any gains will be quickly deployed.

Question 9: Much of extension plan relies heavily on the concept that the extension foresters partner with state climatologists; this is an interesting but needs to be assessed for feasibility. Just how are climatologists involved in the project? How the SECC is involved? Developing joint climatologist/extension partnerships appears to be a good tactic but the objective and outcomes are not well explained. Please provide these. How will these activities be integrated with the research components that address tree testing?

Response to concerns about the Climate/Forestry Extension Partnership:

The Southeast Climate Consortium (SECC) is a major partner in our extension approach (http://www.seclimate.org/). The SECC was co-founded and is co-directed by Jim Jones, a UF faculty member, who is also co-director of the Florida Climate Institute (http://www.floridaclimateinstitute.org/). Dr. Jones will serve as conduit to the SECC and as a senior advisor to our project. The SECC has a long and successful history of working with the research and extension community for agricultural crops and desires to expand their efforts to the forestry community. The SECC website is currently limited in the amount and type of forestry information they can provide their clients, and this climate/forestry Extension effort will provide extensive improvements to this critical area. The State Climatologists from NC, GA, FL, and AL are all members of the SECC and state climatologists across the southern conifer region (Texas through Virginia) have agreed to support this project and participate with outreach and extension activities. Many (VA, NC, SC, GA, AL, FL, TX) have already established communication with local forestry experts. The climate scientists are primarily located at participant Universities and all have a common mission to support the advancement of climate information and science application and education. These scientists serve as a truly local resource for stakeholders as well as state forestry science and extension faculty. Moreover, these climatologists have active communication and networking through the American Association of State Climatologists (AASC).

State climatologists will formally support the proposed research, extension, and outreach activities in four ways to meet the extension objectives:

1. <u>Local Training:</u> Each state climatologist will become a member of the state extension project delivery team to help plan and execute local workshops and distance education training programs that are developed at either the state or regional level. The climatologist will review materials to ensure the climate science is effectively communicated and serve as the state resource for questions and information. For planned field training events, a climatologist will present information related to climate science in general and the project specifically and be available to answer questions. Based on experience developed with the Southeast Climate Consortium, the most effective training will include both climate and forestry extension experts.

2. <u>Climate Expertise Dedicated to Extension</u>: A dedicated climatologist based at NC State University will be an integral partner and climate leader on the regional extension team.

This scientist will have training and experience with extension work through the Southeast Climate Consortium and will develop the climate science training materials in coordination with the regional Extension forestry leaders and facilitate efforts with the State Climatologists across the region. This climatologist will make presentations to industry members at annual cooperative meetings.

3. Climate Expertise to Support Research: State climatologists have diverse academic disciplinary training – many are also experts in climate modeling, use of remote sensing, air chemistry, and applications of climate to production agriculture and forestry. These scientists will be available as resources for the research team to help use climate science effectively in experimental design, application models, and genetic studies. Climate specialists, like forestry Extension specialists will also be invited to participate and provide assistance to the research teams as formal members of their efforts. A full understanding of the strengths and capacities of the various climatologists and Extension foresters will be determined at the outset of the project. Teams will have this information as they begin planning and implementation of the proposed research.

4. Integrating Climate and Forestry Research and Extension Expertise: The extension products will require that researchers and climatologists provide the content and State Extension Specialists provide guidance on the distribution system and strategies that will increase understanding of climate change and its effects on production pine forests. As a result, the development and implementation of the extension products are the essence of integration. A central mechanism for this integration is the Decision Support System (DSS) which requires contributions from forest and SECC climate researchers and extension specialists so that it is accurate as well as useful. We will follow the successful approach that the SECC used to develop a similar system for agricultural crops. The DSS will be developed iteratively and interactively in four 4 phases across the project period, involving large numbers of co-PIs (see response to Question 11 for more details). The DSS will enable forest managers and landowners to understand their management options to adapt forests to improve carbon mitigation even as climate changes. In addition to the DSS, the seed source deployment models will need to engage geneticists and climate specialists. A needs assessment with a stratified sample to elicit responses from underserved landowners, those living in different climate zones, and those with varying levels of education and financial resources will help shape both the extension products and the research questions to be able to respond to each audience appropriately.

Regarding further interactions with the SECC:

Several members of the extension team are already involved with SECC, including the State Climatologists in NC, GA, AL, FL and Dr. Jim Jones, a highly regarded agricultural systems modeler. Moreover, key members of the project leadership, research, and education teams are located at SECC member institutions and are well positioned to use the combined experiences of the SECC. The SECC has a long history of working with the research and extension community for agricultural crops and desires to expand their efforts to the forestry community. There are several goals in the extension team that will specifically explore SECC resources, including:

1. Use of the open-sourced version of AgroClimate.org as a framework for building community decision support systems
2. Use of SECC social scientists and their assessment experience and activities to help determine local information needs and capacity
3. Use of SECC climate research, including regional climate modeling and model downscaling experience and resources to drive both research applications and decision support systems.

