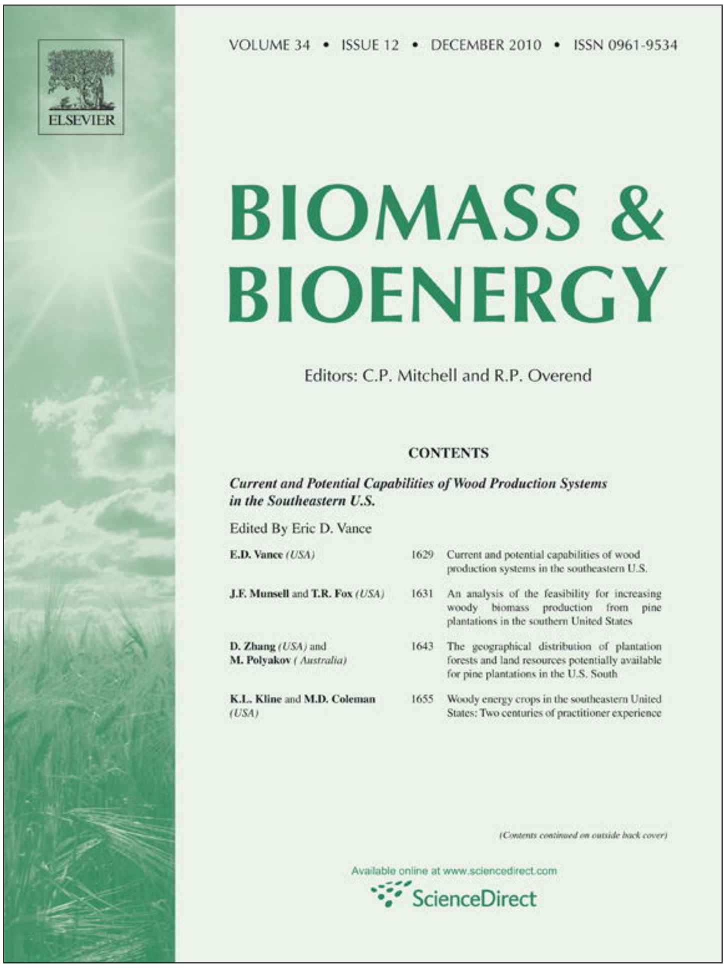

VOLUME 34 • ISSUE 12 • DECEMBER 2010 • ISSN 0961-9534

ELSEVIER

BIOMASS & BIOENERGY

Editors: C.P. Mitchell and R.P. Overend

CONTENTS

Current and Potential Capabilities of Wood Production Systems in the Southeastern U.S.

Edited By Eric D. Vance

(Contents continued on outside back cover)

Available online at www.sciencedirect.com

ScienceDirect

BIOMASS AND BIOENERGY 34 (2010) 1643–1654

Available at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

The geographical distribution of plantation forests and land resources potentially available for pine plantations in the U.S. South

Daowei Zhang [a,*], *Maksym Polyakov* [b,1]

[a] *Forest Economics and Policy, School of Forestry and Wildlife Sciences, Auburn University, Auburn, Alabama 36849-5418, USA*
[b] *Centre for Environmental Economics & Policy, University of Western Australia, M089, 35 Stirling Hwy, Crawley WA 6009, Australia*

ARTICLE INFO

Article history:
Received 17 November 2009
Received in revised form
29 March 2010
Accepted 31 May 2010
Available online 26 June 2010

Keywords:
Forest plantation
Pine plantation
Woody biomass
Land use
Bioenergy

ABSTRACT

In this paper, we provide an assessment of plantation forests and private land resources potentially available for pine plantation development in 11 southern states of the United States. After a sustained growth for 50 years, plantation forests (softwood and hardwood on both private and public lands) amounted to 18 million ha or 24 percent of all timberlands in these states in 2007. The vast majority of the plantation forests were established on private lands with fast-growing loblolly pines and slash pines. While purposeful hardwood plantations were rare, there were hardwood stands growing on failed pine plantation sites. Using a two-stage Markov land use transition model, we forecast that private forest land in these states will decline about 7 percent or from 66 million ha in 1997 to 61 million ha in 2027, primarily due to urbanization, and that private pine plantations will rise nearly 40 percent from 11 million ha to 16 million ha. Further, growth in pine plantations will decline in coming decades, and states with low population and population growth have the greatest increase in plantations. These plantations, along with other woody biomass, are expected to play an important role in the emerging bio-energy sector.

1. Introduction

The U.S. South is the most important timber production region in the country and holds about two-fifths of the timberland, 23 percent of the softwood growing stock, and 44 percent of the hardwood growing stock. In 2002, some 58 percent of U.S. industrial roundwood and three-fourths of total U.S. pulpwood was produced in the region [1]. In the past, most of the softwood forests were natural pine stands. However, currently over half of pine forests are of artificial origin, and pine plantations contribute about one-third of softwood harvest in the region. Because of increasing plantation area and productivity, pine plantations are expected to contribute a growing share of timber harvest in the future [2].

Due to a spike in the prices of fossil fuels and the government's call for renewable energy, there is substantial interest in converting woody biomass to bio-energy. Among the possibilities to use wood biomass for energy are co-firing, and cellulosic ethanol and wood pellets. Further increases in wood fiber production to accommodate growing demand of bio-energy production could be possible by increasing area of intensively managed plantation forests. There have been a number of

* Corresponding author. Tel.: +334 844 1067; fax: +334 844 1084.
E-mail addresses: zhangd1@auburn.edu (D. Zhang), maksym.polyakov@uwa.edu.au (M. Polyakov).
[1] Tel.: +618 6488 5506.
0961-9534/$ – see front matter
doi:10.1016/j.biombioe.2010.05.006

studies that attempt to project the potential of tree planting and intensive forest management in the U.S. South [3–6]. However, these studies modeled dynamics of plantation forests on an aggregate level and did not consider the possibility of diminishing availability of land resources suitable for plantations.

Non-plantation woody biomass is also important in supporting the fiber needs of the emerging bio-energy sector. However, plantation forests simply grow faster and produce more biomass in a given area, and harvesting cutting and transporting timber to a biofuel plant are more economical from plantation forests than from unmanaged natural forests. Further, some environmentalists urge U.S. lawmakers to limit woody biomass that can be used in biofuel production to plantation forests in the name of protecting natural forests. The availability and infrastructure for utilizing harvest residues from unmanaged forests is also limited. Because of these factors, increasing the area and productivity of plantation forests offers greater potential for achieving sustainable increases in wood biofuel production [7].

The objective of this paper is to assemble and synthesize quantitatively the extent and geographic distribution of plantation forests and of private land resources that could be used for forest plantation development in the region in the coming decades. In particular, we model and forecast private land use changes from 1997 to 2027, with timberland and pine plantation being two of several land use types. Our purpose is to assess the historical and current distribution of plantation forests and land resources potentially available for woody biomass production in the future.

This paper differs from other studies insofar as it utilizes parcel level data, and considers land use dynamics between forestry and non-forestry sectors and land use dynamics within the forest sector. Our results could help biofuel producers and policy-makers assess woody biomass supply and identify potential plant locations. The next section reviews the history and current status of plantation development in the region. Sections 3 and 4 present our model, data, estimation results, and land use projections in a spatially

Table 1 – Area of timberland and plantation forest by state, 2007, million hectares.

