# Potential Impacts of Climate Change on Timber Markets in Southern USA

Steven McNulty USDA Forest Service Raleigh NC, USA, Edward de Steiguer USDA Forest Service Raleigh NC, USA, and Robert Abt North Carolina State University, Raleigh, NC USA

**Abstract** During the next century, substantial changes are expected in a variety of environmental variables, including temperature, precipitation and atmospheric $CO_2$. These changes are expected to vary seasonally as well as spatially, and may have profound effects on forest growth and economics across the southern U.S. Fortunately, software and hardware advances permit the study of forest processes at large temporal and spatial scales. Therefore, large-scale computer models of forest response to environmental change will be among the tools that we will use to help manage our nation's forests in the 21st century. In this study, the forest process model PnET-IIS was used to scale forest productivity from the stand level to the regional scale for southern U.S. pine forests. Climate change scenarios were applied to PnET-IIS, and the model was coupled with two economic models to predict how environmental stress will impact forest growth and economic conditions. The first economic model, the Southern Pine Aggregate Market Model (SPAMM), was used to predict regional economic surplus and annual changes in pulpwood stumpage price. The second model, the Sub-regional timber supply (SRTS) model, predicted how pine harvests would change across the region in response to climate change. The results indicated that the magnitude, location and timing of economic changes varied according to which climate change scenario was chosen for the model. However, in all economic assessments, there is a strong indication that forest productivity and economic gain will be shifted northward within the southern U.S. region. Conversely, growth and economic conditions in warmer, drier areas will be negatively influenced by increases in air temperatures. This type of model will be very useful in assessing long-term forest sustainability and potential economic impacts

## INTRODUCTION

Southern pine forests are commercially important and account for approximately half the softwood timber volume harvested in the U.S. (Haynes 1990). However, there is growing public concern that continued emissions of greenhouse gases could cause global climate changes (Gore 1992), that in turn, would impact on the earth's natural systems and, ultimately, on human welfare (Office of Technology Assessment 1991). Hodges et al.(1992) estimated that losses to the southern U.S. forest sector could total \$300 million, with an additional \$100 million being required for management costs. Cline (1992) estimated that economic losses in the lumber industry across the U.S. could reach \$4 billion per year. Such economic assessments are potentially useful to government officials who ultimately may need to evaluate the costs and benefits of legislation on global change, as well as to private, state and federal land managers. The purpose of this study was to examine the potential economic impacts of climate change on regional and sub-regional timber markets and timber supply in the southern United States.

## METHODS

This study analyzed three climate change scenarios in an integrated assessment framework that included a southern pine tree physiology model (PnET-IIS), a geographic information system (GIS), a sub-regional timber supply (SRTS) model, and a regional pine timber market model (SPAMM). The study compared changes in southern pine supply, demand, growth, and economic change under historic climate and three doubled-$CO_2$ climate scenarios.

### Climate Change Scenarios

Precipitation, air temperature, and doubled atmospheric $CO_2$ were considered in the climate change scenarios. Initially, three scenarios were developed to assess the affects of different temperature and precipitation patterns on southern pine growth. The first, called the minimum climate change (MCC) scenario, increased the historic (1951 to 1984) monthly average minimum and maximum temperature by 2°C and increased total monthly precipitation by 20%. A second group of scenarios were obtained using general circulation model (GCM) projections and historic weather data. The two GCM's used in the study were the General Fluid Dynamics Laboratory (GFDL) (Cooter et al. 1993), and United Kingdom Meteorological Office (UKMO) (Cooter et al. 1993) models. The GCM's predicted how precipitation and air temperature will vary from long-term averages for a doubling of atmospheric $CO_2$. Predicted temperature changes were then added to historic (1951 to 1984) average monthly minimum and maximum air temperatures across the southern

United States. When the GCM's were added to the historic climate, 35 years of temperature, precipitation, and doubled atmospheric $CO_2$ change projections were used as input to a physiologically based forest growth model.

## Forest Productivity Modeling

PnET-IIS, is a physiologically based, monthly time-step model that predicts changes in forest hydrology and growth for pine (*Pinus spp.*) across the southern United States. The model incorporates species specific vegetation attributes, soil water holding capacity, and four climate parameters to predict forest growth per acre under historic and future environmental conditions (Aber et al. 1993, McNulty et. al. 1994). Predictions of forest productivity with this model have previously been well correlated with average annual basal area growth measured across the southern US (McNulty et al. 1996). Using Forest Inventory Assessment (FIA) data (Kelly 1991), PnET-IIS predictions of forest productivity per unit area were projected into regional growth using the current volume for southern U.S. pine forests (USDA 1988). Model predictions of future forest productivity included the influence of doubled atmospheric $CO_2$ and were expressed in $ft^3\ acre^{-1}\ year^{-1}$. Total changes in standing volumes were calculated by multiplying growth per unit area by the total area of pine forest across the region.

