Modeling Forest Type Transitions in the Southcentral Region: Results from Three Methods

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ABSTRACT: *In recent years much interest has developed about the dynamics of forest type transitions, especially the transitions of land to and from southern pine plantations. This article presents 50-yr-forest type projections developed from two approaches to specifying the type transition matrices. One approach used transition matrices derived with remeasured plot data for six forest types using USDA Forest Service Forest Inventory and Analysis data. These data tracked transitions that occurred either naturally or artificially on inventory plots during one remeasurement cycle. The second approach relied on expert opinion surveys that predicted trends in the future of forest management. The transition matrices were developed from the responses regarding managers' intentions to regenerate stands following harvest. The survey was developed for the 2000 Forest and Rangeland Renewable Resources Planning Act Timber Assessment (2000 RPA). The timber inventories in eight states in the southcentral United States are projected with these methods of handling type transitions, and the results are compared to the 2000 RPA, which used a combination or hybrid approach to type transitioning. All three techniques conclude the area of planted pine is expected to increase well into the future. They are contradictory, however, in predicting the area other forest types will occupy, especially natural pine and upland hardwoods. Projections based on recent history give us one result; projections based on managers' intentions show another. South. J. Appl. For. 27(3):190–197.*

Key Words: Forest type transition, timber inventory projection, RPA timber assessment, land use, timberland area change, pine plantation, FIA data.

The accuracy of timber inventory projections is important to forest industry, timberland investors, end-use consumers, and policy makers. According to Wall (1983), obtaining better information on the quantity and quality of timberland and how it will be used are important keys to improving that accuracy. Alig et al. (1983) endorsed the call for improving analyses of aggregate forest area change and initiated production of a large body of research on identifying determinants of forestland area change. Alig (1986), Alig and Healy (1987) and Alig et al. (1988) developed econometric approaches to estimating change in forestland area using various demographic and economic variables (e.g., urban and rural population density, per capita income, and government subsidy programs). Hardie and Parks (1997) found that the proportion of high quality land (in a state or region) and the price of pulpwood are also important factors in the estimation of forestland area.

The interest in identifying economic and land use variables as key determinants in estimating forestland area stems from their potential link to policies that promote and affect forestry (e.g., planting programs, tax credits, zoning, etc.). According to Ahn et al. (2000), "These models are particularly useful for policy analysis since they explicitly measure landowner responses to decision variables that can be affected by land use policies."

Although many studies have focused on area entering or leaving the timberland base, less reported research has identified the determinants of type conversion for improving that aspect of the timber inventory projection problem. Given an estimate of future forestland area, the structure of future timber inventories largely depends on the future distribution of forest cover types and management practices. According to Alig et al. (1990), "Failure to account for forest type change over time can lead to miscalculation of resource production and errors in policy design. Timberland value and productivity depend in part on the species of trees that are on the site."

For the purposes of this study, a forest type transition occurs when the species composition on a particular forest

NOTE: Xiaoping Zhou can be reached at Phone: (503) 808-2017; Fax: (503) 808-2020; E-mail: xzhou@fs.fed.us. Manuscript received March 16, 2001, accepted December 6, 2002. This article was written by U.S. Government employees and is therefore in the public domain.

plot changes enough, either naturally or artificially, so that the observed forest type at a future point in time is different than when it was previously classified (typed). Forest type transitions occur for a variety of reasons including natural disturbances, land management activities, and natural succession (Alig and Wear 1992). Alig and Wyant (1985) described a model where the probability of a particular management disturbance can be used to modify the empirical transition probabilities available from the USDA Forest Service Forest Inventory and Analysis (FIA) inventory data. Management disturbance probabilities could be altered through scenario building exercises, possibly based on expert opinion. For undisturbed sites, however, the authors acknowledged the inadequacy of modeling efforts to reflect the ecology of type transitions for the highly aggregated types used in most inventory projection/timber supply studies, and the prohibitive costs associated with refining them. Brooks (1985) used expected revenue (including government cost share payments) to estimate acres planted each year in a projection, and those acres were used to modify empirically determined forest type transitions. The model provided a method of examining the effect of modifications to subsidy programs on inventory projections and type distributions (four broad types). Alig et al. (1999) used the FASOM model (Adams et al. 1996) to make type change a dynamic process that responds to changes in the level of private investment and markets. The model tracks two aggregated forest types (softwood and hardwood) and allows for the transition of hardwood to softwood through the establishment of plantations after harvest.