State	Data	Softwood	Oak–pine	Upland hardwoods	Bottomland hardwoods	Other	Total
AL	Area	3.787	1.259	2.935	1.023	0.011	9.014
	Area planted	2.296	0.257	0.126	0.013	0.002	2.694
	% Planted	60.60%	20.40%	4.30%	1.20%	18.10%	29.90%
AR	Area	2.301	0.825	3.038	1.140	0.002	7.306
	Area planted	1.047	0.114	0.084	0.040	–	1.286
	% Planted	45.50%	13.90%	2.80%	3.60%	0.00%	17.60%
FL	Area	2.881	0.610	1.166	1.346	0.227	6.230
	Area planted	1.785	0.124	0.103	0.015	0.004	2.032
	% Planted	62.00%	20.30%	8.90%	1.10%	2.00%	32.60%
GA	Area	4.455	1.178	2.647	1.469	0.022	9.771
	Area planted	2.738	0.231	0.113	0.012	–	3.094
	% Planted	61.50%	19.60%	4.30%	0.80%	0.00%	31.70%
LA	Area	2.291	0.493	0.957	1.733	0.099	5.573
	Area planted	1.409	0.145	0.117	0.035	0.004	1.711
	% Planted	61.50%	29.50%	12.20%	2.00%	4.50%	30.70%
MS	Area	3.218	0.901	2.171	1.530	0.019	7.838
	Area planted	1.865	0.192	0.104	0.070	0.002	2.233
	% Planted	58.00%	21.30%	4.80%	4.60%	14.10%	28.50%
NC	Area	2.331	0.943	3.155	0.808	0.002	7.238
	Area planted	1.111	0.123	96	0.003	–	1.334
	% Planted	47.70%	13.10%	3.00%	0.40%	0.00%	18.40%
SC	Area	2.387	0.613	1.216	0.906	0.008	5.130
	Area planted	1.236	0.081	0.066	0.004	–	1.387
	% Planted	51.80%	13.10%	5.50%	0.50%	0.00%	27.00%
TN	Area	0.507	0.399	4.072	0.384	0.019	5.382
	Area planted	0.161	0.057	0.025	–	–	0.244
	% Planted	31.90%	14.10%	0.60%	0.00%	0.00%	4.50%
TX	Area	2.094	0.616	1.182	0.804	0.086	4.782
	Area planted	1.012	0.088	0.047	0.006	0.006	1.159
	% Planted	48.30%	14.30%	4.00%	0.80%	6.40%	24.20%
VA	Area	1.264	0.633	3.970	0.254	0.013	6.133
	Area planted	0.745	0.104	0.098	0.004	–	0.949
	% Planted	58.90%	16.40%	2.50%	1.40%	0.00%	15.50%
Total	Area	27.516	8.468	26.509	11.397	0.507	74.397
	Area planted	15.404	1.516	0.979	0.202	0.019	18.121
	% Planted	56.00%	17.90%	3.70%	1.80%	3.80%	24.40%

Data source: Ref. [9].

distributed fashion. The final section summarizes and draws conclusions based on our findings.

2. Current distribution of plantation forests in the U.S. South

Plantation forests in the U.S. South increased drastically in the first three decades after the Second World War, and have grown steadily since the middle 1970s [4,8]. As of 2007, there were 18 million ha of plantation forests, defined as forests with evidence of tree planting or artificial regeneration, in the 11 southern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia). Kentucky and Oklahoma were excluded from this study as the area of plantation forests in these two southern states is small [4]. Plantation forests accounted for 24 percent of timberland in the 11 states. Georgia, Alabama, Mississippi, Florida, and Louisiana were the five states with the largest area of plantation forests. Plantation forests in these five states accounted for about 30 percent of their total timberland respectively.

Table 1 also shows that most plantation forests are pine forests. Some 56 percent of all softwood stands were planted forests, and only 5 percent of the hardwood stands are planted forests. Thus, purposeful hardwood tree planting is relatively rare in the region. For mixed oak–pine forests, some 18 percent are planted forests. These forests often originate from initial pine plantings with subsequent invasion of other (mostly oak) species. Put another way, some 15.4 million ha of all plantation forests (18.2 million ha) are pine plantations.

Table 2 provides area of forest plantation grouped by species. Fast-growing softwood species (loblolly and slash pines) account for some 86 percent of all species that have been planted. Fast-growing hardwood species—yellow poplar, sweetgum, eastern cottonwood, and American sycamore—are insignificant and accounted for only 0.2 percent of all species in planted forests.

Table 3 provides area of pine plantation by state from 1952 to 2007. At only 0.7 million ha in 1952, the total area of planted pine forests grew to 15.4 million ha in 2007, a 21-fold increase in five and a half decades. Although the increase in planted pine forests is widespread across all southern states, planted pine forests are mainly located in states within the Southern Coastal Plain and Piedmont.

Since pine plantations account for the vast majority of all planted forests and there are no large commercial plantations with fast-growing hardwood species, our model and forecast of plantation development in the U.S. South will concentrate on planted pines. In addition, as plantation development in public forests may not respond to market forces, we focus on private pine plantations which covered some 11.3 million ha in 1997 (Table 3).

3. Model of land use changes and data

Land is a limited resource. Historically, land used for plantation forests came from cutover of natural forests and conversion of marginal agricultural land [4,8]. Potentially, all agricultural and other rural lands could be used for forestry, and most forest land could be converted to pine plantations. However, many socioeconomic and biophysical factors limit and influence the chance of a particular land parcel being converted to another use or forest type. Our goal is to analyze observed land use and forest type changes and predict probabilities of conversion of available land resources when socioeconomic factors change.

The most widely used approach to study land use and forest type dynamics is modeling areas or proportions of certain land use or forest type categories within a well defined geographic area, such as a county, as a function of socioeconomic variables and land characteristics aggregated at the level of geographic unit of observation [11–13]. However, one of the shortcomings of this approach is that the pooled specification does not adequately control for cross-sectional variations in dependent variables [11]. For example, pooling the shares of agricultural land, forest land, and urban land together as dependent variables often conceals the dynamics in agricultural, forestry, and urban land use changes over time and space (i.e., different counties). As a result, the model's parameters measure a combination of spatial and temporal effects and cannot be used for inferences regarding land use change or land use change predictions. It is suggested that a specification with cross-sectional fixed effects provides a better measure of temporal relationship [11]. However, the use of cross-sectional fixed effects requires relatively long time series, limits number of cross-sectional elements, and prevents the use of explanatory variables such as land quality and slope that do not have temporal variation.

An alternative approach to modeling land use is to utilize disaggregated data on parcel [14] or sample plot [15] levels. This approach allows better use of physical attributes affecting land use decisions by connecting them to specific units of observation. Some of the studies that utilized the disaggregate approach used plot- or parcel-based observation of land characteristics over at least two time periods in order to directly measure land use transitions. In this case, the probability of a parcel to be allocated to a particular land use was modeled as a function of physical and economic variables, as well as previous land use [15–17]. This allowed the isolation of temporal effects of the factors driving land use

Table 2 – Area of timberlands with the evidence of artificial regeneration by species, 2007.[c]

Species	Area (million ha)	%	% of known recorded
Fast growing softwoods[a]	15.870	86.2	93.8
Other softwoods	0.848	4.6	5.0
Fast growing hardwoods[b]	0.028	0.2	0.2
Other hardwoods	0.166	0.9	1.0
Unknown or not recorded	1.209	6.6	

a Loblolly pines and slash pines.
b Yellow poplar, sweetgum, eastern cottonwood, and American sycamore.
c Not all of these stands are classified as artificially regenerates.Data source: Ref. [9].

dynamics, similar to the fixed effect model of aggregate land use shares.

In this study, we use parcel level data. We assume that land use changes over time and space are results of decisions of the owners of individual land parcels, or cells, in the landscape. A landowner chooses to allocate a parcel of land of uniform quality to one of J possible alternative uses. We assume that the landowner's decision is based on the maximization of net present value of future returns generated from the land. The landowner's expectations concerning future returns generated by different land uses are drawn from the characteristics of the parcel and historical returns. The advantage of this approach over the aggregate approach (such as land use allocation/share at county level) is that it does not require a relatively long time series and it allows the explanatory variables that do not vary over time (*e.g.*, land quality) to be included [17]. The disadvantage is that socioeconomic factors such as land rent or economic return usually are not available at parcel level. This deficiency could be resolved by using either county level data [15,17] or proxy variables that determine economic returns to alternative land uses, such as population gravity index [18].

