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Socioeconomic Studies from the 1994 SOFEW Meeting

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Foreword

The papers published in this volume were originally presented at the 1994 Southern Forest Economics Workers (SOFEW) Annual Meeting held in Savannah, GA. Together, they made up a special session at the SOFEW conference. The topic of this session was the socioeconomic impacts of global climate change on forestry. This research was sponsored in part by the USDA Forest Service's Southern Global Change Program (SGCP) located at North Carolina State University in Raleigh, NC. Ed de Steiguer, former Deputy Director of the SGCP, was organizer of this special session. The manuscripts have undergone only minor revision since the SOFEW meeting.

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Timber Market Impacts of the Climate Change Action Plan

J.E. de Steiguer

Abstract

A timber market model for southern pine pulpwood and sawtimber examined how a cost-shared tree planting initiative designed to sequester carbon impacts the timber market. The benefit/cost ratio measuring market retums on the overall program is 1.4 to 1. The benefit/cost ratio for the stumpage owners is 2.2 to 1, the market benefit/cost ratio to taxpaying consumers is 0.7 to 1. However, the trees are likely to be harvested well before maximum carbon sequestration potential is attained. Two approaches to improving carbon sequestration potential include restricting harvest to longer rotations on private land or planting on national forest lands where harvest age is already restricted by law to culmination of mean annual increment.

The Action Plan

In October 1993, the Clinton-Gore administration issued The *Climate Change Action Plan (the* Plan). The purpose of the Plan is to reduce greenhouse gas emissions in the United States to 1990 levels by the year 2000. According to the Plan (Clinton and Gore 1993), reducing greenhouse gas emissions will prevent changes in the global climate system, raising of sea levels, inundation of coastal areas, damage to ecosystems, and destabilization of agricultural production. The intellectual forerunner of the Plan was the Earth Summit Conference held in Rio de Janeiro, Brazil, in 1992. The principal objective of the Earth Summit was to stabilize greenhouse gas concentrations in the atmosphere.

The Plan states that no single remedy for reducing greenhouse gas emissions exists. Accordingly, the administration intends to use some 50 initiatives in all sectors of the economy to reduce emissions of and enhance sinks for greenhouse gases such as carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons. In addition, the goal is to achieve these reductions in a manner that will not harm the economy.

The Forestry Initiative

Among the 50 initiatives in the Plan is one to accelerate the planting of forests on nonindustrial private lands to sequester carbon emissions. The apparent goal is to plant 815,500 acres on private lands from 1995 to 2000. This planting will occur in stages: 23,300 acres in year one, 46,600 in year two, 93,200 in year three, 186,400 in year four, and 233,000 acres in both years five and six. The program to plant the trees will be delivered under current USDA Forest Service and State Forester delivery systems. The USDA Forest Service will provide technical evaluations and assistance under the Stewardship Incentive Program. Under the cost-share agreement in this program, the Federal government will pay up to 75 percent of planting costs. Recently, USDA tree planting cost-share programs have accounted for about 435,000 acres planted annually. Since 1975, 72 percent of the cost-share acres have been in the Southeastern U.S.

This tree planting initiative should reduce emissions by 0.5 MMT of carbon equivalent. Due to the life-cycle growth of the trees, this carbon reduction will be most visible, according to the Plan, in the years after 2015. The Plan estimates that the market impact will be $40 million (199 1 dollars, undiscounted) in private investment or about $50 per acre. In addition, positive economic impacts will be realized through payments to tree nurseries, forestry consultants, and tree planters.

The Problem

The Plan sets the market impact at the value of the private capital investment induced by the cost-sharing arrangement In effect, the flow of private investment capital is seen as a benefit In fact, this cash flow is an immediate cost to private landowners in exchange for future benefits for everyone. The government portion of the cost-share payments, estimated at $120 million (about $150 per acre), is an immediate cost to society. The true long-term benefits to all parties will accrue in two forms: (1) as reduced environmental damage from atmospheric carbon and (2) as increased merchantable wood in the forestry sector of the economy. This paper explores the latter by estimating changes in producers and consumers surpluses in timber markets resulting from increased wood inventories. Some thoughts on the carbon sequestration potential of this tree planting initiative will also be provided.

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Measuring Market Impacts

The method used to estimate the impact of additional tree planting on the timber market is based on the following premise: additional forest inventory causes a shift in the supply function; this shift lowers stumpage price; and the lower price generates marginal harvest increases. At some point in time, the periodic marginal harvest increases will remove an area of forest equal to the area originally planted. In each harvest period, the changes in economic surpluses resulting from these supply shifts and increased harvests can be calculated. These economic surpluses, discounted to the present, are the measure of the market benefits of the cost-share program.

These surpluses are illustrated in Figure 1, which depicts an idealized annual timber market. Market demand is labeled D, and initial market supply is labeled S. The quantity demanded is a negative function of timber price, while timber supplied is a positive function of timber price. The market is in initial equilibrium where S intersects D, yielding an annual harvest of q* at price p*. The original consumer surplus is equal to area g. The original producer surplus is equal to area f+a.

Standing timber inventory is an undepicted variable in the supply function. It is used as a proxy for the cost of supplying timber (Jackson 1983). An increase in timber inventory reduces timber supply cost, thus shifting supply outward to S'. The new equilibrium yields an annual harvest of q' and a price of p'. Consumer surplus is now equal to g + f + e + d.

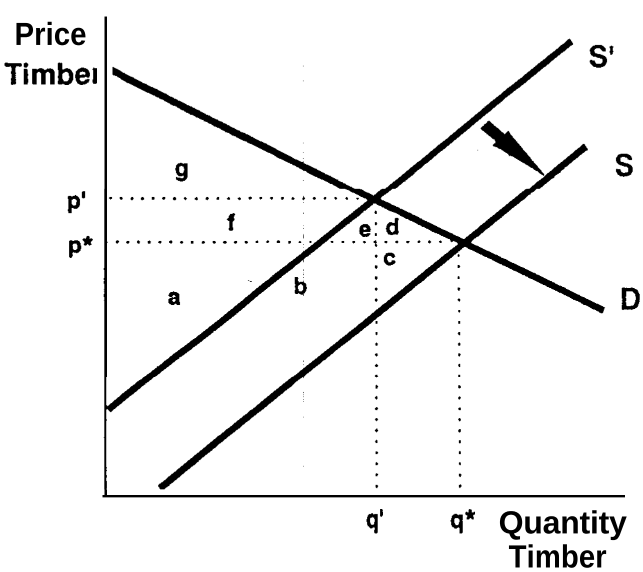

Figure 1—An increase in timber inventory causes on outward shift in the timber supply function.

Producers surplus is equal to a + b + c. Thus, both consumer and producer surpluses change when timber inventory increases. Quite clearly, consumer surplus increases by f + e + d. For producers, the picture is not so clear. Producers lose area f, but gain b + c. These opposing effects result from a decrease in stumpage price (from p* to p') occurring simultaneously with an increase in harvest quantity (from q* to q'). The net effect on producer surplus is indeterminate without further analysis of a specific market situation. Following a similar analysis of technological change in Just and others (1982), it is anticipated that the supply curve shift will result in overall gains in surplus.

The full impact of the cost-share tree planting program or the timber market will require many harvest periods to run its course. During the first harvest period (year one of timber merchantability), the additional inventory of cost-share planted trees shifts the supply curve (S to S'). This, in turn, generates a marginal increase in harvest (q* to q'), which is deducted from inventory. The new inventory amount becomes the initial inventory for period two. The period two inventory is grown for another-year; the supply curve is shifted; and the resulting harvest increase is deducted to form the initial inventory for period three. The process continues for each harvest period until the 8 15,500 acres (the original cost-share planted area) is harvested. The present value of the economic surpluses for all periods is computed by discounting them individually back to the year of the original planting and summing to determine the overall impact of the Plan's tree planting initiative on the timber market.

Models and Assumptions

A model was developed to calculate the impacts of the administration's tree planting program on the timber market. Called the Southern Pine Aggregated Market Model (SPAMM), this single computer model combined equations, methods, and tables from other studies. Southern pine sawtimber and pulpwood market equations were taken from Newman (1987). Calculating economic surpluses was based on some of the methods developed by Holmes (1992). A loblolly pine growth and yield model was taken from Murphy and Stemitzke (1979). A regression equation to separate yield estimates into pulpwood versus sawtimber was developed using data from loblolly pine yield tables (Forbes 196 1) and an equation provided by Avery and Burkhart (1983). The principal SPAMM equations follow:

The inverse market equations (Newman 1987):

Sawtimbcr demand: $Pd = 939.7 - .0003162Qd$
Sawtimber supply: $Ps = -239.82 + .0003255Qs$
Inventory elasticity $(\%\Delta Q/\%\Delta I) = .387$

Pulpwood demand: $Pd = 253.7 - .00011Qd$
Sawtimber supply: $Ps = -289.8 + .0002032Qs$
Inventory elasticity $(\%\Delta Q/\%\Delta I) = 1.198$

The loblolly pine yield equation (Murphy and Sternitzke 1979):

$$V = EXP(3.02439 + .00515(SI) - 20.17542A^{-1} + 1.06693 \ln(BA)),$$

where

V = cubic feet volume per acres
SI = site index
A = stand age
BA = basal area

The equation to estimate product separation:

$$SAWPROP = EXP(.783667 - 49.2315A^{-1}),$$

where

SAWPROP = proportion of stand in sawtimber
A = stand age.
The equation is restricted so SAWPROP cannot exceed 1 .O.

In order to implement SPAMM, several assumptions were made. The following assumptions are the most crucial:

- All plantings will take place in the Southeastern U.S.
- All plantings will be loblolly pine
- Harvesting will begin at a stand age of 20 years
- Newman's equations based on 1950-1 980 data will describe the southern pine stumpage markets into the twenty-first century
- Trees were planted on all 815,500 acres in a single year
- A real discount rate of 4 percent
- Supply curve shifts were parallel (constant costs)
- A site index of 62 and a basal area of 70 for all simulations; both are representative of average conditions for the southern pineries
- Finally, all forest owners were free to sell their timber

Results

The SPAMM results (table 1) indicate that after 45 years of simulated harvesting, 8 16,024 acres of southern pine have been cut solely in response to the inventory-induced supply curve shifts. This is an amount nearly equal to the original 8 15,500 acres planted. Thus, if harvesting began at age 20, all the timber would be eliminated at the maximum stand age of 65 years.

As anticipated, the overall result was a positive combined surplus. Producer and consumer surpluses (table 1) show positive changes in both the sawtimber and pulpwood markets. Sawtimber market surpluses were about equal to those in the pulpwood market. More pulpwood was harvested than saw-timber; however, the pulpwood was harvested sooner, thus the effects of discounting were reduced. The sawtimber was more valuable per unit volume, yet it occurred further in the future thus increasing the effects of discounting.

To gain perspective on the magnitude of the surplus changes, the changes in combined producer-consumer surpluses were also computed as a percentage of average annual total surplus in the two product markets. As table 1 indicates, the relative magnitudes of the surplus changes were small, and the total averaged only about 3.7 percent of the annual timber market total surplus.

Table l-Acres of southern pine harvested, changes in present value of producer (PS) and consumer (CS) surpluses in millions of 199 1 dollars, and total surplus changes as a percentage of average annual pine timber market producer and consumer surpluses after 45 years of timber harvesting

	Sawtimber	Pulpwood	Total
Acres Harvested:	261,520	554,504	816,024
Present value of surplus changes (1991 $ millions):			
Consumers	$43.2	$41.2	$84.4
Producers	$44.4	$44.4	$88.8
Total changes	$87.6	$85.6	$173.2
Total changes as a percent of average annual PS+CS:	2.5%	7.7%	3.7%

Three market benefit/investment cost (B/C) ratios were computed: one for producers, one for consumers, and one for the total program. The present value of producer surplus was considered to be the market benefit accruing to producers as a result of their $40 million investment. Consumer surplus present value was considered to be the market benefit accruing to the general taxpaying public as a result of their $120 million investment. The results (table 2) indicate that the overall program is profitable (1.4 to 1). Private stumpage producers, realizing a B/C ratio of 2.2 to 1, do well on their capital. However, the return to taxpayers is negative because the consumer surplus generates a B/C ratio of 0.7 to 1.

Table 2-Forestry program market benefit/investment cost (B/C) ratios computed as the present value of economic surpluses relative to invested capital

Benefits / Costs	B/C Ratios
Producer surplus/private investment	2.211
Consumer surplus/government investment	0.711
Total surplus/total investment	1.4/1

Carbon Sequestration Potential

Although this study did not compute the carbon sequestration potential of this cost-share tree planting initiative, it is possible to speculate on that result. The most efficient forest management scheme for carbon sequestration would most likely prevent harvesting until the culmination of mean annual increment (MAI). This scheme assumes that the rate of total carbon accumulation on the forest site is identical to the rate of merchantable wood growth.

A casual inspection of merchantable volume yield tables for loblolly pine (Forbes 196 1) indicates that culmination of MAI probably occurs when a stand is between 60 and 80 years of age; the exact age is dependent on site index. However, according to the SPAMM results, most of these stands will be removed—or at least an equivalent amount of forest land will be harvested-well before MAI is attained. Therefore, the net impact on carbon sequestration could be negligible.

Assuming that the sole objective of the tree planting initiative is to ensure that carbon sequestration does occur, harvesting of these private forests should be restricted until culmination of MAI is reached. An alternative to this approach involves planting trees on 8 15,000 acres of National Forest land where harvests are already legally constrained to the culmination of MAI.

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An Exploratory Study of the Economic Impacts of Climate Change on Southern Forests: Preliminary Results

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Abstract

A multiperiod, regional, mathematical programming model was used to assess the economic impacts of global climatic change on the southern forestry sector. Several climate/biological response scenarios were developed and evaluated. Changes in the supply of timber and forest products induced by climate change interact with demand for wood and wood products to generate economic impacts, measured as changes in consumer and producer surpluses over time. The model and scenarios are described and information is drawn together on the sensitivity of model results to scenarios. Directions for further research are suggested.

Introduction

Global climate change could have an impact on forests and forestry in the United States. Regions in the United States may be differentially affected. Forecasts of climatic change and the biological response to climate change in trees and forests are still largely hypothetical. Though much research is being done on aspects of climate change and biological response, conclusions are still preliminary.

This experiment seeks to dimension the potential economic impacts by considering some hypothetical biological responses to climate change. For this exploratory study, scenarios are not based directly on climatic descriptors, but consider hypothetical changes in forest growth rates and in stand establishment costs that might result from climatic changes. Prehminary results for economic impacts are assessed in terms of production, price levels, and economic welfare.

Burton and McCarl are Assistant Professor and Professor, respectively, Texas A&M University, College Station, TX; Adams is a Professor, University of Montana, Missoula, MT; Alig is a Research Economist, Pacific Northwest Research Station, USDA Forest Service; Corvallis, OR, Callaway is a Consultant with RCG/Hagler Bailly, Boulder, CO; and Winnett is a Forest Policy Analyst, U.S. Environmental Protection Agency, Washington, DC.

Literature

Relevant literature can be divided into three categories. Several recent studies have explored the possible impact of climate change on the agricultural sector (e.g., Adams and others 1990; Kane and others 1992). In general, these studies combine hypothesized climatic scenarios with information and assumptions about the biological response of annual crops to temperature, precipitation, and atmospheric composition changes to determine yields and the resulting economic market impacts. Articles have considered impacts at the farm level (e.g., Raiser and others 1993), the national level (e.g., Adams and others 1990), and the international levels (e.g., Reilly and Hohmann 1993; Tobey and others 1992).

In forestry, the extent of knowledge concerning the biological response to climate change is more limited. Short-term experimental results have not yet been validated for the life of the tree. Also, little is known about how the response of an individual tree to climatic changes generalizes to stand and forest levels. Response of the forest as a whole is most important for the analysis of forest-sector-supply changes and resulting economic consequences of climate change.

In this second literature category, a number of studies have examined carbon sequestration in forests as a way of mitigating global climate change. The economic impacts of large tree-planting programs in the United States have been investigated by Adams and others (1993) and Haynes and others (1994) and in Canada by Van Kooten and others (1992). A related, prehminary assessment of economic impacts from forestry programs for mitigating the build-up of atmospheric carbon dioxide is presented in Alig and others (in press).

Third, a few studies have attempted to utilize varying assumptions to dimension the potential impacts of climate change on the forestry sector, Van Kooten and Arthur (1989) examine hypothetical increases in the biomass of specific forests in Canada under three alternative growth assumptions for the rest of Canada and the United States. They conclude that under free-trade assumptions, the overall economic welfare implications of climate change may be negative for Canada. In a similar study, Van Kooten (1990) examines the impact of 5 percent and 7.5 percent increases in harvests in Canada together with increases or decreases of similar magnitudes for United States harvests. He concludes that consumers in both countries benefit but that producers lose and that the overall impact is positive for Canada only when harvests in the United States decline.

Global Climate Change

The change in global climate considered in this study is that induced by increasing concentrations of atmospheric CO_2. Climatic descriptors used in the literature generally come from general circulation models (GCM's). These models are large and complex and disagree on predicted climate for a doubling of CO_2. Adams and others (1990) and Kaiser and others (1993) comment on the disparity of predictions and the sensitivity of results to the climatic descriptor chosen. Robock and others (1993) formally compare the predictions of five GCM's for use in impact analysis and find results highly sensitive to the GCM used.

However, models generally agree that the warming effects will be greatest in the northern and temperate latitudes. In the United States, the Southeastern area may experience a rise in temperature and no change or a slight decrease in precipitation. The northern latitudes and other areas in the United States may experience a rise in temperature and no change or a slight increase in precipitation (Adams and others 1990; Melillo and others 1993; Kind and others 1992). In addition, a potential fertilization effect may result from increased concentrations of CO_2 (Sedjo and Solomon 1989).

The FASOM Model

The model used for this study is the forestry sector of the Forestry and Agricultural Sector Optimization Model (FASOM) (Adams and others 1994). FASOM is a large multisector, regional, multiperiod, nonlinear mathematical programming optimization model written in GAMS (Brooke and others 1988). FASOM maximizes the present value of the sum of the economic surpluses. The model forecasts 10 decades; and the first five, through 2040, are reported here.

For purposes of these exploratory forecasts, predefined FASOM regions of the United States were aggregated. The South included the Southeastern and South Central U.S. The North included the Pacific Northwestern States and the Northeastern U.S. Other regions aggregated the remaining States, these regions were specified along approximate latitudinal and regional lines.

Important exogenous variables in FASOM are public cut, forest products international trade flows, and forest products demand parameters. These variables are generated in the Timber Assessment Market Model (TAMM) (Adam and Haynes 1980). Variables endogenous to FASOM include harvest levels (acres) and production (mmcf) for industrial and nonindustrial private foresters, market prices, and timber harvesting decisions. Softwood and hardwood products considered are sawtimber, pulpwood, and fuelwood.

Inventory existing at the model's starting decade was modeled separately from stock planted during the model run. This allowed exploration of changing stand establishment costs resulting from climate change impacts. While the model may potentially treat existing and new inventory differently, identical changes in the rate of tree growth were assumed for this study. FASOM can distinguish different levels of management intensity and maintains a comprehensive inventory description. Yield estimates and inventory data were taken from the aggregate timberland assessment system (ATLAS) (Mills and Kincaid 1992).

