LAND USE, RECREATION, AND WILDLIFE HABITATS: GIS APPLICATIONS USING FIA PLOT DATA[1]

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Abstract—Spatial contexts govern whether and how land is used. Forest surveys inventory land uses from sampled plots and provide common forest resource summaries with limited information about associated nearby uses, or the landscape context. I used the USDA Forest Service's Forest Inventory and Analysis program of the South-Central States survey region (Alabama, Arkansas, Louisiana, Mississippi, east Oklahoma, Tennessee, and east Texas) to derive landscape context information. Methods employed moving averages (statistical combinations of sample plot observations with those from adjacent sample plots) to portray the spatial context, or "neighborhood" for forest resource appraisals. The survey region had 32,000 plots with land use information, and half of the plots classed as forest land provided more detailed information. Results yielded regional maps with displays of high and low probability of common land uses. For forest land, attributes shown include roads, forest fragment size, and hunting signs. Models of land use "hot spots" of competing and complementary uses are provided, forest land attributes important to selected recreational opportunity and wildlife habitat appraisals are discussed.

INTRODUCTION

The clearing of extensive forested areas for agricultural use was once a common practice in the United States (Williams 1989). Deforestation of this magnitude is not as widely practiced today, but anthropogenic influences continue to affect remnant, as well as regenerated forests. Livestock grazing intrudes upon otherwise exclusive forest land use in pasture-dominated regions (Rudis 1998, 2000). Major roads, urban and built-up land, and associated higher population densities encroach on an otherwise rural forested landscape, thereby reducing timber harvests (Barlow and others 1998). This urban sprawl frequently clashes with other rural land needs (Befort and others 1988).

Silvicultural management regimes, as well as complementary and competitive income sources, may also differ among regions dominated by neighborhoods with important recreational, urban, or agricultural pursuits, or with habitats of critically endangered wildlife populations. Depending on user demand and quality of neighborhood resources (e.g., scenery, game), income from nontimber forest enterprises can vary widely. In the southern United States, for example, lease fees in 1989 for hunting alone averaged between $1 and $15 per acre per year (Thomas and Shumann 1993). Forests near areas with high population densities are unlikely commercial wood sources as nontimber uses (e.g., aesthetics, real estate) may outweigh their use for timber production (Wear and others 1999).

The USDA Forest Service's Forest Inventory and Analysis (FIA) program monitors the status and change in forest land and provides sample-based information about forest resources. Commonly, FIA data users analyze and summarize FIA data from sample plots but often ignore the context, that is, the "neighborhood" of the samples. In addition, attributes that index nontimber forest products and uses are not widely known, such as those associated with recreation opportunities and wildlife habitats.

The main objective of this study was to illustrate the use of landscape context attributes for forest resource appraisals. A second objective was to consider the importance of selected attributes for recreation and wildlife habitat appraisals at the landscape level of analysis. Forest attributes included in this paper include roads, forest fragment size, and hunting signs.

Roads provide access to forests for passive uses like sightseeing and for extractive uses like timber harvesting. Roads and allied roadside vegetation management also alter the wildlife habitat value of forests (Forman and Deblinger 1998). For example, forests with extensive roads are less likely to support viable populations of black bear (Rudis and Tansey 1995) and snakes (Rudolph and others 1998). Roaded forests, by definition, are also less likely to support primitive recreation opportunities, such as hunting and backpacking (USDA Forest Service 1982).

Forest fragment size is inversely related to population density (Rudis 1998). Among bottomland hardwood forests, large fragments (>1,000 ha) are comparatively wetter and older. Large bottomland hardwood fragments contain fewer human intrusions than small (<100 ha) fragments (Rudis 1995). Large forest fragments are in short supply. They are valued for primitive recreation opportunities (Rudis 1987, 1995) and are key habitats for wildlife in need of seclusion from humans (e.g., black bear, venomous snakes) or requiring large expanses of forest land (e.g., Cerulean warbler). Simply because of their size and their scarcity, large forest fragments offer economic opportunities like tourism as well as reserves of future timber supplies. Small fragments have lower potential for a variety of resources but may be suited to other uses, such as picnicking, thermal cover for livestock, and windbreaks in agriculture-dominated neighborhoods.