Let W_{ni} be the return or net present value of parcel n in use i which depends on characteristics of a parcel such as land quality and location, as well as economic conditions. Converting a parcel from use i to alternative use j involves a one time conversion cost C_{nij}, which depends on the land uses that a parcel is being converted from and to, the characteristics of the parcel, as well as institutional settings such as zoning regulations.

Table 3 – Area of timberland and pine plantations by state and year, 1952–2007.

State	1952	1962	1970	1985	1997		2007	
					Total	Private	Total	Private
Timberlands, million ha								
AL	8.400	8.799	8.668	8.727	8.858	8.388	9.014	8.479
AR	7.943	8.082	7.297	6.975	7.430	6.096	7.306	5.911
FL	7.339	6.811	6.581	6.063	5.929	4.783	6.230	4.539
GA	9.700	10.642	10.158	9.563	9.630	8.921	9.771	8.996
LA	6.491	6.490	6.123	5.579	5.549	5.019	5.573	4.929
MS	6.820	6.897	6.789	6.854	7.493	6.715	7.838	6.942
NC	7.925	8.089	8.146	7.466	7.572	6.761	7.238	6.257
SC	4.809	4.925	5.036	4.929	5.040	4.590	5.130	4.531
TN	5.079	5.409	5.188	5.366	5.613	4.980	5.382	4.757
TX	5.294	5.245	5.147	4.676	4.748	4.431	4.782	4.391
VA	6.271	6.375	6.418	6.247	6.252	5.449	6.133	5.189
Total	76.071	77.764	75.552	72.444	74.113	66.133	74.397	64.922
Pine plantations, million ha								
AL	0.067	0.329	0.487	0.770	1.389	1.370	2.296	2.248
AR	0.022	0.065	0.104	0.480	0.744	0.677	1.047	0.981
FL	0.118	0.609	1.070	1.629	1.875	1.664	1.785	1.509
GA	0.144	0.644	1.108	2.038	2.471	2.406	2.738	2.666
LA	0.042	0.361	0.516	0.595	0.878	0.827	1.409	1.352
MS	0.115	0.261	0.378	0.611	1.199	1.121	1.865	1.783
NC	0.039	0.145	0.308	0.653	0.849	0.814	1.111	1.053
SC	0.094	0.307	0.436	0.813	1.081	0.989	1.236	1.143
TN	0.043	0.120	0.128	0.144	0.185	0.175	0.161	0.155
TX	0.042	0.119	0.185	0.486	0.715	0.672	1.012	0.971
VA	0.019	0.095	0.175	0.473	0.596	0.583	0.745	0.725
Total	0.745	3.057	4.894	8.694	11.984	11.297	15.404	14.586
Pine plantations as % of timberlands								
AL	0.8	3.7	5.6	8.8	15.7	16.3	25.5	26.5
AR	0.3	0.8	1.4	6.9	10.0	11.1	14.3	16.6
FL	1.6	8.9	16.3	26.9	31.6	34.8	28.7	33.2
GA	1.5	6.1	10.9	21.3	25.7	27.0	28.0	29.6
LA	0.6	5.6	8.4	10.7	15.8	16.5	25.3	27.4
MS	1.7	3.8	5.6	8.9	16.0	16.7	23.8	25.7
NC	0.5	1.8	3.8	8.7	11.2	12.0	15.4	16.8
SC	2.0	6.2	8.7	16.5	21.5	21.5	24.1	25.2
TN	0.8	2.2	2.5	2.7	3.3	3.5	3.0	3.3
TX	0.8	2.3	3.6	10.4	15.1	15.2	21.2	22.1
VA	0.3	1.5	2.7	7.6	9.5	10.7	12.1	14.0
Total	1.0	3.9	6.5	12.0	16.2	17.1	20.7	22.5

Data for 1952, 1962, and 1970 are from Ref. [10]. Data for 1985 and 1997 are calculated from Eastwide Forest Inventory Data Base 1980–1989 and 1990–1999, respectively. Data for 2007 are calculated from FIA 2005–2007 data. Source: Ref. [9].

Table 4 – Conditional logit model of land use change in the U.S. South.

Variables	Regression coefficients for final land uses (j)		
	j = Agricultural	j = Forestry	j = Developed
Transition specific constants (α_{ij})			
i = Agriculture	4.7961‡ (0.1403)	3.5471‡ (0.1412)	−4.8563‡ (0.1654)
i = Forestry	2.0455‡ (0.1447)	7.1139‡ (0.1438)	−3.9715‡ (0.1666)
i = Other	−2.1032‡ (0.1458)	−0.8899‡ (0.1421)	−9.6583‡ (0.2044)
Attributes of land uses ($\underline{\beta}_j$)			
Piedmont	0.5710‡ (0.0618)	0.4047‡ (0.0621)	0.3480‡ (0.0697)
Mississippi Delta	0.2299† (0.0910)	−1.1043‡ (0.0944)	−1.1298‡ (0.1441)
Mountains and Plateau	1.1996‡ (0.0733)	0.3808‡ (0.0740)	0.5881‡ (0.0852)
Prime farmland	0.4242‡ (0.0575)	−0.0731 (0.0589)	−0.3800‡ (0.0712)
Log (PII)	−0.3543‡ (0.0902)	−1.3321‡ (0.0925)	0.0427 (0.1027)
Change in Log (PII)	0.5710‡ (0.0618)	0.4047‡ (0.0621)	0.3480‡ (0.0697)
Model's fit statistics			
Number of observations	216,783		
Log-likelihood	−53,987		
Pseudo-R^2	0.789		
Pseudo-R^2 vs. all intercepts model	0.094		

Standard errors in parentheses.
‡Significant at 1%, †significant at 5%.

Let $U_{nj|i} = W_{nj} - W_{ni} - C_{nij}$ be the landowner's utility of converting a parcel to new land use j conditional on current land use i. The parcel could be converted to land use j if $U_{nj|i}$ is positive. Furthermore, the parcel will be converted to a land use, for which the utility of conversion is the greatest. The parcel will remain in current land use ($C_{nii} = 0$; $U_{nj|i} = 0$) if $U_{nj|i} < 0\ \forall\ j \neq i$.

Neither returns for each of the land uses, nor conversion costs are directly observable for individual parcels. However, there are observable attributes of plots $\mathbf{x}_n$ that are related to either returns or conversion costs. Furthermore, there might be spatial dependencies Z_{nj} due to the fact that some of the spatially related factors affecting decisions are not observable directly. Utility of land use change can be expressed as $U_{nj|i} = V_{nj|i} + \varepsilon_{nj}$, where $V_{nj|i} = V(\mathbf{x}_n, Z_{ni})$ is the representative utility, and ε_{nj} captures the factors that are affecting utility, but not included into representative utility and is assumed to be random. The probability of converting parcel n to land use j is

Table 5 – Conditional logit model of forest type change in the U.S. South.

