The Effect of Urban Sprawl on Timber

In Mississippi and Alabama, urban population growth is pushing development into rural areas. To study the impact of urbanization on timber harvesting, census and forest inventory data were combined in a geographic information system, and a logistic regression model was used to estimate the relationship between several variables and harvest probabilities. Although proximity to good roads increases the likelihood of harvesting, almost all measures of urbanization-but particularly proximity to development and higher population density--lead to lower harvesting rates. Further, reductions in normal silvicultural harvests outweigh the increases in conversion harvests and lead to a short-run decrease in supply.

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The potential impact of urbanization on the South's timber supply is dramatic. Between 1960 and 1990, the South's share of the nation's population increased from 30.7 percent to 34.4 percent (US Department of Commerce 1992). The amount of land in the South swallowed by metropolitan areas has more than doubled, from 9.8 percent in 1960 to 23.2 percent in 1990 (US Department of Commerce 1965, 1992). The increase in metropolitan land use, or urban sprawl, is out of proportion to the urban population growth and indicates that development is spreading beyond the core cities. Urban development is traditionally more scattered than most other land uses, and most of the increase in urban land comes from forestland (LaGro and DeGloria 1992).

With population increasing and metropolitan areas expanding, much of the South's commercial forestland now falls within counties with populations of 250,000 or more. These metropolitan counties contain 26 percent of the Southeast's timberland-about 28 million acres (DeForest et al. 1991). However, as much as 43 percent of the commercial timberland in metropolitan counties may be unavailable for timber management and should more appropriately be considered real estate (Befort et al. 1988).

Clearly, urbanization directly reduces long-term timber availability as forested lands are lost to urban development. The total impact of urbanization, however, is far greater because timber management is influenced by the interaction of urban and forestry uses far beyond the urban edge. In areas within convenient driving distance of a metropolitan area, forested land has become more valuable for development than for growing timber (Lubka 1982), and active timber managemenr is therefore sharply curtailed. Harris and DeForest (1993) found that 19 percent of Georgia's forestland was in metropolitan counties, yet these counties accounted for only 4 percent of the land enrolled in the Conservation Reserve Programs tree-planting option.

The urban-forest interface is not only a geographic area where forest management meets urban development, but also a political arena where people holding different values for the forest interact (Vaux 1982). These conflicts are more than just boundary disputes; they are vocal opposition to traditional forest management practices (Shands 1991). Former urbanites often introduce regulations to protect suburban and rural areas from perceived damage caused by forest management activities (Cubbage and Siegel 1985; Cubbage 1995). The regulations frequently include requirements for timber harvest permits, buffer zones, and restricted silvicultural practices (Martus et al. 1995).

Numerous authors have investigated how urbanization affects forestry: landowner characteristics influence timber management behavior (Binkley 1981; Romm et al. 1987; Dennis 1989, 1990); forest fragmentation increases management costs by reducing tract size (Harris and DeForest 1993); and tract characteristics-proximity of roads, distance to markets, and ownership category, public or private-also affect timber management decisions (Wear and Flamm 1993).

This study examines how one aspect of timber management—harvesting—is influenced by demographic and physical characteristics associated with urbanization. Demographic data from the US Census Bureau are combined with USDA Forest Service Forest Inventory and Analysis (FIA) data for Alabama and Mississippi using ARC/INFO geographic information system (GIS) software. A binary logit model is developed to examine relationships between harvesting probabilities and demographic and physical characteristics that change with urbanization.

Methods

The first step in developing the database was to create a census tract base map for Alabama and Mississippi. The Census Bureau subdivides counties into tracts of similar population characteristics, economic status, and living conditions. The average population of a census tract is 4,000 people but ranges from 2,500 to 8,000. Tracts vary widely in area depending on population density. Each has an associated set of demographic data.

FIA plot locations (latitude and longitude) were digitally combined with the census tract base map using ABC/INFO. The number of FIA plots contained in each census tract depends on the size of the tract. The FIA and census GIS attribute data were then merged, resulting in a combined set of demographic (census) and physical (FIA) data for each plot.

