MODEL

SOUTHERN FOREST RESOURCE ASSESSMENT USING THE SUBREGIONAL TIMBER SUPPLY (SRTS) MODEL

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ABSTRACT

Most timber supply analyses are focused on broad regions. This paper describes a modeling system that uses a standard empirical framework applied to subregional inventory data in the South. Model results indicate significant within-region variation in supply responses across owners and regions. Projections of southern timber markets indicate that results are sensitive to: 1) estimates of current harvest; 2) conversion of natural stands to plantations; and 3) growth rates associated with plantations. Given projected increases in demand, intensive pine management could ameliorate real price increases. For hardwoods, uncertainty about the viability of intensive management or imports makes supply response projections less conclusive.

Timber supplies in the United States have been a public issue for over a century. Fears of timber shortages prompted creation of the forest reserves, which were authorized in 1891, and have formed the basis for a host of other public policies and programs designed to increase timber supplies or avert potential shortages. While the early fears of timber shortages were either unwarranted, or averted through timely public programs, concerns about adequate timber supplies, especially in some local mill regions, resurfaced in the 1990s (4).

As timber supply and environmental protection issues have become more important, considerable effort is being focused on improving analyses and projection of forest resource trends. In particular, more people are seeking information on timber supplies in specific areas or portions of states, the impacts of mill expansions, and reductions in forestland area due to urbanization and environmental regulation. These informational demands have driven efforts to revise the USDA Forest Service's Forest Inventory and Analysis (FIA) procedures for the southern United States and the development of spatially explicit models to project future scenarios by the USDA Forest Service and the Southern Forest Resource Assessment Consortium (SOFAC). The common thread of these efforts is to develop data and methods to facilitate decision-making by companies, states, and regions.

This article summarizes the Subregional Timber Supply (SRTS) framework for projecting forest inventory and timber prices, which we have been developing for several years. SRTS uses FIA data to project timber supply trends based on current conditions and the economic responses in timber markets. The paper also summarizes recent applications of the SRTS model to the South, with an emphasis on the spatial variation in results and sensitivity of projections to pine plantation acreage and growth assumptions.

MODEL STRUCTURE

SRTS was developed initially to provide an economic overlay to traditional timber inventory models (e.g., ATLAS, (7)) and to develop a consistent methodology for disaggregating the impacts of national and global models (e.g., TAMM (2)) that treated the South as a homogenous supply region (1,2). In an inventory model, the focus is on the impact of a particular harvest scenario on a particular region. In SRTS, the potential price consequences, subregional harvest shifts, and inventory impacts from a harvest scenario are modeled consistently. SRTS has been linked to ATLAS and company-specific inventory models. The integrated inventory model de-

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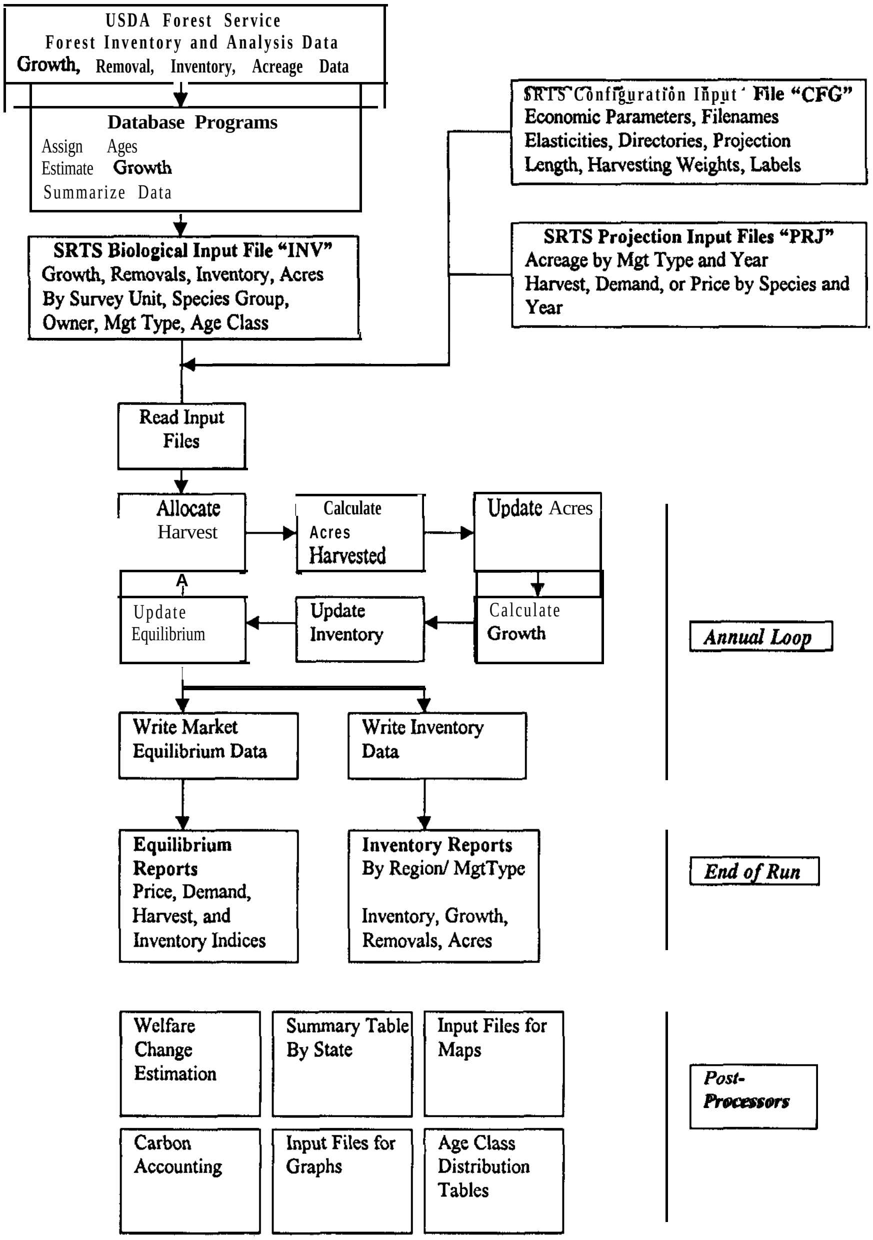

Figure 1. — Flowchart of the Subregional Timber Supply Model.