Variables	Regression coefficients for final forest types (j)			
	j = Pine plantation	j = Natural pine	j = Mixed pine	j = Bottomland hardwood
Transition specific constants (α_{ij})				
i = Pine plantation	3.6277‡ (0.2680)	−0.3570* (0.2102)	0.7280‡ (0.2144)	0.0650 (0.4665)
i = Natural pine	0.4497* (0.2639)	1.5601‡ (0.1884)	0.9224‡ (0.1981)	0.1822 (0.4252)
i = Mixed pine	0.2274 (0.2630)	−0.4763† (0.1901)	1.5417‡ (0.1961)	0.3585 (0.4223)
i = Bottomland hardwoods	−0.3698 (0.2784)	−3.0711‡ (0.2824)	0.0120 (0.2119)	4.0280‡ (0.4196)
i = Upland hardwoods	−1.8706‡ (0.2627)	−4.1815‡ (0.1985)	−1.4463‡ (0.1958)	−0.7533* (0.4197)
Attributes of land uses ($\underline{\beta}_j$)				
Piedmont	−0.5674‡ (0.0537)	−0.2690‡ (0.0511)	−0.2676‡ (0.0440)	−0.1477† (0.0714)
Mississippi Delta	−0.3238* (0.1671)	0.4819‡ (0.1502)	0.0072 (0.1323)	0.9811‡ (0.1459)
Mountains and Plateau	−1.6637‡ (0.0918)	−0.6326‡ (0.0798)	−0.6684‡ (0.0617)	−0.4706‡ (0.1225)
Soil hydricity	−0.2780* (0.1600)	0.5943‡ (0.1316)	0.9281‡ (0.1091)	2.3788‡ (0.1039)
Slope	−0.0366‡ (0.0030)	−0.0186‡ (0.0023)	−0.0147‡ (0.0017)	−0.1509‡ (0.0079)
Log (PII)	−1.1863‡ (0.0770)	−0.1262* (0.0664)	−0.2909‡ (0.0578)	−0.3847‡ (0.0925)
Change in Log (PII)	0.5990† (0.2482)	0.8553‡ (0.2330)	0.2625 (0.2047)	0.5492* (0.3055)
Log (re-measurement period)	1.0324‡ (0.1276)	0.3962‡ (0.0963)	0.1654* (0.0943)	−0.4617† (0.2017)
Model's fit statistics				
Number of observation	40,461			
Log-likelihood	−30,624			
Pseudo-R^2	0.530			
Pseudo-R^2 vs. all intercepts model	0.053			

Standard errors in parentheses.
‡Significant at 1%, †significant at 5%, *significant at 10%.

Table 6 – Marginal effects of explanatory variables on the probabilities of land use change in the U.S. South.

Variables	Marginal effects of explanatory variables on the probabilities of transition to land uses			
	Agricultural	Forestry	Developed	Other
Initial land use				
Agriculture	0.3970‡ (0.0420)	−0.0685 (0.0560)	−0.2083‡ (0.0598)	−0.1201‡ (0.0437)
Forestry	−0.9768‡ (0.0597)	1.3506‡ (0.0483)	−0.2153‡ (0.0619)	−0.1586‡ (0.0572)
Other	−0.2112‡ (0.0318)	0.3615‡ (0.0428)	−0.1995‡ (0.0571)	0.0492† (0.0194)
Attributes of plots				
Piedmont	0.0430‡ (0.0078)	−0.0258‡ (0.0080)	−0.0025‡ (0.0009)	−0.0147‡ (0.0048)
Mississippi Delta	0.2912‡ (0.0235)	−0.2980‡ (0.0209)	−0.0129‡ (0.0030)	0.0197† (0.0092)
Mountains and Plateau	0.1889‡ (0.0167)	−0.1655‡ (0.0156)	−0.0018 (0.0012)	−0.0217‡ (0.0061)
Prime farmland	0.1150‡ (0.0086)	−0.1002‡ (0.0086)	−0.0116‡ (0.0036)	−0.0031 (0.0022)
Log (PII)	0.0024 (0.0054)	−0.0432‡ (0.0070)	0.0336‡ (0.0095)	0.0072‡ (0.0024)
Change of Log (PII)	0.1954‡ (0.0177)	−0.2487‡ (0.0160)	0.0234‡ (0.0074)	0.0299† (0.0125)

Standard errors of marginal effects in parentheses.
‡Significant at 1%, †significant at 5%.

$$P_{nj|i} = \text{Prob}(U_{nj|i} > U_{nk|i}\ \forall\ k \neq j) = \text{Prob}(V_{nj|i} + \varepsilon_{nj} > V_{nk|i}\varepsilon_{nk}\ \forall\ k \neq j) \quad (1)$$

Depending on assumptions about the density distribution of random components of utility, several different discrete choice models could be derived from this specification [19]. Assuming random components are independent and identically distributed (iid) with a type I extreme value distribution, we obtain a conditional logit model [20]:

$$P_{nj|i} = \exp(V_{nj|i}) \Big/ \sum_{k=1}^{J} \exp(V_{nk|i}) \quad (2)$$

The representative utility of converting parcel n from land use i to land use j could be expressed as a linear combination of observable attributes of plots ($\underline{x}_n$), land use specific parameters ($\underline{\beta}_j$), transition specific parameter:

$$V_{nj|i} = V\left(\underline{x}_n\right) = \alpha_{nij} + \underline{\beta}_j'\underline{x}_n - \underline{\beta}_i'\underline{x}_n \quad (3)$$

Substituting (3) into (2) yields:

$$P_{nj,t|i,t-1} = \exp\left(\alpha_{ij} + \underline{\beta}_j'\underline{x}_{n,t-1}\right) \Big/ \sum_{k=1}^{J} \exp\left(\alpha_{ij} + \underline{\beta}_j'\underline{x}_{n,t-1}\right) \quad (4)$$

To remove indeterminacy in the model we restrict $\alpha_{ij} = 0\ \forall\ i = j$ and $\underline{\beta}_J = \underline{0}$, where J is the reference outcome (land use).

It is demonstrated that closeness to population centers (as indicated by population gravity index) could serve as a proxy for returns to alternative land uses and forest management types [18]. In addition to explaining transitions between rural and developed land uses and between forestry and agricultural uses, this index also helps to explain transitions among forest management types. In this study we cover pine plantations as a distinct forest management type.

Table 7 – Marginal effects of explanatory variables on the probabilities of forest type change in the U.S. South.

Variables	Marginal effects of explanatory variables on the probabilities of transition to forest management types				
	Pine plantations	Natural pine	Mixed pine	Bottomland hardwood	Upland hardwood
Initial forest management types					
Pine plantations	0.4677‡ (0.0350)	−0.1631‡ (0.0270)	0.0152 (0.0261)	−0.0896 (0.0602)	−0.2301‡ (0.0453)
Natural pine	−0.0078 (0.0331)	0.1754‡ (0.0252)	0.0653‡ (0.0245)	−0.0504 (0.0554)	−0.1826‡ (0.0416)
Mixed pine	−0.0038 (0.0330)	−0.1204‡ (0.0250)	0.1993‡ (0.0245)	0.0169 (0.0551)	−0.0920† (0.0413)
Bottomland hardwoods	−0.0695† (0.0350)	−0.5203‡ (0.0318)	−0.0098 (0.0266)	0.6273‡ (0.0614)	−0.0277 (0.0458)
Upland hardwoods	−0.0849† (0.0332)	−0.4721‡ (0.0272)	−0.0186 (0.0246)	0.0909* (0.0550)	0.4847‡ (0.0416)
Attributes of plots					
Piedmont	−0.0577‡ (0.0064)	−0.0118* (0.0062)	−0.0108† (0.0049)	0.0079 (0.0091)	0.0723‡ (0.0090)
Mississippi Delta	−0.0795‡ (0.0194)	0.0489‡ (0.0176)	−0.0276* (0.0141)	0.1262‡ (0.0183)	−0.0680‡ (0.0256)
Mountains and Plateau	−0.1750‡ (0.0116)	−0.0150 (0.0105)	−0.0195† (0.0076)	0.0113 (0.0162)	0.1981‡ (0.0134)
Hydric soil	−0.1332‡ (0.0174)	0.0031 (0.0147)	0.0544‡ (0.0109)	0.2862‡ (0.0170)	−0.2104‡ (0.0233)
Slope	−0.0002 (0.0004)	0.0027‡ (0.0003)	0.0031‡ (0.0003)	−0.0184‡ (0.0007)	0.0128‡ (0.0005)
Log (PII)	−0.1364‡ (0.0092)	0.0307‡ (0.0081)	0.0032 (0.0065)	−0.0115 (0.0117)	0.1140‡ (0.0120)
Change of Log (PII)	0.0369 (0.0285)	0.0815‡ (0.0275)	−0.0155 (0.0223)	0.0296 (0.0382)	−0.1325‡ (0.0416)
Log (re-measurement period)	0.1332‡ (0.0160)	0.0359‡ (0.0126)	−0.0021 (0.0117)	−0.1017‡ (0.0268)	−0.0654‡ (0.0202)

Standard errors of marginal effects in parentheses.
‡Significant at 1%, †significant at 5%, *significant at 10%.