When modeling forest type transitions, only two basic approaches continue to receive serious attention: expert opinion (e.g., Moffat 1998, AF&PA 1999), and empirically derived transitions from the FIA data. Although succession is a strong change agent in undisturbed areas, most rapid transitions (capable of influencing the direction of timber inventory trends) usually occur following disturbances, such as regeneration following fire, or more likely, natural or artificial regeneration following harvest or land use change. For the purposes of synoptic analyses of trends in type change where type is broadly defined to aid in the characterization of timber inventories, FIA data provide a good source of historical information about forest type transitions.

In forest cover projections (Alig and Butler 2001, Butler and Alig, in prep.) done for the 2000 RPA, the forest type transition probabilities were initially based on FIA data and subsequently weighted by expert opinion survey results from forest industry landowners (American Forest & Paper Association 1999) and state foresters (Moffat et al. 1998). The purpose of the surveys was to determine the intentions of landowners regarding their anticipated plans for regenerating and managing areas harvested in the future. The forest industry survey was conducted by the American Forest & Paper Association (AF&PA) of its member companies. Because of the difficulty of surveying large numbers of nonindustrial private forest (NIPF) landowners, the opinions of state foresters about the current and future management intentions in their states was used as a proxy. This article presents results of future forest type distributions when they are projected with both empirically derived type transition matrices (using FIA data only) and the matrices developed from the expert opinion surveys referenced above. These two projections are then compared with a third “hybrid” projection developed as part of the 2000 RPA. These results help provide an envelope around land change analyses in the South, highlighting the difference between models based on empirical data and those based on people’s outlook for the future. This may help policy makers and other interest groups better understand the sensitivity of the type transitions built into the 2000 RPA.

Data

The FIA data for seven southcentral states—Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas—were pooled and then stratified by county, ownership, forest type, and a variable to indicate whether or not harvesting activity occurred during the remeasurement period (Teeter and Zhou 2000).[1] There are 443 counties in these states that are designated as forest counties, i.e., there is private forest area within their boundaries. Three private ownership classes are recognized: forest industry, other private, and miscellaneous corporate, which are consistent with the RPA private ownership classifications and definitions for the South (Haynes 2003). This study excluded federal, state and publicly owned forestland from the analysis.

The harvest activity variable associated with each FIA plot describes any crop tree removals since the prior survey. Harvest activity accounts for partial harvest, seed tree and shelterwood cuts, clearcut of merchantable trees, and complete clearcut; nonharvested stands have no evidence of harvesting. Tables 1.1 and 1.2 provide examples of type transition rates for harvested and nonharvested stands for the forest industry ownership class. The forest types are classified by FIA as management types; they are based on a calculation made for each plot regarding species present and a plurality of stocking. For the South, these are planted pine (PP), natural pine (NP), oak-pine (OP), upland hardwood (UH), lowland hardwood

Table 1.1 Type transition rates for harvested stands in the forest industry ownership, derived from FIA data collected between 1989 and 1995.

	Type to					
Type from	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood	Nonstocking
	(%)					
Planted pine	60.3	8.1	17.1	13.6	0.0	0.9
Natural pine	16.1	33.7	26.5	22.3	1.2	0.2
Oak–pine	15.8	12.2	30.4	34.3	6.4	0.9
Upland hardwood	17.7	3.6	15.5	57.1	6.2	0.0
Lowland hardwood	4.8	0.0	4.1	8.8	80.8	1.5

Table 1.2 Type transition rates for nonharvested stands in the forest industry ownership, derived from FIA data collected between 1989 and 1995.

	Type to					
Type from	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood	Nonstocked
	(%)					
Planted pine	90.5	5.2	4	0.3	0.0	0.0
Natural pine	14.3	74.8	8.4	2	0.5	0.0
Oak–pine	37.7	13.7	41.8	5.8	1	0.0
Upland hardwood	19	3.1	23.2	50.2	4.5	0.0
Lowland hardwood	0.0	0.2	3.3	4.9	91.6	0.0

(LH), and nonstocked (NS). Each row in the table represents a forest type as originally classified; the columns represent the classification upon the next measurement. The values in each row represent the percent distribution of the forest type as subsequently surveyed and classified. Table 1.1 indicates that the transition rate from planted pine to natural pine is 8.1% after following harvest, or said another way, 8.1% of the harvested stands of planted pine will transition to natural pine sometime following a harvest (within the survey cycle, which for the South averaged 7.6 yr). Type transition in the absence of harvesting may occur from differences in growth rates among individual species. For example, young oak-pine may transition to pine as the pine stems mature and account for a larger fraction of total volume on the plot.[2] Table 1.2 shows that 90.5% of the pine plantation classified in the last survey will remain in pine plantation type. Similar matrices for "other private" and "miscellaneous corporate" owners were also derived and incorporated in the projections.

