Predicting the Urbanization of Pine and Mixed Forests in Saint Tammany Parish, Louisiana

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Abstract

St. Tammany Parish, Louisiana, has experienced tremendous urbanization, resulting in the loss of timberland. This study's objectives were to develop a model using parish-level data that estimates the probability of urban development in a pine or mixed forest parcel, and to identify the parcels most likely to be developed. The geographic data sets used include satellite imagery from 1981 and 1993, U.S. Census data, population growth estimates from the St. Tammany Parish Government, and road coverages. Logistic regression was used to develop a model that predicts the probability of urban development. Population density, distance to the nearest state or federal highway, distance to the access points to New Orleans, and distance to the nearest interstate interchange all significantly influenced the probability that a parcel would be developed. Using population density predictions for 2003, the model identified the likely development corridor and the timberlands that would be unavailable for long-term fiber production.

Introduction

Rapid population growth in the Gulf South region of the United States reduces the area of timberland in that portion of the country that supplies much of the nation's pine pulpwood and sawtimber (Cordell *et al.*, 1998). St. Tammany Parish (county), Louisiana (Figure 1), is located 30 miles north of New Orleans on the shores of Lake Pontchartrain and has experienced the rapid population growth that exemplifies this trend. In the early 1980s, St. Tammany was a mostly rural parish with landscape dominated by agriculture and forest lands. The parish has experienced tremendous population growth in the past 20 years resulting in the loss of both agriculture and forest lands.

Industry, policy makers, regulators, and landowners have little information on how urbanization affects forest resources at the parish level. A geographic information system (GIS) allows for a graphical depiction of the spatial and temporal dimensions of the biological, physical, and demographic attributes related to urbanization and forest resources. A statistical model may be incorporated into a GIS to illustrate expected changes in forest resources at the parish level as the biological, demographic, and transportation network attributes of the parish change.

Other researchers have used similar techniques to model the effect of changing demographics on natural resources. Wear *et al.* (1998) considered the implications of urbanization on water quality in the southern Appalachians. Wear found that development was more likely to occur along the urban-rural interface; that private lands were more likely to be developed than public; and that the distance to roads, elevation, and slope significantly affected development. Wear *et al.* (1999) also modeled the effect of population growth on timberland area/growing-stock volumes in central Virginia. Population density was the significant factor affecting the area of timberland. Accessibility (measured whether or not roads could be easily constructed), slope, and site index were insignificant. Turner *et al.* (1996) considered the effects of slope, elevation, distances to roads and markets, and population density on changes in land cover. The analysis was performed over time for areas of the southern Appalachians and Olympic Peninsula for both public and private lands. Turner found that slope and population density were the major determinants of change from privately owned deciduous forests to unvegetated areas in the southern Appalachians in the late 1970s through early 1980s.

The primary purpose of this study was to develop the GIS and statistical techniques needed to examine the relationship between urbanization and timber availability in St. Tammany Parish using primarily publicly available information. Ideally, the GIS and statistical techniques would be applied to larger areas and the regional effects of population growth on timber availability could be examined. Three specific objectives were addressed by the study:

- to develop a GIS that incorporates land-cover, demographic, and transportation network attributes of the parish;
- to develop a parish-level statistical model that estimates the probability that a parcel of pine or mixed forest land will be developed; and
- to identify the pine or mixed forest lands most likely to be developed in the future using projected parish population density values.

Methods

Accomplishing the objectives required initially obtaining the data and developing a GIS for the study site. The data obtained

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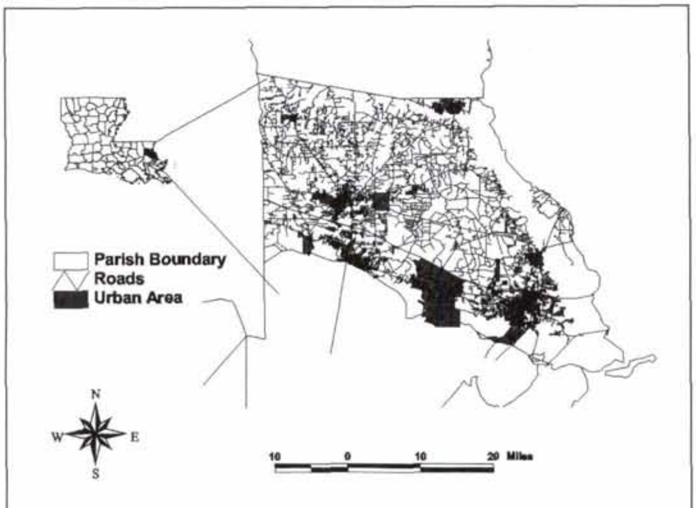

Figure 1. Location of St. Tammany Parish, Louisiana.

for the GIS were used to develop a logistic regression equation that produced a probability of development surface for St. Tammany Parish. The logistic regression equation and GIS then were utilized to assess the impacts of projected population growth on the quantity and location of the parish's forest lands. The steps involved are described below.