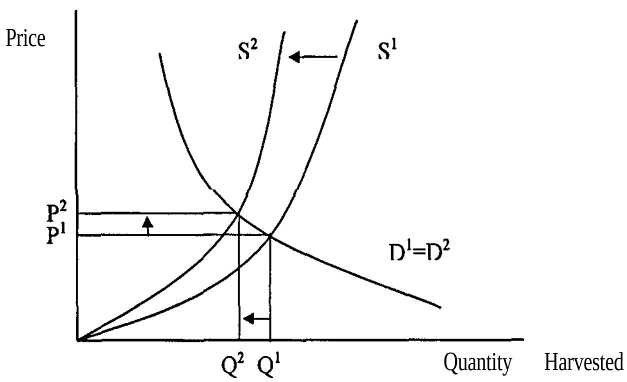

Figure 2. — Subregional Timber Supply Market Model.

scribed here was derived from the Georgia Regional Timber Supply (GRITS) model (3).

Timber market and inventory modules are the two major SRTS model components **(Fig. 1).** Market parameters are first used to solve for equilibrium price changes, where the market is defined by all of the included subregions. Second, the price and supply shift information from the individual regions are used to calculate harvest change by subregion. For the analysis presented here, FIA survey units and industry and other private ownerships in the South were used to define 102 (5 1 units x 2 owner types) subregions in the model. Public lands and harvest were excluded from the model because market forces do not drive their harvest and management decisions.

MARKET MODULE

Usually market equilibrium is modeled to determine the price and quantity that result from exogenous shifts in supply and demand. SRTS was developed to link to inventory models that use timber harvest as the control variable. Thus the SRTS default mode is to take a user's aggregate regional harvest levels and solve for the implicit demand, price, and subregional harvest shifts.

Figure 2 shows how an inward shift in supply due to a reduction in inventory would lead to reduced harvest and higher prices for a given demand.

At the aggregate region level, SRTS models year t harvest quantities as determined by the supply function:

$$Q^S_t = Q^S(P_t, I_t, v_t)$$

And the demand function:

$$Q^D_t = Q^D(P_t, Z_t)$$

where in the reduced form, current harvests, Q_t, are a function of timber prices, P_t, and beginning of period inventory, I_t, and other supply and demand shifters (v_t, Z_t). We assume that marginal cost is increasing in output; therefore, the harvest supply function is upward-sloping $(\partial Q^s_t / \partial P_t > 0)$. Output increases with the level of merchantable inventory available for harvesting $(\partial Q^s_t / \partial I_t > 0)$. A constant elasticity or log-linear functional form is assumed. Both of these partial effects are consistent with empirical analysis of timber supply (2,8,9). While these studies estimate elasticities at a broad regional level, there is little information on price or inventory elasticities at the subregional level. Other factors affecting supply levels (v_t) might include input prices, technological change, land quality, management, and landowner characteristics. Some of these issues can be addressed by changing ownership or management type parameters in the model as will be described.

In harvest exogenous mode, SRTS determines the price and demand consequences in each year of a given harvest level and the supply shift due to modeled inventory changes. The solution sequence proceeds as follows. The region is assumed to start in equilibrium. Since the equilibrium quantity, Q_t, and starting inventory, I_t, are known, the reduced form equation can be used to solve for P_t and the implicit demand shift, Z_t. The subregional proportion of regional harvest is estimated using the same supply framework. The estimated regional price change and subregional inventory change are used to estimate harvest change by subregion. Because the Cobb-Douglas functional form is not additive, each subregion's harvest is adjusted proportionately so that the sum matches regional harvest. The model can be run with the assumption that the subregional supply specifications hold and the aggregate price is found by using a binary search algorithm that determines the market-clearing price by summing the supply response across subregions and owners. In either top-down or bottom-up mode, demand shifts or equilibrium price trends can be exogenous, and the model will solve for the remaining equilibrium parameters, as described in the intensive management discussed later in this paper. The runs described maintained the aggregate market relationship or top-down assumption.

These assumptions imply a competitive market with regions and ownerships facing the same price trend. SRTS is not a traditional spatial equilibrium model where a single point with associated transportation costs represents demand. Instead, demand is assumed to be mobile, either through shifts in procurement regions (e.g., chip mills) or new capacity (e.g., OSB mills), and is assumed to respond to regional differences in stumpage prices. In this formulation, all regions and owners included in a model run are assumed to follow the same stumpage price trend, although levels may differ. Harvests will be shifted

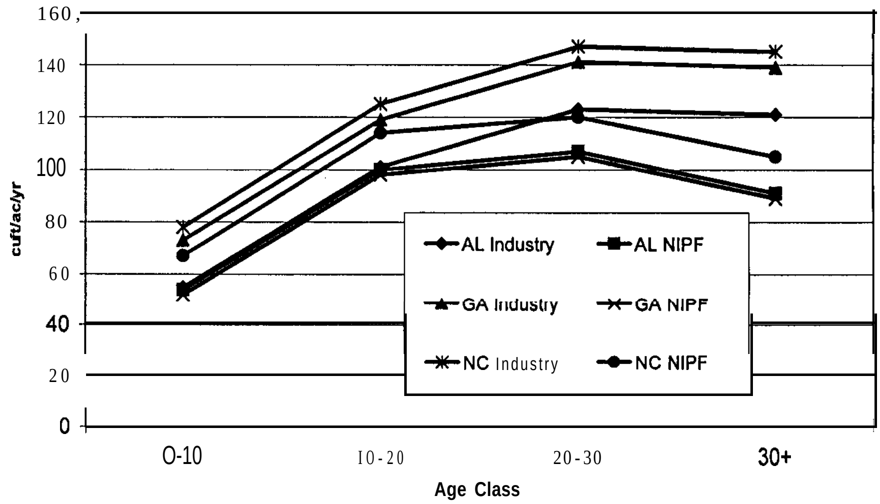

Figure 3. -Coastal plain pine plantation growth estimates.