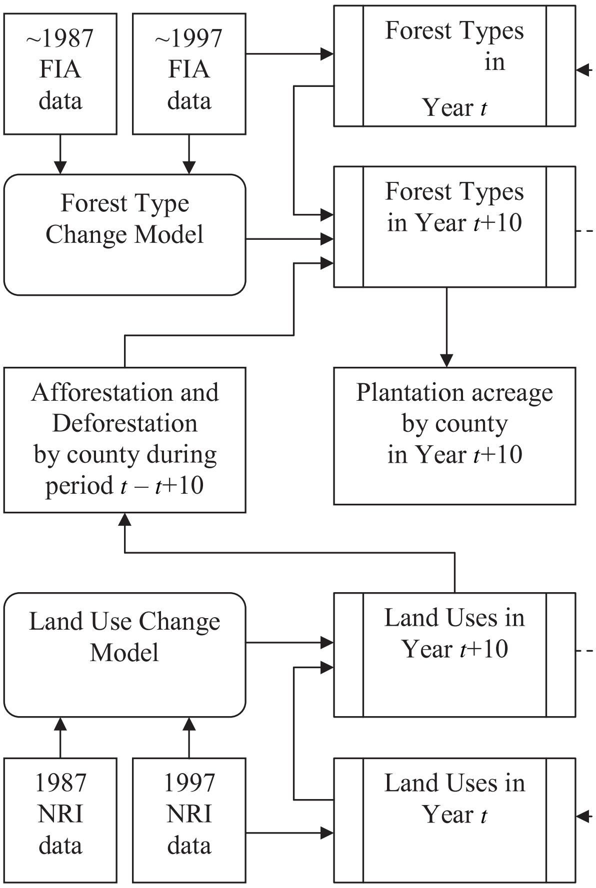

Fig. 1 – The structure of plantation development simulation.

Our model in both stages is based on the classic land use theory, treating forestry/pine plantation as one of the land uses that competes with other uses in each stage. We assume that the dynamics of pine plantations consists of several simultaneous processes: conversion of agricultural lands to forestry land use (including pine plantations), conversion of other forest types to pine plantations, conversion of pine plantations to other forest types, and loss of forest lands (including plantations) to development and agricultural land uses. Theoretically one can simultaneously estimate area of pine plantations along with areas of all other forestry, agricultural and developed land use types. However, because there is no comprehensive data set that allows us to describe all these processes, we use two different data sets and model dynamics of pine plantations in two steps. We model dynamics of broad land uses (forestry, agricultural, developed, and other) in the first stage, and dynamics of forestry specific land uses (pine plantation, other forest types) in the second stage. We derive spatially specific Markov matrices of land use change and forest type change conditional on biophysical and socioeconomic factors and apply them to available land and forest resources to forecast dynamics of pine plantations. The use of two-stage approach is one of the novelties of our study. Other studies either model both specific forestry land use and general land use in a one-step process [21] or general land use/specific forestry land use only [4,6,15]. This two-stage approach allows us to consider the dynamics of forestry and non-forestry land use changes, and to overcome a major data deficiency—inconsistency of total forest area between two of our main data sources.

The first stage models private land use dynamics, which would predict probabilities of transitions among four broad land uses: developed, agriculture, forestry, and other rural uses. For this, we use National Resources Inventory (NRI) data obtained from USDA National Resources Conservation Service [22]. The NRI is a longitudinal panel survey of the nation's soil, water, and related resources designed to assess conditions and trends every five years. For each NRI sample point, data have been collected on land cover, land use, irrigation, soil potential and erosion, conservation practices, resource concerns, and land ownership type. Due to variable sampling intensity, sample points represent different area of land indicated by expansion factors, which are used as weights to aggregate over the sample points. The details of NRI sampling design, data collection, and estimation procedures are discussed in Ref. [23]. The 1997 NRI data set provides data that are nationally consistent for all nonfederal lands for four points in time: 1982, 1987, 1992, and 1997. We use 1987 and 1997 data points and model land use change during 1997–2027 on a 10-year interval. This stage would predict gain of forestry (including plantations) from agricultural and other rural lands as well as the loss of forestry to developed, agricultural and other rural lands. As the latest data available from NRI was 1997, we could not have used the data between 1997 and 2007 to forecast the general land use change.

In the second stage we model dynamics of conversions among forest management types (pine plantations, natural pine, mixed, upland hardwoods, and bottomland hardwoods), which allows us to predict probabilities of conversions to and from plantations. We use data of Forest Inventory Analysis (FIA) collected by USDA Forest Service. Historically, FIA data have been collected on approximately a 10-year cycle for sample plots located on roughly a 5 by 5 km grid pattern. We use data from the inventories conducted in the 11 southern states between 1980 and 1990 (first data point) and between 1990 and 2000 (second data point). These two data points allow modeling transition between forest management types on an approximately 10-year interval.

In both models of land use change and of forest management type change, we cover only private forest lands. We use Population Influence Index (PII) [24], a measure similar to a gravity index as a proxy of socioeconomic drivers. PII is derived from the Census block group population data of 1980, 1990, and 2000. We apply linear interpolation to obtain PII for 1987, and 1997. We use a log form of PII level and rate of change. The other variables used in our models represent site quality: "prime farmland" in land use change model, and slope and soil hydricity (high content of moisture in the soil) in forest management type change model. We assume that sites classified as "prime farmland" are more likely to stay in agricultural production or be converted to agricultural production [17] and that sites on steeper slopes and sites with excess soil moisture are less suitable for pine plantations. Furthermore, to take into account different re-measurement periods in FIA data, we use log of the re-measurement period in the model of forest management type change. The longer the