As in other aspects of this trans-disciplinary, integrated project, effective working relationships require more than periodic conference calls and an expectation of "working together." Project lead climatologists and project lead forestry Extension specialists will schedule a specific session at the first project meeting (early 2011) to plan how best to utilize the combined skills and capacity of their disciplines and networks to most effectively collaborate at the local, state and regional levels. Considerable effort will be spent at this initial meeting discussing concepts and issues of climate science-forest management interactions with both the extension and research teams. Prior to the meeting surveys will assess existing knowledge among current Extension forestry specialists on climate science and forest management knowledge among climate science specialists, and of extension programs and strategies among researchers. In this manner, a strong co-learning environment will be built between the climate outreach specialists, the Extension foresters, and the research community. The proposed extension goals will serve as a template for both a five-year action plan and five annual plans of work. A model state plan will be developed and distributed to all state 1862 and 1890 Forestry Extension project leaders and contacts, even in southern states not engaged in the research activity.

Reaching and Engaging Underserved Audiences:

Across the South, 1890 land-grant institutions have a responsibility to conduct extension programs. Faculty who successfully reach underserved landowners with natural resources programs will be part of the state climate/forestry extension teams to deliver programs and will work closely with the two Project co-PI's from 1890 universities. Landowners in other states will be recruited with the same strategies that are effectively used by these institutions—through community groups and churches, through peers and individuals, and through community events. We anticipate that the successful strategies of the 1890's will help other institutions develop and implement better programs for reaching underserved landowners. Furthermore, entities such as the Federation of Southern Cooperatives (a group representing the underserved farmers and forest owners in the South) will be invited to participate at regional and state planning events.

Institutions that have forestry/natural resources undergraduate programs will be invited to submit applicants for our undergraduate research and education program (ForCCURE). Their work with local schools can help build future generations of better informed landowners.

Regarding measurable extension impacts, effectiveness and outcomes:

Number of landowners and acres expected to be reached

Faculty who direct or participate in the SE University-Industry Cooperatives expect to reach corporate and non-corporate forestland owners who manage over 20 million acres. In addition, forestry consulting companies who are members of the cooperatives manage an additional 7 million acres of non-industrial private forestland (NIPF). Thus, through the cooperatives alone we anticipate reaching forest professionals who manage over 25 million acres of planted southern pine land.

Based on existing Forest extension programs, we project that at least 1,000 landowners in each of ten states (> 10,000 landowners) will be reached in years 1-3 by extension programs and products. We anticipate these landowners will manage an average of 100 acres of forest land each. We also project to reach at least 3000 professional land managers through certified CEU programs. Each is responsible for management practices affecting on average 10,000 acres. In addition forestry consulting firms will be reached through annual University-Industry Cooperatives.

Furthermore, we plan to involve at least 20 landowners across the south in the planning, establishment, and detailed demonstration of key management strategies (stand establishment) on the landowners' property. This will provide the all important "hands-on" outcome results to help determine what is truly important to the stakeholders, and a method to disseminate information long after project funds end (since forest management is a long-term project and may take longer than 5 years visualize results of activities).

Behavior Changes, Gain in Knowledge, and Adoption of Practices

While climate change may motivate our interest in mitigation and adaptation behaviors, it is not necessary for landowners to share our conviction because other values can also motivate appropriate change in behavior. The prospect of greater economic return from participation in carbon markets, for example, only requires they understand the costs and benefits of participation. Our initial data collection activities will help us determine which beliefs are entrenched and where information is lacking in different types of audiences. For example, the Climate and Energy Project in Kansas is an excellent example of successfully separating climate change from attitudes about thrift, patriotism, economic prosperity, and spiritual conviction and rallying residents to take meaningful steps to conserve energy (NYT, October 18, 2010).

Extension foresters work with social science specialists to design appropriate surveys and sample frames that provide reliable and valid results. This is standard procedure in Extension and several Extension forestry projects. Baseline data will be collected prior to educational efforts on beliefs, knowledge, current practices, and behaviors regarding forest management and climate change. Post educational surveys will collect info on 1) immediate knowledge gain, 2) new strategies, tools, and/or practices planned for adoption, 3) potential economic impact (savings, value-added), 4) potential acres impacted. In years 4-5, as outreach activities continue, program participants will be surveyed again to measure 1) new strategies and/or practices implemented, 2) planned practices (takes a long time for some to be implemented in forestry), 3) additional income generated or dollars saved, 4) acres impacted, as well as 5) any heightened awareness, reduction of misconceptions, motivations for behavior changes willingness to change behavior, and behavior change as a result of their program participation.

Surveys of NIPF and industrial private landowners will assess numerous behavior changes by which stakeholders incorporate practices and tools to improve growth and quality of forests, reduce risk of loss from insects, disease, and fire, and mitigate stressors from climate.

Output Assessment

The product-based outcome assessment of this climate/forest extension partnership, by activity, are described below.

> Extension Training - Extension Forestry faculty and State Climatologists in all ten states will participate in training programs coordinated by the Regional Extension Forestry and Regional Climatologist. Upon completion, participants will be able to modify regionally produced materials and conduct extension programs in their state. They will record the number of landowners they interact with and the number of acres that are slated for revised management, based on the climate and forestry recommendations from this program. A regional evaluation plan will enable each state to measure similar variables so that data can be combined to report on regional change in knowledge, beliefs, intention, and behavior.
>
> Web site -Web site analytics will measure and track use. We aim to show increased use that parallels in-person Extension programming in each state.
>
> Web-based Decision Support System - Web site analytics will measure and track users, track questions, assess satisfaction and intent to change. We will also ask if users have received similar information from other sources.
>
> eXtension Community of Practice - The eXtension program tracks use; we will add a user survey to assess questions, beliefs, satisfaction, and intent to change.