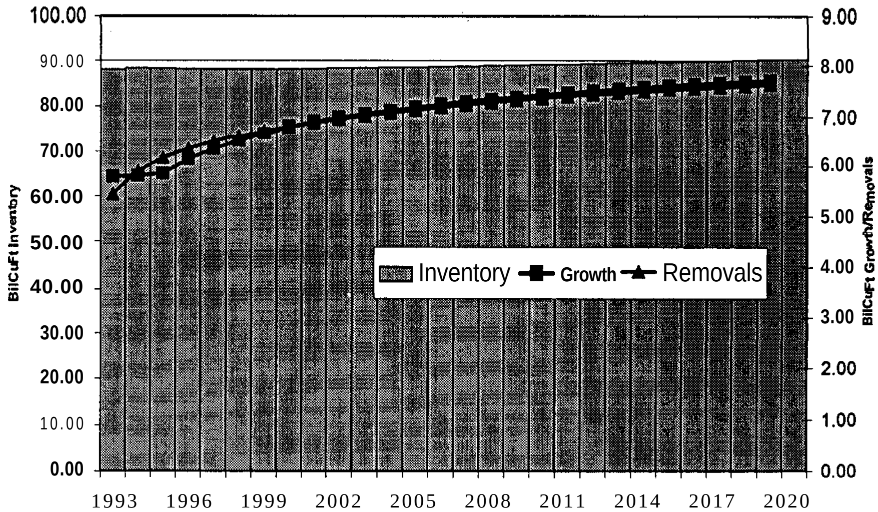

Figure 4. — Southwide baseline softwood inventory, growth, and removals projection.

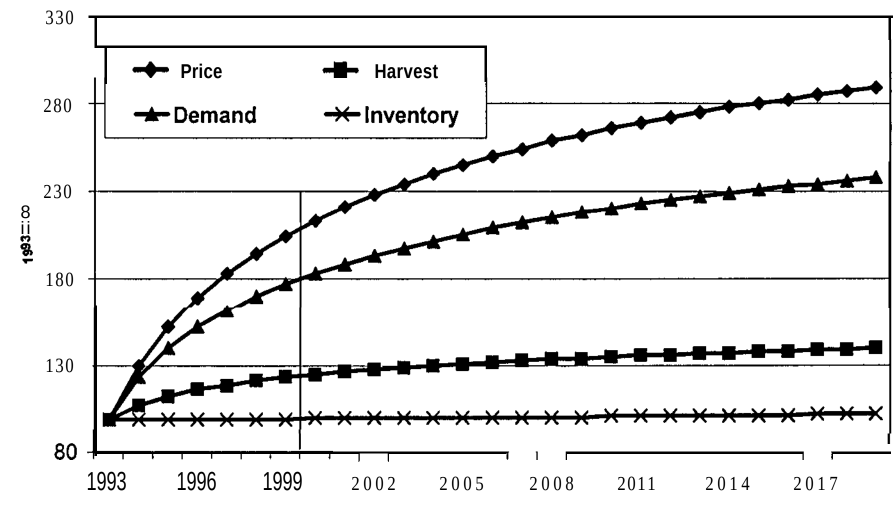

Figure 5. — Southwide baseline softwood equilibrium projection.

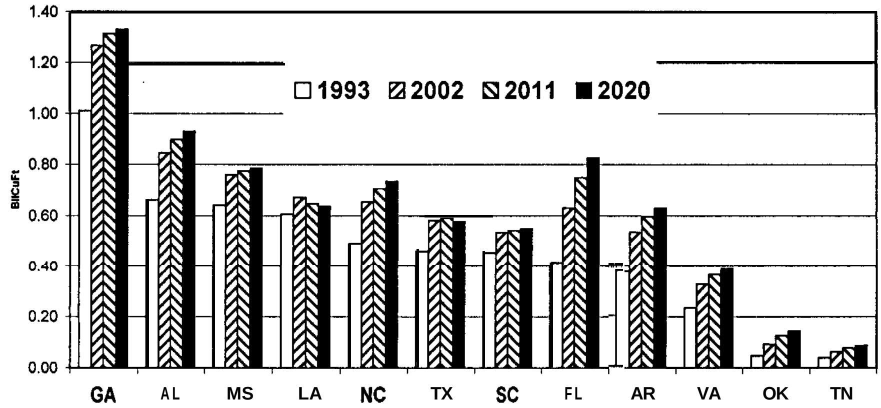

Figure 6. — Baseline softwood harvest shifts by state.

