01998 Springer-Verlag New York, Inc.
The Productivity & Sustainability of Southern Forest Ecosystems in a Changing Environment
Edited by Mickler and Fox

44. An Integrated Assessment of Climate Change on Timber Markets of the Southern United States

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There is growing public concern that continued emissions of greenhouse gases could cause the global climate to change (Gore, 1992). Altered global climate could, in turn, have impacts on the earth's natural systems and, ultimately, on human welfare (Office of Technology Assessment, 199 1). Economic assessments of these potential welfare impacts are useful to government officials who ultimately may need to evaluate the costs and benefits of global change legislation.

The purpose of this chapter was to examine the potential economic impacts of climate change on pine timber markets of the southern United States. Southern pine forests are commercially important as they account for approximately one-half of the softwood timber volume harvested in the United States (Haynes, 1990). The three specific objectives of the study were 1) to develop scenarios of climate change using historic climate data and general circulation models (GCMs), 2) to use the climate scenarios to predict changes in the growth and merchantable inventory of southern pine forests from eastern Texas to Virginia, and 3) to estimate the economic impact of this inventory change on timber producers and consumers in the southern pine sawtimber and pulpwood markets.

Review of Prior Economic Studies

The literature on the economic impacts of global change in timber markets was examined to identify methods and results that might be applicable to the present study. Botkin and Nisbet (1990) have estimated that global warming could have major impacts on commercial forestry, timber supply, recreation, and wildlife that depend upon forest habitats, as well as on water supply and erosion rates. The same authors state that losses from increased fire incidence and insect damage could also occur. de Steiguer (1992, 1993) has discussed global climate change damage to forests as economic externalities, which are the unintentional economic side effects of resource consumption. Sedjo and Solomon (1989) have projected a forest area decrease of 6% as a result of global change. Cline (1992) estimated that economic losses in the lumber industry in the United States could reach $4 billion per year. Hodges et al. (1992) have estimated that losses to the forestry sector in the southern United States could total $300 million with an additional $100 million spent for management costs. Adams et al. (1994) have developed FASOM, which is a forest and agriculture sector model that can be used to examine the impacts of climate change on economic welfare as well as carbon accumulation. The model offers some advantages over earlier models because it examines the shift in productivity between the forest and agriculture sectors. Van Kooten and Arthur (1989) explored the effects of global change on the timber markets of Canada and the United States and found that gains in welfare were experienced principally by the United States. de Steiguer (1994) used the Southern Pine Aggregate Market Model (SPAMM) to examine the economic impacts of tree planting to sequester carbon. Sohngen et al. (1996) developed dynamic global change scenarios for U.S. forests that predicted increases in economic surplus.

Study Methods

This study analyzed five climate change scenarios in an integrated assessment framework that included the following three components: 1) a southern pine tree physiology model, 2) a regional forest projection system, and 3) a pine timber market model for the southern United States. The study compared changes in southern pine inventories under each of the five doubled-carbon dioxide (CO_2) climate scenarios to the inventory under historic "normal" climate conditions. The study, therefore, compared steady-state conditions and did not attempt to examine the dynamic nature of the climate change process. The study methods are presented in the following sequence: 1) climate change scenarios, 2) forest productivity modeling, 3) regional forest projections, and 4) timber market modeling.

Climate Change Scenarios

Precipitation and air temperature were the only variables considered in the climate change scenarios. Carbon dioxide-fertilization effects on forest growth were not examined. Two types of climate change scenarios were developed to assess altered temperature and precipitation patterns on southern pine productivity. 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 climate change scenarios were obtained using GCM projections and historic weather data. The GCMs used in the study were the Oregon State University (OSU), Goddard Institute for Space Studies (GISS), General Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO) models. The spatial scale for which the models were developed varied from the OSU GCM at 4.0" x 5.0" to the GISS GCM at 7.8" x 10.0". Each GCM predicts for each of its grid cells the change in monthly temperature and precipitation that occurs with a simulated doubling of atmospheric levels of CO,. Predicted temperature changes from each of the four GCMs were added to historic (195 1 to 1984) average monthly minimum and maximum air temperatures. Predicted proportional changes in precipitation were multiplied by historic monthly precipitation. These calculations yielded thirty-five years of temperature and precipitation change projections for simulations with the tree physiology model.