Table 1 (p. 12) describes the variables of interest that were derived from FL4 or census data or were developed for the project. The dependent variable ***harvest*** is a binary variable taking the value of 1 if any harvesting occurred on the FIA plot between the last two inventories.

Several variables not necessarily influenced by urbanization are included because of their potential impact on harvesting probabilities. The net volume of growing stock in the previous inventory *(NVGS)* serves as a measure of value and as a crude measure of maturity, both of which contribute to the likelihood of harvest. The volume in the previous period is used because it is the volume before, not after, harvest that influences the harvest decision. Percentage ***slope*** is included because of its impact on harvesting costs.

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The probability of harvest is lower for tracts near built-up areas and urban centers, possibly because of increased nontimber values.

Dummy variables for ***national*** forests, ***other*** public land, forest *industry*, and ***private*** land are included to account for differences in harvesting preferences among these ownership categories.

The remaining variables are included as measures of urbanization. Distance to the nearest all-weather or truck-operable ***road*** directly influences harvesting costs and in turn is affected by urbanization. As urbanization progresses and infrastructures expand, the distance to a road is likely to decrease.

The distance from the FIA plot to an urban or built-up area of 10 or more acres is a measure of forest fragmentation and proximity of urban uses. This distance is represented by a series of dummy variables: less than 1 mile *(dist-urb-1)*, between 1 and 3 miles *(dist-urb-2)*, and more than 3 miles *(dist-urb-3)*.

Population ***density*** is included as a direct measure of urbanization and may also be a proxy for the level of conflict associated with competing land uses. Census tracts with higher population densities may encounter more opposition to certain silvicultural practices than census tracts with lower population densities.

Median household ***income*** is a measure of affluence and is included as a proxy for conflicting values for forested land. Where income levels are high, people may value the amenities associated with the forest and enact restrictive regulations (Cubbage 1995; Martus et al. 1995).

The ***distance*** from each FIA plot to the nearest urbanized area-a city of 50,000 or more-was calculated in ABC/INFO and is included as a continuous measure of urbanization. A squared term *(distance²)* was included to permit nonlinear effects.

Empirical Model

The probability of timber harvest is estimated using a binary logit model as follows:

$$P(Y_i = 1|X_i) = \frac{1}{1 + e^{-Z_i}} \qquad (1)$$

where, for the *i*th observation, Y_i, the binary dependent variable, equals 1 if any harvest activity has occurred since the last inventory, or equals 0 if no harvest activity has occurred: $Z_i = \sum b_k X_{ik}$; X_i denotes the set of K independent variables: and b_k are the estimated parameters ($k = 1, \ldots K$).

Equation (I) represents the cumulative logistic distribution function. The probability of a timber harvest is a function of 13 independent variables and takes the following form:

(2) Probability ($harvest_i$) = f ($NVGS_i$, $road_i$, slope;, $other_i$, $national_i$, industry;, $private_i$, dist-urb-1 $_i$, dist-urb-2_i, dist-urb-3_i, $density_i$, $income_i$, $distance_i$, $distance_i^2$).

Other and ***dist-urb-3*** are omitted to allow inversion of the X'X matrix.

Finally, harvest probabilities are calculated for all plots and the locations of those likely to be harvested ($p \geq 0.50$) are mapped and any geographic patterns are noted.

Results

The descriptive statistics of the variables are presented by harvest category in ***table 2.*** In general, harvested plots have higher per-acre volumes. tend to be privately owned, and are farther than 3 miles from built-up areas than nonharvested plots. In addition, harvested FIA plots are associated with lower population densities (37 people per square mile) than nonharvested plots (50 people per square mile).

During the period between FIA surveys, 33 percent of the plots were subject to some form of harvesting. Parameter estimates, standard errors, and marginal effects of the continuous variables are presented in ***table 3.*** The null hypothesis, that all nonintercept coefficients are equal to zero, is rejected using the test statistic -2 LOG L. The estimated chi-square value, 662.22, has 12 degrees of freedom and is statistically significant at the 1 percent level. The chi-square test is analogous to the F-test in linear regression and tests the overall significance of the model. The model accurately predicted harvest or no-harvest for 70.2 percent of the FIA plots.