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Hunting signs observed and associated with forested areas index a number of phenomena. At the very least, such an index shows the prevailing cultural practice and landowner concern about hunting activities. The presence of more abundant signs in one region or time period than in others also suggests (1) a concentration of landowners with hunting interests or leased land by hunt clubs, (2) greater apprehension over landowner liability, (3) concern for trespass by hunters, (4) conflict between landowners and sportsmen regarding hunting activities, and (5) a shortage in the supply of hunting areas relative to demand. An increase in sign density between surveys suggests a change in landowner attitudes toward hunting activities and a decline in subsistence hunting opportunities by low-income residents.

METHODS

Data used were from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) surveys conducted between 1988 and 1995 for the South-Central States (Alabama, Arkansas, Louisiana, Mississippi, east Oklahoma, Tennessee, and east Texas). FIA sampled land use systematically in a three-phase design involving forest and nonforest determinations from aerial photos, a check of photointerpretation for a portion of these, and a ground sample of a still smaller subsample (Miller and Hartsell 1992.) Although sampling with aerial photographs was 25 times more intensive, geographically referenced observations were available only for ground-sampled plots. Because of this lack of geographic referencing, other sample information was not included.

Each of the 32,000, 0.4-ha ground-sampled plots had an approximate latitude and longitude from reference maps. Samples were spaced at 4.8 km intervals. FIA crews obtained more detailed attribute information on about 17,000 plots classified as forest land. The definition of forest land included areas 0.4 ha and larger, >37 m in width, and not developed for nonforest uses.

To generate land use and forest attribute maps from ground-referenced information, I created a digital map of forest inventory plots (positional accuracy better than 0.8 km) to a geographic surface with the aid of ArcView geographic information science (GIS) software and maps (ESRI, Inc. 1996a, 1999.) Further details and additional examples of early results appear elsewhere (Rudis 1991, 2000, and in press.)

I transferred plot attribute information to 2.4-km grid cells oriented in cardinal directions to increase computation efficiency. The dimension of the grid cell was "small enough to define the most detailed geographic feature" (ESRI, Inc. 1996b), yet large enough to minimize computer memory storage space and software calculations. With a 2.4-km grid, I nominally assigned every plot to a unique grid cell.

For indicator attributes, I recoded observations as 0=absent, or 1=present, averaged the observations for a given range of samples, and obtained average probability of occurrence, in percent. For interval attributes, I used attribute values themselves to calculate averages and compared average values using standard deviations above and below the mean. When needed, I transformed the values to obtain a normalized frequency distribution.

Moving Averages

Averages per grid cell were estimates from plots within a circle of a given radius. The term is referenced as a "spatially moving average." Grain size was defined as the radius of the circle used to calculate the spatially moving average. Only grid cells associated with sample plots contributed to the averages. A grain size of 4.8-km radius encompassed about 13 of the 2.4-km grid cells (7,240 ha), up to five of which contained FIA sample plots. For land use occurrence probability estimation, results yield an occurrence probability of 0, 1, 2, 3, 4, or 5, out of five samples.

The spatially moving average yields an isotropic probability for forest land. Small-scale aerial photographs, however, show forest land as more frequent along the direction of steep terrain and adjacent to water courses, and as associated with particular soils and climates. The simplified averaging procedures used in this report ignored them. Furthermore, because FIA locations of sample plots were on a regular grid, I made no extensive examination of alternative grain sizes.

I employed the circular neighborhood mean statistics function within ArcView with the Spatial Analyst extension (ESRI, Inc. 1999). Calculation of means for forest-collected attributes provided averages for adjacent nonforest land, a scenario in classical statistics comparable to drawing a regression line beyond the range of the sampled region. To mask these areas, I created a layer of grid cells with 20 percent or less forest land probability, based on a 4.8-km radius grain size and averaged from all sampled plots. For the seven-State FIA survey region, this nonforest mask included extensive areas of nonforest land in the Mississippi Alluvial Plain. I also masked out areas with no FIA plot samples (nonsurveyed locations and largely nonforested counties in western Oklahoma, western Texas, and extreme southern Louisiana).

For forested plot attributes, I used a radius of 24 km—a size with resolution suitable for multicounty decisions, e.g., multiagency, Federal, and regional planning. The 24-km radius grain size approximated the size of a county planning area, or portion of a large city, which a larger grain size could obscure. This grain size is likely coarse for local management purposes, but provides broad contextual information. The 24-km grain size yielded averages nominally represented by 25 forested plots. Exceptions were in sparsely sampled, sparsely forested regions, where averages were based on fewer samples.