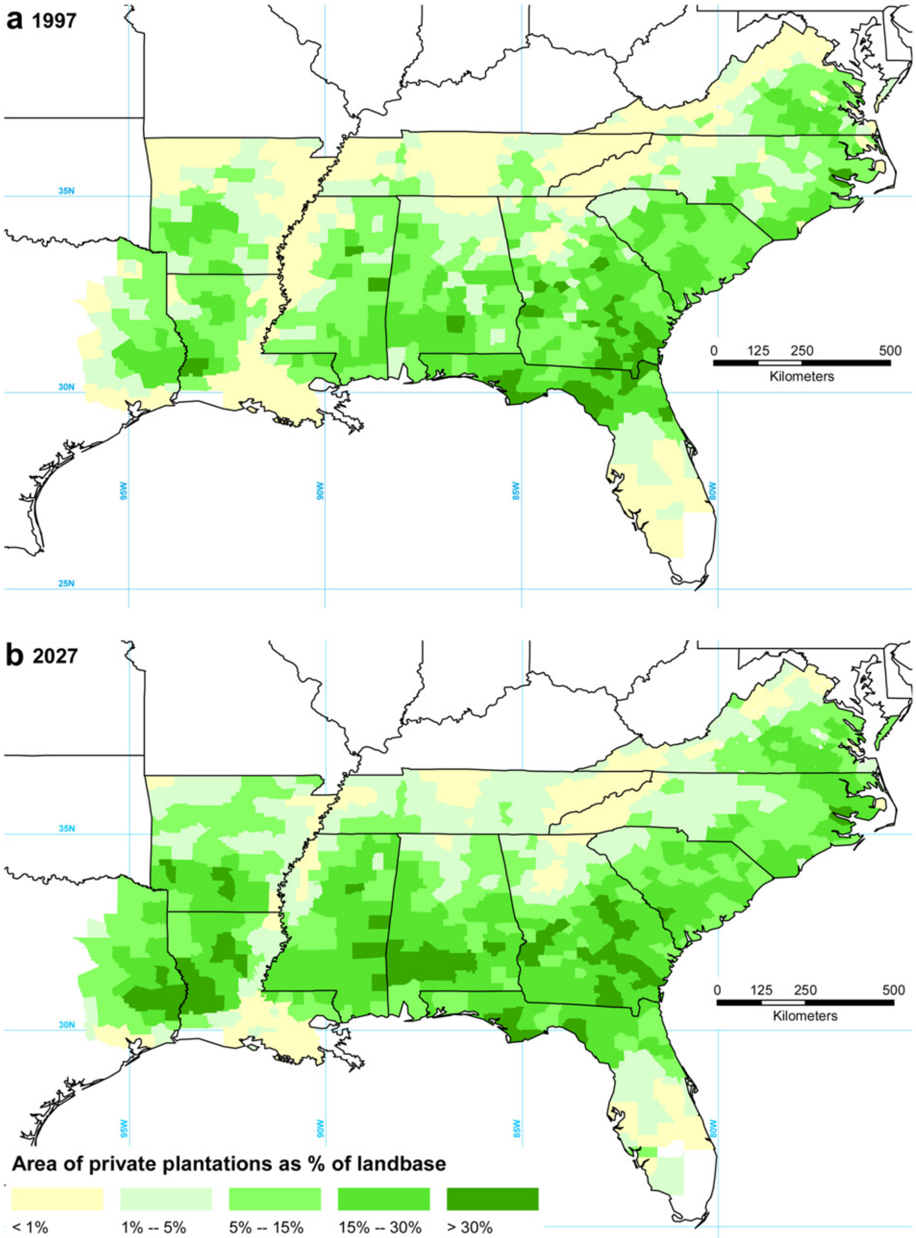

Fig. 2 – Private pine plantations by county in the U.S. South in 1997 (a) and 2027 (b).

re-measurement period is, the greater is the probability to observe forest management type change.

4. Estimation results and predictions

We model separately (i) transitions between land uses and (ii) transitions between forest management types over a 10-year period (1987–1997) using the multinomial logit model in equation (4). The observed responses are incidents of land being retained in the initial land use/forest management type or converted to another land use/forest management type. The predicted values of the dependent variables are vectors of probabilities of transition to alternative land uses/forest management types, which form Markov matrices of the probabilities of transition of land uses and forest management types conditional on biophysical and socioeconomic factors.

The models of land use change and forest management type change were estimated using NLOGIT 3.0 [25]. The results of the estimations of land use change model and forest management type change model are presented, respectively, in Tables 4 and 5. The values of McFadden's pseudo-R^2 are, respectively, 0.792 and 0.530, indicating a good fit of the models.

The coefficients for plot attribute variable indicate the effects a particular attribute has on the probabilities of transitions to each of the final land uses relative to the probability of transition to the reference land use ("other") in land use

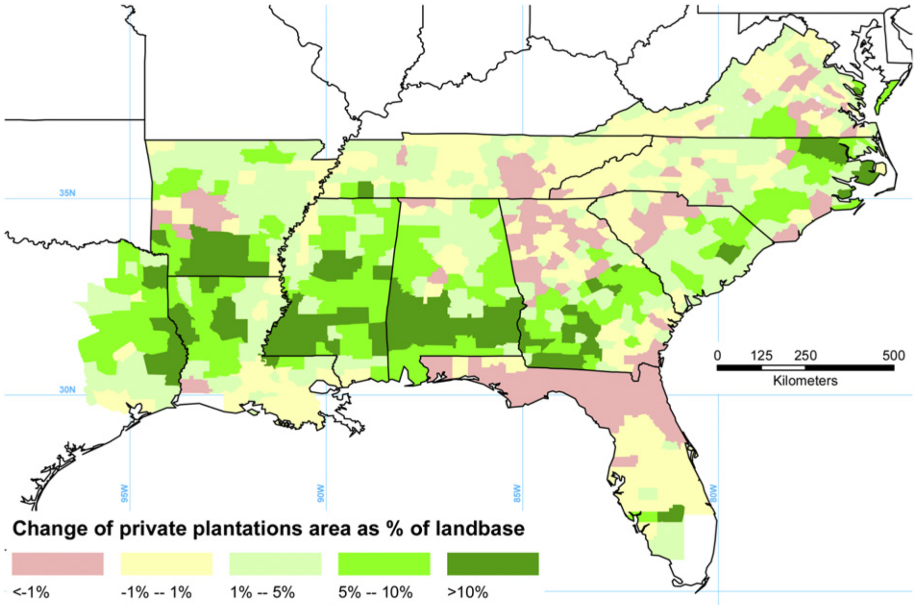

Fig. 3 – Change in private pine plantations by county in the U.S. South, 1997–2027.

change model (Table 4), or the effects a particular attribute has on the probabilities of transitions to each of the final forest management types relative to the probability of transition to reference forest management type (upland hardwoods) in forest management type change model (Table 5). For example, significant and negative coefficient of Log (PII) variable for forestry land use in the land use change model (Table 4) indicates that the higher the value of Log (PII), the lower the probability of retention in or conversion to forestry land use relative to the probability of conversion to "other" land use. Because the values of the coefficients and their errors depend on the choice of the reference outcome (reference land use or reference forest management type), and because the effect of the variable on a particular transition probability is jointly determined by all the coefficients for this variable, the interpretation of the coefficients of conditional logit models is difficult. In order to facilitate interpretation of the results of the regression models, we calculated marginal effects of the explanatory variables on the transition probabilities and their errors estimated at the sample means. The marginal effect of attribute m of a sample plot on the probability of transition to land use or forest management type j is

$$\partial P_j/\partial x_m = P_j\left(\beta_{jm} - \sum_{k=1}^{J}\beta_{km}P_k\right). \quad (5)$$

The standard errors of marginal effects are calculated using the Delta Method [26]. The marginal effects of explanatory variables on the transition probabilities of land uses and forest management types, as well as their errors, are presented in Tables 6 and 7. For example, the marginal effect of "Hydric soil" dummy variable on the probability of transition to pine plantation (−0.1332) (Table 7) indicates that the probability of a particular site to be converted to pine plantation is 0.1332 smaller on hydric soils than on other soil types.

For the land use change model (Table 6), the dynamics among agricultural, forestry, developed, and other land uses is determined by the by land use in the previous period and physiographic region, and influenced by land quality (prime farmland), accessibility to population (as indicated by the PII), as well as population growth (as indicated by PII rate of change). As expected, probability of retention in or conversion to forestry land use is negatively influenced by PII and change of PII (the marginal effects are negative and statistically significant), indicating that conversion to forestry is more likely (and conversion from forestry is less likely) in locations with little population pressure and little population growth. The less productive land is likely to be converted to forestry use, while more productive land (prime farmland) is more likely to be retained in of converted to agricultural use. In general, these results are consistent with findings in previous studies [17,18].