The transitions based on the surveys of industry managers and state foresters are presented in Tables 2 and 3; they present a view of the future based on current knowledge and expert opinion.[3] When compared to the empirical tables, these results show notable differences between recent history, as recorded in the FIA data, and what people expect to occur from management. For example, on medium site forest industry lands, 98% of harvested planted pine acres are expected to be regenerated as planted pine (Table 2), while state foresters conclude nonindustrial private owners will retain 65% of planted pine acres following harvest (Table 3). [4] The industry transition matrices for high and low site classes exhibit similar patterns as these shown for medium sites.

In addition to forest type change, area moves over time between uses and between owners. Alig (in preparation) projects area moving between agriculture and forest uses, between forest and other uses, and between ownerships. To be consistent with the 2000 RPA, the 50 yr timberland area projections by ownership for that study were incorporated into probability matrices of change by period. The net effect is a 2.5% increase in timberland for the southcentral region (Table 4).[5] Behind these increases, however, area change varied by forest type and period. A gain in one period might be followed by a loss the next. The rules guiding change were a set of probability vectors shown in Tables 5 and 6. These conversion rates were developed with empirical data available from FIA plots and reflect changes as they have occurred in recent history. Table 5 gives the percent of timberland converted to nontimberland by owner class and forest type. For example, in each period, 1% of forest industry's natural pine area exits from timber production. Within each forest type, the losses occur over a range of age classes based on the management assumptions made in the 2000 RPA. The land

Table 2. Anticipated forest type transitions for harvested stands on medium sites, derived from a 1998 survey of forest industry owners (AF&PA 1999).

	Type to					
Type from	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood	Nonstocked
	(%)					
Planted pine	98	0.0	1	1	0.0	0.0
Natural pine	82	18	0.0	0.0	0.0	0.0
Oak–pine	82	1	17	0.0	0.0	0.0
Upland hardwood	69	1	0.0	30	0.0	0.0
Lowland hardwood	6	0.0	0.0	3	91	0.0

Table 3. Anticipated forest type transitions for harvested stands derived from a 1998 survey of nonindustrial private owners (Moffat et al. 1998).

	Type to					
Type from	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood	Nonstocked
	(%)					
Planted pine	65	10	11	13	0.0	1
Natural pine	37	21	20	19	2	1
Oak–pine	26	5	33	34	0.0	2
Upland hardwood	5	0.0	2	92	0.0	1
Lowland hardwood	0.0	0.0	1	0.0	95	4

Table 4. Projection of timberland area by owner for the South-Central region, from the 2000 RPA timber assessment (Haynes in press).

Owner	1997	2050	Change	Percent
	(1,000 ac)			
Industry	22,538	22,788	250	1.1
Other private	71,031	71,855	824	1.2
Misc. corporate	9,765	11,275	1,510	15.5
Total	103,334	105,918	2,584	2.5

Table 5. Percent of timberland area converting to non-timberland by owner and forest type, derived from FIA surveys conducted between 1989 and 1995.

	Type					
Owner	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood	Nonstocked
	(%)					
Industry	0.5	1.0	0.8	0.8	0.9	0.0
Other private	7.1	6.8	3.7	5.4	4.1	16.7
Misc. corporate	5.1	7.8	4.0	5.3	5.7	0.0

Table 6. Distribution of area entering the timberland base by owner and forest type, derived from FIA data collected between 1989 and 1995.

	Type					
Owner	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood	Nonstocked
	(%)					
Industry	35.8	11.5	3.8	12.5	32.3	4.1
Other private	21.1	13.0	14.7	35.4	14.4	1.5
Misc. corporate	15.9	10.1	13.6	35.1	25.1	0.2

entering timberland follows the distribution presented in Table 6. Again, the "incoming" acres were assigned within each forest type by age classes according to the RPA assumptions. It was assumed these lands would enter timberland mostly from the reversion or conversion of former agricultural lands. The area entering planted pine was assumed to be the result of deliberate management, entering in the zero age class, while the other forest types were projected to gain area from natural reversion or abandonment of agriculture land and did so over a range of younger age classes. The total timberland area for each projection period then matched projected timberland area used in the 2000 RPA.