Regarding social science research: We agree with the reviewers that significant social science research can be conducted within the project. The proposal calls for five graduate students and post-docs to work directly on the education and extension portion of this program and an additional four individuals to work in economics. We believe these are significant components of social science research. These individuals will be advised by faculty with social science expertise and will work together to explore interesting and relevant social science research opportunities within the scope of the project. For example, the process of building trust and sharing mental models across disciplines is social learning. Tracking its development and understanding what planned and unexpected activities promote social learning may help the regional team share expertise with state teams and pave the way for future interdisciplinary activities. Also, the opportunity to evaluate extension needs and outcomes may enable graduate student/faculty teams to better understand the needs of underserved landowners or strategies for delivering information intended to change behaviors. Social scientists already engaged through the SECC have demonstrated the value of these approaches for assessment of needs, design of DSS tools, and critical analysis of engagement practices (see Breuer et al 2008, 2009, 2010). These activities will be approached in a scholarly manner to enable us to capture lessons learned, to test theoretical models, and to advance extension and education practices.

Question 10: There were a number of questions about the educational activities. The advisory committee will only meet in person twice. Is that enough? While the panel liked the idea of using the GLOBE program in their activities, the panel was not certain there are any GLOBE student protocols that address carbon sequestration. Are there? Similarly, the plan to work with Project Learning Tree is a good idea, but it is not clear if anyone on the proposal team has the expertise in secondary education to develop a secondary module on managed southern pine forests. Both GLOBE and PLT activities will necessitate the involvement of K-12 teachers, but there is no mention of providing professional development to the teachers or to provide any incentive for teachers to participate in the proposal's activities. Please explain. Finally, the graduate student and postdoctoral education plan is simply too vague. How will they be encouraged to engage in the educational or extension activities?

Advisory Committee Meetings: To begin the educational program development process and to advise implementation and evaluation it is essential to meet in person to engage the educator networks in the region. Our intent is to use the well established communication processes---conference calls and list serves---to continually work with the Advisory Committee. Once activity development is underway, a subset of advisors will be engaged to keep each activity on track. If more than two meetings are needed, we can adjust the budget for additional meetings.

About GLOBE: GLOBE activities developed in the first generation included land use cover and tree size measurements. These data can be readily converted to estimate forest carbon pools. According to email conversations, GLOBE is currently developing a new unit on climate change and expects to release these activities in September 2011. GLOBE staff are looking forward to working with us on this project.

About curriculum expertise: Martha Monroe, the coordinator of the Project Learning Tree activity has worked in curriculum development, teacher training, and program evaluation for over 30 years. She is well-respected in environmental education circles and has the confidence of the Project Learning Tree staff. For example, she and her students have recently developed an 18-activity unit for secondary teachers on woody biomass that incorporates environmental, economic, and equity issues and enables youth to explore the question, "Should our community use wood for energy?" The module proposed for this activity will be developed around questions that teachers and students could ask, with answers that address state curriculum goals. We will complement this module with climate, carbon mitigation and forest adaptation information. Expertise on managed southern pine forests will come from extension and research colleagues in this integrated team.

Involving K-12 Teachers: We agree that teachers should be trained through this activity and engaged in program development as much as possible. Professional development for teachers will be provided through the PLT network of state coordinators, the online training program for educators, as well as regional and national conferences for educators. These systems are commonly used for all new PLT materials. The pilot testing of the curriculum will be orchestrated through the PLT subcontract and includes stipends for teachers who will use and evaluate each activity. Funds for state PLT programs to organize workshops that feature climate change and southern pine systems are also built in to the budget.

The ForCCURE coordinators in each state will contact local middle school teachers and inform them of the opportunity to participate in the program. Teachers will be able to join a webinar presentation to learn about the regional project, or access a web site of information about the program and classroom activities. Teachers will be able to register for a classroom presentation and evaluate the presenter and the activity.

About graduate student education: Three graduate students and two post docs will be dedicated to extension and education program development. They will conduct the needs assessment, design and test activities, develop program implementation and training resources, and evaluate impacts. The remaining graduate students and post docs will be primarily assigned to genetics, forest management, and economics projects but will be invited to work with the extension and education activities. In addition:

1. Graduate students will be asked to mentor an undergraduate student through the ForCCURE undergraduate research and teaching activity. These pairs of UG/G students will be able to continue to work together as the undergraduate student develops activities and presents them in middle school classrooms. If the graduate student is nearby, he or she can accompany the undergraduate student to several schools.

2. All graduate students will be able to review and comment on draft versions of all education and extension products. Those who wish to play a greater role in the design and distribution will be encouraged to join their state extension team or work directly on product development with the Aim Leader.

3. Graduate students will attend all in-person meetings and conference calls with researchers. They will be assigned to teams along with their advisors and invited to interact with other teams to help bridge the project aims. They will be encouraged to develop their own parallel network for communication and support that will be limited to graduate students. Although the expectations for graduate students will be governed by their chair/supervisor, the project will make resources available, i.e., travel funds for conference presentations, support to build student interaction and support for explorations into trans-disciplinary research, education, and extension. Moreover, graduate students and postdoctoral scientists will be encouraged to attend and present their research results to industry and government members attending the annual Cooperative meetings. This should help the students learn how to better communicate their results to forest managers who are not necessarily trained within their discipline.

4. A distance education course will be developed for all graduate students. The course may involve Webinar presentations by all the Aim Leaders and Project Managers, readings, and

opportunities to discuss the challenges and opportunities of working in multi-disciplinary teams conducting trans-disciplinary work.