GIS Development

Geographic data sets of random numbers, land cover, census blocks and block groups, federal and state roads, and major access points to New Orleans were obtained or created. All geographic data sets were projected to Universal Transverse Mecator (UTM) zone 16. Additional databases were created for the census block coverage to facilitate the inclusion of demographic information from other data sources. Table 1 lists the information contained in the geographic data sets, data sources, and the associated cover names. A discussion of each geographic data set follows.

Random Points

An 80-meter-resolution grid of random numbers was created in Arc/Info's Grid module. Cell values were assigned a random integer value from 1 through 2,000,000 with cells outside the parish boundary receiving a "no data" value. We selected cells with values between 1 and 100,000 from the random number grid. These cells were randomly distributed throughout the parish, and cell values for this grid were set to either 1 (for cells with values from 1 through 100,000) or "no data" (for cell with values greater than 100,000). This grid identified our randomly located parcels within the parish, and will be referred to as "RANDOM" throughout the remainder of the paper.

Land-Use Data Sets

Land-cover data were obtained from two sources: Stennis Space Center/Environmental Enterprises, USA, Inc. and the U.S. Geological Survey (USGS) National Wetlands Research Center (NWRC). The land-cover classification developed at Stennis was the result of a commercial space technology project by NASA and the private firm Environmental Enterprises, USA, Inc. of Slidell, Louisiana. Stennis used the cluster module of Erdas 7.2 with 1981 multispectral satellite (MSS) imagery to categorize land cover into one of nine groups: coniferous forests, deciduous forests, mixed coniferous/deciduous forests, pasture/agriculture/grasses, cypress/wet deciduous scrub, high density marsh, low density marsh, water, and urban/inert. Specifically, the CLUSTR module of p.c.-based Erdas 7.2 was used to perform an unsupervised classification of the image, setting the maximum number of categories allowed to 50. The 50 classes were re-evaluated based partially on ground-verified data and then regrouped into the nine classes previously listed.

Hydric soil groups digitized from the general soils maps of St. Tammany Parish aided in the determination of wetland (cypress/wet deciduous forest, high density marsh, low density marsh) and riparian (deciduous forests) cover types. The resulting land-cover image created had an 80-meter resolution. Land-cover classifications were field verified by Stennis personnel.

The USGS NWRC developed land cover for St. Tammany Parish as part of the National Geographic Assessment Program

Table 1. The Geographic Data Sets with Descriptions and Sources for the Logistic Regression Model Used to Predict the Probability of Development

Data Description	Geographic Data Set	Source
Random integer grid	RANDOM	Created in GRID and masked to include only areas within the parish
Points remained forested or changed to urban (0 or 1 respectively)	CHANGE	Change detection analysis performed in GRID using Stennis Space Center image (1981) and the USGS National Wetland Research image (1993)
Area of contiguous pine or mixed forest cover (ha)	AREA	Polygon coverages created from Stennis Space Center (for 1981) and USGS National Wetland Research Center (for 1993) satellite images using ArcInfo
Population density by census block	POPDEN	Block locations were obtained TIGER 92 line files and changed to a coverage using ArcInfo. block areas determined from ArcInfo. Block Statistics CD from the U.S. Census Bureau provided total population in each block in 1990. St. Tammany Parish Office of Information Services Provided 2003 population estimates by Census Tracts. Population density was calculated using ArcInfo
Euclidean distance from sample point to nearest state of federal highway (km)	ROADS	Federal and state highways identified through Wessex First Street. GRID was used to determine Euclidean distances
Euclidean distance to the major access points to New Orleans (km)	ACCESS	Digitized points from the screen guided by the parish roads information obtained from Wessex First Street. GRID was used to determine Euclidean distances
Euclidean distance to interchanges on limited access highways (km)	INTERCHANGE	Interchanges were identified through Wessex First Street. GRID was used to determine Euclidean distances

TABLE 2. COMMON CLASSIFICATION SCHEME USED BY ENTERGY SPATIAL ANALYSIS LABORATORY (ESARL) PERSONNEL TO REGROUP EXISTING LAND-COVER IMAGES

ESARL Common Classification Scheme	Stennis Space Center Classification	USGS Classification
Pine Forest	Evergreen Forest	Upland Evergreen Forest Wetland Evergreen Forest Dense Pine Thicket Evergreen Wetland Shrub/Scrub Mixed Wetland Shrub/Scrub Evergreen Upland Shrub/Scrub Mixed Upland Shrub/Scrub
Mixed Forest	Mixed Forest	Mixed Wetland Forest Mixed Upland Forest
Deciduous Forest	Deciduous Forest	Wetland Deciduous Forest Upland Deciduous Forest Wetland Deciduous Shrub/Scrub Upland Deciduous Shrub/Scrub
Urban	Urban/Inert	Vegetated Urban Non-Vegetated Urban Barren
Wetland	Cypress/Wet Scrub High-Density Marsh Low-Density Marsh	Fresh Marsh Intermediate Marsh Brackish Marsh
Agricultural/ Grass/Crop	Agriculture/Grass/ Crop	Agriculture/Grass/ Crop
Water	Water	Water