## Regional Timber Market Modeling

The SPAMM model calculated changes in timber producers and consumers surpluses, plus changes in timber prices and annual harvest levels in southern pine solidwood and pulpwood markets. Measurement of changes in these four economic indicators constituted the timber market economic assessment for the study. A graphical representation of the SPAMM model is given in figure 1. If the market is free of global change effects, timber supply schedule S and timber demand schedule D prevails. Market equilibrium occurs where timber demand D is equal to supply S and quantity q* clears the market at price p*. producers surplus accrues to timber growers in the amount of a+b+c. Mill owners receive a consumer surplus in the amount equal to area d+e+f+g.

The timber market supply schedule in figure 1 represents an aggregation of all individual agent's supply functions.

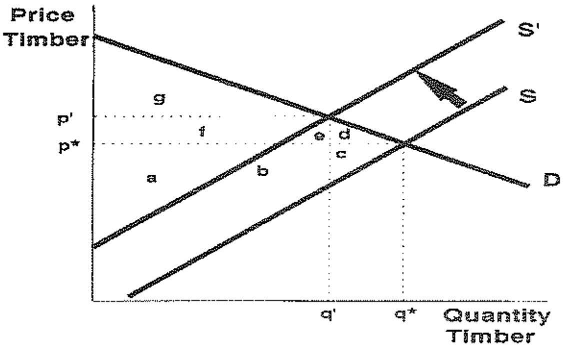

Figure 1. Change in southern pine supply and demand as influence by the climate change scenarios.

Market supply is a negative function of timber price. Timber supply is a function of timber production costs that are in part related to the amount of merchantable timber inventory. Changes in the standing inventory will change production costs. These cost changes are represented by parallel shifts in the entire supply function. Increases in inventory cause a downward shift of the supply function relative to its original position on the price (i.e. y) axis. This result can be confirmed intuitively by observing that the price of a given quantity of timber decreases with a downward shift (i.e., an increase) in supply. Conversely, decreases in inventory, and supply costs, cause an upward shift of the supply function relative to its old position on the price axis. This is confirmed intuitively by observing that the price of a given quantity of timber increases with an upward shift (i.e., a decrease) in supply.

A decrease in timber inventory due to global change will result in an upward shift in the supply function as represented by S' (Figure 1). The intersection of the new timber supply schedule S' and the old demand curve D sets a lower equilibrium harvest quantity q' at the higher price p'. Mill owners would have a surplus equal to area g, and the value equal to area f has been transferred to growers who also retain area a. Area b+c+d+e represents the contribution by southern pine timber markets to total social welfare losses due to global warming. Any increase in forest productivity will cause a downward shift of the original supply curve S. Any increase in the original areas of the welfare triangles due to a downward supply shift would measure the economic benefits from southern pine forestry due to climate change. A working version of the SPAMM model was programmed on a personal computer using the following inverse supply and demand equations from Newman (1987):

Sawtimber demand: $Pd = 939.7 - .0003162Qd$
Sawtimber supply: $Ps = -239.82 + .0003255Qs$
Pulpwood demand: $Pd = 253.7 - .00011Qd$
Sawtimber supply: $Ps = -289.8 + .0002032Qs$

Where: $Ps$ = supply price
$Pd$ = demand price
$Qs$ = quantity of timber supplied
$Qd$ = quantity of timber demanded.

Shifts in the timber supply curve under each of the three climate change scenarios was accomplished in the following manner. The historic regional annual productivity was subtracted from each of the five PnET-IIs simulated changes in regional productivity. These results, in billions of $ft^3$, were divided by the total pine inventory (102 billion $ft^3$) and multiplied by 100 to obtain the annual percentage change in regional pine inventory due to climate change. The percentage change in productivity was apportioned between solidwood and pulpwood market using recent relative wood consumption shares of 66% and 34% for the two markets respectively (Haynes 1990). The percentage changes in inventory were multiplied by inventory elasticity's to obtain percentage changes in harvest quantity. For this study, the sawtimber inventory elasticity = 0.387, and pulpwood inventory elasticity = 1.198 (Newman 1987). The new harvest quantities were substituted into the sawtimber and pulpwood supply equations and solved for the new y-intercept. This procedure provided the newly shifted supply functions, one for each climate change scenario in the pulpwood and sawtimber markets.