Kriging

Unlike the more straightforward "averaging" technique listed above, kriging is memory intensive for large data sets. Kriging yields grid-cell averages based on a distance-weighting scheme, with the nearest sample plots, typically 16, contributing the most information. The radius specified is large to ensure that averages are based on 16 plots, even in a sparsely populated sample region. Contrary to moving average interpolation, changing the radius will usually yield only small differences in resulting patterns.

The analyst must choose among several weighting schemes, based on an examination of the geographic relationship of sampled values and sometimes by knowledge of the spatial association of phenomena under study. In a linear weighting scheme, the value at one grid cell location corresponds directly (1 to 1) with the value at an adjacent grid cell location.

I converted indicator plot values to an indicator probability surface interpolated with kriging, using ArcView with the Spatial Analyst extension and GS+ software (Gamma Design Software 1998). GS+ interpolated the surface with a 2.4 km grid.

Field Attributes

FIA field crews made a general determination of land use on each sample plot. On forest land, they collected traditional timber variables, such as stand diameter class (i.e., stand size in timber reports), forest type, harvest activity, owner class, site productivity, and stand origin. Crews also collected nontraditional variables like livestock grazing, presence of trash, and proximity to urban and built-up land. Maps of other results based on moving averages appear elsewhere (Rudis 2000, and in press).

Selected results in this paper include the use of moving averages to assess forest land, forest fragment (patch) size, road proximity, and hunting signs. More recent results include averages using kriging, with overlays of county-based ecological subregion boundaries (Rudis 1999) to highlight regional, within-State differences. The example includes a spatial prediction of predominant land use.

Land use—The classification of land at 0.4-ha sample plots by use classes. Categories were forest, cropland, pastureland, urban and other land uses, marsh, and noncensus water. Definitions follow Anderson and others (1976) land use classifications. FIA survey manuals describe additional details (FIA Staff 1994).

Forest fragments—Contiguous forest cover unbroken by nonforest cover. A “contiguous” forest meant a patch of forest unbroken by water or nonforest land cover >37 m wide, as determined by field visits and the aid of 1:58,000 scale high-altitude color-infrared aerial photographs. Forest fragment size classes (and midpoints used in averages) were 0.4 to 4.0 ha (midpoint 2 km), 5 to 20 (12), 21 to 40 (30), 41 to 202 (121), 203 to 1,012 (607), 1,013 to 2,023 (1,518), and >2,023 (set at 3,323 ha). Because the frequency distribution of forest fragment size class was lognormal, I calculated averages using logarithm-transformed midpoint values. Though one fragment could be large enough to be associated with more than one sample plot, I assumed every plot was a different fragment.

Roads—Travel corridors associated with vehicular transportation. From the sample plot to the nearest road, FIA field crews measured proximity in 30 m intervals to 1600 m (100 ft intervals, to 5300 ft). FIA field crews judged roads as capable of travel by four-wheel drive vehicles, termed “truck-operable or better” roads.

Hunting signs—Signs encountered by field crews within 400 m (1,320 ft) of a sample plot. These signs listed “no hunting,” “hunting restricted,” or “posted” and were commonly associated with the sample plot.

RESULTS AND DISCUSSION

Figure 1 illustrates the distribution of forest land by sample plot location and by interpolated forest land probability. Forest land probability was low in the Mississippi Delta (western Mississippi, east Louisiana, and eastern Arkansas) and other predominantly agricultural areas along major rivers. Forest land probability was also low in the Blackland Prairie crescent spanning the States of Mississippi and Alabama. Forest land probabilities were higher in other areas.

Forest Fragments

I used forest fragment size class to illustrate an example of an interval attribute. Figure 2 depicts the spatial distribution of mean fragment size. Most of the large fragments were either in mountainous areas, such as the Boston Mountains of the Ozark National Forest, or in low-lying areas, such as the Atchafalaya Basin of Louisiana. Black bear occupy many of these same sites (Maehr 1984). The most fragmented forests (Memphis, Central Tennessee, Longview [Texas], and agriculture-dominated areas) do not contain black bear.

Large fragments that occur on Federal and State land serve as habitats for wildlife in need of seclusion and provide primitive recreational opportunities. Results indicate that the public agencies associated with these areas have been successful in conserving these uses.

Figure 3 (see page 134) illustrates that roaded forests near roads were abundant throughout the South and more abundant in selected regions. An extensive road network appears near forests throughout south Mississippi and parts of other States, particularly within the Southern Coastal Plain. By contrast, roadless forested areas were rare. The only extensive roadless forested area was in Louisiana’s Atchafalaya Basin, which suggests that its scientific and ecological value may surpass its value for forest production or development.