Model and Assumptions

The Aggregate Timberland Assessment System (ATLAS, Mills & Kincaid 1992) was modified to run in SAS (Version 8.2, SAS Institute Inc.) and accommodate type transitions. For the purposes of this study, the model will be referred to as ATLAS-T. The land area change and forest type transition assumptions presented in the last section were treated as endogenous variables, while other management assumptions such as yields, shifts in management intensities, and harvest parameters were consistent with the 2000 RPA assessment assumptions discussed in Haynes (2003). The timber removals were also applied consistent with the assessment, and derived from 2000 RPA base projection. The removals numbers were from the base projection of the 2000 RPA; they were generated by the TAMM system of models (Adams and Haynes 1980) in a process that recognizes the entire US timber sector in solving for an equilibrium price between supply and demand.

In both ATLAS and ATLAS-T, the area treated for harvest is based on available volume, the parameters targeting the inventory, and the amount of volume requested. For each projection period, the model identifies the area to be harvested. The disturbed (harvested) and undisturbed area is then assigned to future (next period) forest cover types according to the assumed transition matrices and grown (projected) to the next period. The ATLAS-T transition process can be expressed as follows:

$$A_{i,m,t+1} = \sum_{k=1}^{4} \sum_{j=1}^{6} A_{i,k,j,t} P_{i,k(j,m)} - A_{i,l,t} P_{i,l(m)} + A_{i,g,t} P_{i,g(m)} \qquad (1)$$

where

i—ownership, *i* = 1,2,3 (forest industry, other private, and miscellaneous corporate);

j—source forest cover types, *j* = 1 to 6 (planted pine, natural pine, oak-pine, upland hardwood, lowland hardwood and nonstocked);

m—destination forest cover types, *m* = 1 to 6 (planted pine, natural pine, oak-pine, upland hardwood, lowland hardwood and nonstocked);

k—disturbance types, $k = 1,2,3,4$ (final harvest, partial cutting, thinning and undisturbed);

t—period t;

$A_{i,m,t+1}$—timberland area for owner i, forest type m at time period $t + 1$;

$A_{i,k,j,t}$—timberland area for owner i, forest type j at time period t under disturbance k;

$A_{i,l,t}$—total timberland area loss for owner i at time period t;

$A_{i,g,t}$—total timberland area gain for owner i at time period t;

$P_{i,k(j,m)}$ —probability of forest type j to be forest type m for owner i under disturbance k;

$P_{i,l(m)}$—area loss probability for forest type m and owner i;

$P_{i,g(m)}$—area gain probability for forest type m and owner i.

Consistent with previous versions of ATLAS, timberland area loss occurs at the beginning of each 5 yr simulation period and area gain occurs at the end of each period. ATLAS-T produced two 50 yr projections, or scenarios, in 5 yr time steps using the same removals. Scenario 1 was developed with the empirical data, while scenario 2 represented the results of the surveys.

Projections

Type transitions in scenario 1 are based on the empirical forest type transition matrices calculated from FIA data for harvested and nonharvested stands (Tables 1.1 and 1.2), whereas scenario 2 incorporates the type transition matrices developed from the ownership surveys (Tables 2 and 3). Scenario 2 does not assume transitions occur outside of harvest because the survey participants were not asked to speculate on the transitions for undisturbed plots. Under this scenario, it is assumed that forest type is fixed until a harvest occurs. Note that in both scenarios, partial cutting or commercial thinning did not change the forest type.[6] The results are presented in Table 7 and illustrated in Figures 1 through 4. Included for comparison are the forest type projections from the 2000 RPA timber assessment. A mutual result under both scenarios shows planted pine area in private ownership increasing dramatically, doubling to 24 million ac by 2050. The biggest differences in the scenarios are the projections for the natural pine and upland hardwood forest types.

Under scenario 1, using empirical trends, the area of natural pine increases 6.7 million acres, or 45%. Nearly all of this increase occurs on nonindustrial private lands, while industrial lands show only a slight increase in natural pine. This is a surprising result for both owners, particularly for industry, given its greater incentive to invest in planting and managing. The empirical evidence does not support a claim that plantations will replace natural pine. As the area of softwood types increases, however, there is a significant trade-off; upland hardwoods experience 20 million ac (46%) reduction. Upland hardwoods cover the largest area at the beginning of the projection, so a larger loss of area is not

Table 7. Summary of starting and projected ending timberland area by forest type and ownership under three scenarios, 2050