With the new supply functions, changes in producers and consumers surplus were calculated in 1991 dollars by computing the area of the welfare triangles using procedures from Holmes (1992). The amounts were not discounted even though global change impacts are likely to occur in the future

### Subregional Timber Market

The Sub-Regional Timber Supply (SRTS) model uses a similar configuration to the SPAMM. Supply is modeled as a function of stumpage price and inventory. The log-linear or constant elasticity functional form is used with supply-price elasticity equal to 0.35 and supply-inventory elasticity equal to 1.0. The SRTS model includes an inventory modeling component that estimates growth, acreage, and inventory changes over time. The basic regional unit of the model is the Forest Inventory Assessments (FIA's) survey unit. The twelve southern states are modeled in 51 survey units that are based primarily on state, physiographic, and ecological boundaries. Changes in inventory from each of these regions are aggregated to estimate inventory change in each region to determine the share of regional harvest from a survey unit. In the model, inventory projections are the result of different starting inventories that result in a change in age class distribution. This leads to a change in price and harvest consequences and a shift in timber supply.

The SRTS model assumes that price is determined by the interaction of supply and demand in the aggregate market. This regional price is then applied to the ownership and may be modeled as separate sub-regions. Harvest allocations are passed to the inventory model which are deducted and the resulting change in inventory is passed back to the economic model to shift the supply curve. The model uses constant elasticity supply and demand curves. The default elasticities in previous studies were those estimated for the Forest Service for use in the TAMM model (Abt 1988). Product demands are treated independently, but harvest by-products are linked through the inventory model. Product differentiation is important because the time investment for pulpwood rotations (20-25 years) is significantly shorter than sawtimber rotations (30-40 years). Changing growth patterns and perceived risk may lead to significantly different impact by products. Demand is modeled as a function of stumpage price and a non-specified demand shifter. The aggregate supply shift is calculated from the inventory changes in each of the sub-regions. After regional price is determined, it is applied to the supply curves of each sub-region to estimate harvest shifts. The inputs to the economic model are the elasticity and an aggregation among ownership's/regions. The model, therefore, not only calculates the price effect of a change in inventory due to climate change, but also calculates shifts in harvest patterns within the region.

## RESULTS

### Climate Change Scenarios

Historically, PnET-IIS predicted that forest growth would be best along the coastal zones. Northern pine productivity would be limited by shorter growing seasons and western productivity would be limited due to water (Figure 2).

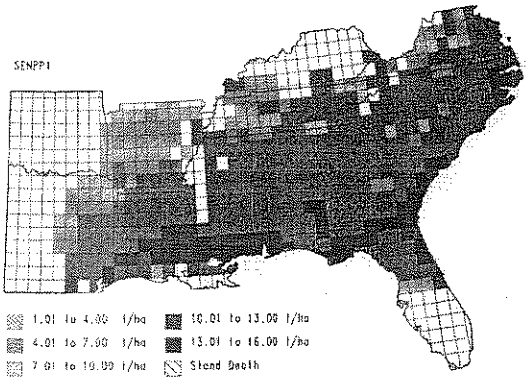

Figure 2. Predicted average annual pine forest growth under historic climate for the southern U.S.

The climate change scenarios significantly altered the timing, range and geographic location of weather within the region. Each of the climate change scenarios predicted up to a 20% change in total monthly precipitation and a 9.1°C increase in monthly air temperature. Annual averages had a smaller range in temperature and precipitation variation. The MCC scenario yielded the largest percentage increase in average monthly precipitation (+20%) and the smallest increase in air temperature (2.0°C). The GFDL model predicted a 3.5°C increase in average annual air temperature and a 4% increase in total annual precipitation across the region (Cooter et al. 1993). The UKMO model predicted a 6.6°C increase in average annual air temperature and a 2% reduction in total annual precipitation across the region (Cooter et al., 1993).