For the forest management type change model (Table 7), we found that the probability of conversion to pine plantations is adversely affected by the soil hydricity and slope, and that conversion to pine plantations is less likely to occur in the Piedmont, Mississippi Delta, and Mountains and Plateau than in the Coastal Plain, which is the reference physiographic region. Thus,

Table 8 – Projections of the area of private timberland in the 11 southern states by forest type between 1997 and 2027, million hectares.

Forest type	1997	2007	2017	2027	Change (1997–2027)
Pine plantations	11.297	14.213	15.609	15.849	+40.2%
Natural pines	11.230	9.748	8.821	8.146	−27.5%
Mixed pine-hardwood	10.232	9.828	9.275	8.681	−15.2%
Bottomland hardwood	10.750	10.164	9.522	8.836	−17.8%
Upland hardwood	22.751	21.802	20.907	19.978	−12.2%
Total	66.260	65.754	64.135	61.490	−7.2%

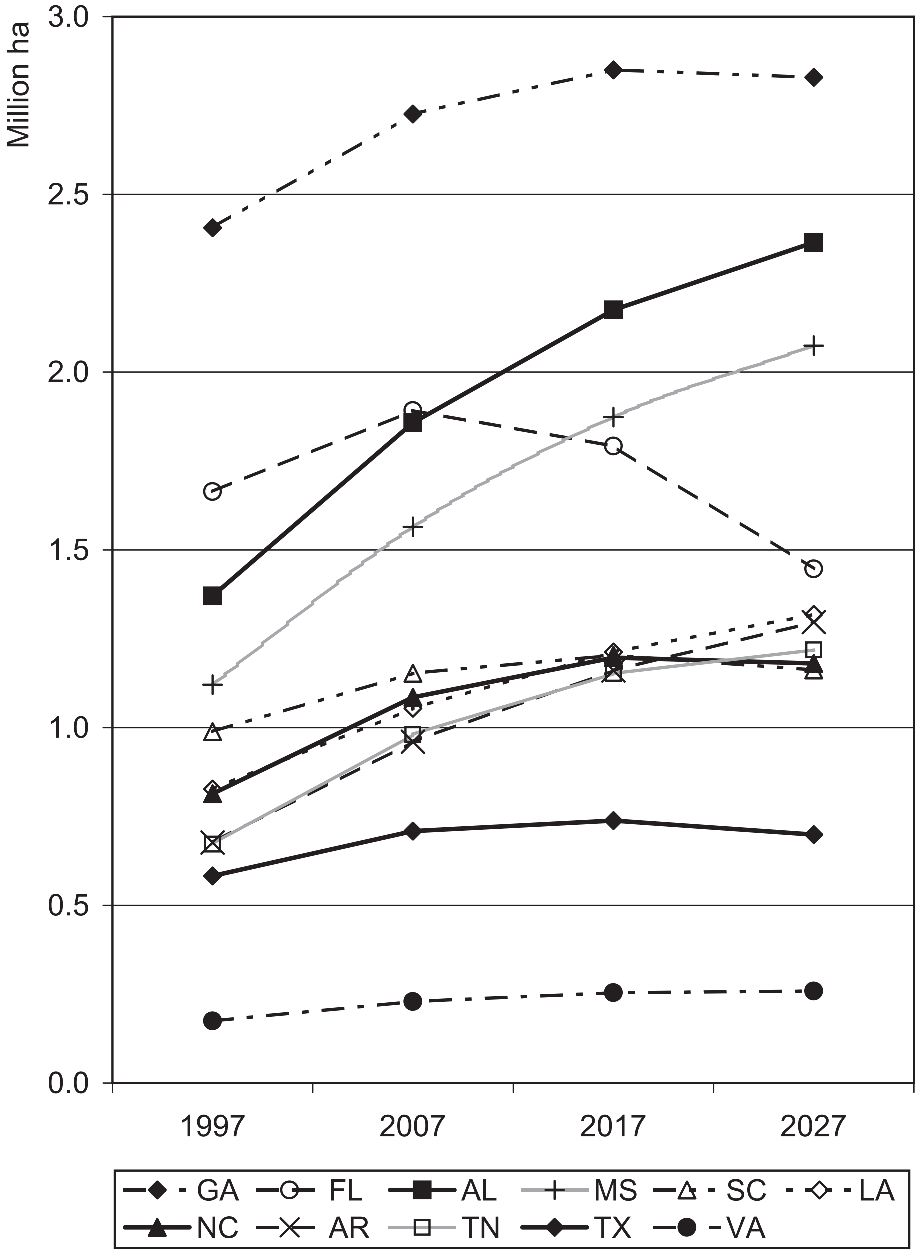

Fig. 4 – Projections of the area of pine plantations on private lands by state, 1997–2027.

the marginal effects for Piedmont, Mississippi Delta and Mountains and Plateau indicate changes relative to the Coastal Plain. The marginal effect of Log (PII) variable on transition to pine plantations is negative and statistically significant, which indicates that all other things being equal, the sites with high population pressure are least likely to be converted to pine plantations. This is perhaps related to the fact that establishing a plantation is a long-term investment and places with high population pressure are likely to be developed in the nearest future. This is consistent with findings for Alabama [27].

Based on these estimation results, we start our simulation from 1997 and proceed in three 10-year intervals to 2027. The conceptual scheme of the simulation is presented in Fig. 1. We assume that the population changes at the same rate it did between 1980 and 2000.

First, we project dynamics of land use changes from 1997 to 2027. For each 10-year step, we aggregate areas converted from agricultural and other rural uses to forestry use, and areas converted from forestry to other uses to the level of FIA units (each state is divided into 2–6 FIA units) and calculate the rate of forest gain and loss. Second, we perform simulation of forest type change. At each 10-year step, we adjust the forest area according to losses and gains, and then simulate forest type change. Finally, we aggregate results of the simulations to state and county level.

The maps in Fig. 2 show spatial distributions of private pine plantations in 1997 and 2027. The map in Fig. 3 shows the dynamics of private pine plantations by county for the period between 1997 and 2027. While Table 8 shows the change in private timberland in these 11 states, Fig. 4 and Table 9 show the dynamics of private pine plantations by state.

Table 9 – Projections of the area of pine plantations on private lands by state between 1997 and 2027, million hectares.

State	1997	2007	2017	2027
AL	1.370	1.858	2.175	2.365
AR	0.677	0.961	1.160	1.297
FL	1.664	1.892	1.792	1.446
GA	2.406	2.726	2.850	2.830
LA	0.827	1.055	1.212	1.318
MS	1.121	1.565	1.874	2.074
NC	0.814	1.085	1.197	1.180
SC	0.989	1.153	1.203	1.162
TN	0.672	0.981	1.153	1.219
TX	0.583	0.709	0.739	0.699
VA	0.175	0.229	0.254	0.259
Total	11.297	14.213	15.609	15.849

Interestingly our forecast for 2007, based on the 1987–1997 data, of 14.2 million ha of pine plantations is close to the actual pine plantation of 14.6 million ha in 2007. Our results show that private timberland is going to decline by about 7 percent between 1997 and 2027 and that the growth of pine plantation forests will diminish in the coming decades. Initially private pine plantation will increase by 20 percent from 11.3 million ha to 14.2 million ha in the first decade (1997–2007), then moderately increase by 10 percent and reach 15.6 million ha in the second decade (2008–2017) and finally only increase by 2 percent in the third decade, reaching 15.8 million ha in 2027 (Table 9).

Fig. 4 shows the forecasted pine forest plantation development by state. Alabama and Mississippi are expected to have the biggest increase in their private pine plantations, while Florida is expected to undergo a dramatic decline. Georgia, South Carolina, and Texas are expected to experience an increase and then a decline in their private pine plantation acreage. Population and population changes are the chief reasons for this discrepancy. All else being equal, the states that have low population and slow population growth will have a larger increase in private pine plantations than those with a large population base and high population growth rate.