5. Through the course and conference, we will measure and track social learning as students gain understanding and experience about their own area of research and the nature of interdisciplinary and integrated research. We anticipate that a journal activity with periodic blogs within and across Aims will be instructive and insightful as the full team moves toward greater understanding of the opportunities presented in this project.

Question 11: With 39 senior / key people on the project, project management is critical. Please provide details about how the management of the project will be conducted, how it will facilitate integration of results, coordination of activities, etc. to meet yearly milestones, and five-year outcomes.

Our project Management Plan lays out the project management structure, which was designed to facilitate communication and collaboration among project scientists across the region, to foster integration across disciplines, to establish accountability, to guarantee deliverables, and to maintain two-way information flow with stakeholders. These structures are in place to meet project goals and milestones in a timely fashion, assure that project direction remains relevant to stakeholders, and allocate resources appropriately. The panel summary indicated reviewers were pleased with the management structure, but wanted to have more detail about project management. This response reiterates and expands on the "Management Plan" section of our submitted proposal.

Background information: Importance of existing research, extension and education networks
One of the primary strengths of this proposal is that the research plan is built on existing research networks. This includes existing field trial and germplasm of the University-Industry Cooperatives, Project Learning Tree, and national and regional extension network infrastructures, but more importantly, it includes several sets of existing social networks of already-collaborating professionals who know each other, and have collaborated successfully together long enough to develop strong professional relationships and trust. One example of the pre-existing social networks in our project team is the co-authorship network that exists among the biophysical scientists in the CAP (Figure 6). Similar social networks exist for the education and extension professionals. These pre-existing connections and relationships serve to speed the development and implementation of new projects, just as it did to put together this CAP proposal in the short time available (March – July 2010). An additional benefit of pre-existing social networks is that they are high in social capital. The networks contain social bonds that are normative in a positive sense, *e.g.* participants are less likely to underperform if they believe they are part of a functional group that depends on them, trust that others are working in their interest, and sense a reciprocal nature of personal and group benefits (Pretty 2003; Putnam 2000; Wilson 1997). While existing social capital is strong and established within the research, education and extension areas, connections exist but are not as well established between these networks. The integration of research networks with education and extension networks is central to the success and efficacy of our efforts. Our integrating activities, such as the first team meeting, should help build these bridges.

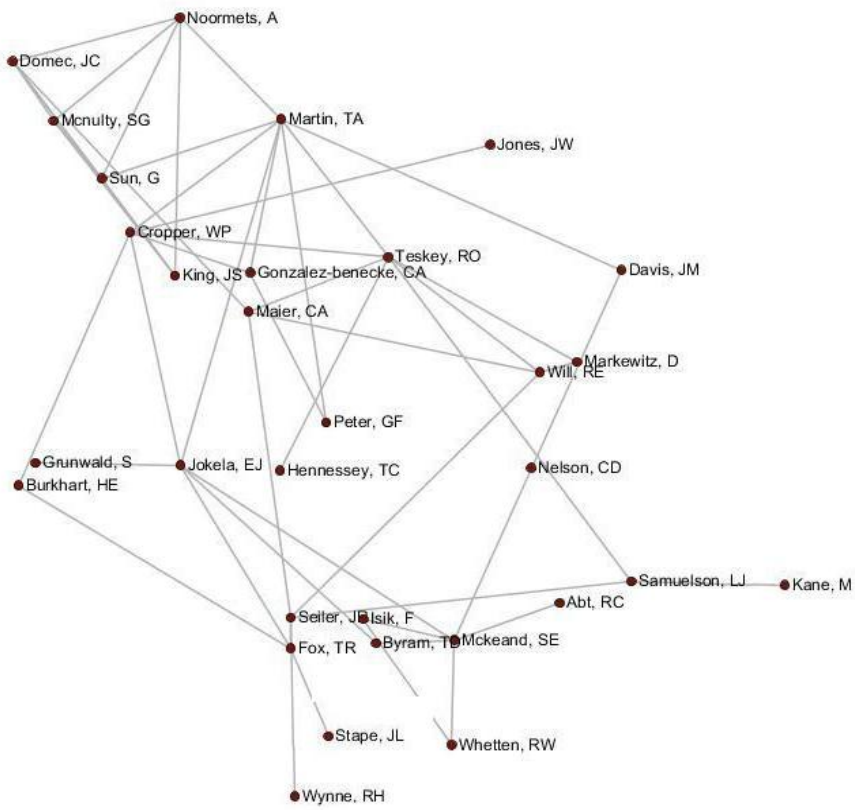

Figure 6. Network diagram showing co-authorship relationships among the biophysical CAP investigators.

Integration of existing networks across three levels: within aims, across aims, and among overarching objectives

The culture of University-Industry Cooperatives is already highly integrative emphasizing research, graduate student training and outreach to industry. This forms a strong base with which to build broader levels of integration. The project needs to integrate across at least three scales: within aims, across aims, and among the three overarching project objectives (Mitigation, Adaptation, and Education/Extension). The project management structure was designed to enhance connections and communication within and among these three levels.

<u>Within aims</u>: The completion of aim goals and deliverables will be coordinated by aim leaders. Each aim has at least two leaders from different universities, to enhance communication and collaboration across the project network. As aim teams are composed of researchers who already participate in one or more of the established networks, communication between members should be strong. Moreover, because teams are principally composed of similar disciplinary experts, communication about the technology and approaches will occur without the need for learning new concepts and languages from

other vastly different disciplines. Because researchers are located across the region, however, communication efforts will focus on keeping everyone informed across this spatial dimension.