Plot attributes not related to urbanization had mixed effects on harvest probability. The estimated parameter for *NVGS* is statistically significant at the 1 percent level, indicating that plots with greater timber volumes are more likely to be harvested. ***Slope*** is not significant, indicating that in Alabama and Mississippi, slope has no effect on harvesting probabilities.

Harvesting probabilities do differ by ownership category. Private owners, both industrial and nonindustrial, are more likely to harvest timber than public owners. The estimated coefficients for *industry* and ***private*** are positive and significant, indicating that these owners harvest more frequently. The estimated coefficient for ***national*** is not significant, indicating no difference in harvesting frequencies between national forests and other public owners.

Urbanization may have indirect effects on harvesting probabilities. The estimated coefficient for ***road*** is negative and significant. As the distance to a truck-operable road increases, the probability of hat-vest decreases. If urbanization results in greater infrastructure that reduces distances to roads, harvesting will be increased.

Proximity of urban uses also significantly affects harvesting. The coefficient on *dist-urb-1* is negative and significant at the 1 percent level: ***dist-urb-2*** is not. Harvest probabilities are lower within a 1 -mile radius of built-up areas than for plots outside a 3-mile radius. Harvest probabilities in the 1- to 3-mile band are not significantly different than outside the 3-mile radius. Any negative effect on harvest probability associated with urban areas extends no more than 1 mile.

Increasing population density is negatively related to harvesting proba-

Table 1. Variable definitions and units of measurement.

Variable	Definition	Units
$Harvest_i$	**Binary dependent** variable indicating presence of **harvesting** activity (clearcut, **partial, seedtree,** salvage cut) since the previous inventory	**1 for presence of any type of harvest. 0 otherwise**
NVGS,	Nat volume of **growing** stock trees in the previous inventory	**Cubic feet** per acre
Road,	Estimated distance from the plot center to the nearest truck-operable road	Coded by feet and miles
$Slope_i$	Percent slope of the site	**1= 0–1** percent, etc.
$National_i$	Ownership dummy variable for national forest	1 for national forests, 0 otherwise
Other,	**Ownership** dummy variable for other public forestland	1 for other public, 0 otherwise
$Industry_i$	**Ownership** dummy variable for forest industry	1 for forest industry, 0 otherwise
Private,	Ownership dummy variable for private forestland	1 for private, 0 otherwise
Dist-urb-1,	Dummy variable for distance from FIA plot to built-up land of 10 acres or more	1 if less than 1 mile, **0 otherwise**
Dist-utb-2,	Dummy variable for distance from FIA plot to built-up land of 10 acres or more	1 if between 1 to 3 miles, 0 otherwise
Dist-urb-3_i	Dummy variable for distance from FIA plot to built-up land of 10 acres or more	1 if greater than 3 miles, 0 otherwise
$Density_i$	Population density of the census tract or block numbering area in which the plot **is** located.	**People** per square mile
Income,	Median household income of people who **live** in the census tract or block numbering area where the plot is located.	In 1989 dollars
$Distance_i$	Straight-line distance from FIA plot to urbanized area (city of **50,000-plus)**	Miles
$Distance^2_i$	Squared version of ***Distance***	Miles squared

bility. The coefficient on *density* is negative and significant at the 5 percent level. Although there may be fewer forested plots in more densely populaced areas, those that remain are less likely co be harvested.

Income was not significant. Affluence of the surrounding census tract has no impact on harvesting probability or may be a poor proxy for conflicting values for forested land.