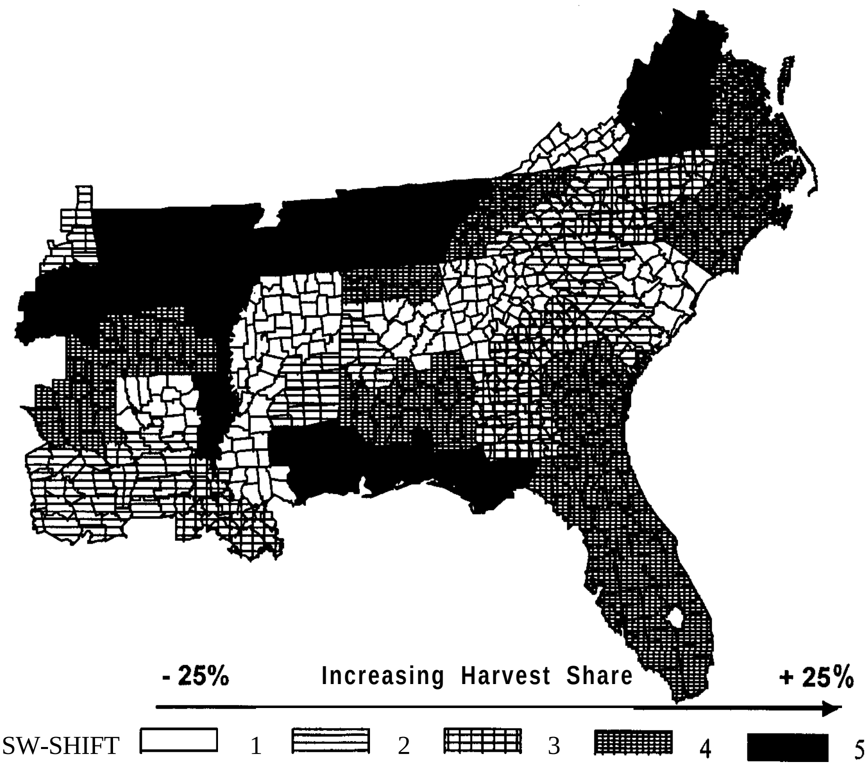

Figure 7. — Baseline softwood harvest shifts by survey unit, 1993 to 2020.

among owners and subregions based on comparative supply advantages.

INVENTORY MODULE

The internal inventory module in SRTS is based on the GRITS model (3). GRITS extrapolated forest inventories based on USDA Forest Service FIA estimates of timberland area, timber inventory, timber growth rates, and timber removals. GRITS classified data into IO-year age class groups by broad species group (softwoods and hardwoods) and forest management type (planted pine, natural pine, oak-pine, upland hardwood, and lowland hardwood). FIA data by species group, forest management type, and lo-year age class are summarized for each relevant region in the analysis. Land area trends by forest management type are exogenous to the model. A limiting factor in the development of GRITS was the availability of published tables for the model parameters. The SRTS model uses tree and plot level data as a basis for the age and growth analyses described later. These data can be derived from the FIA Eastwide Database, which is now available on the Web.

Growth. — SRTS uses lo-year age classes and species/survey unit/owner/management type cells to account for inventory change. To avoid wide variations or "empty" cells, the following growth per acre (gpa) regression equation was estimated by species-group (hardwood, softwood), physiographic region (delta, coastal plain, Piedmont, mountain), and management type (plantation, natural pine, mixed pine, upland hardwood, lowland hardwood):

$$gpa = f\ (state,\ owner,\ age,\ owner*age\ interaction)$$

A cubic age relationship was estimated. This approach allows the shape of the growth-age function to be modeled based on data from an entire physiographic/type combination, but allowed the level of growth to vary between states, and the level and shape of the growth curve to vary between owners. In the FIA database, some plots are not assigned ages. For these plots, a regression relationship between plot characteristics and age was used to assign ages to the plots. **Figure** 3 shows the estimated growth per acre for industry and other private coastal plain plantations for selected states. Due to the extreme variability in plot-level growth estimates, the R-squared estimates ranged between .05 and .30. All regressions were significant. Sensitivity of model results to these estimates is discussed later.

Harvest. — Harvest in SRTS is handled in three steps. The allocation of regional harvest to a subregion/owner is based on supply shifts and is part of the market equilibrium calculation described later. Within a subregion/owner, harvest is allocated across management types and age classes based on assigned parameters. Allocation of harvest across the five management types can be related to either historical removal proportions, current inventory or growth, or any weighted combination of these. For example, to allocate removals based on the average of starting removal and current (year t) inventory proportions, a 0.5 weight would be assigned to each.

Within a management type, the model can allocate harvest across age classes based on starting harvest proportions, current inventory proportions, or oldest age class first. Weighted average combinations of these procedures can also be specified. Empirical examination of harvest allocations in the FIA data indicate for all management types other than pine plantations, harvest allocations across age classes are highly correlated with inventory age class distributions.

Area. — Area trends are exogenous to SRTS. The default specification is to apply one set of management type trends to each region/owner combination. For example, a 1 percent annual increase in pine plantation acreage would be applied to the current plantation acreage in each region. Acres added to a management type begin at age zero. Acres leaving a management type are removed proportionately across all age classes. Growing stock on these acres contributes to current harvest. The projections described here generally use the RPA timber assessment area projections (6) as the base case for southern analysis. The impacts of alternative assumptions are explored later.

SCENARIOS

BASELINE

Based on prior econometric studies of timber markets (2), SRTS maintains relatively inelastic responses to changes in timber prices for both demand (elasticity equals -0.50) and supply. For softwoods, the supply price elasticity was assumed to be 0.29, for hardwoods 0.45. Inventory elasticities were assumed to be 1.0.

For softwoods, the base harvest allocation to management types was weighted toward inventory proportions (0.7) and growth proportions (0.3). Allocation across age classes was based on inventory (0.7) and on oldest first (0.3). For hardwoods, both harvest allocations were based entirely on inventory proportions.