Among aims: The primary purpose of the Integration Leaders is to facilitate integration among aims and to assure that the aims serve the three overarching objectives of the project in each of their respective areas: Mitigation, Adaptation, and Education/Extension. The three Integration leaders were selected because each has demonstrated their ability to lead multi-disciplinary research teams and to integrate across scales within their own research, and because they work in the same building, facilitating frequent communication. During the preparation of this proposal, the Integration Leaders were involved in all e-mail and conference call correspondence for aim groups involved with their respective areas- Tim Martin Aims 1- 6; Martha Monroe Aims 5 and 6, and Gary Peter Aims 1, 3, 4 and 6. This provided invaluable linkages among aim groups, because an Integration Leader was always involved in the conversation to provide wider-scale context to the aim-specific discussions, which served to better integrate and connect the disciplinary and aim-level efforts to the broader project objectives. This same mechanism will continue in the execution of the project. For example, Aim 2 needs to be tightly linked with Aims 1 and 3. Aim 2 team members include Leaders of Aim 1 and 3 and the Mitigation Leader. Aim 4 needs to be tightly linked with Aims 1 – 3, and includes a Leader of Aim 1 and the Adaptation Leader. Aim 6 needs to be tightly linked to Aims 2-4, and includes Leaders and members of Aims 1-4. One leader of Aim 5 is also on the team for Aim 1. In addition, the project manager will have a primary responsibility for enhancing communication and linkage among aim teams.

Among Mitigation, Adaptation, and Education/Extension objectives: To promote integration between these broad objectives, we will use a number of approaches and mechanisms. First, it will be continually emphasized, starting with the first project meeting, that this is an ***integrated*** project, so that the culture of integrating across research, extension and education will be reinforced and participants will remember that they must contribute to all three objectives for the project to be a success. Second, as Extension experts are developing their program, they will seek information from researchers and via Aim Leaders, for input and collaboration on particular topical areas. Third, educators will work with research experts on developing and communicating life cycle analyses as a way to compare forest products with the use of alternative products that involve non-renewable feedstocks or processes that require more energy. Fourth, climate and forestry researchers, educators and extension specialists will directly collaborate on the development of an Open Source Decision Support System suitable for use by forest managers across the region. Fifth, the initial needs assessment required for progress in the economic analysis and the extension program development will be integrated. In all approaches graduate students and postdoctoral researchers will be strongly encouraged to interact with faculty and students across all disciplines and existing networks.

Development of an Open Source Decision Support System as a mechanism for integration

Traditionally, information flow in research and extension networks was one-way, from research, through extension, to stakeholders. However, over the past two decades, as agricultural and natural resource problems became more complex, it has become apparent that this model is no longer adequate, and that mechanisms need to be incorporated to facilitate interaction with and feedback from all players in the network. A central approach for establishing this environment in our project is the development of an open source decision support system (DSS). Our approach is modeled on work undertaken in the Southeast Climate Consortium (SECC, http://seclimate.org/), a group that uses "advances in climate sciences, including improved capabilities to forecast seasonal climate and long-term climate change, to provide scientifically sound information and decision support tools," primarily for agricultural systems. The SECC crop DSS was developed in an iterative fashion through four stages, with continual feedback and interaction between researchers, extension professionals, and stakeholders (Figure 7).

James Jones, senior advisor to our project, and Co-PI Ryan Boyles is involved in the ongoing development of the SECC DSS for crops at http://www.AgroClimate.org, as well as transition to an open-source version. Boyles is taking the lead in the development of the conifer DSS, and Jones will advise on process to maximize researcher / extension / stakeholder interactions during DSS development.

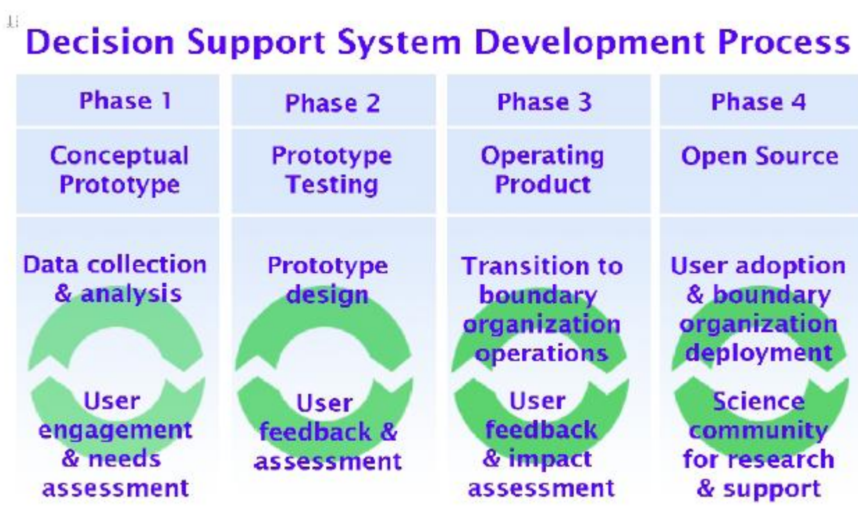

Figure 7. Schematic diagram of process for development of an agricultural decision support system by the Southeast Climate Consortium (Ingram *et al.* 2010).