Forest Productivity Modeling

The PnET-IIS model, a physiologically based, monthly time step model, predicts changes in forest hydrology and forest growth for forest tree species across the eastern United States. (Aber et al., 1995) Model predictions of forest growth with this model have been well-correlated prior to this study with average annual site basal area growth measured in twelve pine stands located from eastern Texas to eastern Virginia ($r^2 = 0.66$, $P < 0.005$) (McNulty et al., 1996).

The PnET-IIS model uses site-specific, soil-water-holding capacity (SWHC), vegetation process parameters for the separate tree species, and four monthly climate parameters (i.e., minimum and maximum air temperatures, total precipitation, and solar radiation) to predict net primary productivity (NPP). Net primary production is defined as annual gross photosynthesis minus growth and maintenance respiration for leaf, wood, and root compartments. Annual gross photosynthesis is a function of gross photosynthesis per unit leaf area and total leaf area. Changes in water availability and plant-water demand place limitations on the amount of leaf area produced. As vapor pressure diminishes and air temperatures increase, leaf area, and gross photosynthesis decrease.

Southern pine respiration is related to the length of time that the trees have to acclimate to changes in air temperature and the total change in air temperature. As the length of acclimation time increases, gross foliar respiration rates decrease, especially at air temperature greater than 30 °C (Strain et al., 1976). The PnET–IIS model calculates temperature change as the difference between the present and prior months' minimum and maximum air temperatures. The optimum temperature for net photosynthesis varied from 23 to 27 °C, and the maximum air temperature for gross photosynthesis varied from 30 to 43 "C. As temperatures increase beyond the optimum photosynthetic temperature, the respiration rate increased, and gross photosynthesis increased slightly or decreased, so proportionally less net carbon per unit leaf area was fixed.

The PnET–IIS model uses constant generalized species-dependent process

Table 44.1. The PnET–IIS Model Default Parameters and Parameters Used in Sensitivity Analysis

Parameter name	Parameter Abbreviation	Model default value
Light extinction coefficient	k	0.5
Foliar retention time (years)		2.0
Leaf specific weight (g)		9.0
NetPsnMaxA (slope)		2.4
NetPsnMaxB (intercept)		0.0
Light half saturation (J m^2 sec^{-1})	HS	70.0
Vapor deficit efficiency constant	VPDK	0.03
Base leaf respiration fraction		0.10
Water use efficiency constant	WUEC	10.9
Canopy evaporation fraction		0.15
Soil-water release constant	F	0.04
Maximum air temperature for photosynthesis ("C)	TMAX	variable
Optimum air temperature for photosynthesis ("C)	TOPT	variable
Change in historic air temperature ("C)	DTEMP	0.0
Change in historic precipitation (% difference)	DPPT	0.0

coefficients (Table 44.1), site-specific soils, and climate data. Soils series data were derived from a geographic information system (GIS)-based soils atlas compiled by the Soil Conservation Service (Marx, 1988). The soil series were hand-digitized from maps at a scale between 1:500,000 to 1: 1,500,000, depending on the state. Soil information associated with each series included SWHC to a depth of 102 cm. All other soil parameter values were held constant across all sites and years (Table 44.1).