Land Use

The last two examples employ kriging to depict land use in east Texas. Figure 4 (see page 135) shows land use in east Texas for the 1992 FIA survey. A linear weighting scheme yielded the highest r-square autocorrelation (> 0.65) and lowest residual sums-of-squares.

Pastureland dominated in the western part of east Texas, urban areas to the southwest (Houston area), and forests to the east. Given these patterns, one might logically expect livestock to use forests in pasture-dominated areas. In fact, livestock grazing occurred on a third of the forests in the western ecological province, compared with 10 percent throughout the south central region (Rudis 1998). The urban-dominated areas encompassed the outskirts of major cities—the most prominent of which was in the southwest corner (Houston metro area, Harris County).

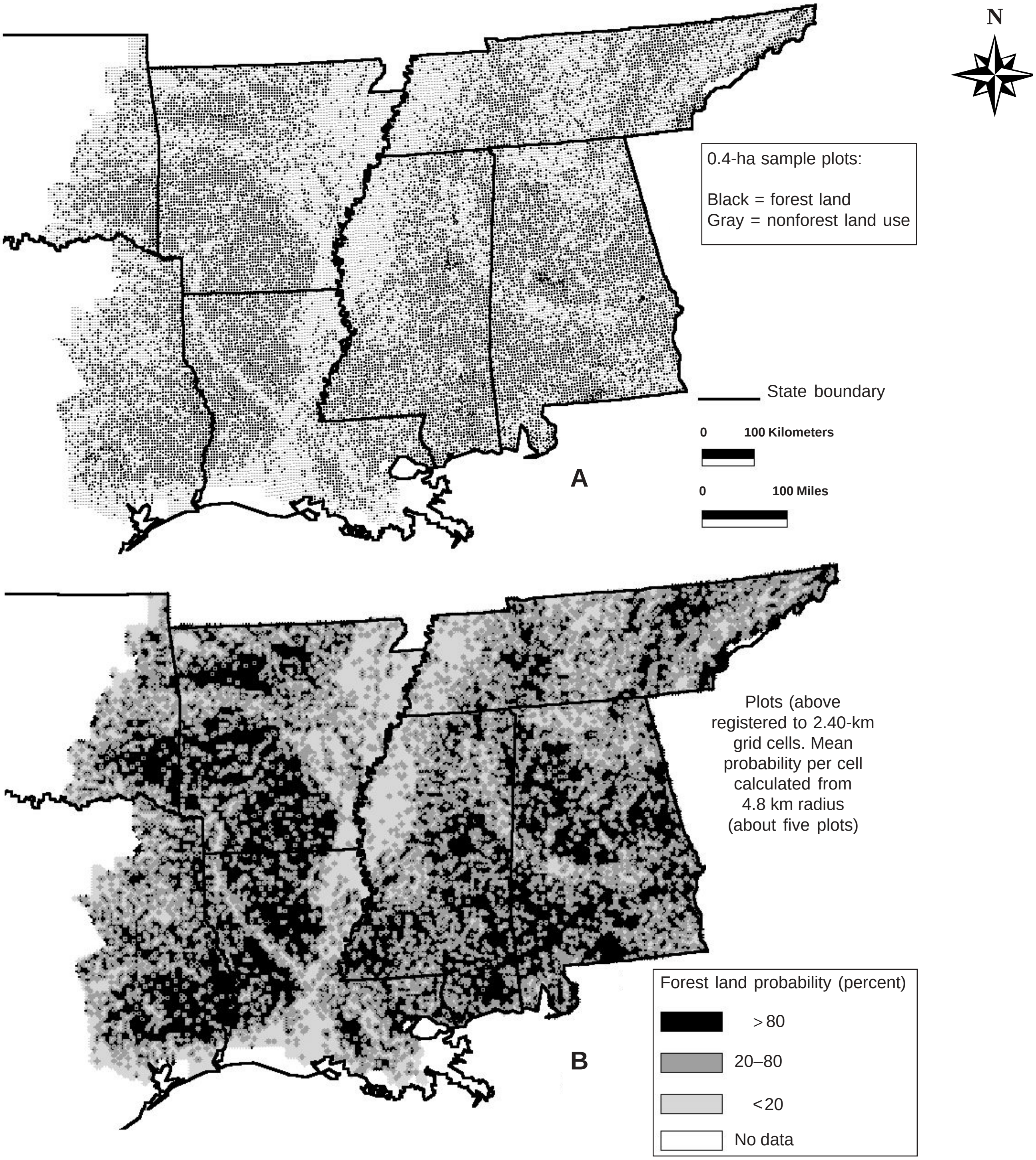

Figure 1—Forest and nonforest land use, U.S. Forest Inventory and Analysis surveys. South-Central United States, 1988–1995: (A) sample plot locations, (b) forest area probability. Forest land probability was generated using a 4.8 km radius moving average and mapped to a 2.4 km grid.