Literature Cited

Albaugh, T.J., H.L. Allen, P.M. Dougherty and K.H. Johnsen. 2004. Long term growth responses of loblolly pine to optimal nutrient and water resource availability. Forest Ecology and Management 192:3-19.

Allen, C.B., R.E. Will and M.A. Jacobson. 2005. Production efficiency and radiation use efficiency of four tree species receiving irrigation and fertilization. Forest Science 51:556-569.

Ayres, M.P. and M.J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. Science of the Total Environment 262:263-286.

Bailey, R. L. and Z. Fang. 2000. Merchantable-stem Green and Dry Weight Prediction Equations Based on a New Segmented-stem Taper Model. PMRC Technical Report 2000-8. 16pp.

Basiliko, N., A. Khan, C.E. Prescott, R. Roy and S.J. Grayston. 2009. Soil greenhouse gas and nutrient dynamics in fertilized western Canadian plantation forests. Canadian Journal of Forestry Research 39:1220-1235.

Binford, M.W., H.L. Gholz, G. Starr and T.A. Martin. 2006. Regional carbon dynamics in the southeastern U.S. coastal plain: Balancing land cover type, timber harvesting, fire, and environmental variation. Journal of Geophysical Research 111:D24S92-doi:10.1029/2005JD006820.

Birdsey, R.A. 1996. Carbon storage for major forest types and regions in the conterminous United States. In: Forests and Global Change Volume Two - Forest Management Opportunities. ed. by R. Neil Sampson and Dwight Hair. Washington, DC: American Forests. pp 1-25.

Bowman, D.M.J.S., J.K. Balch, P. Artaxo, W.J. Bond, J.M. Carlson, M.A. Cochrane, C.M. D'Antonio, R.S. DeFries, J.C. Doyle, S.P. Harrison, F.H. Johnston, J.E. Keeley, M.A. Krawchuk, C.A. Kull, J.B. Marston, M.A. Moritz, I.C. Prentice, C.I. Roos, A.C. Scott, T.W. Swetnam, G.R. van der Werf, and S.J. Pyne. 2009. Fire in the Earth System. Science 324:481-484.

Breuer, N.E., V.E. Cabrera, K.T. Ingram, K. Broad, P.E. Hildebrand. 2008. AgClimate: A case study in participatory decision support system development. Climatic Change 87:385-403

Breuer, N.E., C.W. Fraisse and P.E. Hildebrand. 2009. Molding the pipeline into a loop: the participatory process of developing AgroClimate, a decision support system for climate risk reduction in agriculture. Journal of Service Climatology 1:1-12.

Breuer, N.E., C.W. Fraisse and V.E. Cabrera. 2010. The Cooperative Extension Service as a boundary organization for diffusion of climate forecasts: a 5-year study. Journal of Extension 48: 4RIB7

Castro, M.S., P.A. Steudler, J.M. Melillo, J.D. Aber and R.D. Bowden. 1995. Factors controlling atmospheric methane consumption by temperate forest soils. Global Biogeochemical Cycles 9:1-10.

Cherubini, F., N.D. Bird and A. Cowie, G Jungmeier, B Schlamadinger and S Woess-Gallasch. 2009. Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. Resources, Conservation and Recycling 53:434-447.

Clark, K.L., H.L. Gholz and M.S. Castro. 2004. Carbon dynamics along a chronosequence of slash pine plantations in north Florida. Ecological Applications 14:1154-1171.

Crutzen, P.J., A.R. Mosier, K.A. Smith and W. Winiwarter. 2008. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics 8:389-395.

Davidson, E.A., C.S. Potter, P. Schlesinger and S.A. Klooster. 1998. Model estimates of regional nitric oxide emissions from soils of the Southeastern United States. Ecological Application 8:748-759.

Dwivedi, P., J.R.R. Alavalapati, A. Susaeta and G.A. Stainback. 2009. Impact of carbon value on the profitability ps slash pine plantations in the southern United States: an integrated life cycle and Faustmann analysis. Canadian Journal of Forest Research 39:990-1000.

EPA. 2009. Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Proposed Rule. Federal Register / Vol. 74, No. 99, 24904-25143.

Fellows, A.W. and M.L. Goulden. 2008. Has fire suppression increased the amount of carbon stored in western U.S. forests? Geophysical Research Letters doi:10.1029/2008GL033965.

Gonzalez-Benecke, C.A. and T.A. Martin. 2010. Water availability and genetic family effects on water relations of an 11 year-old loblolly pine (*Pinus taeda*) plantation. Tree Physiology 30:376-392.

Gonzalez-Benecke, C.A., T.A. Martin, W.P. Cropper, Jr. and R. Bracho. 2010. Forest management effects on *in situ* and *ex situ* slash pine forest carbon balance. Forest Ecology and Management 260:795-805.

Gundimeda, H. 2001. A framework for assessing carbon flow in Indian wood products. Environment, Development and Sustainability 3:229-251.

Harmon, M.E., J.M. Harmon, W.K. Ferrell, and D. Brooks. 1996. Modeling carbon stores in Oregon and Washington forest products: 1900-1992. Climatic Change 33:521-550.

Harmon, M.E. and B. Marks. 2002. Effects of silvicultural practices on carbon stores in Douglas fir – western hemlock forests in the Pacific Northwest, U.S.A.: results from a simulation model. Canadian Journal of Forest Research 32:863-877.

Harrison, W. M. and B. E. Borders. 1996. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Alabama and Florida. PMRC Technical Report 1996-1. 49 pp.