The baseline simulation described is a 27-year harvest exogenous projection from 1993 to 2020 for private lands in the South. The base year of 1993 reflects the approximate midpoint of the current set of FIA surveys available for the 12 southern states. The baseline run consists of a 40 percent increase in softwood harvest during the 1993 to 2020 period, and a 50 percent increase in hardwoods. To reflect the large increases in harvest for both softwoods and hardwoods experienced in the last decade, the majority of the projected harvest increase was assumed to occur

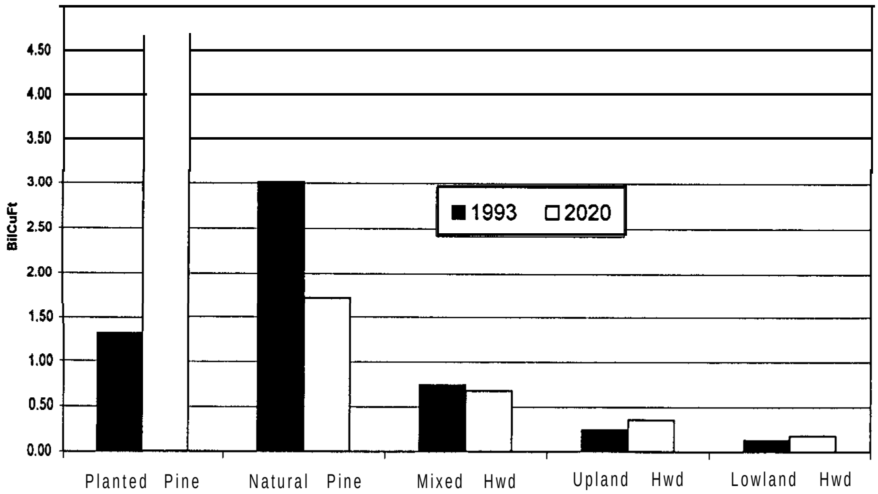

Figure 8. — Baseline softwood harvest shifts by management type.

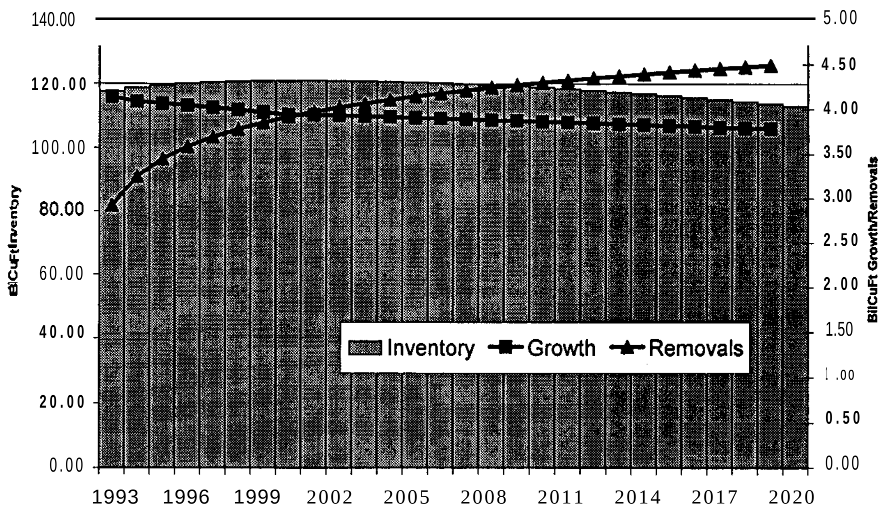

Figure 9. — Southwide baseline hardwood inventory, growth, and removals projection.

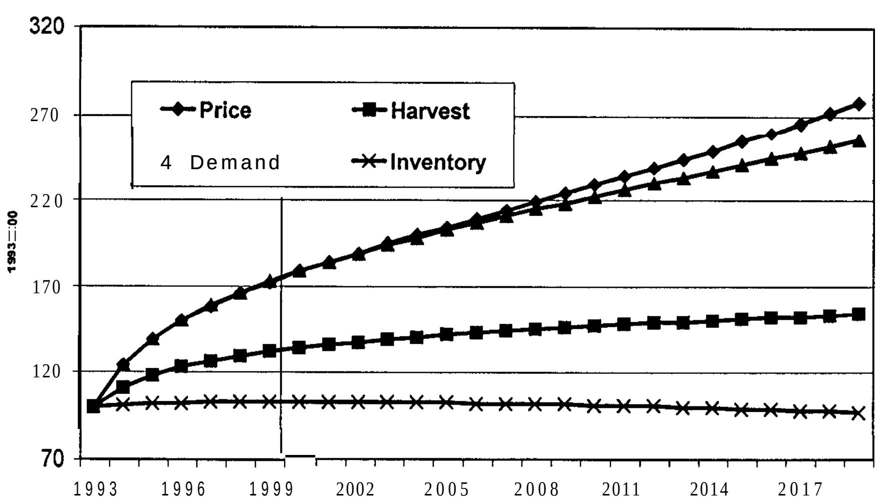

Figure 10. — Southwide baseline hardwood equilibrium projection.

TABLE I. — SRTS base run projections by state.