Each of these patterns suggest that forests in nonforest-dominated areas serve more as shade for livestock or as landholdings for urban uses than as forests with continuing timber production potential. Hence, forest resource appraisals stratified by predominating land-use class—whether it is pasture, urban, or forest—will likely improve estimates of forest resource supply.

Hunting Signs

Forest land with hunting signs represents 11 percent of the resource in the South-Central States FIA survey region (Rudis 1998). The spatial distribution of forests with hunting signs appears in figure 5 (see page 136) for two sample periods. In both surveys, hunting restrictions were more frequent in the northern half of east Texas. One

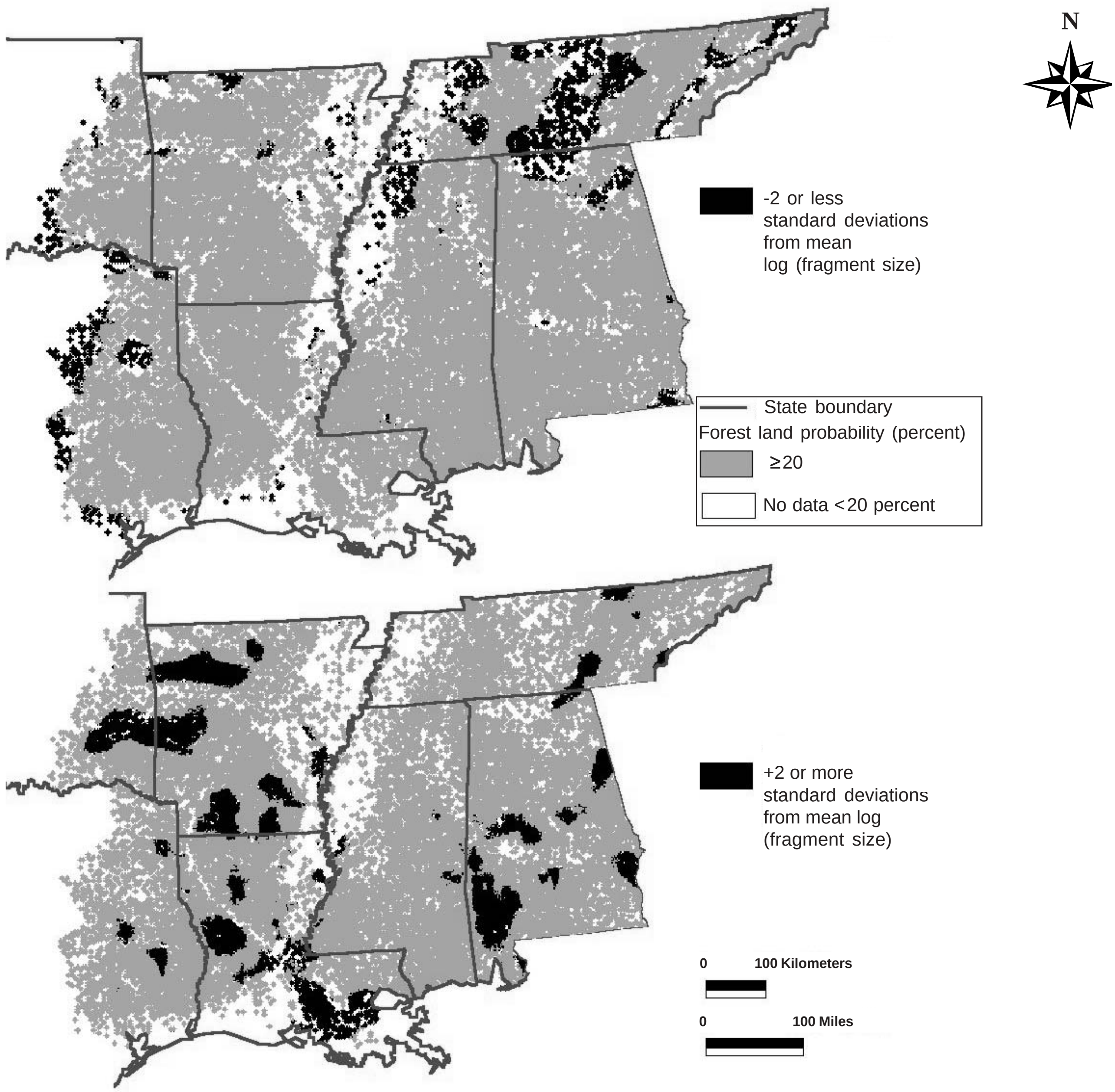

Figure 2—Deviation from average forest fragment class, forest land probability 20 percent or more, South-Central United States, 1988 to 1995 surveys. Averages were generated using a 24 km radius moving average and mapped to a 2.4 km grid.