Hofstetter, R.W., T.D. Dempsey, K.D. Klepzig and M.P. Ayres. 2007. Temperature-dependent effects on mutualistic, antagonistic, and commensalistic interactions among insects, fungi and mites. Community Ecology 8:47-56.

Holland, E.A., G.P. Robertson, J. Greenberg, P.M. Grofman, R.D. Booner and J.R. Gosz. 1999. Soil CO_2, N_2O, and CH_4 Exchange. p. 185-201. *In* G.P. Robertson *et al.* (ed.) Standard Soil Methods for Long-Term Ecological Research. Oxford University Press, New York.

Hutchinson, G.L. and G.P. Livingston. 2002. Soil-Atmosphere Gas Exchange. p. 1159-1182. *In* Dane, J.H., and Topp, G.C. (ed.) Methods of soil analysis. Part 4. Physical methods. SSSA, Madison, WI.

Ingram, K.T., C.W. Fraisse, J.W. Jones, N.E. Breuer, C. Roncoli, J.J. O'Brien, D. Zierden, G. Hoogenboom and D. Letson. 2010. From AgClimate to AgroClimate: Case study of transition from research to operation.

IPCC 2007. Climate Change 2007. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm

Knebel, L., Robison, D.J., Wentworth, T.R., and Klepzig, K. 2008. Resin flow responses to fertilization, wounding and fungal inoculation in loblolly pine (*Pinus taeda*) in North Carolina. Tree Physiology 28: 847-853.

Larson, P.R., D. E., Kretschmann, A. Clark III and J.G. Isen-brands. 2001. Juvenile wood formation and proper-ties in southern pine. Gen. Tech. Rep. FPL-GTR-129, Madison, WI, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 42 pp.

Lindner, M., T. Suominen, T. Palosuo, J. Garcia-Gonzalo, P. Verweij, S. Zudin, R. Päivinen. 2010. ToSIA-A tool for sustainability impact assessment of forest-wood-chains. Ecological Modeling 221:2197-2205.

Lippke, B., J. Wilson, J. Meil and A. Taylor. 2010. Characterizing the importance of carbon stored in wood products. Wood and Fiber Science 42: Sp. Iss. SI, 5-14.

Liski, J., A. Pussinen, K. Pingoud, R. Mäkipää and T. Karjalainen, 2001. Which rotation length is favorable to carbon sequestration? Canadian Journal of Forest Research 31, 2004-2013.

Logan, S. R. 2005. Growth and yield models for slash pine plantations in the Southeastern Coastal Plain. PMRC Technical Report 2005-3. 22 pp.

Maier, C.A. and L.W. Kress. 2000. Soil CO_2 evolution and root respiration in 11 year-old loblolly pine (*Pinus taeda*) plantations as affected by moisture and nutrient availability. Canadian Journal of Forest Research 30:347-359.

Mann M.K., Spath P.L. (2001) A life cycle assessment of biomass cofiring in a coal-fired power plant.Clean Products and Processes 3:81-91.

Markewitz, D. 2006. Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests. Forest Ecology and Management 236:153-161.

Megonigal, J.P., M.E. Hines and P.T. Visscher. 2004. Anaerobic metabolism: linkages to trace gases and aerobic processes. In Biogeochemistry. Ed. W.H. Schlesinger. Elsevier-Pergamon, Oxford, pp 317–424.

Milota, M.R., C.D. West and I.D. Hartley. 2005. Gate-to-gate life inventory of softwood lumber production. Wood Fiber Science 37(CORRIM Special Issue):47-57.

Myers, R.L. and J.J. Ewel, Eds. 1990. *Ecosystems of Florida.* Orlando, FL: University of Central Florida Press. 765 p.

Noormets A, Gavazzi M, McNulty SG, Domec JC, Sun G, King JS, Chen J. 2010. Response of carbon fluxes to drought in a coastal plain loblolly pine forest. *Global Change Biology* 16: 272-287.

Oneil, E.E., L.R. Johnson, B.R. Lippke, J.B. McCarter, M.E. McDill, P.A. Roth and J.C. Finley. 2010. Life-cycle impacts of inland northwest and northeast/north central forest resources. Wood Fiber Science 42(CORRIM Special Issue): 29-51.

Palosou, T., T. Souminen, W. Werhahn-Meesa, J. Garcia-Gonzalo and M. Lindner. 2010. Assigning results of the Tool for Sustainability Impact Assessment (ToSIA) to products of a forest-wood-chain. Ecological Modeling 221:2215-2225.

Peter, G.F., D.E. White, R. De la Torre, R. Singh and D. Newman. 2007. The value of forest biotechnology: A cost modeling study with loblolly pine and kraft linerboard in the Southeastern USA. International Journal of Biotechnology 9: 415-435.

Pienaar, L.V., B.D. Shiver and J.W. Rheney. 1996. Yield prediction for mechanically site-prepared slash pine plantations in the southeastern coastal plain. PMRC Technical Report 1996-3. 57 p.

Pingoud, K., J. Pohjola and L. Valsta. 2010. Assessing the integrated climatic impacts of forestry and wood products. Silva Fennica 44:155–175.

Pingoud, K., A.L. Perälä and A. Pussinen. 2001. Carbon dynamics in wood products. Mitigation and Adaptation Strategies for Global Change 6:91-111.