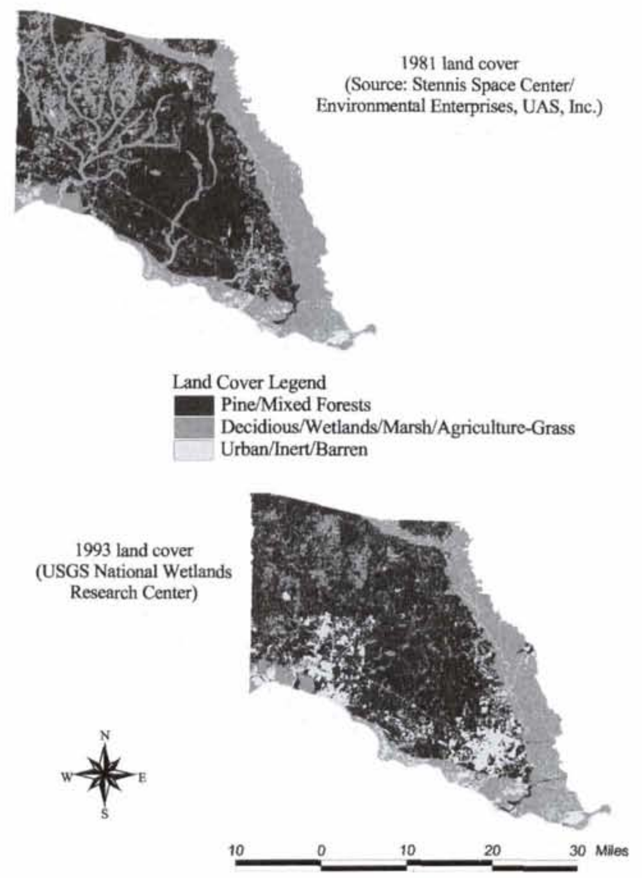

Figure 2. Land cover in 1981 and 1993.

(GAP). 1993 Thematic Mapper (TM) satellite scenes with a 30-meter resolution were categorized into 21 groups by the USGS (Hartley *et al.*, in preparation): fresh marsh, deciduous wetland forests, evergreen wetland forests, mixed wetland evergreen forests, deciduous upland forests, evergreen upland forests, mixed upland forests, dense pine thicket, deciduous wetland shrub/scrub, evergreen wetland shrub/scrub, mixed wetland shrub/scrub, deciduous upland shrub/scrub, evergreen upland shrub/scrub, mixed upland shrub/scrub, agriculture/grasses/crops, vegetated urban, non-vegetated urban, wetland barren, upland barren, intermediate marsh, and brackish marsh.

The USGS also incorporated information from the 1989 National Wetlands Inventory to aid with wetland land-cover classification; Hydric soils were not used. Entergy Spatial Analysis Research Laboratory (ESARL) personnel performed extensive field verification of the land cover at 190 randomly selected locations throughout St. Tammany Parish.

Both the Stennis Space Center and the USGS images were imported into Grid (ArcInfo's raster module). The USGS image was filtered to remove small areas of land cover consisting of only a few pixels (≤0.36 hectares, i.e., four pixels or less) and then resampled with the small clusters of pixels removed to provide a land-cover grid with an 80-meter resolution. The resulting USGS grid was then spatially comparable to the Stennis Space Center grid. Next, both the Stennis and USGS land-cover grids were regrouped into seven categories: pine forests, deciduous forests, mixed forests, wetlands, agriculture/grasses, urban/inert/barren, and water. Table 2 list the common land-cover classification scheme used by ESARL to produce similar 1981 and 1993 land-cover grids for change detection purposes. Figure 2 presents the land cover of St. Tammany Parish in 1981 and 1993 (three land-cover categories for illustration purposes).

Most of the generalizations from the 21 USGS categories to the new seven-category classification scheme are obvious. However, the field verification of the USGS land-cover classification resulted in several needed changes. Field verification indicated that both young pine plantations and thinned pine forests appear as a mixed land-cover type on the satellite images. In the regrouping of the USGS land-cover classifications, the mixed as well as evergreen shrub/scrub cover types were included in the pine forest category. The pine forest category better reflects the land use than do the evergreen or mixed shrub/scrub, or mixed forest categories.

Certain forestry practices (windrowing, bedding, and burning) and grasses within pine plantations will also produce a land-cover reflectance that is confused with that of agriculture/grasses/crops. To remedy this problem, areas that were classified as an agriculture/grasses/crops cover type in 1981, but were classified as evergreen or mixed forests in 1993, were identified and reclassified as pine forests. We also identified areas that were classified as coniferous forests in 1981, but were classified as agriculture/grasses/crops in 1993. The field verification revealed that most of these lands were industrial forests that had been replanted with pine. No conversions from forests to agricultural lands were found by field verification. The 1982 through 1992 Census of Agriculture (Bureau of the Census, 1994) indicates that the number and size of farms and the acreage of farm lands have greatly decreased in St. Tammany Parish since 1982. Conversions from forests to agricultural lands is uncommon in the parish.