	Softwoods				Hardwoods			
	1993	2002	2011	2020	1993	2002	2011	2020
	(1,000 ft.^{3})							
Alabama								
Inventory	10,269,267	10,363,246	10,511,396	10,675,324	11,139,891	12,153,977	12,182,267	11,675,210
Growth	714,414	848,449	911,119	945,694	566,739	539,239	530,182	520,347
Removals	662,349	844,401	897,476	928,846	340,632	501,678	562,525	597,901
Arkansas								
Inventory	7,192,355	7,988,840	8,589,667	9,036,041	9,276,618	9,211,733	8,835,442	8,364,324
Growth	511,663	604,905	648,055	672,124	296,557	281,422	273,485	267,854
Removals	379,345	535,477	596,116	628,730	243,308	314,986	322,541	324,314
Florida								
Inventory	6,886,992	7,899,113	8,736,927	9,343,507	4,608,375	4,972,532	5,109,380	5,126,748
Growth	542,966	725,384	818,352	882,032	147,528	131,591	131,675	132,156
Removals	417,332	630,025	749,446	825,657	75,192	109,440	124,470	135,258
Georgia								
Inventory	13,515,964	12,893,469	12,476,714	12,239,224	14,631,439	14,481,775	13,607,374	12,428,033
Growth	972,701	1,205,253	1,275,326	1,310,173	438,685	405,679	391,951	376,235
Removals	1,010,813	1,268,805	1,314,932	1,331,514	351,650	480,262	509,629	517,606
Louisiana								
Inventory	8,830,450	7,746,802	7,120,238	6,820,999	7,945,859	8,093,962	7,932,502	7,694,307
Growth	513,173	573,673	599,896	614,148	306,702	282,729	272,813	266,096
Removals	605,936	671,155	647,499	636,218	231,304	293,335	295,439	295,588
Mississippi								
Inventory	7,327,039	6,935,925	6,776,939	6,713,539	9,837,189	9,094,418	7,811,906	6,531,034
Growth	627,373	724,846	762,646	776,893	451,822	409,393	387,556	369,748
Removals	640,199	159,439	774,522	784,473	423,767	542,173	531,108	508,052
North Carolina								
Inventory	11,229,810	11,410,221	11,506,263	11,601,036	17,517,735	17,675,547	17,042,676	15,996,994
Growth	557,106	661,527	711,086	745,376	529,050	510,046	503,023	493,285
Removals	490,565	654,777	705,969	734,846	400,420	553,588	600,592	626,035
Oklahoma								
Inventory	1,092,790	1,601,849	1,989,410	2,221,271	1,376,006	1,730,053	1,981,742	2,135,824
Growth	106,067	142,169	157,516	164,320	69,665	70,912	73,401	74,719
Removals	46,892	93,134	125,869	144,827	22,350	39,855	53,041	64,188
South Carolina								
Inventory	6,847,346	6,172,820	5,847,965	5,736,068	7,920,412	7,231,121	6,300,975	5,350,003
Growth	378,385	477,621	511,891	534,246	185,868	171,614	162,245	153,720
Removals	455,573	535,098	542,232	550,102	215,152	269,985	267,981	259,330
Tennessee								
Inventory	2,287,755	2,536,826	2,887,667	3,196,442	11,961,729	14,265,739	16,015,192	17,181,705
Growth	86,345	102,264	112,369	119,505	468,075	475,538	485,731	492,104
Removals	39,899	63,077	77,350	87,637	152,154	254,158	327,796	392,251
Texas								
Inventory	6,581,405	6,455,967	6,169,308	5,864,068	4,706,024	4,839,952	4,616,918	4,217,720
Growth	488,147	550,616	557,048	542,863	199,140	186,151	179,042	171,793
Removals	460,650	581,073	590,091	577,353	140,280	198,378	215,427	222,544
Virginia								
Inventory	5,927,299	6,273,832	6,580,457	6,816,361	16,596,601	17,098,032	16,896,282	16,240,629
Growth	296,039	362,832	391,311	412,261	476,710	464,193	460,817	453,962
Removals	235,326	327,960	365,905	389,090	325,476	460,507	512,606	546,978
South								
Inventory	87,988,472	88,278,902	89,192,948	90,263,877	117,517,878	120,848,843	118,332,649	112,942,531
Growth	5,794,378	6,979,535	7,456,613	7,719,626	4,136,540	3,928,500	3,851,918	3,772,011
Removals	5,444,878	6,964,420	7,387,400	7,619,287	2,921,684	4,018,341	4,323,150	4,490,047

in the beginning of the projection period (see growth trend in **Fig. 4)** by using a logarithmic trend.

We assumed a 50 percent increase in forest industry pine plantation growth rates over the FIA-based data during the projection period. A 25 percent increase was assumed for nonindustrial plantations. Other SOFAC growth and yield analyses have suggested that such growth increases should be attainable (5). This growth rate change is applied with a logarithmic function over time so that most of the increase is experienced in the first half of the projection. The growth rate change is assumed to affect all age classes.

The largest management-type transitions in timberland in the South have been the increased acres of pine plantation and the corresponding decrease in natural pine acres. Pine plantation acres were assumed to increase from 1993 to 2000 based on baseline rates, but they were held constant from that point forward at about 26 percent of the private land base. Acres were removed from natural and mixed pine types based on their relative abundance in the subregion. Together, these assumptions imply that total timberland acreage is constant during the projection period.

INTENSIVE MANAGEMENT

Recent data suggest that large gains in plantation growth can be realized through the use of fertilization and herbicide treatments (5). As an example of how the model could be used to examine timber supply issues, an alternative intensive management scenario was developed. The implicit demand shifts calculated in the baseline scenario were applied in this scenario. The model was used to estimate the price and harvest consequences of altering plantation management relative to the baseline, assuming the same demand as the baseline run.

Industry plantation growth rates were increased to 75 percent higher than current FIA rates by the end of the projection period; nonindustrial plantations were assumed to show 37.5 percent greater annual growth. Plantation acres increased from 20 to 36 percent of the private timberland base from 1993 to 2020 using 1993 RPA trends. The increase in growth rates will have an immediate effect on inventory, but the changes in acreage beyond the year 2000 only begin to influence supply by

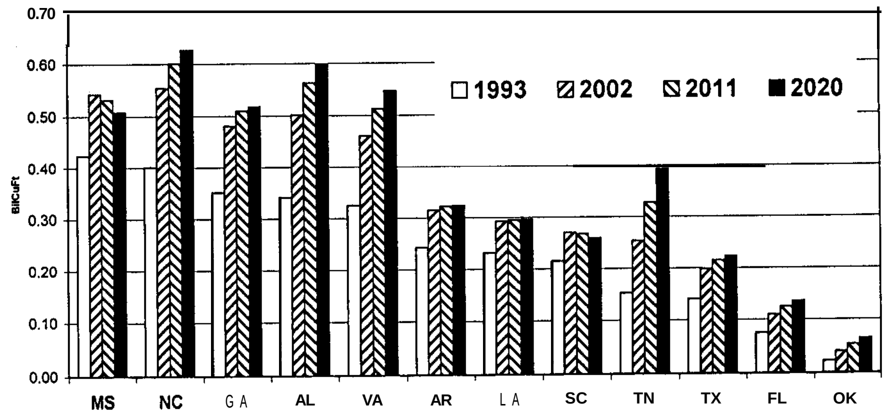

Figure 11. — Baseline hardwood harvest shifts by state.