The final measure of urbanization-distance to an urban center of 50,000-plus population-is also significant. The coefficients on ***distance*** and ***distance2*** are significant at the 1 percent level. Holding other factors constant, the relationship benveen distance and harvest probability is positive between 0 and 124 miles and reaches a maximum at 62 miles. Beyond 124 miles, the relationship between distance and harvest probability is negative. However, the mean distance from an urban center to an FIA plot is less than 50 miles. For most plots, those within a 62-mile radius of an urban center, harvesting probabilities decrease closer to the urban area.

Very few forested plots with high harvest probability ($p \geq 0.5$) occur close co urbanized areas (*fig.* I, ***p. 14***). Whether rhis is a significant result or due co a relatively low number of forested plots cannot be determined. No other geographic pattern is apparent.

Table 2. Descriptive statistics for harvesting model variables (n=6,581).

Variables	Mean	Standard deviation	Mean of harvested plots	Mean of non-harvested plots
NVGS	1076.62	693.69	1,427.42	922.46
Road	9.03	11.1	6.57	9.24
Slope	6.34	9.21	6.09	6.47
National	0.06	0.23	0.03	0.07
Other	0.03	0.17	0.02	0.04
Industry	0.20	0.40	0.21	0.19
Private	0.72	0.45	0.75	0.70
Dist-urb-1	0.13	0.34	0.10	0.15
Dist-urb-2	0.23	0.42	0.24	0.23
Dist-urb-3	0.64	0.48	0.67	0.62
Density	46	112	37	50
Income	19,483	5,248	19,133	19,640
Distance	47.38	26.70	49.30	46.51
Distance^2	2,957.30	3,166.37	3,118.31	2,885.22

Discussion

As did previous studies, this study found similar relationships between harvesting and tract characteristics unrelated to urbanization, such as timber volume (Binkley 1981; Dennis 1990) and ownership category (Wear and Flamm 1993).

The effects of urbanization on harvesting probabilities are complex. Despice the obvious-that as urban centers expand, forested areas must be harvested to make way for urban uses—this study has found little to suggest that urbanization results in a net increase in harvesting. Almost all measures of urbanization examined in this **study are associated** with lower harvesting probabilities. Proximity to urban land uses, higher popularion densities, and proximity co urban centers all lead to lower harvesting rates on forested plots. Only proximity to a truck-operable road increases the likelihood of harvesting.

The study did not differentiate between types of harvesting. The explanation for lower harvesting probabilities associated with urbanization may lie in the mix of harvest types. Two broad categories of timber harvests are of interest: harvests in anticipation of conversion to urban land uses and "normal" silvicultural harvests. Most conversion harvests will be clearcuts but may include some type of modified seed-tree or shelterwood cuts for real estate purposes. In contrast, silvicultural harvests include intermediate cuts, improvement cuts, and any final harvests where regeneration is intended.

Given that the frequency of conversion harvests must increase as urbanization pressures increase, there must be more-than-offsetting decreases in the frequency of silvicultural harvests in these same areas to **account** for the negative relationship benveen harvesting of all types and measures of urban-

Table 3. Harvest probability model: Parameter estimates and marginal effects of explanatory variables.

Variable	Parameter estimate	Standard error	Marginal effect††
Constant	-2.603	0.297'	
NVGS	0.717E-3	0.330E-4*	0.1596-3
Road	–0.120E-1	0271 E-2'	–0.265E-2
Slope	–0.299E-2	0.310E-2	-0.661 E-3
National	-0.462	0.247	—
Industry	1.001	0207 .	—
Private	1.024	0.199'	—
Dist-urb-1	-0.392	0.976E-1	—
Dist-urb-2	0.180E-1	0.680E-1	—
Density	-0.1 10E-2	0.440E-3†	–0.233E-3
Income	–0.469E-6	0.675E-5	-0.151 E-6
Distance	0.124E-1	0.474E-2*	0.274E-02
Distance2	–0.100E-3	0.360E-4'	–0.221E-4
	2 LOG L = 662.22	df = 12	n = 6,581

**Statistically* significant at *the 1 percent level.*
†*Statistically significant at the 5 percent level.*
††*Marginal effects represent the change in the probability of harvest (evaluated at the mean probability Of 0.330) for a one-unit increase in each of the continuous independent variables.*