hypothesis is that because both forests and public land areas are relatively limited to the north, landowners may be (1) selling more private land leases for hunting on a per-acre basis, and (2) resisting public use of forest land for hunting. Analysts need additional evidence, such as deer kill surveys, sportsman license sales, or landowner studies, to draw definitive inferences. The suggested increase in restricted forests for Wood County, TX, bears further investigation.

FUTURE PROSPECTS

Critical to any mapping scheme is having geographically referenced observations from which to draw inferences. From a mapping standpoint, the more information received from all sampled plots, not just those visited on the ground and not just those having detailed attributes only for forested land, the better will be the resulting estimation of the “neighborhood.” Studies have already implicated road density, road proximity, and fragment size class in the distribution of wildlife populations (Rudolph and others 1998, Rudis and Tansey 1995) and recreation uses (Rudis 1987). The next steps in the analyses are to improve the reliability of these indices as surrogates for the number of recreation users, the percentage of landowners with specific intentions, and the number of hunters. Such improvements could take the form of user and landowner surveys.

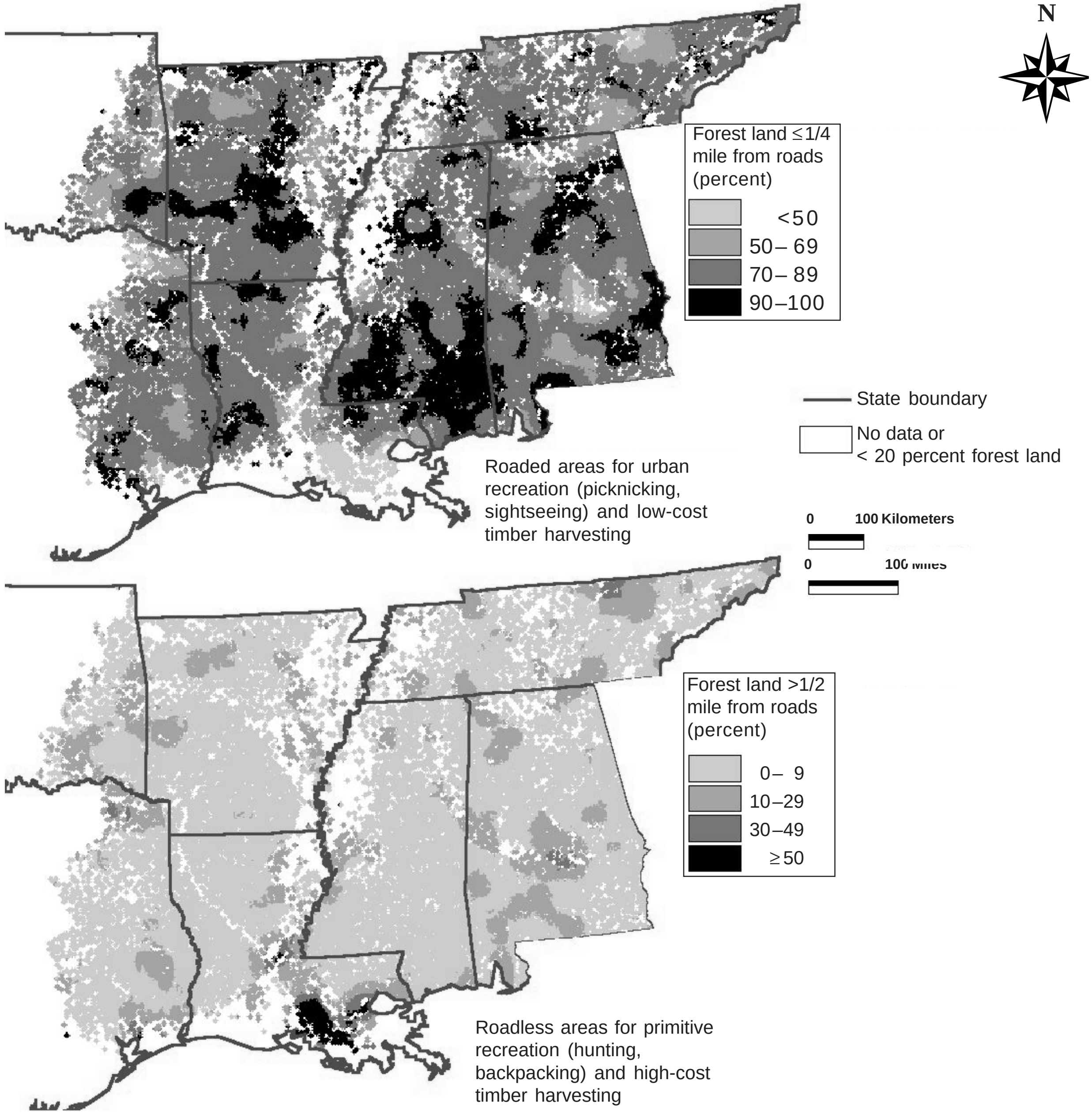

Figure 3—Roadless and roaded forest probability, forest land probability 20 percent or more. South-Central United States, 1988-1995 surveys. Averages were generated using a 24 km radius and a 2.4 km grid interpolation.

Map certainty is the confidence of an attribute's value at a given location and attribute variation near the location. A straightforward appraisal of map certainty is to list the number of samples used to estimate the value of each grid cell. Among land-use attributes, map certainty is greater in regions with more samples. Among forest land attributes, map certainty is greater in regions with abundant forests. Map certainty in land use estimates is relatively uniform because FIA sampling is regularly spaced throughout the survey region. Certainty in mapped forest attributes information is lower in sparsely forested regions, such as the Mississippi Delta, and higher in densely forested regions, such as the Boston Mountains of Arkansas.

Relaxation of the isotropic forest probability assumption and incorporation of information from other data sources are other ways to improve resulting maps. Incorporation of classified digital imagery from satellite sensors permits a reduction in the grain size (and an increase in the resolution) of sensor-detected earth cover classes, while still providing thematic information from ground-sampled observations. Concurrence of prediction in attributes mapped from other geographically referenced, correlated data, such as soils, climate, and geology, boosts confidence in attribute variation for a given location.