Scenarios

This exploratory study considered eight possible scenarios induced by global climate change effects. They were designed as an attempt to dimension the potential impact of climate change. The first four evaluate the effects of across-the-board changes in tree growth rates, or yield, each decade. Thus, these yield changes are compounded over the decades. The first scenario postulates an increase of 5 percent in tree growth rates everywhere in the United States. The second postulates an across-the-board decrease in growth rates of 5 percent. Two scenarios consider national growth rate changes of plus 10 percent and minus 10 percent.

In addition, two scenarios explore the different effects from increased warming at different latitudes in the United States. The warming, coupled with a slight decline in precipitation, may negatively impact timber yields in the Southern U.S. At the same time, yields in the Northern U.S. may rise. Therefore, a pair of southern decline scenarios were constructed. One postulates a 5-percent decline in yield in the South, a 5-percent increase in the North, and no change in other regions. A second southern decline scenario explores the impact of a lo-percent decrease in the South, a lo-percent increase in the North, and no change in other regions.

Last, two scenarios were constructed to evaluate the impact of increased establishment costs in the South, with no change in the North or other regions. Increased temperature and decreased precipitation in the South may increase the mortality of very young trees, resulting in increased stand establishment costs. One scenario hypothesizes a doubling of costs in the South; a second considers a tripling of stand establishment costs in the South.

Scenario Results

Base Scenario

Figure 1 contains a graphical description of some key variables in the base scenario. Production of forest products in the United States over the next five decades shows a general increase in the southern region, a fall in northern production until late in the forecast period, and a fairly steady decline in the rest of the country. Acres harvested (fig. 1) reflect a similar pattern, first rising and then declining in the next century. Inventory levels, softwood and hardwood combined, rise correspondingly over the next half century.

The patterns of harvest and production evident in the base scenario are probably the result of interactions between the age class distribution of the initial regional inventories and the terminal conditions. In addition, in a mathematical programming model, a small change in relative prices can trigger large swings in activity levels or, in this case, production levels in the various regions.

The economic welfare bar chart in figure 1 shows the present value of the sum of economic surpluses in the model discounted to 1990. Domestic consumer surplus (DCS) is by far the largest share of total welfare. Domestic producer surplus is DPS. The surplus attributable to the public cut (Pub) is about half that of domestic producers. Foreign surplus (For) is not visible. Some surplus is attributable to the present value of model terminal conditions (Term).

Forest Products Production

Figures 2 and 3 present some results for forest products production in the across-the-board increase/decline scenarios. At the top of each figure is a bar chart for the southern region; below are charts for the northern region and the other regions. When growth rates rise 5 percent nationally, production of forest products tends to shift slightly to the North and to the other regions when compared to the base scenario. When growth declines 5 percent, production shifts to the South slightly when compared to the base scenario.

These patterns are more evident in figure 3, which portrays results for a lo-percent increase and a lo-percent decline in national yiekls. The magnitudes of the changes are slightly huger. However, none of the four scenarios shows any substantial variation from the base scenario in forest products production.

Figure 4 shows production results for the southern decline scenarios. When growth rates decline 5 percent in the South, rise 5 percent in the North, and do not change in other regions, production moves slightly from the South to the North in the last decades of the forecast. When the changes are 10 percent, the pattern is slightly more pronounced.

Increased warming and less precipitation in the South may increase mortality of very young trees, causing establishment costs to rise substantially. Two scenarios hypothesized a doubling and a tripling of stand establishment costs in the southern region. Figure 5 shows production results from these scenarios. Increased stand establishment costs cause a very slight shift of production away from the South. The variation in results over the decades is probably due, in part, to initial age class distributions.

In general, when yields rise nationally, the North gains slightly. When yiekls decline nationally, the South gains. When yields shift away from the South, production rises in the North and other regions. When costs rise in the South, production shifts to other regions.

Price Levels

Figures 6 and 7 show the price level indices for all eight scenarios relative to the base scenario. Consumer prices and producer prices are analyzed separately, though the patterns of change in response to the hypothetical scenarios are similar. As expected, an increase in growth results in a fall of real prices relative to the base scenario (figure 6).

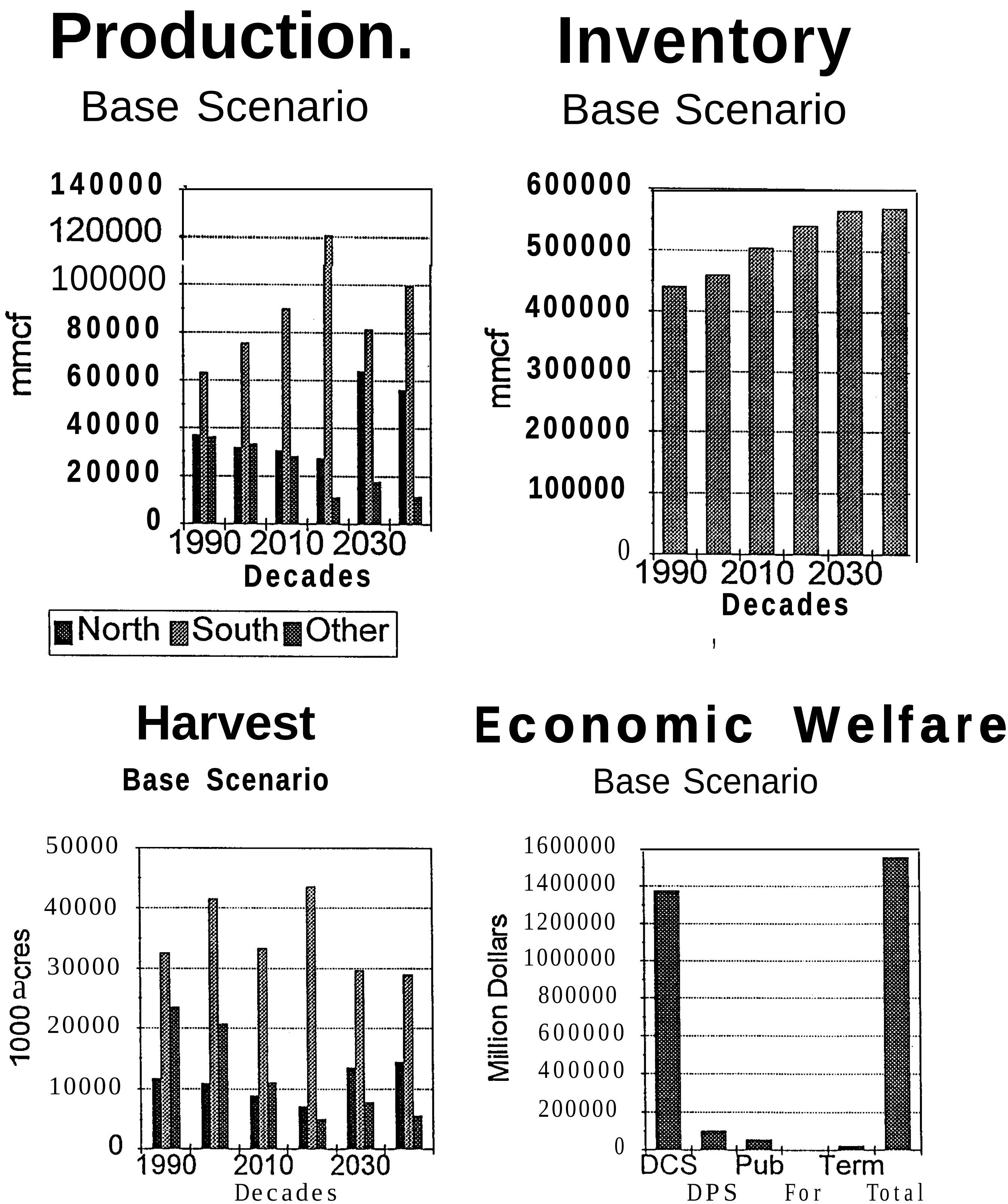


Figure 1-The base scenario.

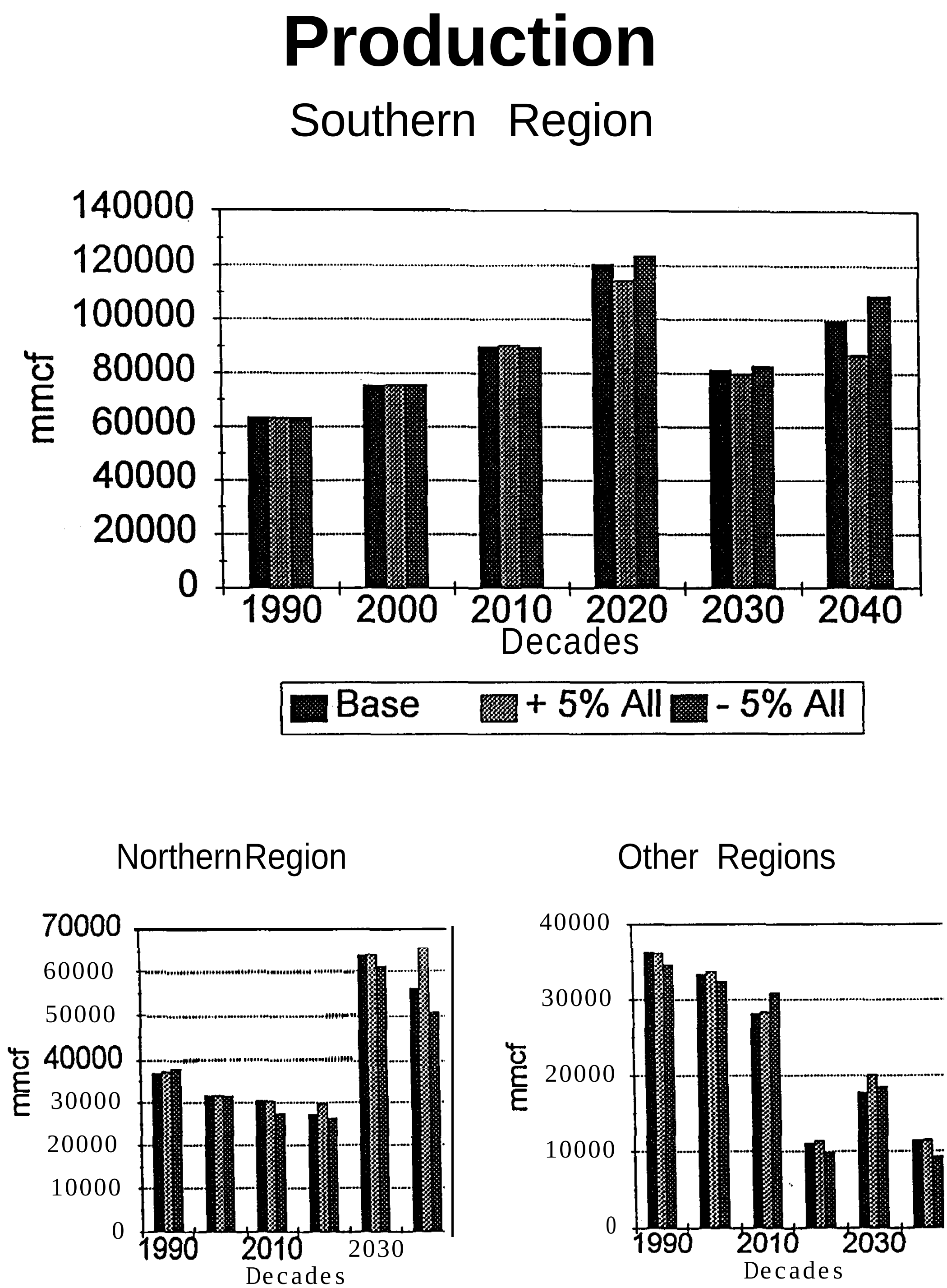


Figure 2-Regional production for 5-percent national yield change scenarios.

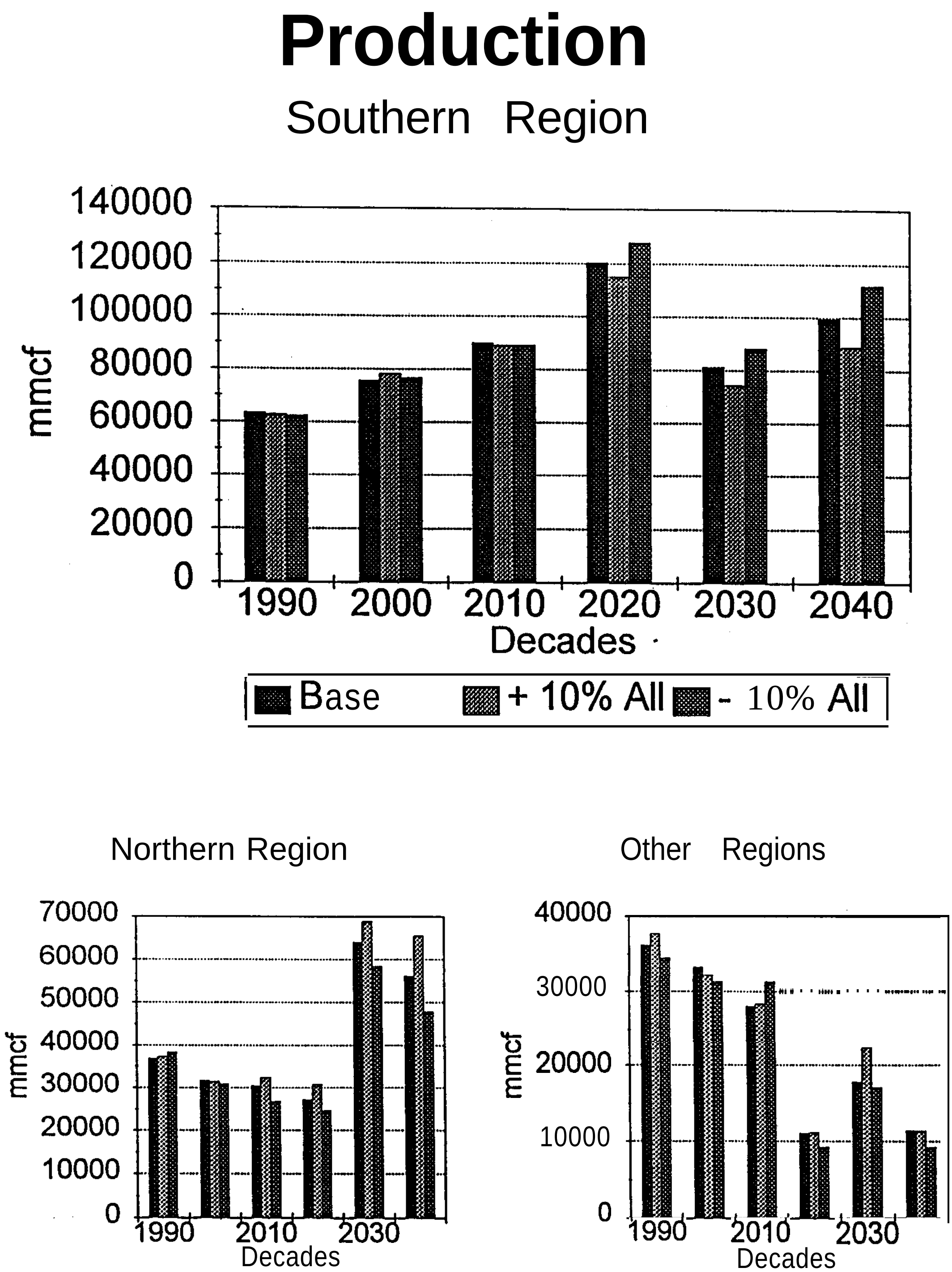


Figure 3—Regional production for IO-percent national yield change scenarios.

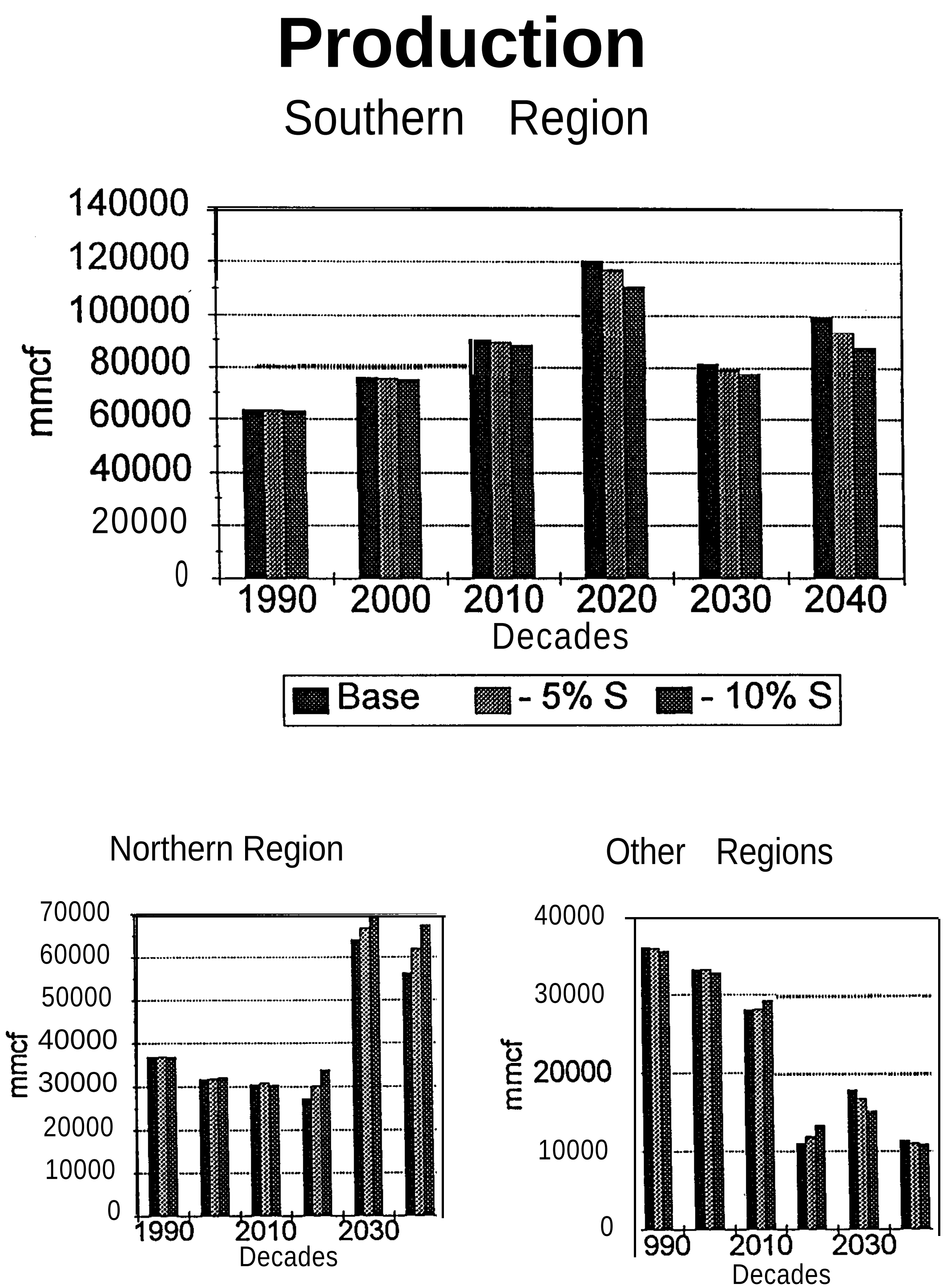


Figure 4-Regional production for southern yield decrease scenarios.