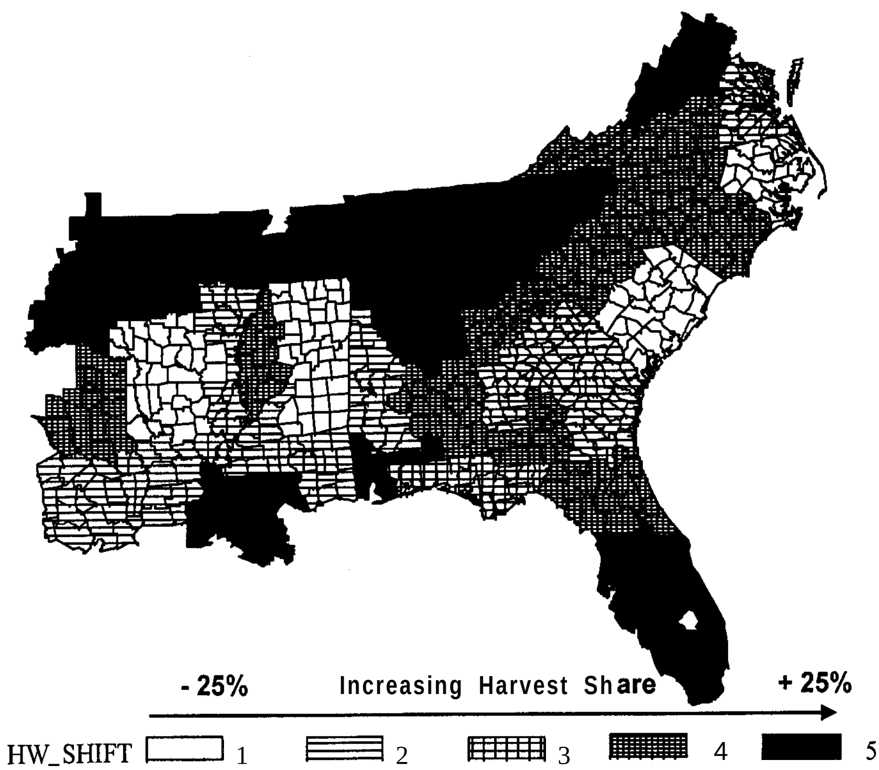

Figure 12. — Baseline hardwood harvest shifts by survey unit, 1993 to 2020.

the end of the projection period. Given that both scenarios are based on the same demand trend, increased supply implies prices should be lower and harvest higher in the intensive management scenario relative to the baseline.

RESULTS

The state-level inventory results are shown in **Table 1.** All of the results reflect private inventories only. **Figure 4** shows the Southwide softwood inventory results. An increase in plantation acres and a 50 percent (25%) increase in industry (nonindustrial private forest (NIPF)) plantation growth rates largely offset the 40 percent increase in harvest. **Figure** 5 shows the increasing harvest and inventory trends as indices along with the price and demand trends that are consistent with the harvest assumption. Since harvest is increasing faster than inventory, there is upward pressure on prices, which more than double in real terms by the end of the projection. Most of the harvest and price increases occur in the 1990s with only a 35 per-

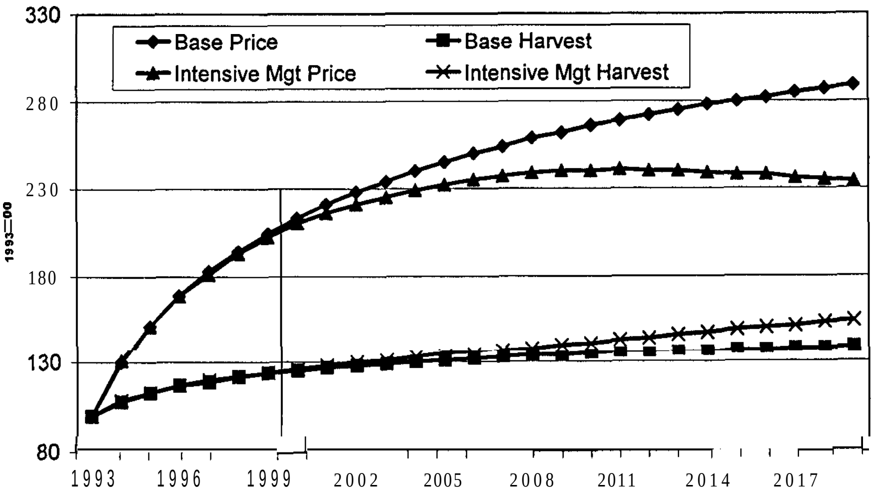

Figure 13.—Southwide softwood baseline and intensive management equilibrium projection.

cent increase in real prices from 2000 to 2020. Increasing harvest rates even with higher prices during the last two decades of the projection correspond with an implicit 30 percent demand increase.

Figure 6 shows the movement of softwood harvest among states during the projection period. These figures are the sum of detailed survey unit and ownership inventory data available from the model. Given the growth assumptions for plantation acres and yields, those states with the largest concentrations of industry plantations (Georgia and Florida) had the largest harvest increases. States that had less favorable growth/drain ratios based on the last available survey, for example Louisiana, lost harvest relative to other states.