The Forest Health Atlas (Marx, 1988) provided cooperator and first-order station data, which was originally acquired from the National Climatic Data Center (NCDC). Cooperator station data included average minimum and maximum monthly air temperature and total monthly precipitation; first-order station records included relative humidity. After checking for accuracy, the database was interpolated on a 0.5" x 0.5" across the southern United States (Marx, 1988). The gridded databases of minimum and maximum air temperature, relative humidity, and precipitation were compiled into a single database and run through a program to calculate monthly solar radiation (Nikolov and Zeller, 1992) at a 0.5" x 0.5" grid. Solar radiation values were then combined with average monthly maximum and minimum air temperatures and total monthly precipitation and input into PnET–IIS to obtain predictions of changes in forest growth.

Converting Net Primary Productivity to Regional Changes in Forest Growth

The PnET–IIS model predictions of biological productivity under the climate change scenarios were converted into regional estimates of merchantable inventory change for use in the SPAMM economic market analysis. These changes in merchantable inventory can come from two sources. First, the geographic extent of pine forests may change. This was calculated by changing the total present-day 6 1.8 million acres of southern pine forests (USDA, 1988) proportional to the ratio of the number of GCM grid cells that were shown to be without pine production following the PnET–IIS climate simulations vs those that originally had pine production. Second, the merchantable growth of the residual stand may change. In these calculations, it was assumed that the present merchantable forest inventory and growth data obtained from the USDA Forest Service Forest Inventory and Analysis (FIA) database was representative of a historically normal climate. Furthermore, the changes from existing merchantable forest growth and inventory were assumed to be proportional to the ratio of PnET–IIS predicted changes in total biological productivity under the various climate scenarios to the PnET–IIS predicted total biological productivity under historic normal climates. Although present FIA estimates for total pine merchantable inventory are 102 billion cubic feet, while annual growth of these forests has been 5.4 billion cubic feet (USDA, 1988).

Timber Market Model

The SPAMM mode1 calculated changes in timber producer and consumer surpluses, and also 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 represented in (Figure 44.1). If the market is free of global change effects, timber supply (schedule S) and timber demand (schedule D) prevail. Market equilibrium occurs when 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 44.1 represents an aggregation of all individual agent's supply functions. Market supply is a negative function of timber price. Timber supply is a function of timber production costs, which are, in part, related to the amount of merchantable timber inventory. Timber inventory is thus used as a proxy for the cost of supplying timber (Jackson, 1983). 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, and therefore supply costs, causes 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 causes an upward shift of the supply function relative to its beginning position on the price axis. Again, this can be 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 caused by global change will result in an

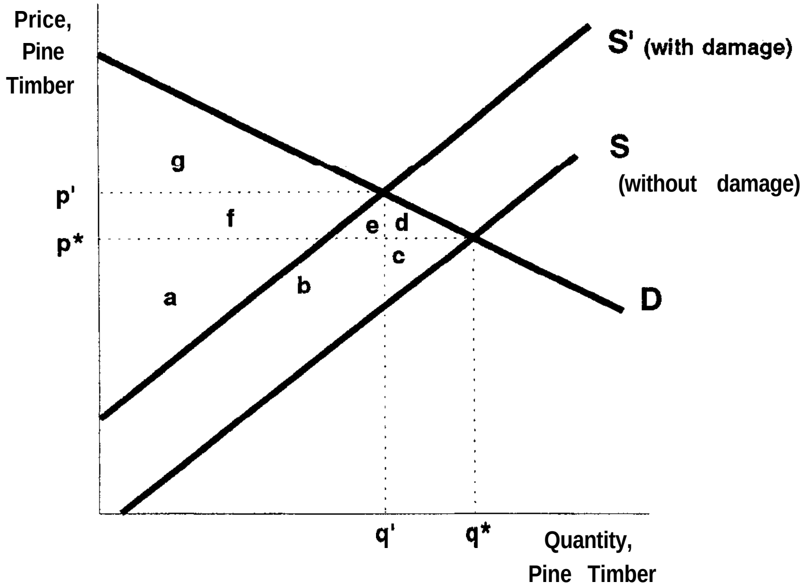

Figure 44.1. A decrease in timber inventory caused by global change will result in an upward shift in the supply function from S to S'. Mill owners would have a surplus equal to area g, and the value equal to area f has been transferred to growers who also retain area a. Area b + c + d + e represents the southern pine timber market welfare loss resulting from global warming.