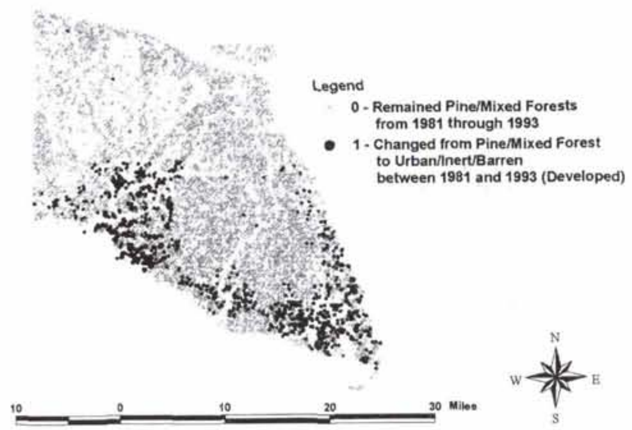

Figure 3. Map of randomly selected parcels used to develop probability of development model.

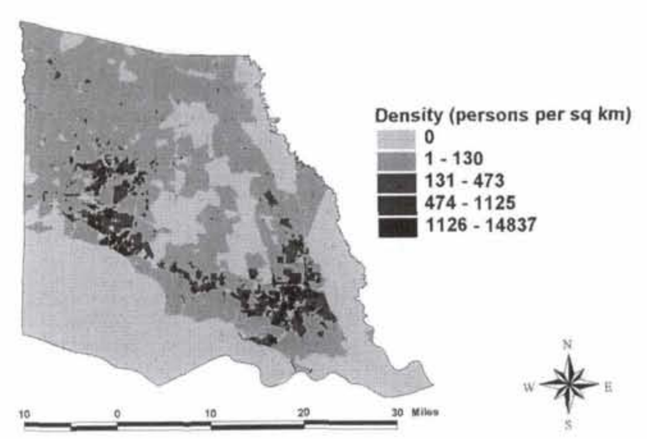

Figure 4. Population density in 1990.

With both land-cover grids now spatially compatible and with similar land-cover classification schemes, a change detection analysis was performed. Areas that were pine or mixed forests in 1981 and remained pine or mixed forests in 1993, and areas that were pine or mixed forests in 1981 but were urban/inert/barren in 1993 were identified, with all other areas receiving a no data value. The hydric soils mask used by Stennis to determine wetland areas was inherently applied in the change detection analysis (i.e., no pine forest was located on hydric soils).

Three covers resulted from the change detection analysis: a point coverage containing our dependent variable, a polygon coverage containing the area of contiguous forest cover in 1981, and a polygon coverage containing the area of contiguous forest cover in 1993. A grid used to identify the dependent variable resulted from the multiplication of RANDOM (values of 1 or "no data") and the change detection grid. The product grid was converted to a point coverage that contained all the centroids of the 100,000 randomly selected cells. Approximately 87,000 of the 100,000 randomly selected cells contained agricultural lands, deciduous forest, swamp/marsh lands, or other land covers not considered in this analysis. Values for these cells were set to "no data." The remaining 12,751 cells were converted to a point coverage that identified parcels that either remained pine/mixed forests from 1981 until 1993, or that changed from pine/mixed forests to urban/inert/barren during that time. To create our dependent variable, a value of zero (0) was assigned to points that were forested in 1981 and 1993, and one (1) was assigned to points that were forested in 1981 but urban/inert/barren in 1993. The point coverage of the dependent variable is referred to as "CHANGE" throughout the remainder of the paper. Figure 3 illustrates RANDOM and CHANGE.

Parcels form the 1981 and 1993 land-cover data that contained pine and mixed forest were selected from their corresponding grids. Polygon covers were created, providing the contiguous area of pine and mixed forests for each of those years: a cover for contiguous area in 1981 and a cover for contiguous area in 1993. These coverages of the contiguous area of forest are collectively referred to as "AREA" throughout the remainder of this document.

Demographic Data Set
The census geographic data set contained demographic information about St. Tammany Parish. This set was the source of demographic information used in the regression analysis. Maps of census blocks from the TIGER 92 CDROM from Louisiana (Bureau of the Census, 1993) were obtained and used to generate a polygon coverage through Arc/Info's TIGER Tool. The state FIPS identifier, parish FIPS identifier, Census Tract-Block Numbering Area (CTBNA) identifier, and block identifier were concatenated in the coverage to generate a unique identifier for each census block in St. Tammany Parish. The coverage containing the uniquely identified census blocks was dissolved to remove contiguous blocks with identical identifiers, thus creating a polygon coverage of more than 4000 census blocks; lines that represented roads, rivers, and other similar features were removed by the dissolve.