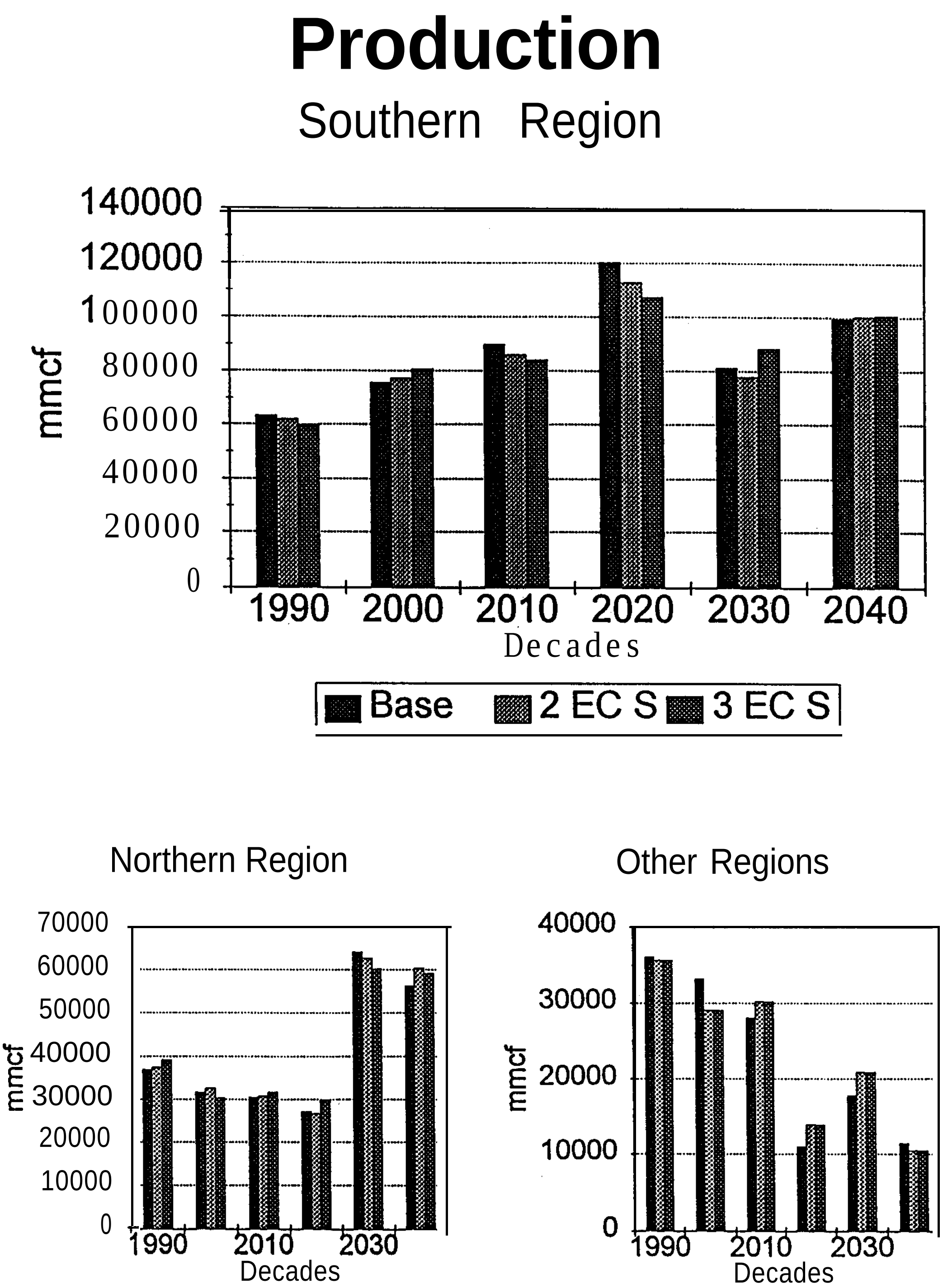


Figure 5—Regional production for increase in southern establishment cost scenarios.

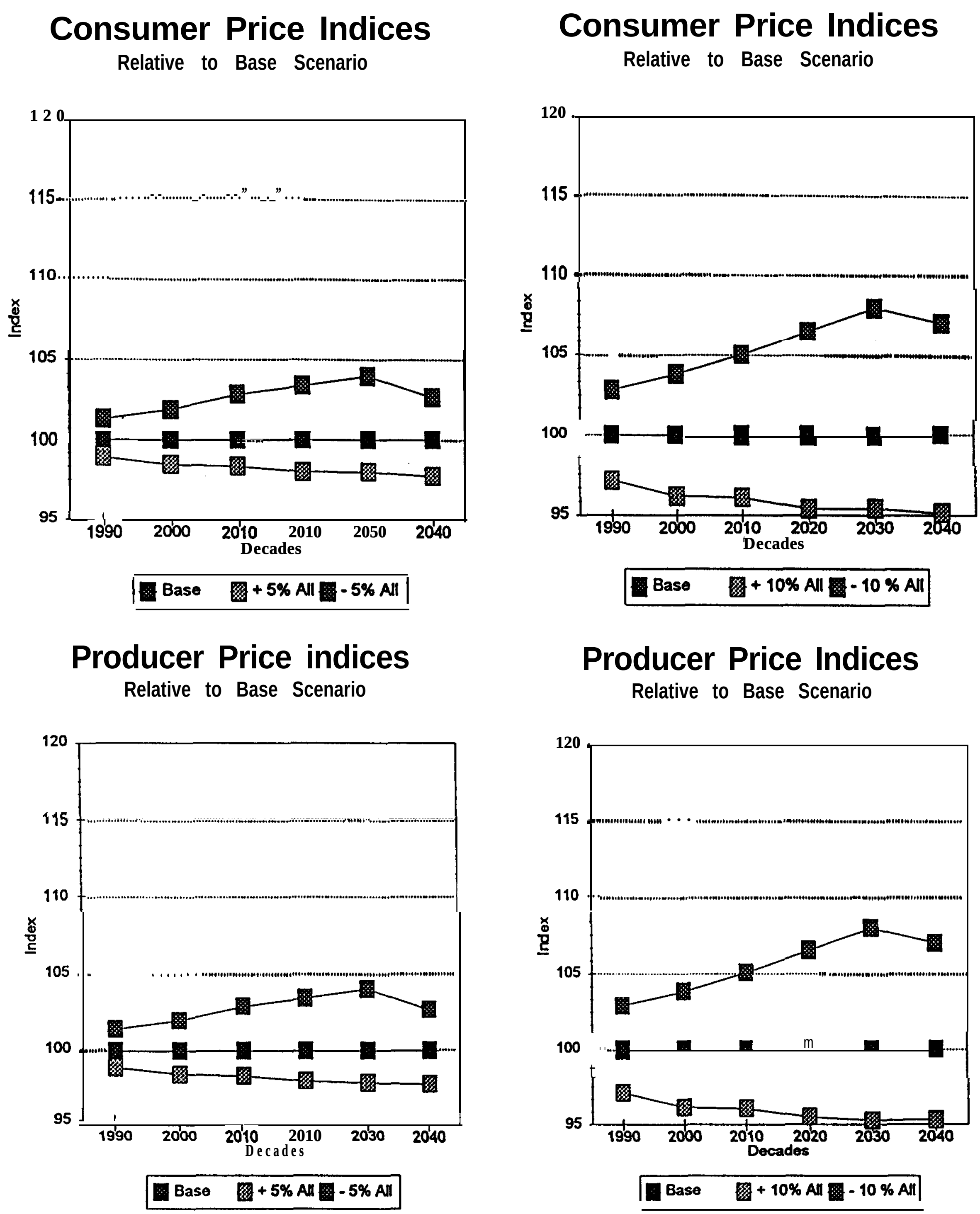


Figure 6—Price indices for national yield change scenarios.

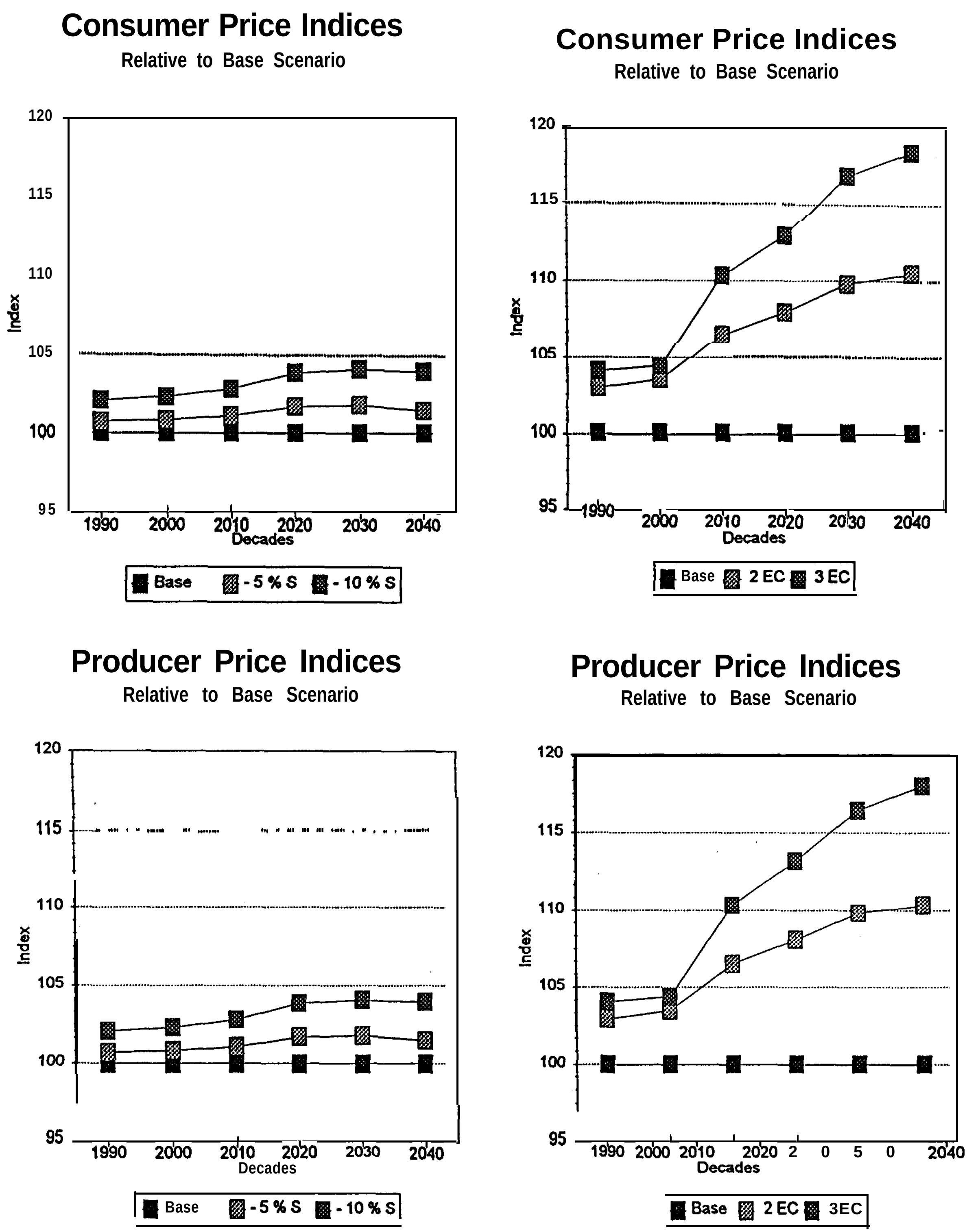


Figure 7—Price indices for southern yield de-crease scenarios.

When the increase is 5 percent, real prices fall by roughly 3 percent over the 50 years. 'When the increase is 10 percent, real prices fall by roughly 6 percent over the 50 years. When growth rates fall, real prices rise relative to the base scenario. A S-percent decline in yields results in about a 4-percent gain over 50 years and a lo-percent decline results in an S-percent rise in real prices over the base scenario.

The southern decline scenarios both result in a real price rise. In figure 7, a 5-percent decline in southern growth rates, coupled with a 5-percent rise in yields in the north leads to about a 2-percent rise in price levels. The yield changes do not offset because volume is much higher in the South. Thus, the southern decline dominates the markets. Similarly, a lo-percent decline in southern yields, coupled with a lo-percent increase in northern yields leads to a 4-percent overall increase in price levels.

An increase in the establishment costs of stands in the South has the biggest impact on price levels. Relative to the base scenario, a doubling of establishment costs in the South, with no change in costs in the North or other regions, leads to a lo-percent increase in price levels over the 50 years. A tripling of establishment costs results in price level increases of just under 20 percent relative to the base scenario. A change in southern costs has a marked impact because the volume of timber production in the southern region is relatively large.

Welfare Effects

Figure 8 shows percentage change in the present value of total welfare for each of the eight scenarios relative to the base scenario. Basically, when yields increase overall, the economic surpluses in the model increase. When yields decline overall, economic welfare also falls. When yields decline in the South, even with increased growth rates in the northern region, total welfare falls because the volume of production is so large in the South. This also explains why establishment cost increases in the southern region cause welfare to fall. However, no change in total welfare is larger than 1 percent of the welfare in the base scenario.

In figure 9, the surpluses of domestic consumers and producers is analyzed separately. When yields rise nationally, consumers gain. When growth rates fall, they lose. The largest decline in domestic consumer surplus is caused by increased stand establishment costs in the South but is still less than 4 percent of the consumer surplus in the base scenario.

On the other hand, producers lose when yields rise nationally. In other scenarios, they gain surplus relative to the producer surplus in the base scenario. Again, the largest change, an increase, occurs when stand establishment costs rise in the South. Producers gain almost 30 percent over their surplus in the base scenario when stand establishment costs triple.

The welfare impacts in these markets are governed by the relative elasticities of supply and demand. The demand parameters are taken from TAMM and supply is affected by the global climate change scenarios. While the percentage changes for producers may seem high, consumers experience a greater present value dollar impact because consumer surplus is large relative to other economic surpluses in the model.

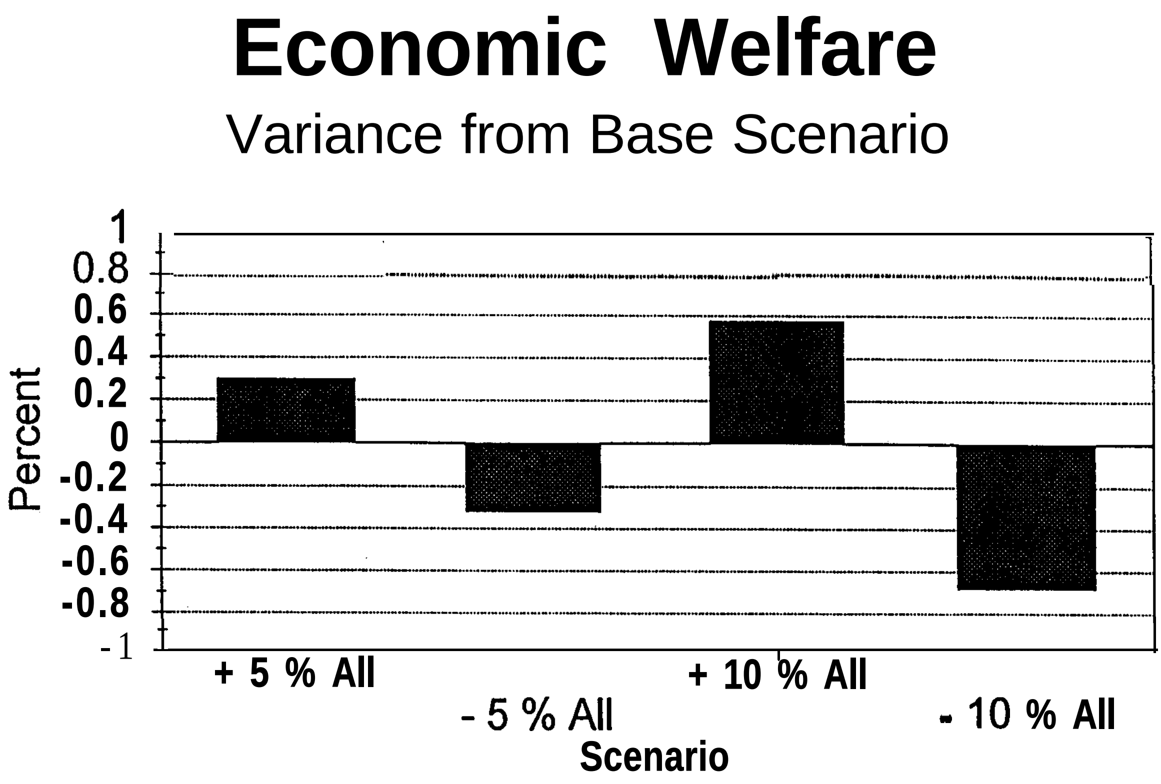
Summary and Conclusions

The results of this exploratory study show that regions of the United States may be affected differently by global climate change. If yields increase nationally, the Northern U.S. can produce relatively more forest products. If yields decrease nationally, the Southern U.S. can produce more. If yields in the South decline while they rise in the North, production of forest products is projected to shift away from the South. If stand establishment costs rise in the South, production can shift away from the South.

Changes in producer and consumer prices relative to the base scenario are fairly small in magnitude. When southern costs rise, price levels increase more substantially.

The economic welfare impact of these global climate change scenarios is small-less than a l-percent change from the base scenario for all eight hypothetical cases. In general, when yields rise, consumers gain. When yields fall or costs rise, producers gain.

This preliminary analysis of the potential impact of global climate change on southern forestry has sought to indicate the dimensions of possible economic impacts. If yield changes are 10 percent or less, national and regional impacts should not be large. However, regions of the country may experience different climate change impacts. There will be effects on prices, which will cause changes in related markets.