		Forest types				
Ownership	Scenarios	Planted pine	Natural pine	Oak–pine	Upland hardwood	Lowland hardwood
		(1,000 ac)				
Forest industry	Start (1997)	7,054	4,104	3,926	4,337	3,058
	Scenario 1	11,565	4,150	2,809	1,748	2,475
	Scenario 2	13,152	1,676	2,420	2,392	3,190
	2000 RPA	12,851	2,694	2,934	1,795	2,415
Other private	Start (1997)	4,404	9,381	11,100	36,027	9,981
	Scenario 1	10,005	15,073	13,413	19,865	13,348
	Scenario 2	9,964	5,372	10,312	34,758	11,106
	2000 RPA	7,668	9,922	12,064	30,392	11,319
Misc. corporate	Start (1997)	953	1,496	1,327	3,549	2,405
	Scenario 1	2,522	2,496	1,752	1,933	2,529
	Scenario 2	1,646	790	1,448	4,534	2,711
	2000 RPA	1,761	2,194	2,029	2,269	2,479
All private total	Start (1997)	12,411	14,982	16,354	43,913	15,444
	Scenario 1	24,092	21,719	17,974	23,546	18,352
	Scenario 2	24,762	7,838	14,180	41,684	17,007
	2000 RPA	22,280	14,810	17,026	34,957	16,213

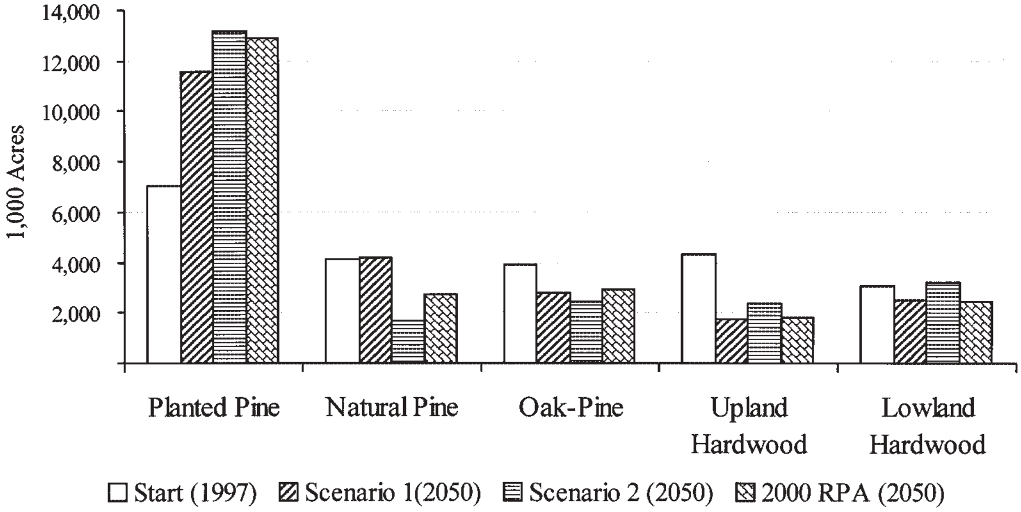

Figure 1. Area projections by forest type on forest industry timberland in the southcentral region of the United States under three scenarios.

surprising; however, the magnitude is greater than any other predicted change. Most of the reduction is due to the conversion to planted pine following harvest. Transition to natural pine and oak-pine also occurs as softwoods gain ground on the hardwood trees, and some upland hardwood area loss occurs (Table 5). If we assume the oak-pine type to be an equal mix of hardwoods and softwoods, the results of scenario 1 indicate the southcentral region will have a future slightly dominated by softwood types with a ratio of 11:10. This is a significant change from today's 2:1 ratio favoring hardwoods.

Scenario 2 shows how area projections that represent opinion and expectations differ from projections based on historical trends. The increase in planted pine area is consistent with scenario 1, but the area of natural pine takes a dramatic 7.1 million acre drop. This is a complete change from the 7 million acre gain in natural pine seen under scenario 1. Recall that the overall trend is for timberland area to increase (Table 4); therefore, scenario 2 indicated that forest industry owners will replace almost 60% of their natural pine with other forest types while nonindustrial private owners replace 43% of their natural pine holdings. In addition to conversions to other forest types, natural pine has one of the highest rates of loss (land withdrawn from timber production) among forest types for both ownerships (Table. 5).