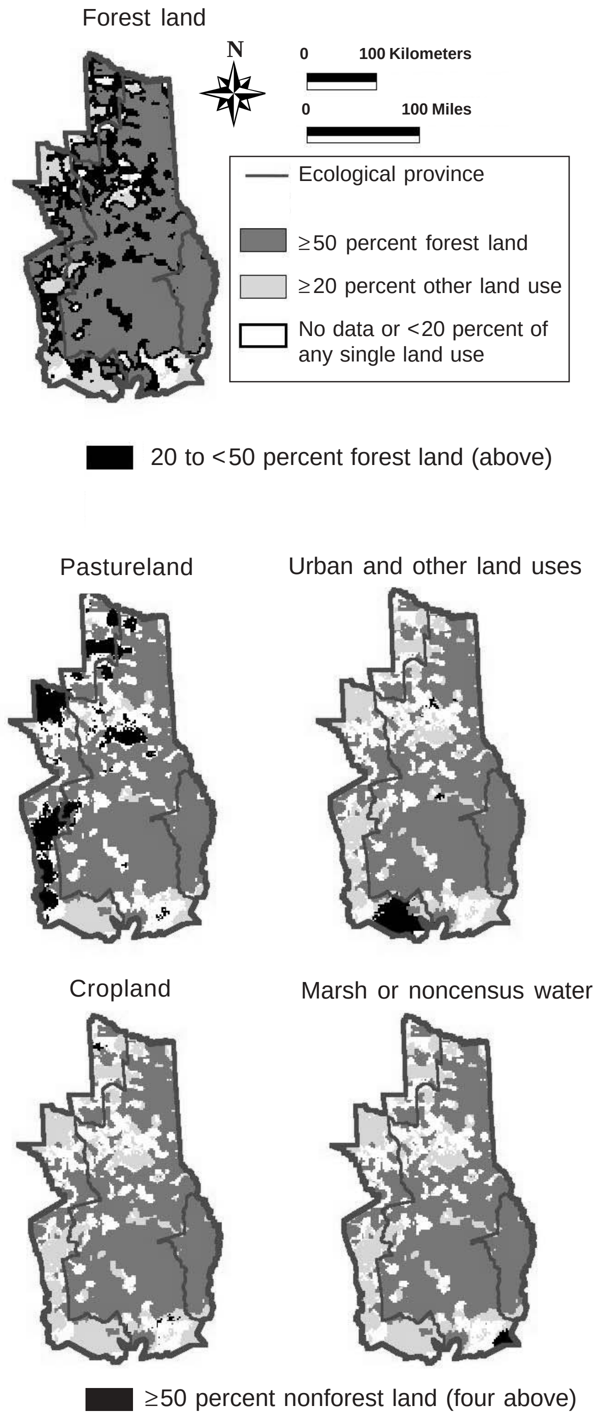

Figure 4—Land use probability, east Texas Forest Inventory and Analysis survey. Averages were generated using kriging with a linear weighting scheme for the 16 nearest samples and a 2.4 km grid interpolation.

In conclusion, GIS provides additional tools for evaluating the spatial context of FIA plots for forest resource appraisals, particularly the context of associated nontimber values. Examples in this paper portray land use, wildlife habitat, and recreational opportunities. Knowing where the phenomena occur, even in general terms, provides the analyst with added information