These state projections mask significant within-state variation. **Figure 7** shows that the predominate softwood harvest trend is toward coastal plain plantations and to regions with relatively favorable growth/drain ratios (e.g., Tennessee and Arkansas). The shading of the map indicates whether a region is losing, maintaining, or gaining relative regional share of softwood harvest. Those regions shown in large cross-hatching (labeled 3, **Fig.** 7) had supply curves that were shifting out at about the same rate as the regional average. The lighter areas (1 to 2) had lower inventory increases, the darker areas (4 to 5) had higher inventory increases. Some of these areas have very small softwood resources (e.g., the Mississippi Delta region), and so the percentage increases may be misleading in terms of regionwide significance as shown in **Figure 6.** The South Carolina figures are biased by the high mortality and subsequent low net growth associated with Hurricane Hugo.

Figure 8 reveals that plantations soon become the dominant source of pine harvest. By the year 2004, less than half of softwood harvest comes from natural stands. The trend continues so that by 2020, over two thirds of softwood harvest comes from plantations.

The supply situation for hardwoods is significantly different. Based on the latest FIA statistics, hardwood growth exceeds harvest by about one-third. Using the logarithmic trend, however, harvest increases by 34 percent in the first 3 years of the projection, which appears consistent with recent production and tax data. Hardwood growth declines slightly during the projection due to the loss of hardwood and mixed pine acres and a younger average stand age resulting from increased harvesting. While the growth rate relative to inventory is higher in young stands, the total volume of growth per acre is smaller.

The juxtaposition of the increasing harvest trend and the flat inventory **(Fig.** 9) lead to higher hardwood prices **(Fig. 10)**, with real prices more than doubling by the end of the projection. Given an inelastic aggregate hardwood supply curve that remains relatively stable during the projection, the price and demand trends are driven by the harvest increase. **Figures 11** and 12 show that harvest is shifting out of coastal plain areas into the Piedmont regions, Tennessee, and the Ozarks.

While a likely short-run response to a scarce softwood supply situation is intensive management, this is less feasible for hardwoods. Hardwoods are predominantly owned by nonindustrial owners, often for non-timber objectives. Intensive hardwood plantation silviculture is in its infancy and is unlikely to have an impact in the next 10 to 15 years except as a strategically located resource for a few forest products firms. The economic response to increasing hardwood prices is likely to be two-fold. If intensive softwood culture successfully increases pine inventories, there is likely to be a reversal of the historical trend to invest in technologies to substitute hardwoods for pines in southern pulpmills. Further, as hardwood prices increase, the viability of importing fiber or pulp becomes stronger. Both of these responses have the potential to ameliorate hardwood price increases by reducing domestic harvest.

Figure 13 shows the market impacts of substantially increasing plantation growth on a plantation acreage base that is assumed to continue expanding after 2000. The same demand trend applied to the faster growing softwood resource leads to lower prices and higher harvest levels, especially at the end of the projection period. Real prices increase only about 15 percent after the 1990s and then decrease as the new plantation acres affect supply. All of the trends toward increased dependence on plantations were accelerated in these scenarios, with plantation-abundant states gaining slightly more harvest and harvest from natural stands declining faster relative to the baseline.

CONCLUSIONS

SRTS is a partial equilibrium market simulation model that can be used to analyze various forest resource and timber supply situations. It uses a biological inventory projection model and a conventional supply/demand framework to project future timber prices and inventories given exogenous assumptions about land area and demand. The model facilitates sensitivity analysis of results to changes in price and inventory responsiveness, area and growth trends, harvest allocations, or other factors.

The SRTS scenarios described herein imply that the intensive and extensive margin of pine plantation management will be the key factor determining the future of softwood timber supply in the South. While this version of the model doesn't predict the management response, it does show the spatial implications of various scenarios. With industry pine plantations being concentrated in the coastal plain, and hardwood harvest shifting to the Piedmont, it is clear that the regional dynamics imply different land use and policy implications for different subregions of the South. These are the types of issues that SRTS was meant to address. It has been linked to both TAMM and the Global Trade Model to allow interaction with national and global markets, while providing regional detail.

The model has also been used to examine implications of local impacts (i.e., hurricanes, mill expansions, chip mills) in a way that recognizes local forest inventory characteristics and the integration of markets. The scenarios examined here treated the South as one competitive market. The model can be used to run subregions independently, or to allow only partial adjustment of harvest between subregions or owners.

There are several weaknesses in the simple approach described here. The empirical basis of the model implies that historic relationships are assumed to hold for the projection period. While this may be reasonable for short- to intermediate-run projections, it becomes less defensible for projections beyond 20 years. For example, use of inventory as the sole supply shifter implies that historical relationships between harvest and total inventory will hold in the future. In areas with dramatic changes in land use, such as urbanization, historical relationships are not likely to hold. Further, the age class distribution of the inventory is not used in the regional equilibrium. Management intensity is currently exogenous to the model. While it would be relatively simple to develop a normative profit maximizing approach to modeling management intensity, there is little empirical work available to characterize observed responses. This version of the model does not separate products within species-groups. A revised version of the model is being developed that specifically addresses the impact of land use, management intensity, and inventory characteristics on subregional supply.

Current work on SRTS is focused on the multi-product version and linkages to land-use change models of the South. These modifications should better reflect changes in the extensive margin of timberland and the dynamics at the interface of the urban and agricultural sectors. SRTS has been used to disaggregate the national RPA projections within the South and has been adopted for strategic analysis by several forest industry firms. The model is being continually updated to address specific issues or to reflect more recent data. The current version, however, provides a useful first step in determining the spatial implications of various local, regional, and global policy questions.

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