Scenario 2 also shows a large change in the outcome for upland hardwoods. The trend is still down, but only 5% overall. Industry is projected to reduce upland hardwoods by 45%, but this is 1.9 million acres vs. the 2.6 million acre reduction in scenario 1. Nonindustrial private owners show a 1% reduction, and the overall loss of upland hardwood is just 2.2 million acres. Under scenario 2, oak-pine is also moderately reduced (13%) whereas lowland hardwoods show a 10% increase. Industry oak-pine acres are reduced by 38%, again reflecting owner preferences for pine, but at the same time some industry hardwood preference is shown through a 4% increase in lowland hardwoods (the only hardwood gain for industry). In total, lowland hardwoods increase in nearly all projections, consistently increasing for the other private ownership and decreasing only slightly for the empirically-based

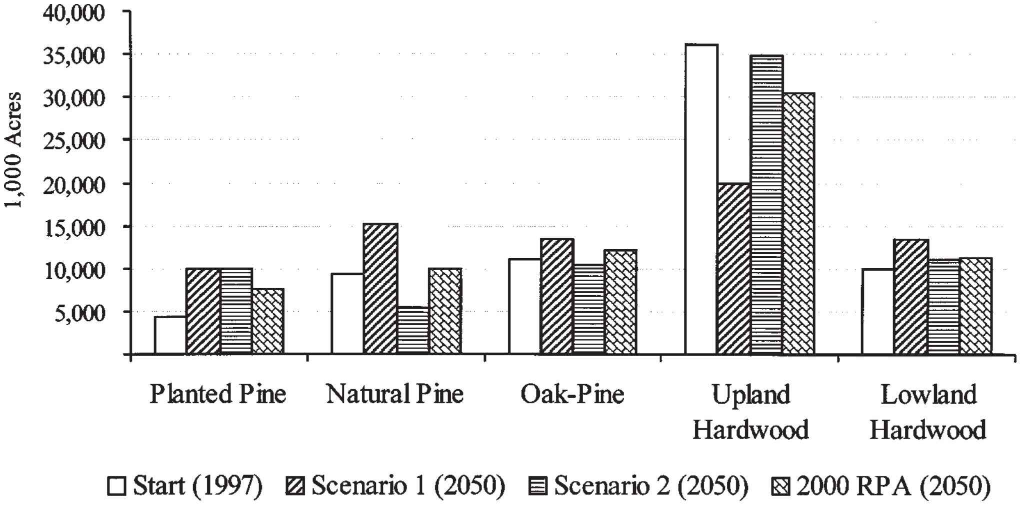

Figure 2. Area projections by forest type on other private timberland in the southcentral region of the United States under three scenarios.

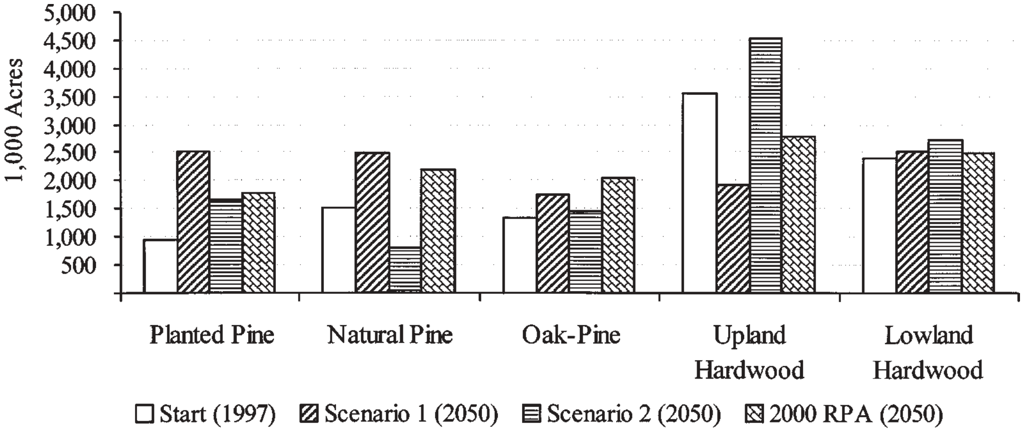

Figure 3. Area projections by forest type on miscellaneous corporate timberland in the southcentral region of the United States under three scenarios.

projections for industry lands. Overall, scenario 2 differs from scenario 1 in that it shows a future where hardwood types continue to dominate the area of timberland with roughly a ratio of 13:8.

In most cases the results from the 2000 RPA timber assessment fall between scenarios 1 and 2 and are often closer to our scenario 1. They show the area occupied by pine plantations will continue to rise, from 12% today to roughly 22% of the total private timberland base in the southcentral region by 2050. Planted pine will continue to be the dominant forest type on forest industry timberlands, increasing from the current 31% of timberland area to 56% of industry timberland. For the nonindustrial private owners, the projections show that upland hardwoods, which initially account for almost half the timberland, will remain the largest forest cover type, but likely at lower levels than today.