A unique identifier matching the TIGER 92 census block identifier was created for the database from the Block Statistics CD (Bureau of the Census, 1993) that contained the total population for each block. The database file was then imported into Arc/Info and joined with the TIGER 92 coverage that contained the census block locations. Population density was calculated by dividing the total population of a census block by the square-kilometer area of the block. By intersecting this coverage with CHANGE, a point coverage containing the population density at the randomly selected parcels was created. This coverage is referred to as "POPDEN" throughout the remainder of this document. Figure 4 depicts the population density of St. Tammany Parish in 1990.

Federal/State Highways and Interstate Interchanges
Interstates, and federal and state highways are able to handle high volumes of traffic and are constructed to higher standards than local roads. These roads serve as the primary arteries to the parish and tend to encourage residential as well as commercial development. The highways theme (ArcView feature file) contained the U.S. routes and state routes in St. Tammany Parish. Interstate highways were omitted. A theme identifying interchanges on interstate highways was also created. These themes were obtained from Wessex First Street through Arcview, and shape files were created. However, this information is publicly available from the USGS at 1:100,000 scale and from the TIGER 92 data provided by the Census Bureau.

The two data sets (the federal and state, and interstate interchange shape files) were imported into Arc/Info and converted into a coverage using the SHAPEARC command. The files were imported as line features and converted to 80-meter-resolution grids The Euclidean distances to the nearest federal or state highway and to the nearest interstate interchange were calculated using Grid. The grid containing the Euclidean distance to the nearest federal or state highway is referred to as

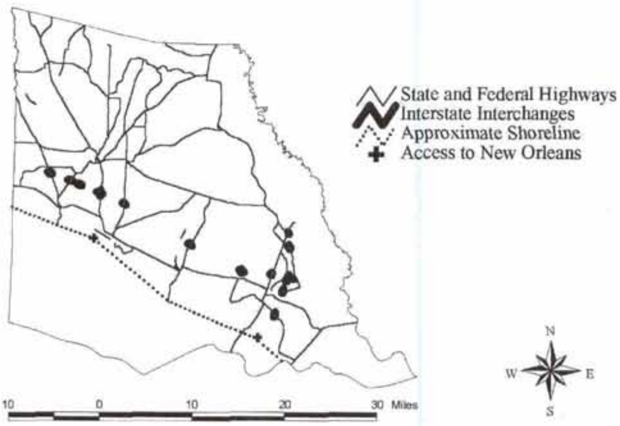

Figure 5. Transportation network: state and federal highways, interstate interchanges, and access points to New Orleans (excludes interstate highways).

"ROADS." The grid, referred to as "INTERCHANGE," contains the Euclidean distance to the nearest limited-access highway interchange.

Access to New Orleans

Many St. Tammany Parish residents commute to New Orleans. Lake Pontchartrain separates the parish from New Orleans and must be crossed by St. Tammany Parish commuters by one of three bridges. Two bridges (U.S. 11 and Interstate 10, collectively called the twin spans) connect Slidell to New Orleans and the third connects Mandeville to New Orleans (Causeway). The portions of the parish nearest these access points grew rapidly between 1981 and 1993, suggesting that distance to these locations may be an important factor in urbanization. We marked the entrances of the twin spans and the causeway bridge to create a coverage. A grid that contains the Euclidean distance to the nearest bridge access to New Orleans was developed for the analysis. This grid is referred to as "ACCESS." Figure 5 presents the transportation network in St. Tammany Parish and identifies the state and federal highways, interstate interchanges, and access points to New Orleans.

Preparing Data for SAS

All grid data sets (ROADS, INTERCHANGE, ACCESS) were masked with an 80-meter-resolution grid created from CHANGE. The resulting grids contained only information for the randomly selected parcels and then were converted to point coverages. The point coverages for ROADS, INTERCHANGE, and ACCESS, as well as the polygon coverages AREA and POPDEN, were intersected with CHANGE to create the coverage "SASDATA" containing the dependent and explanatory variables needed for the logistic regression analysis. The Point Attribute Table (PAT) from SASDATA was exported into a comma and quote delimited format through INFO (use the export command with the BASIC format option). SAS was able to import the comma delimited file format.

Statistical Model Development

We used logistic regression to estimate the probability that a particular parcel of pine or mixed forest would be developed. The dependent variable (CHANGE) was binary, with zero (0) indicating that the parcel of land was pine or mixed forest in 1981, and remained pine or mixed forest in 1993. A one (1) indicated that the parcel of land was pine or mixed forest in 1981 but was developed (urban/inert/barren) in 1993. Based on prior research (Munn and Evans, 1998; Alig *et al.*, 1988; Alig, 1986), several independent variables were evaluated; the final model included population density (POPDEN), distance to access points to New Orleans (ACCESS), the distance to a federal or state highway road (ROADS), the distance to the nearest interchange on a limited access highway (INTERCHANGE), and the area of contiguous pine or mixed forest cover in 1981 (AREA).