upward shift in the supply function, as represented by S' (Figure 44.1). The intersection of the new timber supply schedule S' and the 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. Areas b + c + d + e represent the contribution by southern pine timber markets to total social welfare losses resulting from 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 resulting from a downward supply shift would measure the economic benefits from southern pine forestry caused by 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):

$$\text{Sawtimber demand: } Pd = 939.7 - .0003162Qd \quad (1)$$

$$\text{Sawtimber supply: } Ps = -239.82 + .0003255Qs \quad (2)$$

$$\text{Pulpwood demand: } Pd = 253.7 - .00011Qd \quad (3)$$

$$\text{Sawtimber supply: } Ps = 289.8 + .0002032Qs \quad (4)$$

in which: 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 five 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 then multiplied by 100 to obtain the annual percentage change in regional pine inventory resulting from 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 elasticities (i.e., the ratio of the percentage change in the quantity of timber harvested to the percentage change in forest inventory) to obtain percentage changes in harvest quantity. For this study, the sawtimber inventory elasticity = .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 producer and consumer surplus were calculated in 199 1 dollars by computing the area of the welfare triangles using procedures from Holmes (1992). The amounts were not discounted even though global change impacts probably will occur in the future. D'Arge et al. (1982) suggested that discounting may not be appropriate for global change-related losses because it implies that the welfare of future generations is of reduced importance than that of present generations.

Study Results

Climate Change Scenarios

Each of the climate change scenarios predicted increases in average monthly precipitation across the southern United States, with the exception of the UKMO model (Table 44.2). The latter showed a very slight decrease in average monthly precipitation. The MCC scenario yielded the largest percentage increase in average monthly precipitation (1.2%). Each of the climate scenarios indicated increases in average monthly air temperatures across the southern United States (Table 44.2). The UKMO model was the largest at 6.6 °C; while the MCC scenario was the smallest at 2.0 "C.

Projections of Southern Pine Timber Volume

The annual productivity under historic ambient conditions was 5.4 billion ft^3 (Table 44.3). The MCC scenario yielded a volume of 5.1 billion ft^3. The four GCM scenarios yield the following volumes in billion ft^3: 1) OSU 4.0, 2) GISS

Table 44.2. Average Total Monthly Precipitation (cm) Across the Southern United States (1951 to 1980)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average (s.e.)
Average	10.9	10.7	12.9	10.9	11.9	11.2	12.8	11.2	10.6	8.2	9.2	11.5	11.0 (0.4)
Model						Percentage Change From Historic Values							
MCC	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20 (0.00)
OSU	0.88	0.98	0.75	0.83	1.00	1.00	1.13	1.35	1.27	1.20	0.95	1.05	1.03 (0.05)
GISS	0.85	1.31	0.91	1.01	1.22	1.27	1.31	1.05	1.00	0.84	0.76	0.82	1.03 (0.05)
GFDL	1.29	1.06	0.99	1.31	1.22	0.70	1.31	0.78	1.04	1.03	1.03	1.16	1.08 (0.05)
UKMO	0.81	1.05	1.09	1.18	1.08	0.99	0.91	0.95	1.03	0.80	0.93	1.06	0.99 (0.03)