We project that rate of increase in pine plantation area will decline in the coming decades, unlike other projections (i.e., SRTS) which forecast a linear rate of growth [28,29]. In our projections, area available for new pine plantations is decreasing due to development, which would reduce forest land by some 7 percent from 1997 to 2007. Our projections of pine plantation acreage for 2027 are much less than the two inelastic timber demand (timber demand elasticity = –0.50) scenarios, but close to the two elastic timber demand (timber demand elasticity = –5.0) scenarios reported in Ref. [28].

5. Conclusions and discussion

In this paper we looked at the current status and geographical distribution of planted forests and developed a model to forecast private pine plantation development in the U.S. South. We forecast forest land and pine plantation development based on a two-stage model of land use change, with forestry being one of several general land use types in the first stage and pine plantation being one of several specific forestry land use types in the second stage.

Most pine–oak plantations grew out of failed pine plantations. The pine plantations are concentrated on the Coastal Plain and on private lands. Our results show that fast-growing pine plantations account for some 86 percent of all planted forests and that commercial planting of fast-growing hardwood species is rare.

Our forecast of pine plantations in private lands is presented at the county level at a 10-year interval. We predict that private pine plantations will increase by about 40 percent, from 11.3 million ha in 1997 to 15.8 million ha in 2027. The increase in pine plantations occurs in states and regions that have a small population base and a low population growth rate. Our model does not cover public forests and cannot be used to forecast hardwood plantation development in the region. Nonetheless we do not expect tree plantations in public lands to change significantly because the management of these lands is largely immune to population and market forces. Nor do we expect that hardwood plantations on private lands will increase substantially in the coming decades unless economic conditions favor fast-growing hardwood species over pines.

Our model is built on historical data. As such, our forecast is unlikely to catch significant institutional changes that take place recently and in the future. One such institutional change is the 2007 Energy Independence and Security Act which requires a huge increase in the use of renewable fuels from some 24 hm^3 in 2008 to 136 hm^3 in 2022. Biofuels from nonfood feedstock (including cellulosic woody biomass) would be required to increase nearly zero to 60.6 hm^3 in the same period. Further, innovation and learning from subsidized demonstrations could improve the cost effectiveness of fuel production and could drive up demand for woody biomass from forest plantations and natural forests in the coming years. On the supply side, the adoption of new technologies such as genetically improved seedlings and government subsidies through tax relief and cost-sharing programs could greatly increase the area of plantation forests in the region.

Acknowledgements

We acknowledge the financial support from the National Research Initiative of the Cooperative State Research, Education and Extension Service, USDA (Grant #USDA-2005-3540015262), U.S. Forest Service Southern Research Station, National Council for Air and Stream Improvement (NCASI), and Auburn University Center for Forest Sustainability. Eric Vance and three anonymous reviewers of this journal provided helpful comments, and Shawn Bucholtz kindly gave us PII data linked to NRI sample points. Any remaining errors are the responsibility of the authors.

REFERENCES

[1] Smith WB, Miles PD, Vissage JS, Pugh SA. Forest Resources of the United States, 2002. USDA For. Serv. Gen. Tech. Rep. NC-241. St. Paul, MN; 2004.

[2] Siry JP, Cubbage FW, Malmquist AJ. Potential impacts of increased management intensities on planted pine growth

and yield and timber supply modeling in the south. Forest Products Journal 2001;51(3):42–8.
[3] Kline JD, Moses A, Alig RJ. Integrating urbanization into landscape-level ecological assessments. Ecosystems 2001;4 (1):3–18.
[4] Li Y, Zhang D. A spatial panel data analysis of tree planting in the U.S. South. Southern Journal of Applied Forestry 2007;31 (3):175–82.
[5] Wear D, Greis JG. Southern forest resource assessment. Asheville, NC: U.S. Forest Service Southern Research Station; 2002.
[6] Zhou X, Mills JR, Teeter LD. Modeling forest type transitions in the south central region: results from three methods. Southern Journal of Applied Forestry 2003;25(3):190–7.
[7] Cook J, Beyea J. Bioenergy in the United States: progress and possibilities. Biomass and Bioenergy 2000;18:441–5.
[8] Zhang D. Market, policy incentives, and development of forest plantation resources in the United States. In: Incentives and the development of forest plantation in Asia Pacific. Bangkok, Thailand: Food and Agriculture Organization of the United Nations Asia Pacific Forestry Commission; 2004.
[9] USDA Forest Service. Forest inventory mapmaker (version 3. 0). Southern Research Station. http://www.ncrs2.fs.fed.us/4801/fiadb/fim30/wcfim30.asp [accessed 11.08.08].
[10] USDA Forest Service. The South's Fourth Forests: Alternatives for the Future. Forest Resource Report No. 24. Washington, DC; 1988.
[11] Ahn S, Plantinga A, Alig RJ. Predicting future forestland area: a comparison of econometric approaches. Forest Science 2000;46(3):363–76.
[12] Alig RJ, Healy RG. Urban and built-up land area changes in the United States: an empirical investigation of determinants. Land Economics 1987;63(3):215–26.
[13] Parks PJ, Murray BC. Land attributes and land allocation: nonindustrial forest use in the Pacific Northwest. Forest Science 1994;40(3):558–75.
[14] Irwin EG, Bockstael NE. Interacting agents, spatial externalities, and the endogenous evolution of residential land use patterns. Journal of Economic Geography 2002;2(1):31–54.
[15] Lubowski RN, Plantinga AJ, Stavins RN. Land-use change and carbon sinks: econometric estimation of the carbon sequestration supply function. Journal of Environmental Economics and Management 2006;51(2):135–52.
[16] Bockstael NE. Modeling economics and ecology: the importance of a spatial perspective. American Journal of Agricultural Economics 1996;78(5):1168–80.
[17] Polyakov M, Zhang D. Property tax policy and land use change. Land Economics 2008;84(3):396–408.
[18] Polyakov M, Zhang D. Population growth and land use dynamics along urban–rural gradient. Journal of Agricultural and Applied Economics 2008;40(2):649–66.
[19] Train KE. Discrete choice methods with simulation. Cambridge, UK: Cambridge University Press; 2003.
[20] McFadden D. Conditional logit analysis of quantitative choice models. In: Zarembka P, editor. Frontiers of econometrics. New York, NY: Academic Press; 1973.
[21] Zhang D, Nagubadi RV. Timberland use in the Southern United States. Forest Policy and Economics 2005;7:721–31.
[22] Natural Resources Conservation Service. 1997 National resources inventory (revised December 2000). Washington, D.C.: Natural Resources Conservation Service, U.S. Department of Agriculture; 2000.
[23] Nusser SM, Goebel JJ. The national resources inventory: a long-term multi-resource monitoring program. Environmental and Ecological Statistics 1997;4(3):181–204.
[24] Breneman VE. Population accessibility: analysis of US Bureau of Census 1990 block group level population data. Washington DC: USDA Economic Research Service; 1999.
[25] Greene WH. Nlogit version 3.0 reference guide. New York: Econometric Software, Inc.; 2002.
[26] Greene WH. Econometric analysis. Upper Saddle River, NJ: Prentice-Hall; 2000.
[27] Polyakov M, Majumdar I, Teeter L. Spatial and temporal analysis of the anthropogenic effects on local diversity of forest trees. Forest Ecology and Management 2008;255: 1379–87.
[28] Abt RC, Cubbage FW, Pacheco G. Southern forest resource assessment using the subregional timber supply (SRTS) model. Forest Products Journal 2000;50(4):25–33.
[29] Prestemon JP, Abt R. Timber products supply and demand. In: Wear D, Greis JG, editors. Southern forest resource assessment. Asheville, NC: USDA For. Serv. Southern Research Station; 2002 [chapter 13].