Equation 1 is the logistic model used for the analysis (Hosmer and Lemeshow, 1989): i.e.,

$$\pi(x_i) = \frac{e^{\mathbf{X}_b}}{1 + e^{\mathbf{X}_b}} \tag{1}$$

where, for each parcel "i," $\pi(x_i)$ is the probability that a 0.64-ha parcel will change from pine or mixed forest to urban/inert/barren, and $\mathbf{X}_b$ is the matrix of independent variables ($b_0 + b_1X_1 + \ldots + b_nX_n$).

Equation 2, the logit equation, is the log transformation of Equation 1: i.e.,

$$\ln[\pi(x_i)] = \mathbf{X}_b \tag{2}$$

where, for each parcel i, $\ln[\pi(x_i)]$ is the log odds that a 0.64-ha parcel (80- by 80-meter pixel from the satellite image) will change from pine or mixed forest to urban/inert/barren, and $\mathbf{X}_b$ is the matrix of independent variables ($b_0 + b_1X_1 + \ldots + b_nX_n$).

The logit model developed contained continuous independent variables which greatly reduces the number of data sets (covers and grids) that must be generated. Equation 3 is the specific logit model used to estimate the log odds that a pine or mixed forest parcel will be developed: i.e.,

$$\ln[\pi(\text{CHANGE}_i) = b_0 + b_1\,\text{POPDEN}_i + b_2\,\text{ROADS}_i + b_3\,\text{ACCESS}_i + b_4\,\text{AREA}_i + b_5\,\text{INTERCHANGE}_i \tag{3}$$

where

- CHANGE_i = 1 if parcel i changed from pine forest to urban/inert/barren, 0 if it remained pine forest;
- POPDEN_i = population density of the block containing parcel i;
- ROADS_i = the Euclidean distance (km) to the nearest primary or secondary road to parcel i;
- ACCESS_i = the Euclidean distance (km) from the Twin Spans in Slidell or the Causeway in Mandeville to parcel i;
- AREA_i = the area (ha) of contiguous forest cover in 1981 for parcel i; and
- INTERCHANGE_i = the Euclidean distance (km) from parcel i to the nearest interstate interchange.

Projecting Future Timberland Locations

Once the model was developed, projections were made for 2003 using the same model structure. Data for all variables except population density and contiguous land area were held constant. A new value for the contiguous area of pine/mixed forests (AREA), obtained from the 1993 polygon cover of pine and mixed forest (previously described), was used. Estimates of future population density were obtained from the St. Tammany Parish Government (St. Tammany Management Information Services, personal communication, 1998) and were used for the values for POPDEN. These data were utilized to the predict the development of pine/mixed forest lands by 2003.

The location of pine/mixed forests likely to be developed and the remaining pine/mixed forests then could be determined based on the predicted probability of development values. The only changes evaluated for the study were the loss of pine and mixed forests. Changes from agricultural to forests,

Table 3. Estimated Maximum-Likelihood Parameters, Standard Errors, Wald Statistics, and Probability of a Greater χ^2 for the Probability of Development Model

Variable	Parameter Estimate	Standard Error	Wald χ^2	Pr > χ^2
INTERCEPT	−0.4757	0.1287	13.6699	0.0002
POPDEN	0.00549	0.000257	455.8191	0.0001
ROADS	−0.5364	0.0602	79.3417	0.0001
ACCESS	−0.690	0.00929	55.1429	0.0001
INTERCHANGE	−0.1638	0.0155	111.9281	0.0001
AREA	−0.0001	0.000006	2.7955	0.0945

Notes:
- $n = 12{,}751$
- POPDEN = population density (person/square km)
- ROADS = distance (km) to the nearest non-limited access primary or secondary road (all U.S. and state routes)
- ACCESS = distance (km) to nearest access point to New Orleans (major metropolitan destination)
- INTERCHANGE = distance (km) to nearest interstate interchange
- AREA = contiguous area of pine/mixed forest in 1981

forests to agricultural, or urban to forests were not evaluated for a number of reasons. First, the objective of the study was to assess the impact of urbanization on forested areas only. Commercial forest areas were of primary concern so forest areas with a significant pine presence were selected. In St. Tammany Parish, deciduous forests grow in wet/riparian areas that limit commercial usage.

More importantly, assessing the changes between agricultural lands and forests was complicated by the satellite data used in evaluating land-use change. Specifically, distinguishing agricultural lands from recently harvested forest land was difficult, at best, with the satellite images employed. While this problem was alleviated somewhat by field verification, efforts were focused on examining the forest to urban change patterns.

Results

Model Development

The results of the regression indicate that the development of pine and mixed forest tracts in St. Tammany Parish were influenced by demographic and spatial factors. Specifically, population density, distance to state and federal highways, distance to commuter access routes to New Orleans, and distance to interstate interchanges are significantly related to development. Area of contiguous pine and mixed forest cover was not significantly related to the log-odds of development.