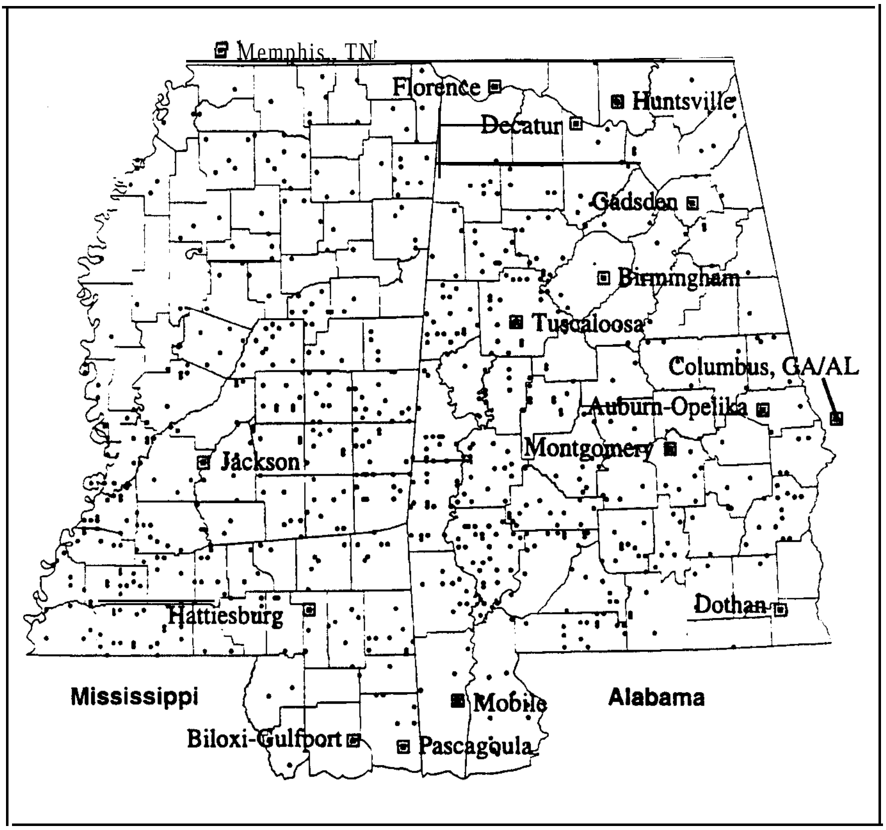

Figure 1. **FIA plots with high (≥ 0.5) harvest probability and urbanized areas (cities with 50,000-plus population) in Mississippi and Alabama.**

ization. Two factors may contribute to the decrease in the frequency of silvicultural harvests.

First, as noted previously, active timber management is sharply curtailed in areas prone to urbanization (Lubka 1982; Harris and DeForest 1993). Like many timber management activities, silvicultural harvests have relatively long payback periods. Landowners may elect to forgo silvicultural harvests if the payoff of increased or improved growth is likely to occur after the anticipated conversion horizon.

Second, as more and more forestland on the urban fringe is converted to urban uses, the nontimber amenity value of the remaining forestland increases, resulting in less management for timber production and more management for nontimber values. For both of these reasons, the frequency of silvicultural harvests on the remaining forestland is likely to decrease.

Regardless of the reason for the decrease in silvicultural harvests, there are important implications for timber supply. Obviously, land-use conversions ultimately lead to a long-run decrease in timber supply because of losses to the timberland base. Our study suggests that there is also a short-run decrease in timber supply as the reductions in silvicultural harvests outweigh the increases in conversion harvests. Clearly, further investigation is needed to examine the issues raised in this study. Ongoing studies are exploring whether the trends illustrated in Mississippi and Alabama extend across the South and how the factors influencing harvest probabilities vary by type of harvest. Future research should also examine how timber harvesting proximate to urban areas is affected by the spatial configuration of surrounding tracts by size, ownership type, and land use.

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