Average Monthly Air Temperature Across the Southern United States (°C) (1951 to 1980)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average (s.e.)
Average	6.4	8.2	12.2	17.1	21.1	24.7	26.4	26.0	23.2	17.7	12.1	8.2	16.9 (2.2)
Model							Additive Change (°C)						
MCC	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0 (0.0)
OSU	+5.0	+3.2	+4.0	+3.8	+3.2	+3.7	+3.5	+3.1	+3.6	+3.7	+2.3	+3.0	+3.5 (0.2)
GISS	+3.8	+3.8	+5.8	+4.2	+3.8	+3.8	+3.5	+3.2	+5.3	+4.6	+5.4	+4.1	+4.3 (0.2)
GFDL	+5.6	+4.7	+4.3	+3.3	+3.6	+3.8	+3.7	+3.9	+4.8	+5.2	+2.6	+1.9	+4.0 (0.3)
UKMO	+6.7	+6.6	+7.1	+6.5	+5.6	+6.1	+6.7	+6.9	+6.7	+6.7	+6.6	+7.2	+6.6 (0.1)

Prediction use the United Kingdon Meterological (UKMO) general circulation model (GCM), the General Fluid Dynamics Laboratory (GFDL) GCM, the Oregon State University (OSU) GCM, and the Goddard Institiute of space Studies (GISS) GCM. As a comparison, the minimum climate change scenario (MCC) uses a constant increase in air temperature and percentage increase in precipitation. All models were run in conjunction with historic (1951 to 1984) climate data through PnET–IIS.

Table 44.3. Estimated Changes in the Annual Growth, Total Acreage, and Total Annual Productivity of Pine in the Southern United States, for Historic Climate and Five Climate Change Scenarios

Climate scenario	Annual growth (ft^3/ac)	Change in annual growth (%)	Total acreage (10^6 ac)	Annual change in acreage (%)	Total annual growth (10^9 ft^3)	Annual Change in Growth (%)
Ambient	87		61.8		5.4	—
MCC	82	-6 %	61.8	0 %	5.1	-6 %
OSU	65	-25	60.8	-2	4.0	-26
GISS	62	-29	60.6	-2	3.8	-30
GFDL	57	-34	58.1	-6	3.3	-39
UKMO	47	-46	35.6	-42	1.7	-69

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.

3.8, 3) GFDL 3.3, and 4) UKMO 1.7. Thus, for the MCC climate scenario and all four of the GCM climate scenarios, the total annual forest productivity of southern pine was shown to decrease when compared forest productivity under historic ambient climate conditions.

The annual change in total forest productivity as a percentage of regional timber inventory ranged from − 0.3% for the MCC scenario to − 3.6% for the UKMO scenario (Table 44.4). These values were used with the inventory elasticities to shift the timber market-supply curves. The negative signs indicate a decrease in timber supply that will result in a loss in economic welfare in southern pine timber markets.

Timber Market Assessment

In the solidwood market, the decreases in total economic surplus ranged from approximately $2.7 million per year under the MCC scenario to $32.2 million per year for the UKMO scenario (Table 44.5). The decreases in consumer surplus ranged from $1.3 million per year with MCC scenario to $15.9 million with UKMO. In the solidwood market, the OSU and GISS scenarios yielded consumer surplus decreases of approximately of $6 million per year, and the GFDL scenario predicted a $9 million consumer surplus decrease per year. The changes in solidwood market producer surplus for each climate scenario were about the same magnitude as the consumer surplus changes (Table 44.5).

In the pulpwood market, the decreases in total economic surplus ranged from about $1.2 million per year under the MCC scenario to $17.7 million per year for the UKMO scenario (Table 44.6). The decreases in consumer surplus ranged from $453 thousand per year with MCC to $6.2 million with UKMO. The OSU, GISS and GFDL scenarios yielded consumer surplus decreases of approximately $2 to $3 million per year. Producer surplus in the pulpwood market decreased $836 thousand per year with MCC scenario. Producer surplus decreases with UKMO

Table 44.4. Changes in Total Annual Growth of Pine Forests as a Percentage of Total Pine Inventory for the Southern United States, for Ambient Climate and Five Climate Change Scenarios

Climate scenario	Annual percentage change in pine inventory
Ambient	
MCC	-0.3%
OSU	-1.4
GISS	-1.6
GFDL	-2.1
UKMO	-3.6