Table 3 presents the maximum-likelihood parameter estimates, standard errors, Wald statistics, and probability of a greater Wald statistic for the multivariate model described in Equation 3. The signs of the parameters indicate the direction of the influence a variable has on the log-odds that a parcel of pine or mixed forest will be developed. For example, as POPDEN (population density) increases, the log-odds (as well as odds and probability) that a forested parcel will be developed increases. Conversely, as ROADS, ACCESS, or INTERCHANGE increase, the log-odds that a forested parcel will be developed decreases. AREA (area of contiguous pine/mixed forest in 1981) cover had no significant impact on whether or not a parcel was developed.

The odds reflect the relative influence of each variable in the model when compared to a baseline. We define the baseline to be the mean values for POPDEN, ROADS, ACCESS, INTERCHANGE, and AREA. Holding all other variables constant at baseline, as population density in a census block (POPDEN) increased 100 people/km^2, the odds of development increased 73 percent. As distance from a forested parcel to a state or federal highway (ROADS) increased by 1 km, the odds of development decreased 42 percent. As distance from a forested parcel to the major commuter access routes to New Orleans (ACCESS) increased by 1 km, the odds of development decreased 50 percent. As the distance from a forested parcel to the nearest interstate interchange (INTERCHANGE) increased by 1 km, the odds of development decreased 15 percent. As the contiguous area of pine/mixed forest in 1981 (AREA) increased by 100 hectares, the odds of development decreased by less than 0.1 percent, further indicating that the contiguous area of pine and mixed forest does not significantly affect development.

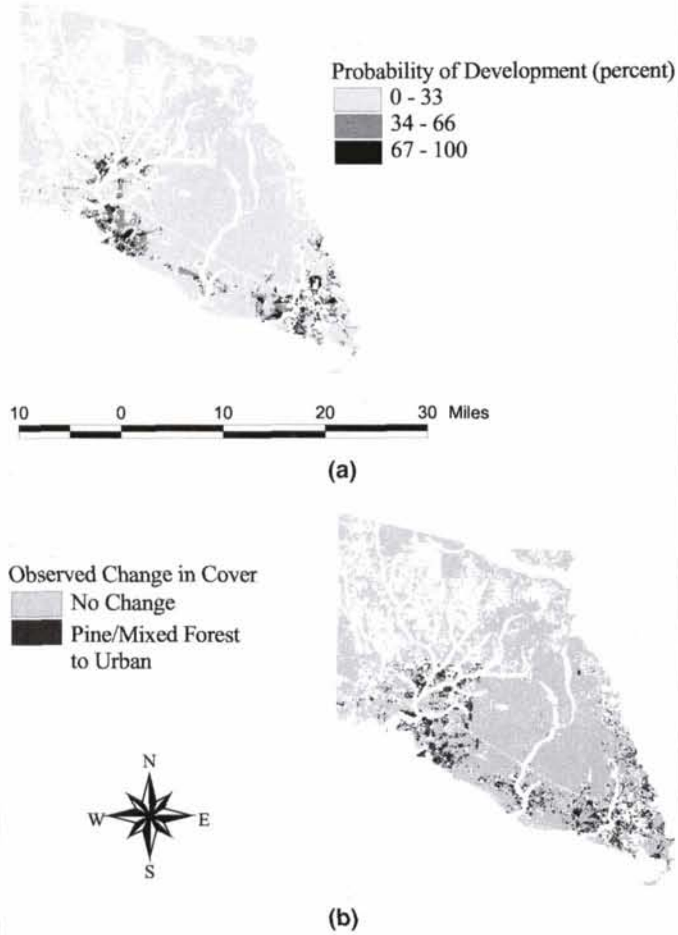

Figure 6. Probability of development of pine and mixed forest between 1981 and 1990, and the observed development between 1981 and 1993.

The Hosmer and Lemshow goodness-of-fit test ($\chi^2 = 43.355$ with 8 df and $p = 0.0001$) indicates that a better model may exist. The null hypothesis for this test is the model fits well; rejecting the null is undesirable. Information such as zoning, amenities, and incentives and disincentives to development are not incorporated into this model. Inclusion of such information may improve model fit, and such information may be more easily accessible in the future. The variables included in the model presented above significantly affect development, but excluded information, if it can be identified, could greatly improve fit.

A probability surface was created in the GIS by using Equation 1 with the estimated coefficients found in Table 2 and the variable values determined for the entire parish. Recall that each variable listed in Table 2 has a corresponding ArcInfo grid that contains values for those variables. Figure 6 identifies the pine or mixed forest parcels that were developed between 1981

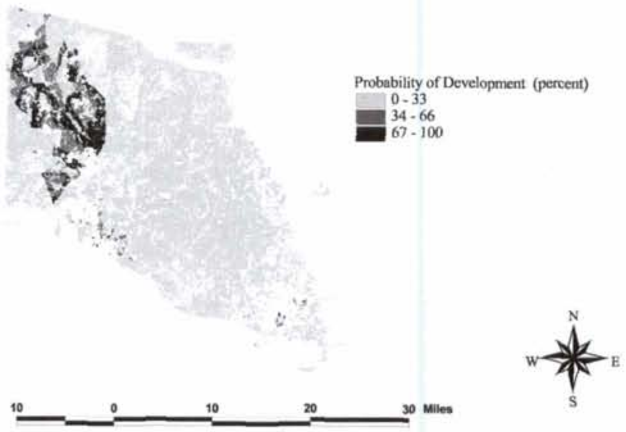

Figure 7. Probability of development of pine and mixed forest between 1993 and 2003.

and 1990 at different probability thresholds (Figure 6a), and identifies the forested parcels that were observed to have been developed during that period (Figure 6b).