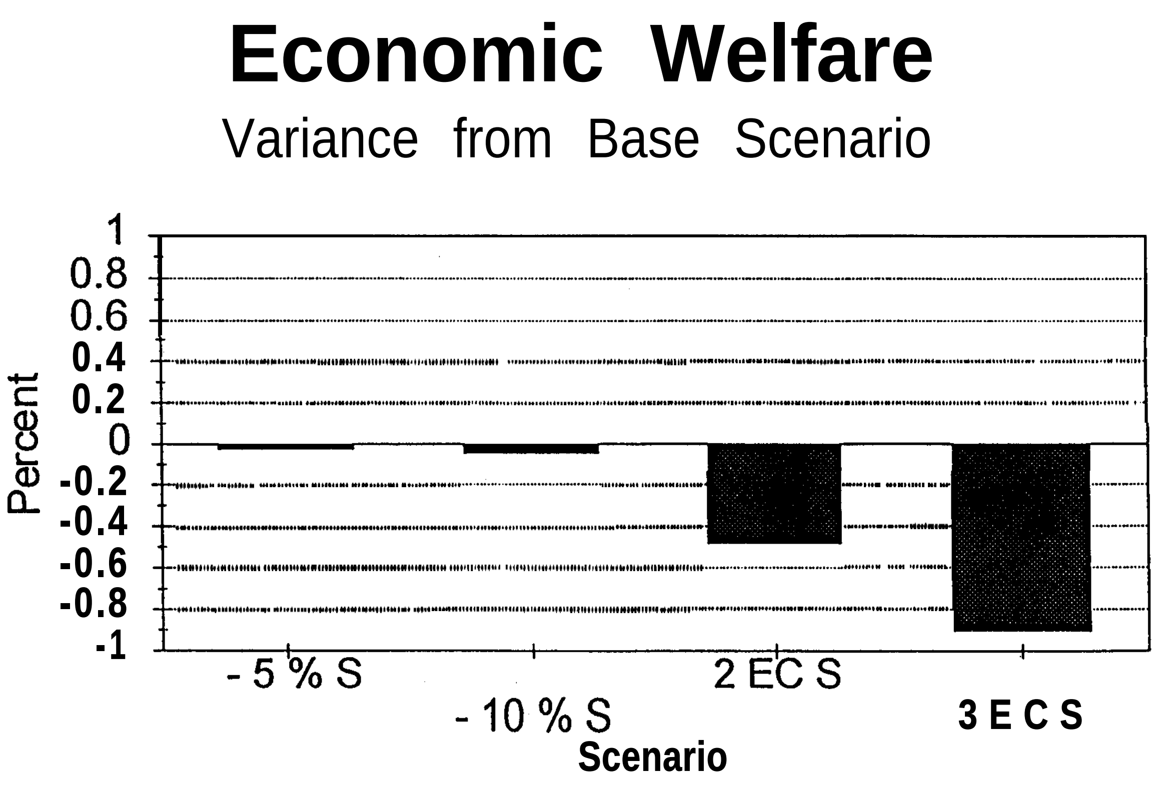
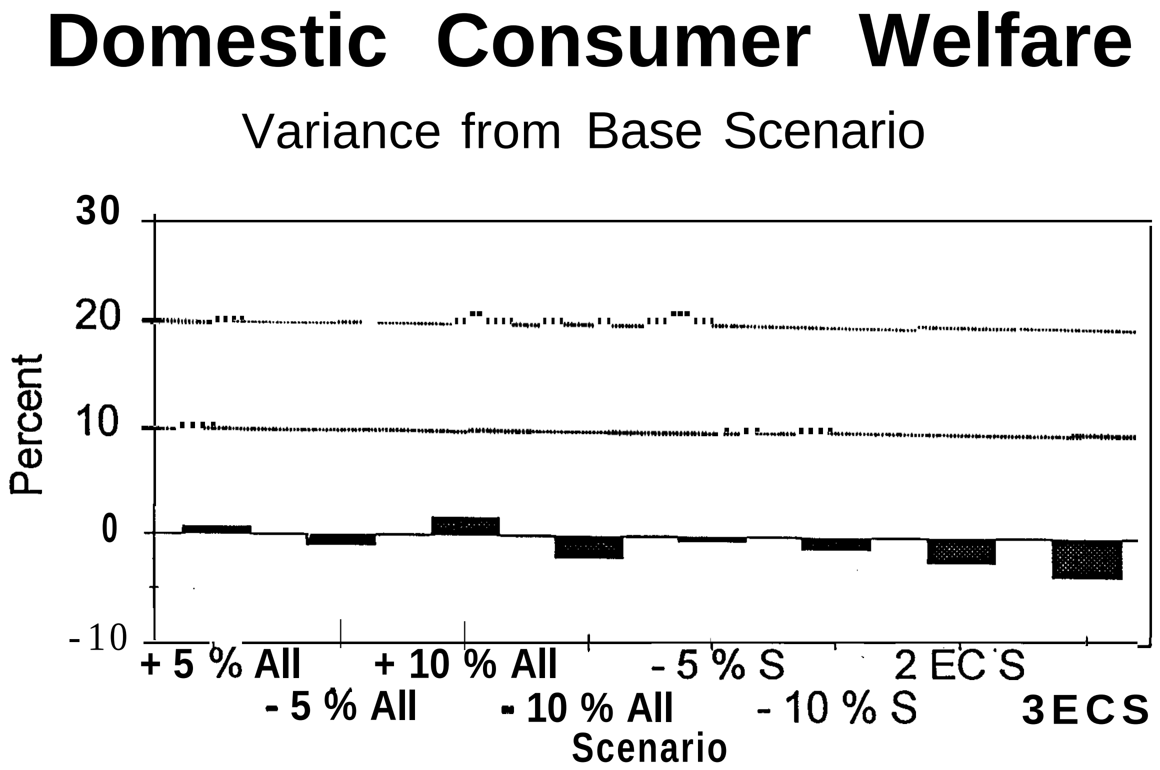


Figure 8—Economic welfare for all scenarios.



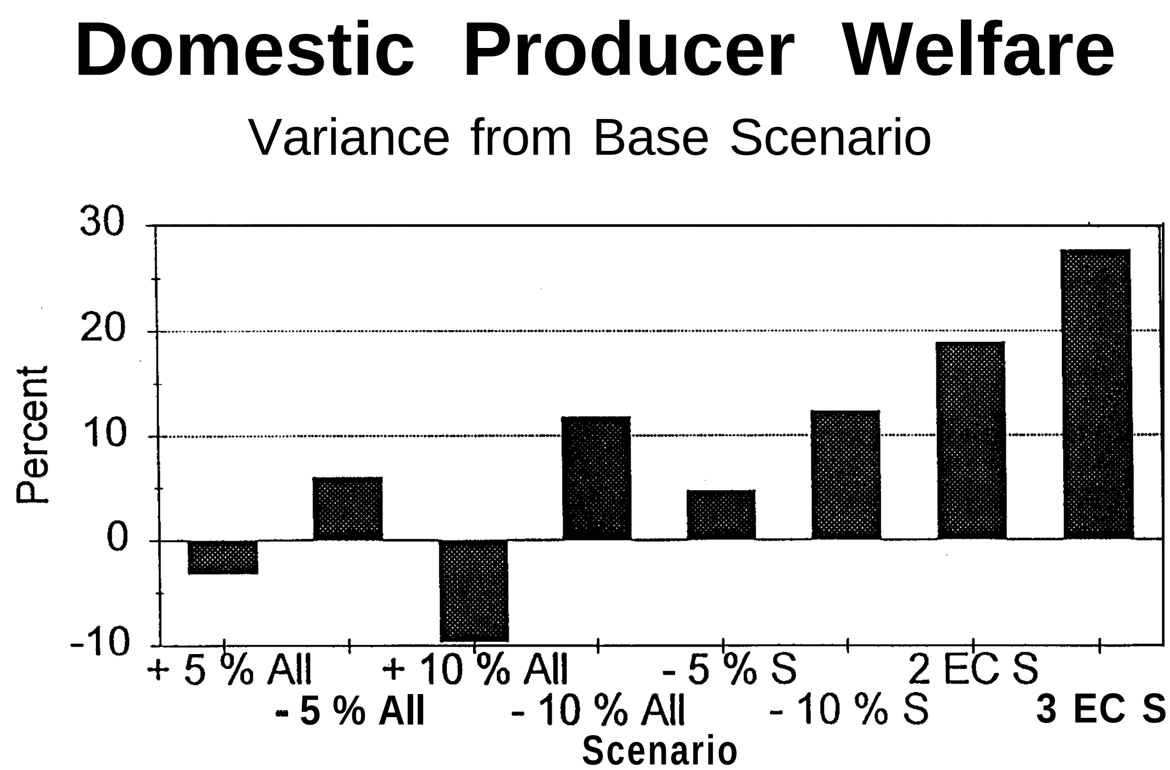


Figure 9—Consumer and producer surpluses for all scenarios.

Research Directions

Further analysis of these eight hypothetical scenarios will result in a better understanding of potential impacts of climate change. In addition, a more complete set of scenarios, aimed at more fully measuring potential climatic impacts, needs to be developed. These scenarios should be based on climatic descriptors taken from GCM's and variations in growth rates over time.

Work is currently underway to endogenize important forestry sector variables, such as international trade flows, that are exogenous in this version of the model. Trade with Canada is especially important to incorporate endogenously into the model. The impact of changing public harvest decisions under global climate change and potential government programs needs to be assessed.

The sensitivity of results to certain aspects of model construction or specific variables needs to be explored. The magnitude of the impact of terminal conditions and the initial age distribution of inventory on model performance under various scenarios need to be evaluated. An exploratory look at the potential impacts of radical changes in demand, perhaps a result of carbon sequestration programs or future shifts in technologies which radically impact the demand for wood, should be assessed.

The FASOM model (Adams and others 1994) will be an important tool in the understanding of global climate change impacts on the forestry sector. The eight hypothetical scenarios considered in this preliminary analysis suggest some dimension and direction of potential climate change impacts.

Acknowledgment

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The Value of Biophysical Information for Assessing the Economic Impacts of Global Climate Change

James T. Gunter, Donald G. Hodges, and James L. Regens

Abstract

Global climatic change has become a major policy and scientific issue during the past decade. This study was designed to identify the biological data required to evaluate the economic impacts of climate change on forestry in the Southern U.S. The primary data needs include changes in the range of commercially important tree species, changes in tree productivity and wood formation, and changes in the incidence of forest pests.

Introduction

For the past decade, scientists, policy makers, and resource managers have debated the likelihood of a significant global warming and the likelihood of meaningful climatic changes induced by global warming. Despite some notable critics, much of the scientific community agrees that accelerated atmospheric warming-an enhanced greenhouse effect-is occurring or will occur primarily due to the rapid atmospheric accumulation of carbon dioxide (CO,) and other trace gases from the burning of fossil and biomass fuels (Blake and Roland 1988; MacDonald 1988; Ramanathan 1988; Smith and Tirpak 1989). This accumulation may absorb significantly more long-wave radiation than in the past, thereby warming the earth and raising the mean global temperature (Dowd 1986; Houghton and Woodwell 1989). Because weather and climate are partly influenced by the long-wave radiation given off by the earth, important climatic changes are possible (Henderson-Seller and McGuffie 1987).

The correlation between temperature changes and atmospheric CO, concentration concerns many scientists. Barnola and others (1987) quantify the correlation between atmospheric CO, and changes in global mean temperature through ice core analysis. Machta (1983) documents the rise in CO, concentration in the atmosphere. Because correlation and rising CO, concentrations do not prove global warming, scientists continue to refine the theory and describe mechanisms other than atmospheric CO, concentration that influence mean global temperatures.

Although much uncertainty exists about the mechanisms that could enhance or negate global warming, the best information to date suggests that the earth's mean global temperature couldriseby 1.5t05.1 °C within the next 50 to 100 years (Smith and Tirpak 1989). Such rapid changes in temperature accompanied by changes in precipitation patterns would affect a wide range of ecosystems, including forests (Bazzaz 1990; DeLaune and others 1987; Smith and Tirpak 1989). The ability to grow crops would change depending on mean temperatures and precipitation amounts and timing. The same factors would affect forest distribution. In North America, forests would likely migrate northward or to higher elevations over time. Climatic changes might occur more rapidly than forests' ability to migrate. Stress-induced mortality in the southern range extremes would likely out-pace northward migration.

While this could significantly affect the southern forest industry and the economy of the Southern U.S., few researchers have attempted to investigate the economic implications of climate change on resource-based sectors or on regional economics, primarily because the information needed to conduct such analyses is lacking (Cubbage and others 1992; Regens and others 1989). This study will provide the initial comprehensive review of the data requirements, availability, and uncertainty for evaluating the economic impacts of climate change. Specifically, the primary purposes of the study are to identity the biophysical data required for assessing the economic effects of global climate change on timber production in the South and to assess the availability of those data. Such insights will aid future socio-economic studies of climate change. The four objectives of the study follow:

1. Identify the biophysical information needed to evaluate the socioeconomic impacts of climate change on forestry in the south;

2. Inventory sources of currently available data on future climate scenarios, forest response, and potential impacts on forest management operations;

3. Appraise the uncertainties in the available data and the impact of the uncertainty on economic projections; and

4. Identify gaps in the required data.

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Literature Review

The greenhouse effect results from the emission of greenhouse gases during production and consumption of goods and services. Using the current knowledge of the costs that emissions impose, society has determined the acceptable damage levels and the optimal quantity of social welfare to be provided. Because of the damage that global warming may inflict in the future, society is reevaluating the social cost of greenhouse gas emissions, redetermining acceptable damage levels, and reexamining the optimal quantity of social welfare to be provided.

de Steiguer (1992) describes how society determines the optimal quantity of social welfare to be provided and how society adjusts this quantity as needs change. The marginal cost that society is willing to pay for emissions must equal the marginal benefit society receives from the emissions (fig. 1 a). At equilibrium, society has determined that at price p, q units of emissions are provided. Consumers receive a surplus equal to the area in the triangle marked consumer surplus, while producers receive a surplus equal to the area in the triangle marked producer surplus. The sum of consumer and producer surpluses represents a measure of the social welfare associated with the emissions level. Social welfare is a measure of monies consumers and producers have available to invest or spend on goods and services.

Problems occur when the marginal cost (MC) of emissions increase, as shown by a lefhvard shift of the MC curve to MC' in figure 1 b. Now the quantity of social welfare provided decreases, as indicated by the changes in consumer and producer surpluses. Both consumers and producers suffer a decrease in surplus, indicating both consumers and producers have less money to spend. Society may decide this situation is unacceptable and act to increase the level of social welfare provided or decrease the burden on affected groups.

Increasing the level of social welfare to a desirable level typically involves privatizing part of the cost associated with emissions previously socialized (see fig. 2). This may result in higher prices for some goods and services until innovation ends unacceptable emissions. This action forces the marginal cost curve of emissions to the right, towards the original marginal cost curve shown in figure 2. Determining the marginal cost of greenhouse gas emissions to society is a critical step in determining the acceptable level of damage from greenhouse gas emissions.

Global Economic Theory and the Enhanced Greenhouse Effect

Maler (1992) describes the externality of greenhouse gas emissions as an overuse of a globally common resource. Overuse is the result of a Nash equilibrium.' Each country maximizes its net national welfare by allowing the atmospheric emission of greenhouse gases until the national net welfare gained from the emission of an additional ton of greenhouse gases is zero (marginal costs equals marginal benefits). The sum of the emissions from each country is greater than the Pareto efficient use of the atmosphere for emissions.' Because unilateral actions to limit greenhouse gas emissions by a country could result in a short-term economic disadvantage for that country, unilateral actions should not be expected.

To achieve a Pareto efficient use of the atmosphere, countries should emit greenhouse gases only to the point at which emitting an additional ton of gases would reduce net global welfare. Determining the globally desirable concentration of greenhouse gas emissions (the level at which the marginal benefit to global welfare equals the marginal cost to global welfare) requires international cooperation and accurate regional information (Maler 1992).

To identity the globally acceptable level of damage from greenhouse gas emissions, specific regional damage caused by emissions must be determined (Cline 1992; Yohe 1991). Possible adaptive strategies must be identified for each region and incorporated into global policy decisions (Cline 1992). Because of the uncertainty associated with the impacts of greenhouse gas emissions, Cline (1992) suggests that ranges of damage need to be developed for specific periods in the future. Other investigators agree that regional estimates of damage are necessary.

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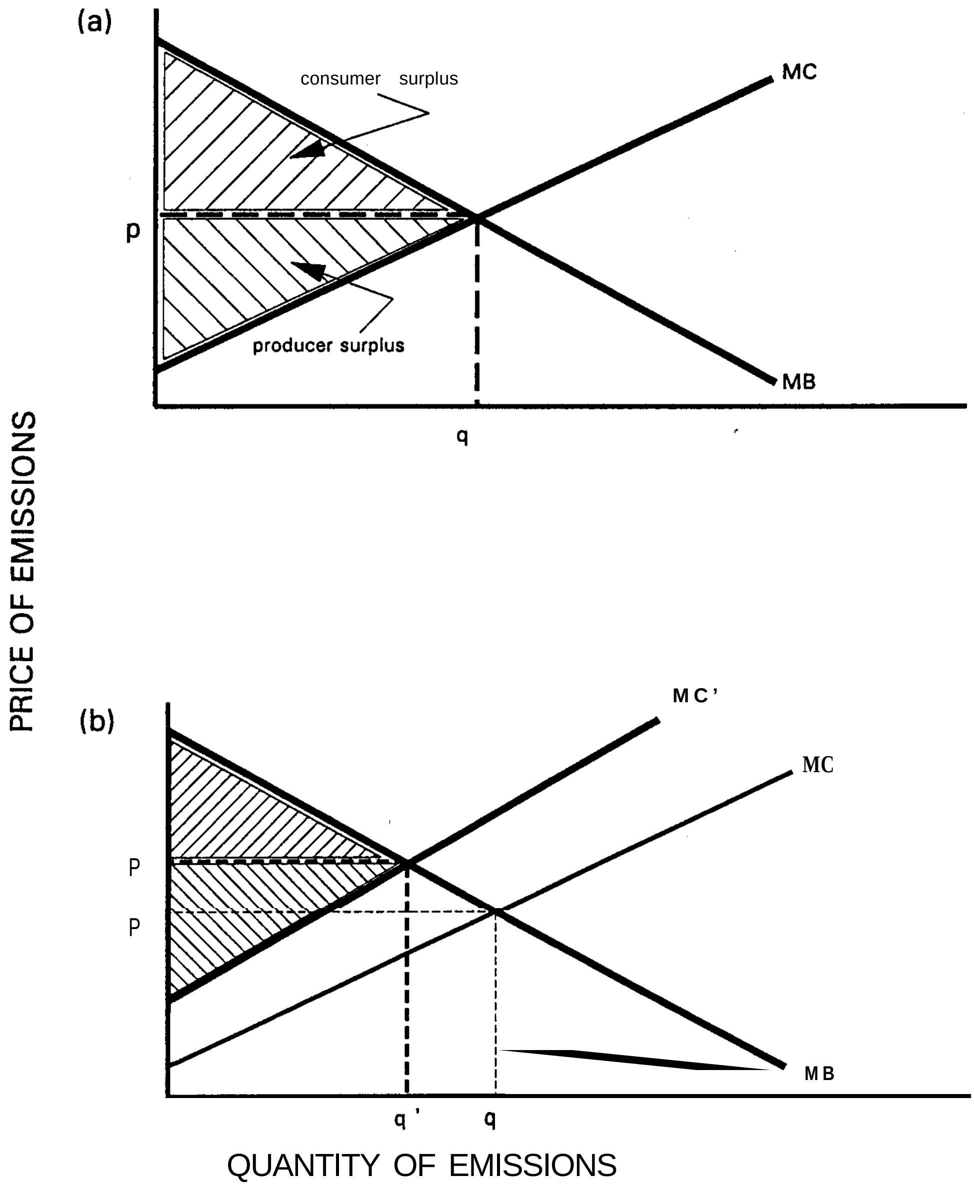
[1] Samuelson and Nordhaus (1989) describe a Nash equilibrium as a situation in which all parties "lose" but parties who violate the stable condition "lose big" while others who do not violate the stable condition "gain big." If all parties cooperated, then all parties could gain, but violation of a cooperative agreement results in big gains for the violator and big losses for the others. There is incentive to violate cooperative agreements.

[2] Samuelson and Nordhaus (1989) defme Pareto as an outcome in which no reorganization could occur that would raise the satisfaction of one individual without lowering the satisfaction of another.