This is consistent with our expectations. The type transition matrices developed in the 2000 RPA timber assessment were done by combining empirical transition probabilities, which address both disturbed and nondisturbed transitions, with the survey results, which address only transitions following harvest. This was an attempt to get the best from both techniques, grounding people's expectations in a historical context.

Discussion and Conclusions

The scenarios presented in this article illustrate how projections of the future are influenced by the assumptions made regarding the use of observed behavior and the use of people's perceptions. Observing the past and projecting it forward has limitations, as does basing the future on the management objectives of the "experts." In both cases, however, the projections agree that an increase in planted pine is expected to occur, continuing a trend among private landowners. This is a fairly strong argument that some increase in capacity will occur. The projections disagree on the fate of other forest types. Expert opinion suggests plantations will predominantly replace stands of natural pine, while recent history indicates upland hardwoods will face conversion. Projecting recent history significantly reduces the area supporting hardwood forest types, while expert opinion suggest the balance will

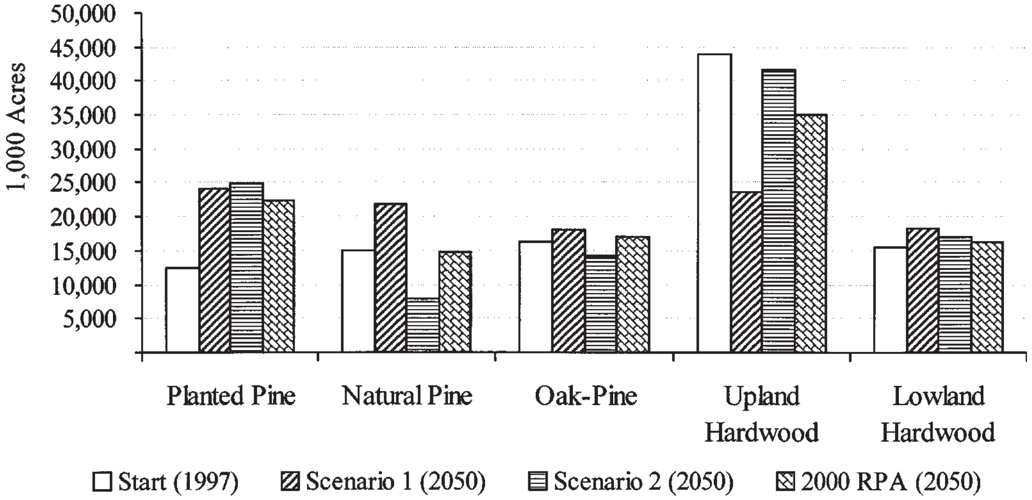

Figure 4. Area projections by forest type for all private timberland in the southcentral region of the United States under three scenarios.

remain close to what it is today. Perhaps, by combining these two sets of assumptions, the 2000 RPA timber assessment projections followed the most logical way to address this difference. Though the 2000 RPA projection shows a reduction of hardwood area, the result is a compromise of the scenarios.

While these projections agree on planted pine, it is likely that changing environmental policies and increasing pressures from urbanization will affect transition rates in unforeseen ways. These models do account for recent withdrawals of timberland for environmental and urban uses, but if future rates of change differ from these assumptions, the actual number of acres available for timber production may not match the projections. To refine and quantify indicators of urbanization and its effects on forests, county level census data might be a third source of information to consider in this analysis. Incorporating a broader set of information has the potential to enhance our understanding of landowner behavior, which likely will lead to more accurate modeling of timberland area. The study presented here illustrates the potential bias that can occur when projections are based on just one set of information.

Endnotes

[1] The data for Kentucky were excluded because they did not contain the required variables.

[2] In an oak-pine stand, pines account for 25 to 50% of the stocking. When the 50% threshold is exceeded the stand is typed as pine (Hansen et al. 1992).

[3] There is only one “other private” owner category because the survey completed by state foresters does not distinguish between the “other private individuals” and “miscellaneous corporate” ownerships.

[4] Medium site: land determined capable of supporting tree growth of between 50 and 85ft^3/ac/yr at the culmination of mean annual increment (also correlated with site index 56–70, base age 25).

[5] Tribal, or Native American lands, are not included in the projections.