2003 Projections

Projections to 2003 were developed based on the model parameters estimated above. Population projections were provided by the St. Tammany Parish government (St. Tammany Management Information Services). These values were used as POPDEN with the contiguous forest area in 1993 (AREA), distance to the closest state and federal highways (ROADS), distance to the closest commuter access point to New Orleans (ACCESS), and distance to the nearest interstate interchange (INTERCHANGE) to predict pine/mixed forests development in 2003. Values for ROADS, ACCESS, and INTERCHANGE remained unchanged from the values used to estimate the model parameters. Figure 7 illustrates the probability surface of development for 2003.

Discussion and Conclusions

These results indicate that the modeling/GIS approach could be useful in not only explaining current land-use change trends, but also in predicting future land-use scenarios based on projections of the independent variables. This will prove to be valuable to researchers as well as local government planners or land managers. In St. Tammany Parish, for example, the local government has recently adopted growth management zoning. The model developed as part of this study allows planners to evaluate future growth patterns based on population projections and infrastructure changes, identifying portions of the parish that may require growth management zoning. More important to resource management, the results will highlight areas of primary concern to local forest industry in terms of future timberland availability. The study reveals that as much as 16 percent of the forested area and 19 percent of the pine inventory could be lost to urbanization by 2003. This obviously has important implications for private companies and state agencies concerned with future timber supplies in southeastern Louisiana.

Employing a GIS to model forest lands lost to urbanization presents several advantages. First, much of the information needed for the model is publicly available in digital form that can be easily utilized. For example, the USGS provides digital line graphs of the nation's roads and the U.S. Census Bureau provides population estimates and demographic data. Second, a GIS allows analysts to assess not only the amount of forest land that will be lost to urbanization and other uses, but also the spatial distribution of the remaining forests. This may be invaluable for making industrial and policy decisions as well as evaluating the environmental and economic impacts of urbanization in a landscape. Finally, information exists that can be used in conjunction with or incorporated into the urbanization probability model to provide even more accurate estimates of how much and which forest lands will be developed. Information such as local zoning maps, spatial referenced growth management ordinances, and local tax structure will likely be digital in the future, and can be utilized to improve population estimates and identify areas where development is to be encouraged or discouraged.

The model can be expanded to examine a multi-parish region. A U.S. Forest Service Forest Inventory Analysis unit (FIA—typically five to ten contiguous counties) level re-estimation of the model would allow us to better utilize FIA volume data. The U.S. Forest Service performs ground-based inventories forest land in some regions of the country recording tree species, age, size class, volume, forest type, land use, and other information. Use of FIA volume data was limited in St. Tammany Parish by the small number of survey plots (31) that exist in the parish. A regional-scale model should be re-estimated using population density data from the block and block-group level. The models must be compared and evaluated for significant differences. Blocks, although desirable from a spatial-scale perspective, have two significant drawbacks at this time. One is data management. A five- to ten-parish region may have more than 30,000 blocks, which can significantly impact the ability to store, manipulate, and verify data. The other drawback to using block-level population density data is simply that predictions of future population density are not available at the block level. Block-group estimates are available. Although predicted population density can be proportionally divided among blocks based on historic ratios (as we did), population density is the most important factor affecting the probability of urbanization. An estimate at the block-group level will eliminate bias that may result from proportionally dividing population among blocks.

Land cover that has been consistently classified from satellite imagery would improve the model. Area and volume estimates may be more accurately estimated using a land-cover classification scheme that is consistent between periods. The classification scheme should be consistent with FIA forest types and size classes or an aggregation of FIA forest types and size classes to improve volume estimates. Using FIA data to help classify forest types and size classes from satellite imagery would improve the ability to predict the probability of development of forests.

In summary, the GIS/Land-Use Change Model developed for this study provides industrial and governmental decision makers with a means for predicting future development in rapidly urbanizing areas and/or the impacts of this development on timberland resources. With further refinements and a regional approach to allow for the use of FIA plot-level data, the GIS/Land-Use Change Model can provide reasonable projections of future timberland area, distribution, and volume. Moreover, the approach can be easily applied to other resource management questions, including urbanization effects on erosion and water quality, endangered species habitat, and recreational and aesthetics factors, and can provide projections of both total effects and their spatial distribution.

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