MB = marginal benefit

MC = initial marginal cost

MC ' = increased marginal cost curve

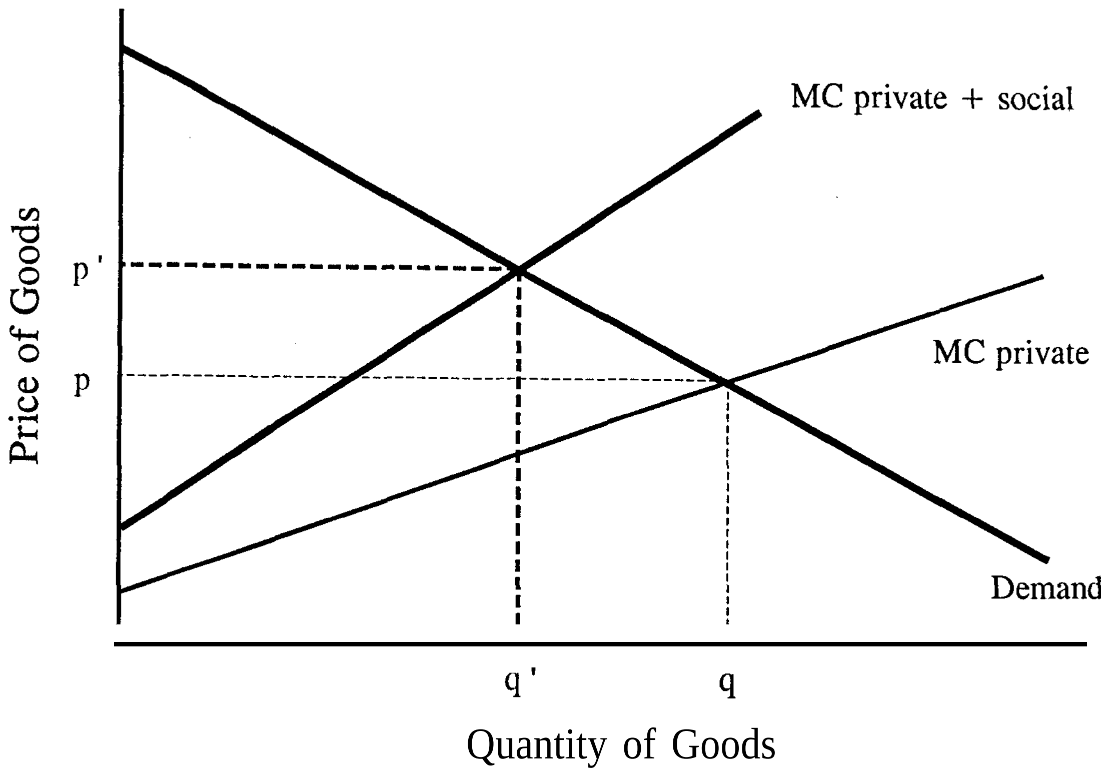
P = initial price

p' = price after an increase in marginal cost

q = initial quantity of social welfare provided

q' = quantity of social welfare provided after an increase in marginal cost.

Figure l--(a) An illustration of consumer end producer surpluses and the equilibrium price and quantity of emissions. **(b)** The **effect an increase in marginal cost bss on consumer** and producer surpluses and the equilibrium price **and** quantity of emissions



q = quantity of goods consumed

q' = quantity of goods consumed after social cost privatized

p = price of goods consumed

p' = price of goods consumed after social cost privatized

Demand = demand for goods

MC private = private marginal cost associated with the production of goods

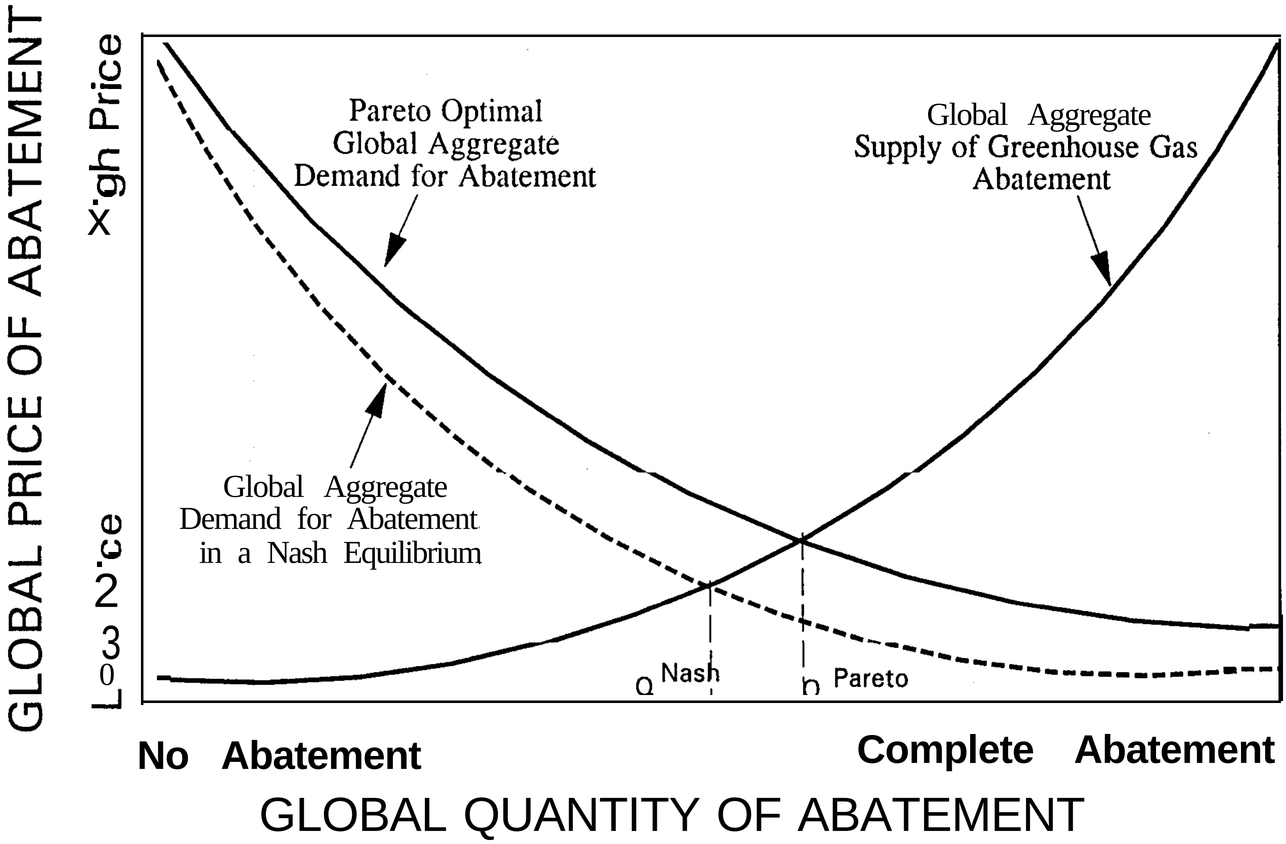
MC private + social = the private marginal cost + the social cost of externalitites associated with goods

Figure 2—An illustration of the impact that privatizing the cost associated with externalities has on the market price of goods and the quantity of goods consumed.

Regional Economic Theory and the Greenhouse Effect

The literature reveals the need to link the global environmental and economic consequences of greenhouse gas emissions to regions. This linkage is necessary because although greenhouse gases are emitted by many countries, the environmental and economic consequences associated with these emissions may be different for every country and region.

First, the enviromnental damage and the associated economic cost of greenhouse gas emissions must be determined regionally. A globally acceptable level of environmental damage and economic cost must be determined from this regional information (Maler 1992). Next, likely regional adaptive strategies must be identified and considered in global policies to abate greenhouse gas emissions (Cline 1992). Finally, the marginal benefits and marginal costs of greenhouse gas emissions abatement must be considered for each region. To achieve a Pareto efficient use of the atmosphere for greenhouse gas emissions, the global marginal cost of abatement must equal the global marginal benefit (Maler 1992). Figure 3 illustrates Maler's central idea. The marginal costs and benefits realized from emissions abatement are not likely to be evenly distributed throughout every region of the world. Global negotiations will be necessary to ensure that countries that have high marginal costs of abatement but low marginal benefits from abatement have sufficient incentive to comply with the greenhouse gas emissions levels determined to be optimal (Maler 1992).



Q^{Nash} = Nash equilibrium emissions level

Q^{Pareto} = Pareto efficient emissions level

Figure 3—An illustration of the supply and demand for greenhouse gas emissions abatement as the global market moves from a Nash equilibrium emissions level to a Pareto efficient use of the atmosphere for emissions.

Methods

Data Requirement Identification

The first, and most crucial, phase of the study is to identity the data needed to evaluate the economic impacts of climate change on forestry in the Southern U.S. An analytical framework similar to that described by Hodges and others (1992), illustrated in figure 4, was used and emphasized the potential impacts of climate change to forest management and timber production through the first phase of processing. The emphasis on timber production reflects its importance to the southern economy. Forest products constitute the first or second most important manufacturing sector in most of the Southern States (USDA Forest Service 1988). As a consequence, any change in the outlook for timber management and production will be of great interest to the forestry sector and policy makers in the South.

The framework identifies the economic impacts of greenhouse gas emissions through the secondary impacts suffered by the forest industry. The primary biological data needs are grouped into three components. These include those listed in "Direct Impacts of Air Quality on Forest Productivity," "Impacts on Forest Productivity," and "Changes in Wood Properties." The impacts of air quality on forests involve the tradeoff between damage from pollution associated with greenhouse gases and the potential fertilization effects of an enriched CO_2 atmosphere. Several researchers have noted the possibility of increased productivity as a result of an enhanced CO_2 environment. Specifically, seedlings of several tree species increased height and diameter growth when exposed to increased CO_2 levels (Funsch and others 1970; Pastor and Post 1988; Rogers and others 1983). More recent studies suggest that tree response could vary significantly by species and age. Bazzaz and others (1990) found that while several northeastern tree species responded positively to increased CO_2 levels, shade tolerant trees exhibited a greater response. Clearly, better information on the direct impact of air quality on tree physiology is required.

Climatic change could cause some southern tree species to migrate northward or become locally extinct. Southern pines will be eliminated or greatly reduced in Georgia, Mississippi, and North Carolina if projected climatic changes occur (Joyce and others 1990). The range of loblolly pine is projected to increase to the North, however, the overall site index will decrease as the forests shift to poorer sites (Miller and others 1987; Woodman and Furiness 1989). Accurate information about future forest distribution and site quality is required.

Climatic change could influence the incidence of wildfire and pest outbreaks. Fire could increase substantially in regions where droughts or longer dry summers are projected (Simard and Main 1987). Similarly, insect outbreaks and disease epidemics could increase significantly, although specific magnitudes are unknown. It is likely that major forest pests will adapt to climatic changes sooner than tree species (Hedden 1987).

Finally, wood formation and quality are likely to be affected by climatic change. With longer, drier summers, the amount of latewood produced would decline while more low density earlywood would be produced during the wetter spring months. Thus, the specific gravity of wood would decline resulting in a reduction in the strength of lumber and paper products.

Based on the framework presented above, key data needs were identified:

1. Ranges of commercially important tree species are required;

2. Changes in site quality are required;

3. The net effect of air quality, climatic change, and pest and wildfire incidence on forest productivity are required, and

4. Changes in wood quality are needed.

At the present time, these data needs reflect some of the basic uncertainties associated with climatic change.

Available Data Inventory

The second phase of the study entails inventorying all available sources of the required biophysical data. Because of the effort already expended assessing General Circulation Models (Cooter and others 1993), we focused our attention on models designed to simulate forest response to climatic change and on other data needs.

Forest response models are designed to process climatic and biological data to project the future structure and distribution of forests and species composition. Solomon and West (1987) discuss the desirable characteristics of forest response models:

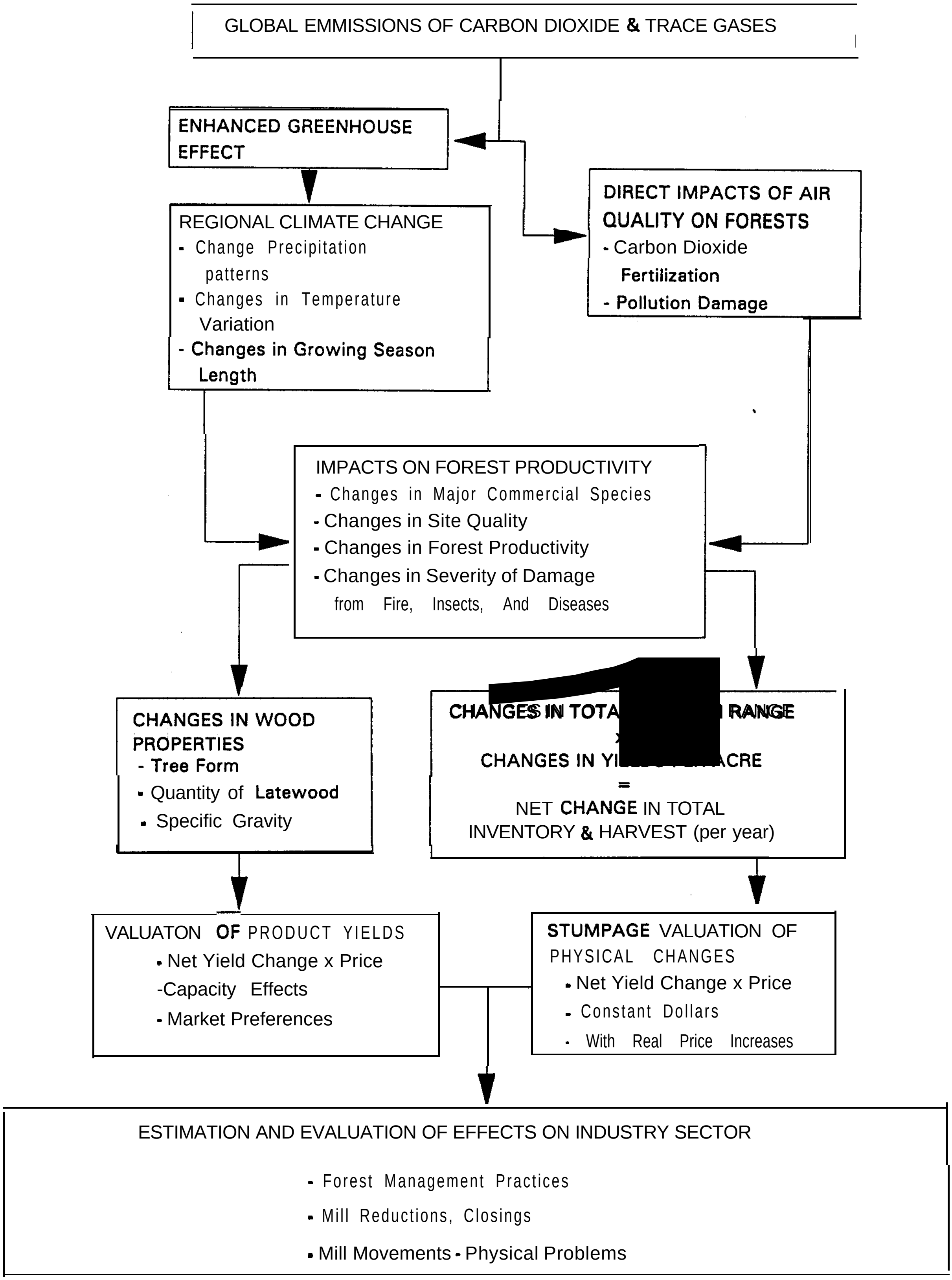


Figure 4-A framework to investigate the regional socio-economic impacts of greenhouse gas emissions on the forest-dependent economy of the Southern U.S.

1. Models must predict forest responses to climatic change at the tract level

2. Models must reflect the complex of the forest ecosystem

a. Multiple species must be considered

b. Multiple developmental stages must be modeled

c. Forest responses to competition must be modeled

d. Other environmentally limiting factors must be modeled

Computer models that simulate interactions among several species by silvical characteristics and limited by environmental stress offer the most valid approach to date.

The forest response models that have been used to project the biological impacts of climate change can be broadly classified as physiologically based models or community-based models. Physiologically based models are designed to predict the response of individual plants to changes in the environment. These models do not consider competition between plants or possible changes in nutrient cycling (Joyce and others 1990). Community-based models predict future forest species composition on a large scale. Such models, however, do not consider the timing of reforestation or the factors that will affect reforestation in the future. Descriptions of both types of forest response models follow.

FORENA

Forest of Eastern North America (FORENA) is a gap-dynamic model developed from Forest of East Tennessee (FORET) and Janak, Botkin, Wallis (JABOWA). FORENA 'grows' forests in annual time steps with 1/5 acre gaps occurring with the death of mature trees. FORENA has, to some degree, all of the characteristics previously listed. FORENA predicts forest response to environmental change by allowing extrinsic environmentally limiting factors to affect the intrinsic processes of birth, death, and growth. These intrinsic processes are controlled by species specific constants. The environmentally limiting factors explicitly modeled include growing degree days (GDD), drought days (DD), and winter hill. The effects of CO, fertilization, changes in nutrient cycling, changes in water-use efficiency, possible changes in the maximum temperature at which photosynthesis can occur, growth benefits that may occur for a longer growing season, and possible changes in fire, insect, and disease damage are unknown and not modeled.

Temperature is an essential input that general circulation models (GCM's) can provide. GDD and winter kill are calculated from daily temperature. FORENA randomly selects daily temperatures within a predetermined variance around the input means. General circulation models provide only mean temperatures. Variance must be determined from historical or theoretical sources.

Maximum and minimum GDD are determined for each tree species from the southern and northern range extremes, respectively. Temperatures above 5.5 °C add to GDD's. Tree growth is adjusted for each species by GDD's. If GDD's exceeds the maximum or minimum optimal GDD's determined for each tree species, growth reduction occurs. For each species, maximum growth is a parameter from which only reductions in growth are possible. Longer growing seasons would result in less growth in the southern extremes. The range in which optimal growth would occur would shift north.

Monthly mean precipitation is another essential input which GCM's can provide. FORENA determines monthly precipitation by randomly selecting a value from a predetermined variance about the input mean. Again, GCM's do not provide variance data. Historical or theoretical sources must be used.

Drought tolerance is calculated by determining the minimum amount of rainfall each species must have during the growing season. The western range extreme for each species provides this information. Minimum precipitation is divided by the length of the growing season to provide a constant for each tree species. This constant is multiplied by the length of the growing season for the modeled site to provide the drought tolerance parameter DD's for each species on the site. Tree growth slows as DD's increase from zero to the species maximum. Beyond maximum DD's, growth is zero.

Changes from optimal conditions in GDD's and DD's adversely affect species growth. In FORENA, slow growth is defined as one-tenth of the empirically measured maximum possible growth for a species. The event of slow growth increases the possibility of tree death. Two independent death processes determine tree survival. Senescence decreases radial growth, decreases crown/stem ratio, increases root mortality, decreases root regeneration capacity, and decreases tree resistance to pathogens. To account for the effects of senescence, FORENA logrithmically increases the probability of tree death with age.

Additional environmental factors also influence the probability of death, such as late frost, too much or too little water, fire and lighting damage, too little sunlight, insect defoliation, and nutrient deficiencies. FORENA increases the probability of death after two consecutive years of slow growth. Drought tolerance, shade, stand density, winter kill, and growing season length account for some of these environmental factors.

, MAESTRO

Maestro is a physiologically based forest response model. The model measures the response of established forest trees to changing climatic conditions. Maestro does not allow for forest tree replacement and cannot be used to determine future forest composition. Maestro has several desirable properties. The effects of possible CO, fertilization and changes in water-use efficiency can be considered. Maestro also considers photosynthetic reactions to temperature changes. The input of specific site and soil parameters would allow Maestro to make regional predictions based on these parameters. Finally, because Maestro measures changes in net photosynthesis, crude estimates of insect and disease response to changes in forest vigor may be possible by tree species and site.