## Regional Southern Pine Timber Volume Change

The annual productivity under historic ambient conditions was 5.4 billion $ft^3$ (USDA,1988). The MCC scenario yielded a growth rate of 7.9 billion $ft^3$. The PnET-IIS model predicted that annual forest productivity would be 7.2 billion $ft^3$ using the GFDL scenario and 4.9 billion $ft^3$ using the UKMO scenario. Thus, for the MCC and GFDL climate scenarios, predicted forest productivity increased while the UKMO scenario predicted a decrease in forest productivity, compared to historic productivity (Table 1). These regional values were used with the inventory elasticity to shift the timber market supply curves, demand, and harvest schedules across the southern U.S. in SPAMM. Within the region, changes in forest productivity were not uniform across the region. The MCC scenario predicted the largest increase in productivity over the driest parts of the region (i.e., Texas, Oklahoma). These increases occurred because the increase in air temperature was relatively small (+2.0°C), and the increase in precipitation was large (+20%). With the other two climate scenarios (i.e., GFDL, UKMO), increases in forest productivity increase northward, while the warmest portions of the south were predicted to have stable or decreasing productivity. In the extreme UKMO scenario, the model predicted that the southern most sections of the region could no longer sustain pine growth. The change in sub-regional productivity was passed along to SRTS for economic analysis.

## Regional Timber Market Assessment

In the combined pulpwood and solidwood market, the change in total economic surplus ranged from +$715 million under the MCC scenario to -$234 million for the UKMO scenario. The decreases in consumer surplus ranged from +$396 million with MCC scenario to -$130 million with UKMO.

Sawtimber stumpage prices were also affected by the change in forest productivity. Relative to 1991 prices and a 4% discount rate, stumpage prices were predicted to fall by 1.44 to 1.06% by the year 2060 if the MCC or GFDL climate change scenarios should occur. Stumpage prices fall because forest inventory, hence timber supply, increase relative to timber demand under the MCC and GFDL climate scenarios. Stumpage prices under the UKMO climate scenario rise because timber supply decreases relative to demand. These changes in stumpage price represent regional averages. Locally, stumpage prices could likely have a much wider fluctuation. Under the UKMO scenario, some areas within the southern U.S. could see significant reductions in productivity. It may become commercially unprofitable to establish pulp mills in these areas. These changes could have devastating impacts on local economies.

## Sub-regional Timber Market Assessment

The SRTS model examined how the market would shift across the region and within the region. This model is designed to address how sub-regional economies could be impacted due to changes in forest productivity. The SRTS model predicted that removals would be roughly proportional to increases or decreases in changing forest growth. For example, under UKMO scenario, pine removals would increase in North Carolina (NC), South Carolina (SC), Virginia (VA), Arkansas (AR), Oklahoma (OK), and Tennessee (TN), while removals will decrease in Georgia (GA), Mississippi (MS), Alabama (AL), Louisiana (LA) and Florida (FL) (Figure 3).

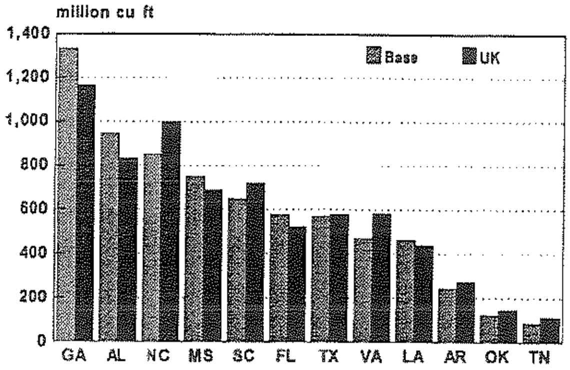

Figure 3. Change in annual forest harvest by state under historic (Base) and the UKMO (UK) climate scenarios.

The other climate scenarios predicted different patterns of softwood removals across the region, depending on changes in forest growth. Generally, the SRTS model predicted an acceleration of harvest in the mid-Atlantic region Alabama v. North Carolina. These changes have significant implications to the potential planting strategies of forest industry.

## CONCLUSIONS

The annual economic impacts of global climate change on southern timber markets were positive for the MCC and GFDL scenarios, and negative for the UKMO scenario. The changes in precipitation and temperature contributed to a change in forest productivity that in turn, caused economic loss or gain. The economic impacts were positive or negative to both timber producers and timber consumers depending on the applied scenario. Sub-regionally, the northern section is predicted to experience increased harvesting associated with increased pine growth. This will produce a positive economic benefit to the local economy. Conversely, decreases in harvest across the warmer, drier portions of the region will likely cause negative economic consequences.

Although the potential impacts of climate change across the southern U.S. are substantial, the greatest utility of this research may be in the development of a biological/economic model framework. This framework will allow for the assessment of multiple environmental stresses including ozone, nitrogen deposition, and changing land use pressure. Long-term implications of these stresses may have greater economic impacts than that of climate change. Future research will focus on the implications of additional forest stresses on southern U.S. timber markets.