Powell, T.L., R. Bracho, J. Li, S. Dore, C.R. Hinkle and B.G. Drake. 2006. Environmental controls over net ecosystem carbon exchange of scrub oak in central Florida. Agricultural and Forest Meteorology 141: 9-34.

Pretty, J. 2003. Social capital and the collective management of resources. Science. 302:1912-1914.

Price, S.J., R.R. Sherlock, F.M. Kelliher, T.M. McSeveny, K.R. Tate and L.M. Conron. 2003. Pristine New Zealand forest soil is a strong methane sink. Global Change Biology 10:16-26.

Pueltmann, M.E., R.E. Bergman, S. Hubbard, L.D. Johnson, B. Lippke, E. Oneil and F.G. Wagner. 2010. Cradle-to-gate life-cycle inventory of US Wood products production: corrim phase I and phase II products. Wood Fiber Science 42(CORRIM Special Issue): 15-28.

Putnam, R. D. 2000. Bowling Alone. New York: Simon and Schuster. 541 pp.

Randerson, J.T., F.S. Chapin, J.W. Harden, J.C. Neff and M.E. Harmon. 2002. Net ecosystem production: A comprehensive measure of net carbon accumulation by ecosystems. Ecological Applications 12:937-947.

Raymer, A., T. Gobakken, B. Solberg, H. Hoen and E. Bergseng. 2009. A forest optimisation model including carbon flows: Application to a forest in Norway. Forest Ecology and Management 258:579-589.

Row, C. and R.B. Phelps. 1996. Wood carbon flows and storage after timber harvest. In: R.N. Sampson and D. Hair, Editors, Forests and Global Change, Vol. 2: Forest Management Opportunities for Mitigating Carbon Emissions, American Forests, Washington, DC, pp. 59-90.

Russell, M.B., Amateis, R.L., Burkhardt, H.E. 2010. Implementing regional locale and thinning response in the loblolly pine height-diameter relationship. Southern J. Applied Foresttry 34: 21-27.

Samuelson, L.J., J. Butnor, C. Maier, T.A. Stokes, K. Johnsen and M. Kane. 2008. Growth and physiology of loblolly pine in response to long-term resource management: defining growth potential in the southern United States. Canadian Journal of Forest Research 38:721-732.

Shiver, B. D. and S. W. Martin. 2002. Twelve-year results of a loblolly pine site preparation study in the Piedmont and Upper Coastal Plain of South Carolina, Georgia, and Alabama. South. J. Appl. For. 26(1):32-36.

Schlesinger, W.H. 1997. Biogeochemistry: an analysis of global change. Academic Press, San Diego, CA. 588 pp.

Schmidtling, R.C. 2001. Southern Pine Seed Sources. General Technical Report, United States Department of Agriculture Forest Service. SRS-44:35.

Squillace, A.E., O.O. Wells, and D.L. Rockwood. 1980. Inheritance of monoterpene composition in cortical oleoresin of loblolly pine. Silvae Genetica 29:141-152.

Sugimura, W.Y., D.G. Sprugel, L.B. Brubaker and P.E. Higuera. 2008. Millennial-scale changes in local vegetation and fire regimes on Mount Constitution, Orcas Island, Washington, USA, using small hollow sediments. Canadian Journal of Forest Research 38:539-552.

Tilman, D., P.B. Reich, H. Phillips, M. Menton, A. Patel, E. Vos, D. Peterson and J. Knops. 2000. Fire suppression and ecosystem carbon storage. Ecology 81: 2680-2685.

Twilley, R.R., E.J. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E.H. Siemann, R.G. Wetzel and R.J. Zimmerman. 2001. Confronting climate change in the Gulf Coast region: Prospects for sustaining our ecological heritage. Union of Concerned Scientists and The Ecological Society of America, Washington, D.C. 82 pp.

Ungerer, M.J., M.P. Ayres and M.J. Lombardero. 1999. Climate and the northern distribution limits of *Dendroctonus frontalis* Zimmermann (Coleoptera : Scolytidae). Journal of Biogeography 26:1133-1145.

White, M.K., S.T. Gower and D.E. Ahl. 2005. Life-cycle inventories of roundwood production in Wisconsin – Inputs into an industrial forest carbon budget. Forest Ecology and Management 219:13-28.

Wilson, P. A. 1997. Building social capital: A learning agenda for the twenty-first century. Urban Studies. 34:745-760.

Xiao, J., Q. Zhuang, D.D. Baldocchi, B.E. Law, A.D. Richardson, J. Chen, R. Oren, G. Starr, A. Noormets, S. Ma, S.B. Verma, S. Wharton, S.C. Wofsy, P.V. Bolstad, S.P. Burns, D.R. Cook, P.S. Curtis, B.G. Drake, M. Falk, M.L. Fischer, D.R. Foster, L. Gu, J.L. Hadley, D.Y. Hollinger, G.G. Katul, M. Litvak, T.A. Martin, R. Matamala, S.G. McNulty, T.P. Meyers, R.K. Monson, Munger, J.W., W.C. Oechel, K.T. Paw U, H.P. Schmid, R.L. Scott, G. Sun, A.E. Suyker and M.S. Torn. 2008. Estimation of net ecosystem carbon exchange for the conterminous United States by combining MODIS and AmeriFlux data. Agricultural and Forest Meteorology 148:1827-1847.

Yin, R., L.V. Pienaar and M.E. Aronow. 1998. The productivity and profitability of fiber farming. Journal of Forestry 96:13-18.