[6] As applied here, partial cut harvest is a treatment used to perpetuate, not change, a forest type. Examples include “commercial thinning, seed tree or shelterwood regeneration and use of the selection system to maintain an uneven age stand” (Hansen et al. 1992).

Literature Cited

Adam, D., and R.W. Haynes. 1980. The 1980 softwood timber assessment market model: Structure, projections, and policy simulations. For. Sci. Monogr. 22. 64 p.

Adams, D., R. Alig, J. Callaway, B. McCarl, and S. Winnett. 1996. The forest and agricultural sector optimization model (FASOM): Model structure and policy applications. USDA For. Serv., Res. Pap. PNW-RP-495. 60 p.

Ahn, S., A.J. Plantinga, and R.J. Alig. 2000. Predicting future forestland area: A comparison of econometric approaches. For. Sci. 46(3): 363–76.

Alig, R.J. 1986. Econometric analysis of the factors influencing forest acreage trends in the southeast. For. Sci. 32(1):119–134.

Alig, R.J., D.M. Adams, and R.H. Haynes. 1983. Long-range projection of forest area change: New approaches are needed. J. For. 81(11):723–727.

Alig, R.J., D.M. Adams, J.T. Chmelik, and P. Bettinger. 1999. Private forest investment and long-run sustainable harvest volumes. New For. 17:307–327.

Alig, R.J., and B. Butler. 2002. Land use and forest cover projections for the United States: 1997–2050. P. 93–115 *in* Proc. Soc. of Am. For. 2001 Nat. Conven. Staebler, R. (ed.). Soc. Am. For, Bethesda, MD.

Alig, R.J., W.G. Hohenstein, B.C. Murray, and R.G. Haight. 1990. Changes in area of timberland in the United States, 1952–2040, by ownership, forest type, region, and state. USDA For. Serv. Gen. Tech. Rep. SE-64. 34 p.

Alig, R.J., and J.G. Wyant. 1985. Projecting regional area changes in forestland cover in the USA. Ecol. Mod. 29:27–34.

Alig, R.J., and D.N. Wear. 1992. Changes in private timberland. J. For. 90(5):31–36.

Alig, R. (in prep.). Land use changes involving forestry in the United States: 1952 to 1997, with projections to 2050. USDA For. Serv., Gen Tech. Rep. PNW-GTR.

Alig, R.J., and R.G. Healy. 1987. Urban and built-up land area changes in the United States: An empirical investigation of determinants. Land Econ. 63(3):215–226.

Alig, R.J., F.C. White, and B.C. Murray. 1988. Economic factors influencing land use changes in the southcentral United States. USDA For. Serv., Res. Pap. SE-272.

American Forest and Paper Association (AF&PA). 1999. AF&PA surveys of industrial forest management intensity. Unpubl. rep. On file with John Mills, Pac. Northw. Res. Sta., For. Sci. Lab., P.O. Box 3890, Portland, OR 97208-3890.

Brooks, D.J. 1985. Public policy and long-term timber supply in the South. For. Sci. 31(2):342–357.

Butler, B., R. Alig, et al. (in prep.). Forest cover projections for the 2000 RPA Assessment, by region, 1997 to 2050. USDA For. Serv. Gen Tech. Rep. PNW-GTR.

Hansen, M.H., T. Frieswyk, J.F. Glover, and J.F. Kelly. 1992. The eastwide forest inventory database: Users manual. USDA For. Serv. Gen. Tech. Rep. NC-151. 48 p.

Hardie, I.W., and P.J. Parks. 1997. Land use with heterogeneous land quality: An application of an area base model. Am. J. Agric. Econ. 79:299–310.

Haynes, R.W. (2003). An analysis of the timber situation in the United States: 1952–2050. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-560.

Mills, J.R., and J.C. Kincaid. 1992. The aggregate timberland assessment system (ATLAS): A comprehensive timber projection model. USDA For. Serv. Gen Tech. Rep. PNW-GTR-281. 160 p.

Moffat, S.O., F.W. Cubbage, A.J. Cascio, and R.M. Sheffield. 1998. Estimations of future forest management intensity on NIPF lands in the South: Results of the Southern State Foresters’ survey. SOFAC Rep. Research Triangle Park, NC. South. For. Resour. Assess. Consort. 7 p. + app.

Teeter, L., and X. Zhou. 2000. Final report to SOFAC: Trends in forest management type changes in the southcentral region. Coop. Agree. SRS 33-CA-97-154.

Wall, B.R. 1983. Future timberland area: A crucial but illusive variable in timber economy models. J. For. 81(11):721–722.