## ACKNOWLEDGEMENTS

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## REFERENCES

Aber, J.D.;C. Driscoll, C.A. Federer, R. Lathrop, G. Lovett, J.M. Melillo, P. Steudler, P.; and J. Vogelmann, A strategy for the regional analysis of the effects of physical and chemical climate change on biogeochemical cycles in northeastern (U.S.) forests. Ecological Modeling 67, 37-47, 1993.

Abt, R.C., State-level timber market projections. In: USDA Forest Service, The South's Fourth Forest: Alternatives for the Future. Washington, D.C.45 p., 1988.

Cline, W.R., The Economics of Global Warming. Institute for International Economics. Washington, DC. 399 pp, 1992.

Cooter, E.J.;B.K. Eder, S.K. LeDuc, L. Truppi, General Circulation Model Output and Forest Climate Change Research and Applications. USDA Forest Service General Technical Report.SE-85. Dec. 1993.

Gore, A., *Earth in the Balance*. Houghton Mifflin Company. Boston. 407 pp., 1992.

Haynes, R.W., An analysis of the timber situation in the United States: 1989-2040. USDA Forest Service General Technical Report RM-199. Fort Collins, CO. 268 pp., 1990.

Holmes, T.P., Economic effects of air pollution damage to U.S.forests, in *The Economic Impact of Air Pollution on Timber Markets: Studies from North America and Europe*, edited by J.E. de Steiguer, USDA Forest Service Southeastern Forest Experiment Station, p. 19-26, 1992.

Kelly, J.F., *USDA Forest Service Survey Methods.* in *Alabama's forest resources: past, present and future*. Auburn University, AL: Auburn University, 1991.

Marx, D. H., 1988. Southern forest atlas project. In: The 81st annual meeting of The Association Dedicated to Air Pollution Control and Hazardous Waste Management (APCA), Dallas, Texas, p. 1-24, 1988.

McNulty, S.G., J.M. Vose, W.T. Swank, J.D. Aber, and C.A. Federer, Landscape scale forest modeling: Data base development, model predictions and validation using a GIS. *Climate Res* 4, 223-231, 1994.

McNulty, S.G.; J.M. Vose, and W.T. Swank, Loblolly pine hydrology and productivity across the southern United States. *Forest Ecology and Management.* 86, 241-251, 1996.

Newman, D.H. An econometric analysis of the southern softwood stumpage market: 1950-1980. *Forestry Science.* 33(4),932-945, 1987.

Office of Technology Assessment, Changing by Degrees: Steps to Reduce Greenhouse Gases. US Congress, Washington, DC. 42 pp. 1991.

Sohngen B. L. and R.O. Mendelsohn, Integrating Ecology and Economics: The Timber Market Impacts of Climate Change on U.S. Forests. Working Paper. Yale School of Forestry. New Haven. 31 pp., 1995.

U.S. Department of Agriculture, Forest Service, The South's Fourth Forest: Alternatives to the Future. Report 24. U.S. Government Printing Office. Washington, DC. 512 pp., 1988.

Table 1. Estimated changes in the annual growth, total acreage, and total annual productivity of pine in the southern U.S., for historic climate and three climate change scenarios. Note: For the southern pine forests: total acreage = 61.8 million, total volume (or inventory)= 102 billion $ft^3$, annual harvest = 5.4 billion $ft^3$, annual growth = 5.4 billion $ft^3$.

| Climate Scenario | Annual Growth ($ft^3\ ac^{-1}$) | Change in Annual Growth (%) | Total Acreage ($10^6$ ac) | Annual Change in Acreage (%) | Total Growth ($10^9\ ft^3$) | Change in Total Growth (%) |
|---|---|---|---|---|---|---|
| Ambient | 87 | --- | 61.8 | --- | 5.4 | --- |
| MCC | 128 | +47 | 61.8 | 0.0 | 7.9 | +47 |
| GFDL | 116 | +33 | 61.8 | 0 .0 | 7.2 | +33 |
| UKMO | 78 | -10 | 58.7 | 5.0 | 4.6 | -15 |

Table 2. Annual changes in producer surplus, consumer surplus, total surplus, and sawtimber stumpage price for the combined southern pine market under three climate change scenarios, 1991 dollars discounted at 4% for 70 years.

| Climate Scenario | Change in Producer Surplus ($10^6$ dollars) | Change in Consumer Surplus ($10^6$ dollars) | Change in Total Surplus ($10^6$ dollars) | Change in Annual Sawtimber Stumpage Price (%) |
|---|---|---|---|---|
| MCC | 396 | 319 | 715 | -1.44 |
| GFDL | 294 | 237 | 531 | -1.06 |
| UKMO | -130 | -105 | -234 | +0.47 |