Maestro has several drawbacks. The model only permits estimating the response of coniferous monocultures. Sitka spruce and radiata pine are used to validate the model; data needed to model southern pines must be collected. Maestro requires the X, Y, and Z coordinates of every tree in the modeled forest. Also required are parameters that describe leaf inclination angle and distribution throughout the tree crown by leaf age, as well as the total area of leaves within a tree crown. Maestro does, however, have subroutines within the model that will calculate leaf spatial distribution and inclination angles if none are provided. Other required leaf parameters include the transmittance and reflectance of photosynthetic radiation (PAR), near infrared radiation (NIR), and thermal radiation. Maestro is very data intensive.

The inputs Maestro would require from GCM's are sunshine duration, cloudiness, wind speed, air temperature, water vapor saturation deficit, and hourly flux densities of PAR, NIR, and thermal radiation on horizontal surfaces and their corresponding beam fractions. Some required soil parameters include temperature and the reflectance of PAR, NIR, and thermal radiation. GCM's may not provide radiation information as an hourly output, but they do internally predict this information.

Evaluating Available Information

Evaluating the available information will involve identifying gaps in the data requirements and evaluating the utility of the available data. Identifying data gaps will be relatively straightforward. Any data requirement characterized in phase two where information is unavailable will be identified as a data gap. For these, attempts will be made to identity any research underway to provide these data and expected date of completion. An effort will also be made to identify any related information that could be used to fulfill the data requirements.

The most crucial aspect of this phase will consist of evaluating the utility of the existing data for assessing the economic impacts of climate changes. The primary problem will be to evaluate the importance of the data for economic evaluation, the range of available predictions, and the most reliable estimates. The principal objective of this phase is to describe the range of currently available projections and where possible, evaluate how the economic impacts would be affected by the range of projections. Four broad classes of data will be examined:

1. Changes in the ranges of commercial timber species

2. Changes in site quality

3. Changes in forest productivity due to carbon dioxide fertilization

4. Changes in wood formation and quality

The uncertainty or low credibility of the estimates derived from limited biophysical information is the primary factor limiting the decision relevance of such assessments. First, uncertainty stems from major gaps in the information about underlying dose-response relationships over variable time horizons. Second, because preferences are for environmental goods not directly observable in markets, there are always questions regarding the estimated monetary value of the benefits. Third, even when those preferences are monetarized, aggregating them to derive social preferences can be problematic. As a result, doubt about the confidence that can be attached to estimates, even when preferences are well defined, is a general constraint to using this type of analysis in the decision-making process.

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A Value-Based, Multi-Scalar Approach to Forest Management

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Abstract

In this paper, a value-based, multi-scalar approach to forest management is proposed as a means to incorporate public concerns expressed for diierent time horizons into the management of public forest land Under such an approach, public values-including both economic and environmental concerns-sre assessed at the local level and provide the basis for managing public forests on multiple scales using the principles of hierarchy theory. This approach assesses intergenerational concerns that may be expressed on different, incommensurable scales and then develops appropriate hierarchical models of the ecological relationships that relate to those values. Using a multi-scalar approach resource managers can select forest management practices at diierent scales to reflect those multiple public values. By managing the forest at diierent scales within liits derived from the values of citizens, tradeoffs between competing uses of the forest may be minimized.

Introduction: Challenges for Forest Managers

Forest management practices have often been criticized for inadequate consideration of the public's environmental concerns in the pursuit of economic resource use. With issues ranging from the preservation of endangered species, such as the red-cockaded woodpecker, to the siltation and pollution of rivers and lakes, forest managers face several new and difficult challenges for managing public resources in the future. New tools and techniques will be needed to meet the multiple and apparently conflicting demands for the forest resource while facing these challenges.

In particular, as the accumulated effects of localized management practices are manifested on increasingly larger scales, there is a need for a new approach to forest management that can account for both the multiple values and concerns of the public, as well as the potentially large-scale impacts from forest management practices.

In "Thinking Like a Mountain," Aldo Leopold (1949) describes the short-sightedness of wolf eradication as a resource management practice. From the irruption of deer and devastation of the mountainside that followed the extirpation of this predator, he saw how the wolf was part of a complex interrelationship that unfolded on the mountain's time frame, not man's. Such large-scale and longer-term impacts from resource management continue to be an issue for land managers. Increasing calls for "whole ecosystem management," such as in the Greater Yellowstone area, are clear expressions of the need to consider these large-scale dynamics in resource management to maintain the functioning of ecological systems that support many different features of the natural environment (Norton 199 1).

Coordination of forest management activities with other resource management efforts is becoming increasingly important. Forestry practices, such as clearcutting, can significantly impact aquatic systems. A system that can identify and account for these indirect effects and larger-scale considerations in local-level forest management will be needed to ensure the success of these other programs. Noss and Harris (1986) note that wildlife preservation strategies have typically been static and limited in scope. These strategies have generally focused on individual species, while the factors that affect those species and their habitat are part of larger-scale ecological dynamics. They suggest that the emphasis on endangered species and the assumption of an ecological "equilibrium" system is insufficient for the maintenance of species diversity over the long term. The problem with narrowly focused static approaches is that they fail to recognize that individual plant or animal communities and even whole ecosystems are part of larger dynamic processes that represent the context within which they function (Costanza and others 1992; Leopold 1949; Norton 1992; Noss and Harris 1986). These dynamic patterns, however, exist on many scales, each providing a slower changing context for the faster changing processes on smaller scales. To effectively manage for multiple and indirectly related public objectives, such as water quality and wildlife preservation, forest and other resource managers must recognize these larger-level processes and incorporate them into their planning and management efforts.

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Another problem for forest managers is that many of the impacts on publicly valued resources may result from activities that take place on both public and private land. For example, erosion within a watershed and its impact on public water resources is not limited by property lines. In the South where a significant portion of the forest land is privately held, consideration of private land management activities is particularly important. Public land management must be coordinated with the management of private land, or public forest managers must be able to mitigate the effects of private activities on public resources. Ecological models that characterize these relationships and a management system that can incorporate these considerations are needed to both preserve and use public resources into the future.

Forest managers will also require a management and planning process that can address the effects on forests from exogenous factors, such as acid rain, air pollutants, and global climate change. Ecological models that can indicate how ground-level ozone affects the growth rates and composition of the forest would be one example. Alternatively, large-scale concerns, such as global climate change, may mean that forest managers will be called upon to proactively manage the forest as a carbon-sink in addition to managing for the demands of the timber industry and recreationists.

Perhaps most important is the need to recognize that public values may themselves exist on different scales. The problem is that when timber harvesting jobs and wildlife preservation are compared in terms of the present, they seem to represent competing value positions (Norton in press). However, they do not necessarily require a one-or-the-other trade-off. The point often overlooked is that both of these forest "uses" require the continued functioning of larger, "landscape-level" ecological systems if they are to be sustained into the future. Neither economic productivity nor aesthetic and instrumentally valued natural features can be protected without protecting the complex, organized system that provides the ecological context on which all these values depend (Norton 199 1). A system that can manage public resources such as forests at these various scales is necessary to minimize trade-offs and maintain the ecological integrity of natural systems that support publicly valued uses and features of those resources.

The Concept: Multi-Scalar Management

To meet these challenges and to help avoid politically determined restrictions on economic resource use, we propose a scalar system of resource management. The idea is to develop a scientifically informed, public value-based constraint system on economic resource management. A two-stage model for such a management system has been suggested by Norton (1992) (fig. 1) . Potential impacts from different management practices are located in this "risk decision space" by the degree of reversibility of the impact (horizontal axis) and the scale of the impact (vertical axis). Activities whose impacts fall in the large lower-right area are sufficiently addressed by traditional economic approaches. The multi-scalar approach, however, supplements traditional economic methods of resource management by placing constraints on practices that have large-scale and potentially irreversible impacts. These would be management activities with impacts falling in the upper left-hand comer of figure 1.

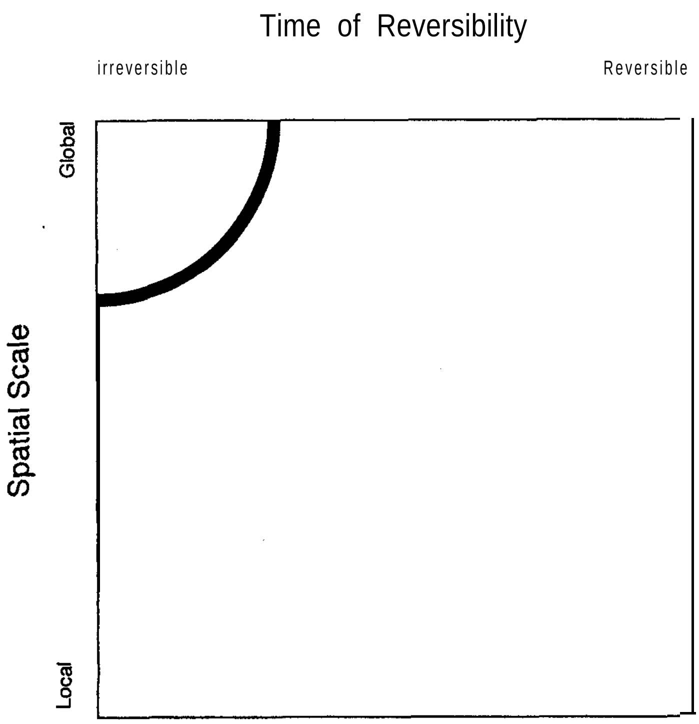

Figure l--Risk-decision square for locating management impacts

However, restrictions are not necessarily placed on activities with any large-scale or irreversible impact. In our approach, public values are used to define the type and scale of impacts that fall into the upper comer; public values define where the demarcation line falls.

Hierarchy Theory

Following arguments that suggest that evolutionary processes favor nested, hierarchical organization (Simon 1962), hierarchy theory has been applied to the functioning and relationships of ecological systems (Allen and Starr 1982; O'Neill and others 1986). It represents one way to characterize complex ecological phenomena that are interrelated but may occur at different scales. In a hierarchical structure, any given "system" operates as both a part of a larger system and, at the same time, as an independent "whole" in itself As a "whole," a system exerts some constraint on its component "subsystems" that are themselves both wholes and parts. As a "part," that same system operates as an integrated component of a larger whole (Allen and Starr 1982). Through this type of structure, the stability of ecological systems is maintained.

This stability results from its constraint system. It is, however, a dynamic stability. The self-assertiveness of a constraining environmental system within its larger "environment" essentially protects the smaller-scale "subsystem" that it controls (Allen and Starr 1982). Disturbances can be "incorporated" by a system when it exerts control over a factor that is not controlled at lower levels of organization (O'Neill and others 1986). For example, the forest as a whole minimizes local temperature variations through evapotranspiration, while individual trees cannot (O'Neill and others 1986). Under certain conditions, however, this constraint system can be broken with effects that propagate up the hierarchy (Johnson 1993). Leopold's (1939) examples of the effects of predator eradication and the problems of early German monoculture forestry illustrate these types of larger-scale effects that result from changes in local-level activities.

For forest management in the future, hierarchy theory provides a conceptual basis for incorporating economic resource management at the local level within the need to maintain regenerative systems at larger scales. In a scalar system of management, local activities can be constrained by a hierarchy of longer-term, higher-level considerations. That is, in a hierarchical structure, management at the local level may vary considerably according to local desires as long as they do not interfere with objectives established for management at larger scales and over longer time frames.

In our approach, the goals for resource management at each scale are defined by ecological dynamics at those scales associated with the maintenance of publicly valued natural features and resource uses. Basically, management at any particular scale focuses on sustaining valued natural resources or features through time by ensuring, via scalar constraints, that management activities and exogenous impacts remain within the bounds of higher-level ecological dynamics operating in longer time frames. By recognizing ecological constraints, multi-scalar forest management can help to avoid the larger-scale impacts that result from exceeding a critical threshold at a lower level.

Hierarchy theory also provides a useful conceptual framework for modeling ecological systems to address scale-related resource management issues (Johnson 1993). This is important because the descriptive scientific models traditionally used to characterize various ecological systems may not be sufficient for resource management in the future. Since no single or "fundamental" hierarchical description of nature exists (Allen and Starr 1982; Johnson 1993; O'Neill and others 1986), there is no single model that could be used to evaluate the many ecological impacts of different forest management strategies. Because a particular system may be described in several ways, it has been suggested that an appropriate hierarchical description should be based on the phenomena we are interested in observing (O'Neill and others 1986). Since certain characteristic properties "emerge" depending on the scale of observation (Allen and Starr 1982) and since ecological systems can be described in several different ways depending on what we are interested in observing, the development of models for ecological resource management is necessarily a prescriptive science (Haskell and others 1992). This is particularly important for issues of scale in resource management. The correct scale on which to address a management problem is determined by what society wants to accomplish with that system (Norton 1992). That is, an ecological system can and should be modeled differently depending on what forest services we are interested in managing.

Thus, in our approach, public values are used not only to define resource management at different scales, but they are also used to define the ecological models of the systems to be managed. This is important because appropriate management objectives cannot be completely determined without relevant scientific understanding of the relationships that affect publicly valued natural features and resource uses. As a framework for organizing ecological systems, hierarchy theory helps scientists, forest managers, and the public identity relevant ecological dynamics and variables operating at each scale. Through an iterative and ongoing process of interaction with the public and forest managers, scientific study can be guided towards developing hierarchical models that inform public understanding of ecosystem functioning in a way that helps to define resource management to achieve public goals (Norton 1992).

The Advantages of a Multi-Scalar Approach

A multi-scalar approach to forest management has many advantages. This approach can incorporate multiple public values into a multi-scaled management strategy and also provide a framework through which ecological models can be developed to identity appropriate constraints for resource management at various scales. Importantly, our approach is designed in such a way that forests can continue to be managed for economic use at one level within constraints imposed by ecological considerations at higher levels so that trade-offs between seemingly conflicting values can be minimized.

With its focus on management at different scales, this approach also provides a system through which to account for many of the factors which complicate contemporary forest management. Because it recognizes the importance of regenerative landscape-level processes in maintaining all publicly valued natural "goods," scalar management can help to avoid large-scale or irreversible impacts and minimize trade-offs. Through its emphasis on multi-scaled public values, this approach provides guidance to forest managers in response to the impacts of exogenous factors. For example, air pollution has been documented to have several different impacts on forests leading to decline (MacKenzie and El-Ashry 1989). Forest managers could adjust their management practices in order to mitigate impacts on timber production or mitigate further impacts on aquatic systems by minimizing their contribution. Either way, ecological models that characterize the relevant variables and dynamics can help forest managers determine how their activities influence publicly valued resources and identify appropriate strategies.

A multi-scalar approach can also help to coordinate forest management with other efforts to maintain publicly valued environmental resources. Although maintaining the viability of fish populations has not generally been the responsibility of forest managers, the management practices on public forest lands nonetheless affect river and lake systems through soil erosion and nutrient runoff (Morris and others 1992; Salverda 1968). Given a publicly expressed concern for the health of rivers and lakes, our approach requires the formulation of a hierarchical model of ecological relationships appropriate for considering these impacts in forest management. In a similar fashion, forest management could also serve as a means to proactively address global warming by increasing net primary productivity to enhance the role of the forest as a CO^2 sink (Morris and others 1992). Models that can characterize the impact on the atmosphere and the ecological relationships associated with carbon fixation would facilitate such activities.

Applying Multi-scalar Public Values to Forest Management

Once we have accepted the role of public values in defining not only the management but also the ecological science upon which it relies, the problem of developing a value-based management strategy becomes one of translating these values into management objectives at different scales. To do this, we must associate different values with ecological systems at appropriate scales as noted above. Before this can be done, however, several questions must be answered. These questions include whose values are to be counted, how are they to be assessed, how can they be translated into management objectives, and how are the values of different communities to be integrated.

"Bottom-Up" Valuation

Wilkinson and Anderson (1987) note that in the past, public forest management and planning was a decentralized activity where local managers used their knowledge of the specific characteristics of the local forests they managed to both protect and use the resource. In the 1920's timber management plans determined the amount of timber that could be harvested from "working circles," which were areas large enough to support local forest-based industries. These efforts included an explicit concern for protection of the local watershed, and recreation was increasingly considered in the plans. However, as private timber lands were cleared in the post-war building boom of the 1950's, this relatively uncontroversial planning framework began to break down as increasing demands were placed on the national forests for all their resources. The result of the controversy over multiple-use forest management was legislation that established national planning along with a range of legal standards for local forest planning and management. The need for Federal action arose from both timber industry demands as well as increasing public demands for the preservation of existing wilderness areas.

This change, in effect, imposed national-level values on local-level forest management. Wilkinson and Anderson (1987) note that the unit planning framework that replaced multiple-use plans in the early 1970's was intended to ensure greater consistency between national and local land use priorities. In this new framework, "Area Guides" advised forest planners of an area's relative ability to achieve national objectives for various resources (Wilkinson and Anderson 1987). In essence, local resources were no longer being managed to meet locally defined needs as expressed by local values.

To see how this may affect ecological systems, it is important to look at how cultural institutions define the relationship between man and his environment. In his ecological history of New England, William Cronon (1983) illustrates how different social institutions led to different interactions between humans and the environment that shape the landscape in different ways. The role of values, including cultural beliefs, is an important part of this. Most importantly, the notion of resources as commodities and monetary wealth as an indicator of status weigh into Cronon's description. The latter concept in particular has a significant impact on resource use.

European markets . at least in theory "erected a shrine to the Unattainable: Infiite Needs. " Those needs were determined not only by the local communities that became established in colonial New England but by all distant places to which those communities sold their goods. The landscape of New England thus increasingly met not only the needs of its inhabitants for food and shelter but the demands of far away places' markets for cattle, corn, fur, timber, and other goods whose "values" became expressions of the colonists' socially determined needs. (Cronon 1983: p. 166) A similar phenomenon occurred in the southern forests as the region sought to finance industrial development and thus, increase their wealth through the exploitation of its forests (Williams 1989).

While both the Native Americans and the colonists shaped the land to meet their own purposes, they did so in fundamentally different ways. The colonists, with their experiences of timber as a scarce resource in England, saw the forests as an abundant resource to be exploited. With no prior experience within the landscape of the New World, they did not see forests as an integral part of their lives. In contrast to the colonists, however, the Native Americans had a much closer understanding of the land through a longer historical association with it, and they were able to maintain the functioning of its ecological systems and coexist within it.

The point is that local forest land must be managed based on the values expressed by local citizens who are familiar with their surrounding landscape and its unique features. Centralized planning, as mandated by Federal laws, runs the risk of failing to adequately reflect the relationship of local residents to their landscape even as it tries to balance preservation and harvesting interests in the aggregate. This is again a problem of scale, but one of the scale of management. Thus, we believe that local values must form the basis for managing local forests and serve as the foundation from which the larger scales of management must be derived.

Assessing Scalar Public Values

With local values as a starting point, the task assessing these values requires attention. Using Sagoff' s (1988) hypothesis that citizens may make different choices depending on the context of a question, we can formulate a procedure for assessing public values in different time frames. Assuming three levels of values-individual, intergenerational, and evolutionary-three time horizons can be considered. These do not represent absolute time periods but ranges reflecting the different contexts for consideration of values.

TO assess "individual" values for local forest management in the short term, members of a local community can be asked to state their preferences in terms of the present. In this context, it is likely that they will assume the current rules of economics and express values based on present worth, discounting benefits that accrue in the future. In this case, citizens might express a preference for timber harvesting jobs or recreation-related jobs over increased protection of natural resources. The values expressed in this context should be consistent with those assessed using traditional economic methods.