about likely timber supplies, occurrence "hot spots" of predominant and potentially competing resource uses, and change over time.

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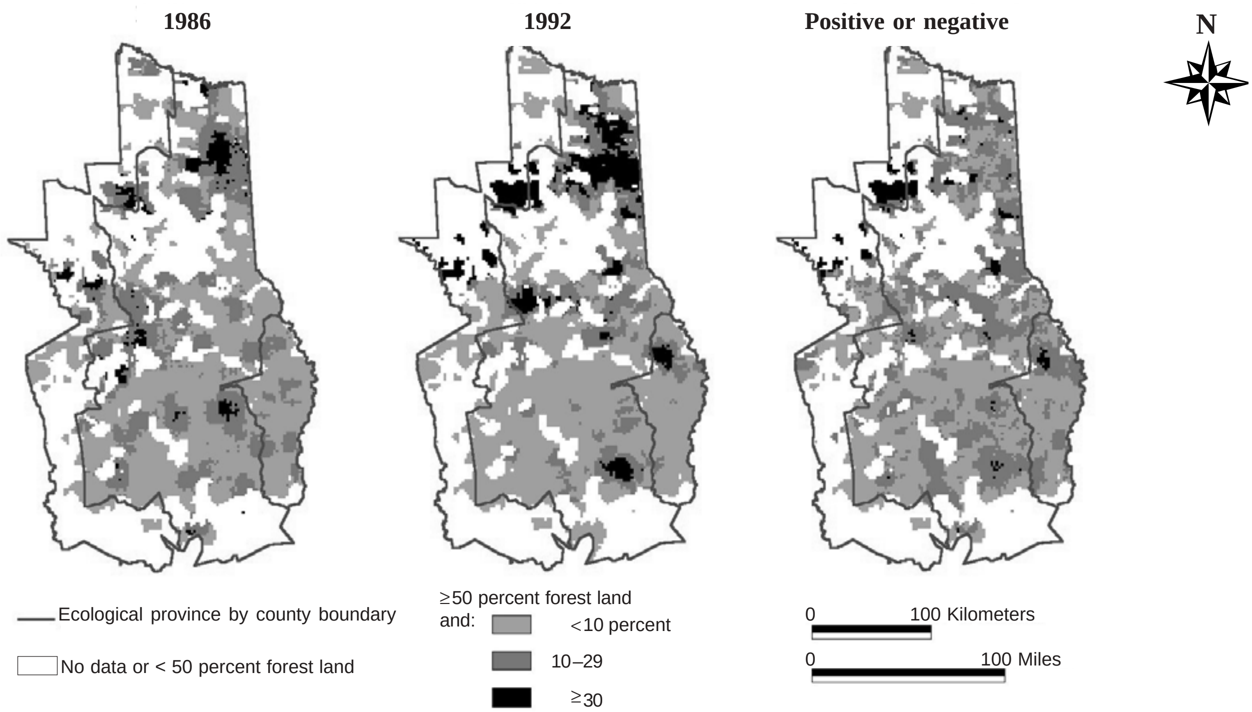

Figure 5—Forests with restrictive hunting signs, forest land probability 50 percent or more, east Texas, 1986 and 1992 surveys, and change since 1986. Average probability of forests with restrictive hunting signs was generated using a 24 km radius and a 2.4 km grid interpolation. Forest land probability was generated with kriging, as in figure 4.

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