Table 44.5. Annual Changes in Economic Surplus, Stumpage Price and Annual Harvest for the Southern Pine Solidwood Market Under Five Climate Change Scenarios in 1991 Dollars

Climate scenario	Change in producers surplus (thousands of dollars)	Change in consumers surplus (thousands of dollars)	Change in total surplus (thousands of dollars)	Change in stumpage price (%)	Change in annual harvest (%)
MCC	-1,363	-1,324	-2,687	.12	-.08
OSU	-6,129	-5,954	-12,083	.56	-.35
GISS	-6,809	-6,615	13,424	.63	-.39
GFDL	-9,530	-9,257	-18,787	.88	-.54
UKMO	-16,321	-15,855	-32,176	1.51	-.93

Table 44.6. Annual Changes in Economic Surplus, Stumpage Price and Annual Harvest for the Southern Pine Pulpwood Market Under Five Climate Change Scenarios in 1991 Dollars

Climate scenario	Change in producers surplus (thousands of dollars)	Change in consumers surplus (thousands of dollars)	Change in total surplus (thousands of dollars)	Change in stumpage mice (%)	Change in annual harvest (%)
MCC	836	-453	-1,289	.36	-.12
osu	-4,176	-2,260	-6,436	1.82	-.60
GISS	4,988	-2,701	7,689	2.16	-.72
GFDL	5,790	-3,134	-8,294	2.49	-.84
UKMO	-11,494	-6,222	-17,716	4.94	-1.68

Table 44.7. Combined Annual Changes in Economic Surplus for Southern Pine Solidwood and Pulpwood Markets under Five Climate Change Scenarios in 1991 Dollars

Climate scenario	Change in producer surplus (thousands of dollars)	Change in consumer surplus (thousands of dollars)	Change in total surplus (thousands of dollars)
MCC	-2,199	-1,777	-3,976
OSU	-10,305	-8,214	-18,519
GISS	-11,797	-9,316	-21,113
GFDL	-15,320	-12,391	-27,711
UKMO	-27,815	-22,077	-49,892

was about $11 million per year. The OSU, GISS and GFDL scenarios yielded producer surplus decreases in the pulpwood market that ranged from about $4 to $6 million per year.

Combined annual surplus decreases for both the solidwood and pulpwood markets (Table 44.7) ranged from about $4 million for MCC scenario to $50 million for UKMO. Although the OSU and GISS scenarios yielded total surplus changes of about $20 million a year, the GFDL scenario was about $27 million per year.

Summary

The annual economic impacts of global climate change on southern timber markets were negative in each case. The changes in precipitation and temperature contributed to a loss in forest productivity that, in turn, caused economic losses. The economic impacts were negative to both timber producers and timber consumers.

However, although global change did cause annual economic losses, these do not appear to be particularly large in relative terms. For example, the annual losses in economic surplus predicted by the UKMO model were $50 million per year. This represents only about 1% of the $5 billion total annual southern pine timber market surplus. (In Figure 44.1, total surplus is represented by the triangular area bounded by demand function D, supply function S, and the price axis.) The MCC scenario predicted annual economic losses of less than one-tenth of 1% of total annual timber market surplus. The annual losses predicted by the GISS model were about four-tenths of 1% of total timber market surplus.

Future versions of the PnET–IIs and SPAMM models could provide improved estimates of global change impacts on southern forests. Changes to future versions of the model would include the addition of a CO, component to the PnET–IIS model. The present version does not have the capability of analyzing CO, effects on forest growth. The probable effect of a CO, model component would be to increase tree growth and thereby reduce damages or, perhaps, even show a gain in tree growth. Another improvement would be to make the physiology and economic models capable of dynamic analysis. That is, permitting the models to analyze the transitional impacts of global change over a long-time period. In this manner, the cumulative, rather than static, effects of global change could be analyzed. The results of such a dynamic analysis might be a more dramatic effect of global change on southern forests.

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