Next, in the context of a "constitutional convention," community members could be asked what values should guide forest management over the long term, including what, if any, environmental "goods" should be maintained for future generations. That is, ignoring your current situation, how would you rewrite the rules for your children? In the context of suggesting resources or natural features that they wish their great-great-grandchildren will be able to utilize and/or experience, citizens may modify their usual discounting across time because they are not constrained by their current economic situation (Norton, in press). In this context, citizens may express a desire to preserve a certain vista or ensure that future generations will be able to fish in a particular river, lake, or stream. These are the values that may not be captured by traditional methods because they represent values that operate on a different scale than short-term economic concerns. They are values that are not necessarily exclusive of present-oriented concerns for employment.

On a third level, community members may be asked what values they associate with the very long term. Values at this scale could be a desire to ensure the survival of the human species or alternatively a more inclusive value that reflects concern for the evolutionary potential of other species and natural systems. Minimizing the impact or reducing the possibility of global climate change might be a value expressed in this context. These values as well as those previously discussed can be transformed into management goals at various scales that provide constraints on local-level management activities through a multi-scalar management system.

However, the process of assessing these values may not be as simple as gathering citizens together and asking them questions about their economic and environmental values. The problem is that non-economic values associated with particular places and environmental features may not be explicitly recognized by individuals. Edward Relph suggests that the landscapes within which we live are "inconspicuous backgrounds" to our everyday experiences: "For much of the time, landscapes stay as unobtrusive backgrounds to other more important concerns, but occasionally they are brought forward into our awareness . . . in certain affective states . . we may be predisposed to notice the world around us" (1985 : p. 24). On the local level, the value assessment process can serve to draw out this background and its scalar dimensions. Furthermore, the local view of the surrounding landscape may not be captured by descriptions in "scientific" language (Mugerauer 1985).

Mugerauer (1985) suggests that "environmental hermeneutics" can be employed to discover the subtle relationship between a community and its local environment. This involves an understanding of the local language and the meaning of the environment within that language and the meaning of the environment within that language including its historical dimensions. This does not mean that anthropologists or linguists must be dispatched to assess the value of the environment and its specific features for a local community. It merely implies that a more interactive approach should be employed to draw out these values. An ongoing discussion between local residents, forest managers and scientists that educates the citizens about ecological relationships can draw out these values and the ecological importance of the landscape in the "background" of the features they value.

An interactive approach to assessing local values has an additional advantage. In a highly mobile society such as ours, there is little time to develop experiences with a particular place as we move from one location to another; people don't have the time it takes to recognize and experience the features of one's surrounding landscape. An interactive valuation process can educate residents about their local place and bring about a recognition of the landscape and values associated with maintaining larger-level processes. This allows them to make more educated decisions about the values and goals they choose for the management of public forest lands.

Through this interactive value assessment process, local values provide two pieces of information for multi-scalar management: (1) values to emphasize in the management of the local area and (2) values that need to be maintained by larger-level systems. These values can then be used to determine both economic and environmental resource-management goals supported by the local residents.

Translating Values into Scalar Management Objectives

An interactive approach is not only necessary from a value assessment perspective, but it also provides the means through which to determine appropriate hierarchical models and management goals for forest managers. As noted earlier, because specific management goals cannot be understood prior to scientific understanding, developing goals and hierarchical models that characterize the dynamics that affect valued natural features should be an experimental and interactive process. Biologists and ecologists must be part of this process to help the public and forest managers define the appropriate spatiotemporal scale on which to define the system to be managed (Norton 1992). Through an interactive and experimental process, the boundaries of the system and the ecological dynamics relevant to those objectives can be identified and appropriate goals for management can then be defined (Norton and Ulanowicz 1992).

On the local level, individual values can be used to define the boundaries of the system to be managed and linked to appropriate dynamics at that scale. For example, to maximize job opportunities for a timber community, silvicultural techniques for economically sustainable timber management have been well developed. The forest can be maintained in several different ways including the use of even-aged stands with clearcutting or old growth uneven-aged stands with selective cuts, as well as other types of practices. At this level, the boundaries of the system to be managed are usually defined at the stand level, which is about 100 hectares or less (Morris and others 1992). At this scale, site factors play an important role and represent the relatively stable context within which the trees of a stand grow. These include soil conditions (especially nutrient flows), topography, aspect on a slope, and climate (Spur-r and Barnes 1980).

Conversely, the value of maximizing recreational attractions could translate into the management goal of establishing and maintaining a "wilderness" area. Since wilderness areas are not confined to a single forest stand but represent a collection of various forest habitats, the scale of management for these systems must necessarily be larger. The boundaries of the area to be managed might be set at the range of the largest ranging species (Noss and Harris 1986). In this case, it is important to manage for diversity within the management unit. This might involve minimum technical interference in natural forest development so that plant and animal associations develop and natural forest succession proceeds uninterrupted by man (Morris and others 1992). Management may also involve some protection from impacts such as recreational use and, in more interventionist practices, fire suppression.

In our approach, intergenerational values represent social constraints on shorter-term preferences. These values are associated with longer time horizons and will generally correspond to management objectives at larger spatiotemporal scales. These higher-level objectives provide the basis for constraints on management practices at lower levels, because to maintain a natural "good" expressed by these values over this longer time frame, the ecological processes of the relevant system at this scale must be maintained. This means that once an intergenerational value is translated into a relevant hierarchical system and management goal, the lower-level components that contribute to that system should be constrained by appropriate limits.

Thus, a larger-scale management program can be established, as defined by intergenerational value choices to monitor and coordinate the activities of lower-level forest management. For example, the major outputs from catchment basins include water and its associated load of dissolved nutrients and particulate matter (Nelson 1970). The transport of. soluble nutrients is a primary concern in terms of the health of aquatic systems because of the adverse impacts of increased concentrations of phosphorous and nitrogen. (Morris and others 1992). However, sedimentation from soil erosion and rates of water yield can also have a significant impact (Morris and others 1992). These factors represent the principal issues of concern in terms of managing the forested watershed to minimize aquatic impacts.

When combined with assessments of the current health of the aquatic systems of concern, these variables can be converted into appropriate management goals that would then have to be incorporated into local management plans. This does not mean that uniform restrictions on specific activities, such as fertilizer use or clearcutting, Would be placed on all lands within the watershed. Instead a watershed-level hydrologic model could be used to identity where higher levels of fertilizer are likely and unlikely to adversely impact the aquatic system. This means that economic forest management, in accordance with the local values in specific areas, could continue as long as the practices did not violate the watershed-scale requirements for maintenance of the aquatic systems.

Importantly, studying natural dynamics and experimenting with conservation practices provides both scientific progress and increasing public knowledge of the role of ecosystem dynamics in maintaining publicly valued resources and natural features. Through such an approach, hierarchical models and management objectives can be sorted out according to their usefulness in clarifying, explaining, and achieving public goals (Norton 1992).

Integrating Values at Higher Levels

Before a multi-scalar management strategy can be fully defined, the longer-term intergenerational values of local citizens must be integrated with the values of citizens in other local areas. On the local level, the basic principles of economics may be used for determining management activities because they are compatible with the values at this scale. However, local practices defined by these values operate with higher-level constraints in our approach. Since intergenerational values are associated with the longer term, the corresponding ecological systems and dynamic processes that maintain a resource or natural feature in that time horizon generally occur on larger scales, which may require the management of practices outside the boundaries of the local community.

In such a case, citizens from all communities with intergenerational values that require landscape-level management must be brought together so that they can achieve a consensus on what the management goals for higher levels should be. In this manner, the higher-level constraints that are imposed upon local management activities through landscape-level management will not be forced from the "top-down" but will be based on local values with knowledge of the particulars of local ecosystems. Using the process described above, it might be determined that maintaining viable fish populations in rivers and lakes is important to the residents of several communities. For example, by agreement residents within an area might conclude that they wish to maintain one particular fork of a river or, on the other hand, they might wish to maintain all the rivers in their area. If they chose to maintain all the rivers in the area, the watershed to be managed would be much larger than just one fork. In each case, landscape-level management would apply certain constraints on forest management practices within the corresponding watershed. A similar integration could theoretically be performed for global-level concerns, although the difficulties of doing so are quite large.

Conclusion

In conclusion, what we have proposed is an alternative to traditional approaches to forest management. It is intended to provide constraints on economic forest management when those practices may interfere with the maintenance of resources and natural features that are valued by the public for the longer-term. It is a multi-scalar management system based on locally assessed values, which attempts to provide relevant ecological information and, thus, facilitate those value choices through an interactive and ongoing process involving forest managers and ecological scientists as well as the public. Through this system of ecologically informed scalar management, we believe our approach provides a framework for addressing multiple public values which can meet many of the challenges facing forest managers today. Perhaps most importantly, our approach seeks to facilitate a system of forest management that can maximize fulfilhncnt of public preferences by developing ecological models that characterize the variables and dynamics relevant to publicly valued resources and natural features at various scales.

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Regional Changes in Land Uses and Cover Types: Modeling Links between Forestry and Agriculture

Ralph J. Alig, Darius M. Adams, and Richard W. Haynes

Abstract

Changes in land use and cover types are important components of global change, including alterations of forests' capabilities to provide environmental services. One environmental service receiving increasing attention is forests' capacities to sequester carbon, reducing atmospheric carbon dioxide related to global warming concerns. We are designing and testing multi-period models for evaluating the effects on welfare and markets from the large-scale forestry programs proposed for sequestering additional carbon in terrestrial ecosystems. Preliminary results for a case study in the Southeastern U.S. indicate that effects can be substantial from afforestation programs of several million acres, including spill-over effects across regions. Preliminary results from a forest and agricultural sector optimization model reflect the interrelated timber harvest and reforestation decisions of industrial and nonindustrial private owners. Both private ownerships are projected to increase areas of planted pine up through 2000 under all scenarios. Weals0 discuss the next steps in this line of research and possible improvements in modeling systems.

Introduction

Concentrations of radiatively important trace gases, such as carbon dioxide, are increasing in the atmosphere, largely through anthropogenic emissions (Houghton and others 1993). Possible changes in the area, cover types, and ages of forests are important when examining carbon sequestration by forests in the context of global warming analyses. As background for examining tree planting scenarios, we first provide a brief historical summary of land exchanges between forest and agricultural uses in the Southeastern U.S.[1] We then compare projections of changes in timberland area in the Southeast from both a forest sector model and a model that links forest and agricultural sectors. Last, we discuss future research working toward improved models for projecting area changes for terrestrial ecosystems in global change studies and assessments.

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[1] Agricultural uses in this paper refer to crop land and pastureland Range land is considered a minor land use in the Southeast The Southeastern region consists of Florida, Georgia, North Carolina, South Carolina, and Viiginia

Afforestation is an important option for additional carbon sequestration by forests (Haynes and others 1994; Moulton and Richards 1990). In the United States, opportunities for afforestation are the greatest in the South. Because atforestation shifts land uses from agricultural to forest, a linked model of the two sectors can enhance analyses of welfare and market effects (Adams and others 1994). At the same time, we need to consider other forest activities. For example, anthropogenic disturbances in Southeastern forest ecosystems and other human-related factors, including the conversion of timberland to urban and developed uses, will influence the future condition of Southeastern forests.

Historical Land-Use Exchanges Between Forest and Agricultural Sectors in the Southeast

The Southeastern U.S. is an important timber supply region, and its 88 million acres of forest land equal 12 percent of the United States total (Powell and others 1993). Forest land covers 60 percent of the Southeastern landscape and consists of areas at least 10 percent stocked by forest trees of any size and areas formerly stocked to this level that will be regenerated naturally or artificially. If national averages are used, the current forest area represents about two-thirds of what was forested in the Southeast in 1630. Most of the forest has been converted to agriculture, but opportunities for reallocating some of the marginal and environmentally sensitive agricultural land back to forests are substantial, with estimates ranging from 10 to 30 million acres in the South (Moulton and Richards 1990; USDA Forest Service 1988).

In parts of the Southeast, land has repeatedly shifted back and forth between agriculture and forest uses in this century. For the first time since 1600, forest area stopped decreasing around 1920, when the conversion from forest to agriculture slowed appreciably. Crop damage from the boll weevil, erosion of farmlands, and adjustments in the agricultural economy prompted many farmers to abandon their land in the 1920's and 1930's. This process was accelerated, in part, by the Great Depression (Powell and others 1993), and many acres of farmland reverted to forest naturally. Cropland decreased further in the 1950's and early 1960's but increased during the following 20 years. A large jump in the 1970's was fueled by expanded global demand for agricultural exports.

Around 1980, the National Agricultural Lands Study was initiated in response to the apparent loss of prime cropland to urban and other uses. However, subsequent data indicated that these concerns were, in part, unfounded. Moreover, reductions in export demand for agricultural products decreased pressures on agricultural output. Congress passed the Conservation Reserve Program (CRP) in 1985 to convert about 40 million acres of erodible cropland to other vegetative covers. Under the CRP trees have been planted on about one million acres of erodible cropland in the Southeast, which represents 40 percent of the acreage planted under this program in the United States.

In the late 1980's, concerns about cropland availability continued to diminish. The second RCA Appraisal (USDA SCS 1989) projected over 100 million acres of idle cropland in the United States under the assumption of reduced farm programs.

Tree planting on all ownerships increased appreciably after 1950 (Alig and others 1990a). The area of planted pine in the Southeast increased more than ten-fold between 1952 and 1985, from 1 .O million acres to 12.6 million acres. The majority of the planted pine is on forest industry lands (fig. 1); however, the nonindustrial private forest (NIPF) ownership contains most of the opportunities for additional tree planting. In the Southeast, the NIPF ownersbip embodies 70 percent of the timberland[2] and essentially all the afforestation opportunities.

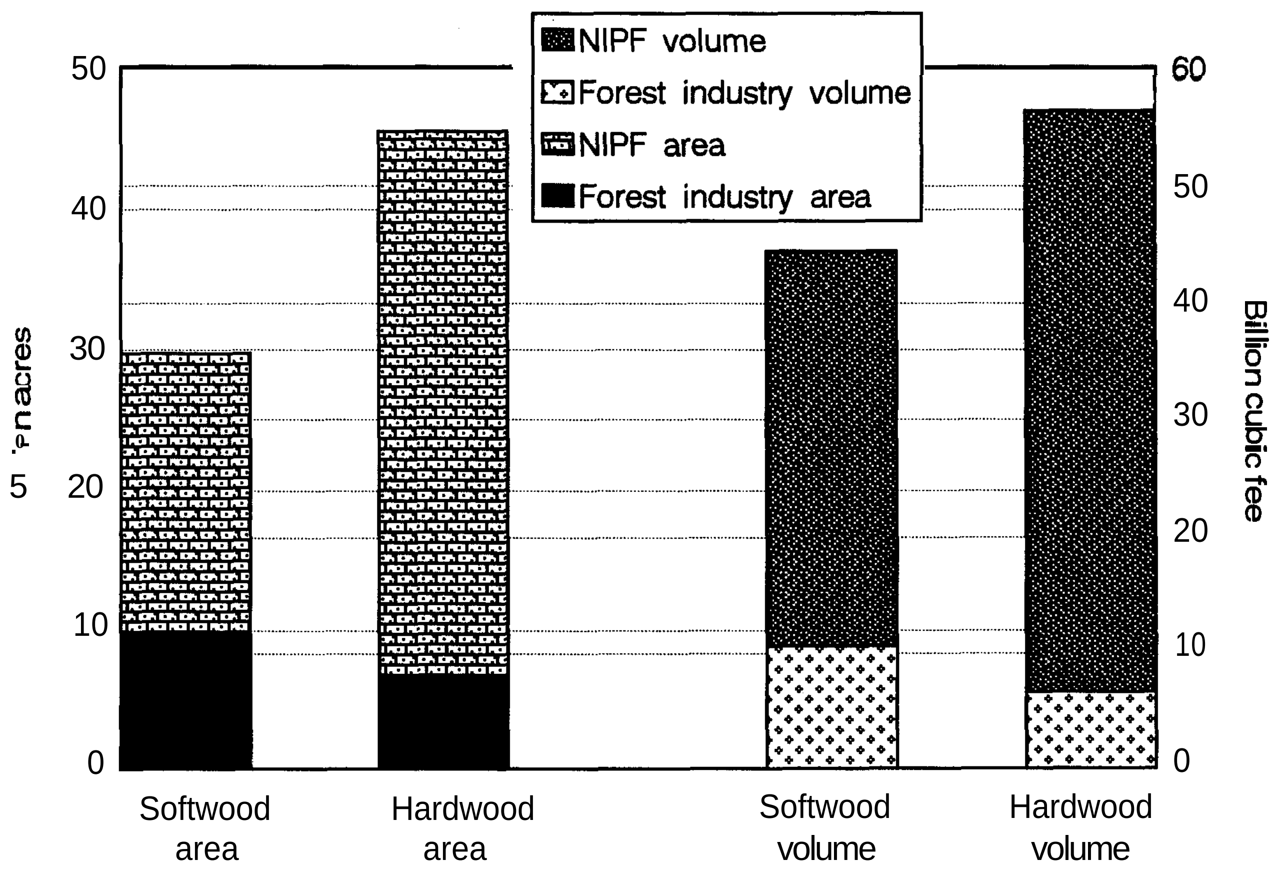

Figure l-Areas of softwood and hardwood timberland, in millions of acres, and softwood and hardwood growing stock volumes, in billions of cubic feet, by private ownership in the Southeast, 1992.

[2] Timberland is forest land that is not reserved for other uses and is capable of producing crops of industrial wood.

Crop and forest uses have shifted considerably on the NIPF ownership, influenced in part by government programs (Alig 1985). Although some cropland has reverted to forests, the area of timberland in the Southeast has continued to decline, especially on the NIPF ownership (Powell and others 1993). Even with CRP, the nation's largest tree planting program ever over a 5-year period, timberland area continues to decrease. Timberland area in the Southeast dropped from 85.2 million acres in 1987 to 84.8 million acres in 1992 (Powell and others 1993), and about 50 percent of the reduction occurred on the NIPF ownership. However, this does represent a slowing in the rate of loss of forest area when compared to the 2.5-million-acre reduction between 1977 and 1987.

In summary, excess land in the agricultural sector contributes to an uncertain future for the direction and rate between the shifting of land between agriculture and forest. Continued net conversion of forest land to urban and developed uses is likely, given the projected increases in population and personal income. As the current CRP tree planting program ends, policy makers are considering its renewal on a smaller scale. Even this scaled down program would include tree planting on erodible pastureland and other programs that could sequester additional forest carbon. Tens of millions of acres of marginal and environmentally sensitive cropland and pastureland, primarily in the South, are suitable for planting trees (Moulton and Richards 1990). Some of that area has already been planted through government programs like the CRP, and we now look at what might happen to timber markets if large areas in the remaining suitable acreage are planted to trees.

Modeling Impacts on Timber Markets from Tree Planting Programs

A policy issue with implications for multiple natural resource users is the possible consequences of competition for land between the forest and agricultural sectors and conversion of some timberland to urban, developed, and reserved uses. With these possible land-use shifts, modelers must explicitly consider the pathways for land moving into and out of forest. Land is converted from forest to agriculture when the present value of expected land rents in agricultural uses exceed that from timber growing and from agriculture to forest when the reverse is true (Alig 1985). When included in natural resource models, conversion of forest land to urban/developed use has been typically modeled exogenously, as illustrated in the projections for the 1989 RPA Assessment (Alig and others 1990b).

Forest Sector Model

In earlier large-scale appraisals, the TAMM/ATLAS[3]/Area Change modeling system has been used in regional and national forest assessments in the United States (Adams and Haynes 1980; Haynes 1990). As part of a group of linked models, TAMM is a regionahzed timber market equilibrium model that projects production, consumption, and prices in product and stumpage markets. The ATLAS component projects timber inventory volumes on timberland by ownership and region (Mills and Kincaid 1992), using exogenous projections of timberland area by owner, region, and forest cover type from Area Change models (Alig and Wear 1992). The ATLAS model uses timber removal calculations from TAMM to project timber inventory volumes and growth. This information is then fed back to the TAMM model, for recalculating the equilibrium level of timber removals, the process is repeated iteratively until a tolerable convergence is reached. In a related application, Haynes and others (1994) analyzed opportunities for sequestering additional forest carbon under scenarios that included recycling, tree planting, changing levels of public timber harvest, and other policies in the United States.

Linked Forestry and Agriculture Model

The Forest and Agricultural Sector Optimization Model (FASOM) is a dynamic, nonlinear programming model under development and testing that links the forest and agricultural sectors to model land-use competition (Adams and others 1994). FASOM uses relationships and data from the TAMM/ATLAS/Area Change modeling system to model the dynamics of tree growth, harvesting, and demand for delivered logs in an inter-temporal optimization framework

[3] Timberland Assessment Market Model (TAMM/Aggregate Timberland Analysis System (ATLAS); for a discussion of a recent application, see Haynes (1990).

that includes land-use allocation (figure 2). Timber yield estimates and cost estimates for tree establishment and management (Moulton and Richards 1990; Birdsey 1992) are usedindetemlinin g afforestation opportunities. These data are supplemented with forest-survey plot data used in the ATLAS model for national timber assessments.

The forest sector of FASOM depicts the use of existing timberland, reforestation decisions on harvested land, and afforestation of agricultural land. For example, planting agricultural land to trees or intensified management of existing timberland influences future stumpage prices, thereby affecting financial desirability of timber investments. FASOM assumes that owners fully foresee and adjust to price changes, while fixed price expectations are implicit in the TAMM/ATLAS/Area Change modeling system (Haynes and others 1994).

FASOM endogenously selects optimal timber management for softwood and hardwood acres on private timberland. Previous models used estimates of timber management that were pre-set based on expert opinion. Moreover, part of the modeling of timber management includes endogenous projections of area changes for forest types, which represents an improvement over earlier models.

Comparing Projections from Single and Two-Sector Models

We used five sets of forest projections for the Southeast to evaluate the importance of different assumptions and modeling stances. Two sets are preliminary projections by the TAMM/ATLAS/Area Change system from the 1993 Resources Planning Act (RPA) Assessment Update (Haynes and others, in press): (1) the baseline and (2) an afforestation scenario examined in the 1993 RPA Assessment Update. The remaining three sets are preliminary projections from the FASOM model: (3) baseline, (4) afforestation scenario, with the same amount of exogenous afforestation imposed in (2); and (5) baseline for a forest-only version of FASOM without the endogenous links between the forest and agricultural sectors. In the forest-only version of FASOM used in the fifth set of projections, no land is transferred in response to market forces between forest and agriculture. Exogenous or pre-set transfers of timberland to urban/developed uses are imposed, and exogenous or preset timberland gains from tree planting under existing government cost-sharing programs are imposed.

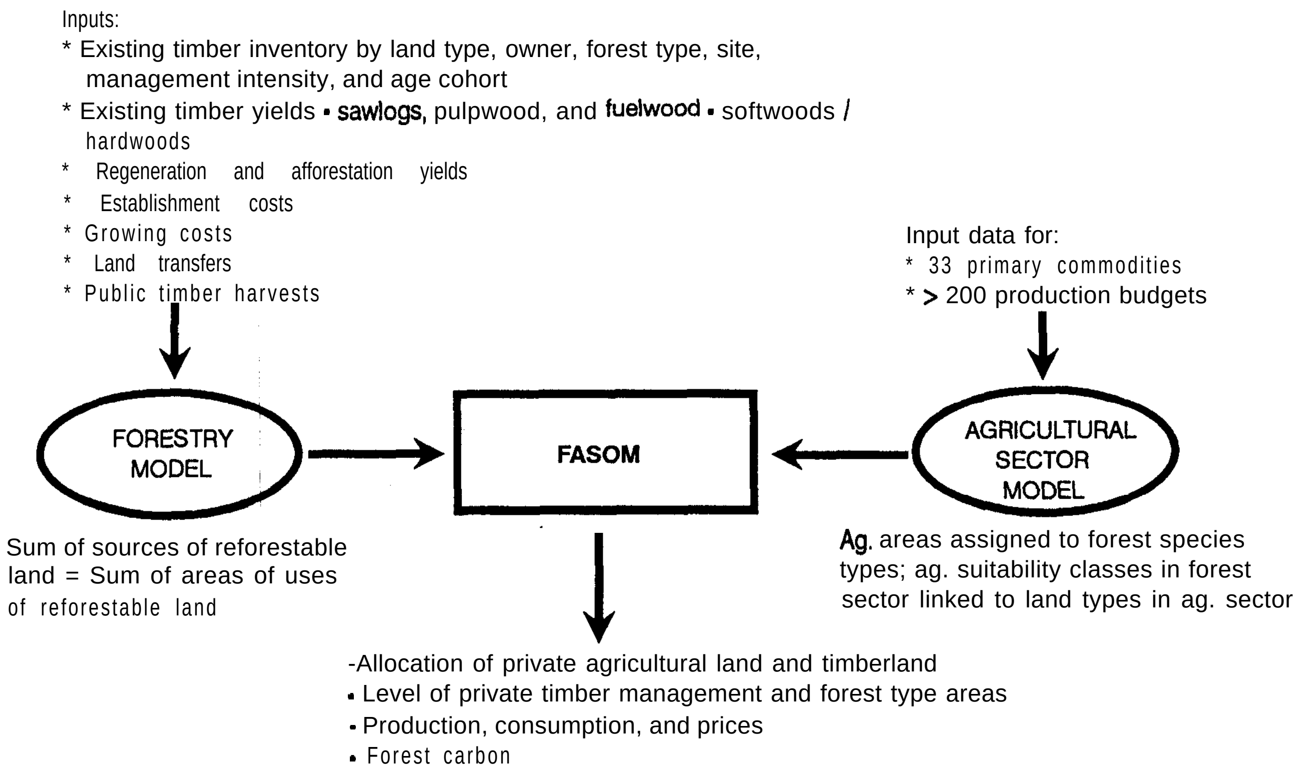

Figure 2—Schematic of linked Forest and **Agricultural** Sector Model (FASOM)

Changes in timberland area influence market prices and quantities in two important ways. First, when area is shifted to non-forest uses or converted to other timber types, at least part of the timber inventory is usually marketed and contributes to current harvest. Second, in the longer term, area changes either increase or reduce the aggregate forest growth and inventory potential. The degree of the market response will depend, in part, on how timber investors respond to the associated stumpage price changes. In addition, higher stumpage prices could drive up resource costs, resulting in regional shifts in production, as illustrated when recent public timberland withdrawals in the Pacific Northwest shifted production to other regions.

In this paper, we are primarily interested in what the alternative sets of projections indicate about the welfare and market impacts of large scale increments of tree planting on NIPF lands, including any regional spill-over effects. In table 1, we report preliminary model outcomes in terms of projected areas of planted pine and softwood inventories in the Southeast. In this section, we discuss selected fmdings from preliminary forest resource projections (as of early 1994) to illustrate types of changes in forest area and timber inventories that may affect carbon sequestration by forests under different scenarios. Others (Adams and others 1994; Birdsey 1992; Turner and others 1993) are translating projected forest inventory changes into carbon sequestration changes, which is outside the scope of this paper.

RPA Assessment Update Baseline

The RPA, as amended by the National Forest Management Act of 1976, directs the Secretary of Agriculture to prepare a Renewable Resource Assessment each decade and a Renewable Resources Program every 5 years. The 1993 RPA Assessment Update analyzes major changes in supply and demand since the 1989 RPA Timber Assessment (Haynes 1990). Key assumptions on the supply side pertain to investments in tree planting and intensity of timber management.

In the 1993 RPA Assessment Update, timber investment assumptions differ markedly for the NIPF and industrial private ownerships. For example, in the Southeast, forest industry owners are projected to convert a substantial proportion of natural pine and hardwood forest types to planted pine over the next several decades (USDA Forest Service 1988). Industrial owners reforest substantial amounts of timberland with plantations and manage timber relatively intensively (e.g., precommercial thinning, fertilizing, and commercial thinning) (Alig and Wear 1992). In contrast, NIPF owners follow historical trends of less intensive timber management but are receptive to government programs of technical and financial assistance for reforestation and afforestation.

Opportunities for increasing productivity on timberlands in the Southeast are substantial, and many offer attractive financial rates of return (Haynes 1990). Only a part of this potential increase in productivity on timberlands is reflected in the RPA baseline projections. Potential changes in climate could also affect future productivity (Burton and others, in press). However, the RPA baseline assumes a future in which the climate follows historical trends.[4]

NIPF softwood timber inventories in the Southeast are projected to fall steadily through 2040 (table 1), while the area of planted pine increases by about 4 million acres between 1990 and 2040. Softwood growing stock inventories on forest industry timberland are projected to increase through 2040, while planted pine area increases by approximately 4 million acres from 1990 to 2040. The combined effect on private softwood timber inventories is a projected reduction through 2020 and an ensuing increase of about 6 percent by 2040.

Tree Planting Program Under 1993 RPA Assessment Update

Policy makers have considered expanding tree-planting programs to increase the amount of carbon sequestered by forests. Moulton and Richards (1990) document the availability and cost of converting marginal and environmentally sensitive crop and pastureland for tree planting. Other studies (e.g., USDA Forest Service 1988) suggest that much of this area would be economically attractive for tree planting, particularly in the Southern U.S. even without factoring in the social benefits of carbon sequestration.

Based on a scenario where 5.8 million acres of pastureland are afforested in the south-central region by 2000 (Haynes and others, in press), the 1993 version of TAMM/ATLAS/ Area Change models projects stumpage prices similar to baseline projections up to 20 10. After 20 10, they fall below baseline projections for the Southeast. The effects of the tree planting in the south-central region spill over into the Southeast and depress stumpage prices from the year 2020 on.

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[4] An alternative future is included in the RPA Assessment Update that explores the forest-resource implications of significant change in the earth's C l i i .

Table 1-Comparison of projected areas of planted pine, in millions of acres, and softwood growing stock inventories, in million cubic feet, for forest industry and NIPF ownerships in the Southeast, under five alternative projections

Projection	Projection Year 1990	2000	2020	2040
		Forest industry		
1993 RPA Update Baseline				
Planted pine area	7.3	9.7	11.0	11.2
Softwood inventories	10,750	11,988	16,538	24,661
1993 RPA Update Tree Planting				
Planted pine area	7.3	9.7	11.0	11.2
Softwood inventories	10,750	11,988	16,565	24,872
FASOM Linked[5]: Baseline				
Planted pine area	7.3	11.3	15.3	15.8
Softwood inventories	10,750	10,711	28,897	23,743
FASOM Linked: Tree Planting				
Planted pine area	7.3	9.5	15.3	15.9
Softwood inventories	10,750	10,486	25,875	22,476
FASOM Forestry-Only Baseline				
Planted pine area	7.3	11.5	15.3	15.8
Softwood inventories	10,750	9,900	29,191	23,542
		NIPF		
1993RPA Update Baseline[1]				
Planted pine area	6.0	8.2	10.0	10.2
Softwood inventories	34,590	32,249	27,024	21,387
1993 RPA Update Tree Planting				
Planted pine area	6.0	8.2	10.0	10.2
Softwood inventories	34,590	32,230	27,096	21,903
FASOM Linked[1]: Baseline				
Planted pine area	6.0	10.1	9.9	13.2
Softwood inventories	34,590	28,939	28,151	29,777
FASOM Linked: Tree Planting				
Planted pine area	6.0	9.8	14.2	12.0
Softwood inventories	34,590	29,366	26,195	29,464
FASOM Forestry-Only Baseline				
Planted pine area	6.0	10.9	14.4	8.9
Softwood inventories	34,590	29,856	26,378	30,721

Using a 1989 model version , Haynes and others (1994) simulated the forest resource and market impacts of this scenario. Results showed somewhat larger effects on stumpage prices than the 1993 model. Even when tree planting is spread over 10 years, sizable increments of merchantable timber are eligible to enter certain key timber markets as the trees start to mature. In the primary region of tree planting, the South, stumpage prices are notably depressed after 20 10.

FASOM Preliminary Baseline

Projected softwood inventory levels in 2000 are lower under the preliminary FASOM baseline than those from the TAMMlATLASlArea Change model. Projected softwood inventories are lower for both the forest industry and NIPF ownerships because private owners harvest more timber and plant more area to pine in the first decade. However, later in the projection period, private softwood inventories are notably higher than those under the TAMM/ATLAS/Area Change baseline. Higher inventory levels result from a higher amount of accumulated tree planting in the FASOM baseline, reflecting the financial attractiveness of planting opportunities identified in earlier studies (e.g., USDA Forest Service 1988).

Tree-Planting Program with Preliminary FASOM Linked Model

Preliminary FASOM projections for a tree-planting program of 5.8 million acres in the south-central region differ in some notable ways from those with the TAMMlATLASlArea Change model. In particular, stumpage prices projected by FASOM after 2010 do not fall as much. This occurs, in part, because forest owners foresee long-term price changes and adjust to them immediately. With perfect foresight, both groups of private owners effectively adjust in the first decade. In total, compared to the TAMMlATLASlArea Change projections, more timber is harvested and area reforested in the first decade, which reduces future price changes.

Another difference between methods from the two sets of models is that the FASOM model projects the block of afforested acres to be harvested as a group and then converted back to agricultural use after harvest. Thus, by 2020, the projections-with and without the tree-planting program—differ little within the FASOM set. In contrast, building in the tree planting program causes the TAMM/ATLAS/Area Change projections to differ substantially in that projection period compared to the baseline.

In a related study, which lacked a dynamic forest modeling component, Adams and others (1992) analyzed the social costs and impacts on timber and agricultural markets when sequestering carbon by tree planting. Results indicated a range of outcomes, including higher food prices and welfare losses for some private forest land owners. Total social costs rose dramatically with increases in tree planting. Projected impacts on the agricultural sector (e.g., agricultural production) relative to the forest sector were small for a tree-planting program of 50 million acres. For the forest sector, economically disruptive impacts of large-scale tree planting are consistent with those projected by Haynes and others (1994).

Forestry-Only FASOM Preliminary Baseline

To test the sensitivity of forest resource projections to reduced land competition, the agriculture sector in FASOM was deactivated for this set of “Forestry-Only” projections. The projections for the NIPF ownership are affected most when compared to the FASOM-linked baseline projections, with projected areas of tree planting higher in the first part of the projection period under the Forestry-Only mode. Less competition for land reduces opportunity costs associated with alternative land uses and also causes forest industry to plant more acreage in the first decade. The planted area under the Forestry-Only scenario increases significantly when hardwood acres are converted to planted pine on the NIPF ownership. Proportionately less hardwood acres are available on forest industry lands for conversion to pine (see fig. 1).

Summary

Projected near-term impacts of afforestation on stumpage markets are relatively small in TAMMlATLASlArea Change projections, but preliminary FASOM projections indicate immediate adjustments to market signals by private owners. In the FASOM model, owners adjust optimally in their planning to reduced future stumpage prices. In contrast, the TAMM/ATLAS/Area Change modeling system projects a relatively large increase of tree plantations in a neighboring region, which depresses stumpage prices after 20 10. These effects are influenced strongly by the assumed response of NIPF and other private owners to market signals and their ability to foresee price changes. In the real world, markets and owners probably respond somewhere between the two extremes. Because tree planting may substantially boost future timber inventories, the possibility of greatly depressed timber markets in future decades bears some consideration by policy designers.

Discussion and Next steps

The sets of alternative preliminary projections indicate that forest area is a key determinant of future long-term forest inventories, which influence stumpage prices and returns to landowners. The relatively rapid adjustments in markets and by landowners indicated by the FASOM model are sometimes different from the observed behavioral tendencies of NIPF owners. For example, study of the fate of subsidized plantings indicates that they tend to stay in trees after government contracts expire (Alig and others 1990a).

The possibility of governmental intervention in markets also complicates attempts to project forest resource changes tied to owner behavior. The Southeast is particularly likely to be influenced by agriculture and forestry programs because so much land is suitable for both purposes. Agricultural programs have influenced forests and forestry by encouraging the cropping of forest land. Such agricultural programs have affected the forest land base and the forest types because land returned to forest through government programs is generally planted to pine. In the Southeast, agricultural programs have probably contributed to a net loss of NIPF timberland area of 7.8 million acres between 1952 and 1992 (Powell and others 1993), while tree planting programs have contributed to the 4.4 million-acre or eight-fold increase in NIPF planted pine area between 1952 and 1985 (USDA Forest Service 1988). In total, forest policies influence land use allocation less than they alter forest management through subsidy programs (e.g., Forestry Incentives Program), tax incentives, and technical assistance.

The amount of land-use change is also affected by decisions about other variables, such as intensifying timber management and transfers of land between owners. The NIPF ownership accounts for all projected private timberland losses in the 1993 RPA Update baseline. The losses attributed to ownership shifts through acquisition of NIPF timberland by the forest industry represent a relatively small part of the total projected net decrease.

In recent years, major programs or policies with implications for future forest are a have been implemented. The CRP has added over 2.5 million acres of timberland, primarily in the South. The Farm Bill will be considered for renewal in 1995, and related developments should be monitored. Significant uncertainty inherently accompanies long term projections, and the direction and extent of land-use exchanges with agriculture are an important part of the uncertainty associated with future forest-area projections (Alig and Wear 1992).

Next Steps

The future scenarios suggested by the five sets of preliminary projections are based on specific assumptions and the unknown evolution of different sectors of the economy. The projections are subject to change, and future work will address the aforementioned sources of uncertainties in three ways: (1) investigation of factors that influence changes in forest cover types at a regional scale in the Southeast, including economic and demographic variables, (2) development of methods for the endogenous projection of forest-type changes in a regional timber resource assessment system, and (3) projection of forest type changes under different future scenarios and evaluation of the economic effects of selected forest management alternatives.

Both natural and economic factors contribute to the amount and composition of forest types in the Southeast. We are investigating the rate of transition in forest types in the Southeast for the last two periods covered by forest-survey remeasurements. Information on transition relationships will be incorporated into the TAMM/ATLAS/Area Change modeling system. The enhanced modeling system is intended to aid in the Southern Global Change Program's assessment of potential external economic impacts of global change on southern forest ecosystems.

Other Impacts

Possible improvements in modeling approaches and data bases are desirable to analyze the forest resource, environmental, and economic implications of alternative forest management strategies for sequestering different amounts of atmospheric carbon. To increase usefulness for policy makers, evaluation of the regional and national impacts of expanded tree planting requires a comprehensive assessment of both resource-based and market-related impacts. Other models that can interface with the TAMM/ATLAS/Area Change and FASOM models can provide information on the effects of changes in forest cover area and stand structure on non-timber components, such as wildlife habitat and forest recreation opportunities. Efficient interdisciplinary modeling of these effects is more likely with carefully planned linkages between physical, ecological, and economic modeling systems.

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