People, Space and Time: Factors That will Govern Forest Sustainability

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Introduction

People and their social organizations are the most substantial agents of change in forested ecosystems throughout the world. Even in the developed countries in the temperate latitudes, ongoing growth and the transformation of economies continue to reshape forested landscapes. Resulting changes in both the extent and the structure of forests hold consequences for ecological function and environmental health. Accordingly, it is important to understand how people have and may further change the condition of forested landscapes in order to gauge the prospect for forest sustainability.

Specifically, a better understanding of how people make choices regarding land and resources in pursuit of various benefits is needed. Lands shift into and out of crop production in response to crop prices. Timber is harvested from forests based on the value of various forest products. People set aside their land for recreation in the pursuit of peace and quiet as congestion increases. The cumulative human impact on landscapes is a consequence of all individual choices intended to pursue individuals' goals in response to the general scarcity of goods and services produced by lands in the region. This is especially true in the U.S. South where nearly all land is held by private owners. People are at the center of sustainability for other reasons as well. It is ultimately the provision of goods and services, including environmental services such as clean water and air, that motivate social concerns for sustainable development, and it is only through social systems—e.g., resource markets or political institutions—that any substantial changes in forested systems could be achieved. Understanding

how these systems interact with individual behavior to shape landscapes is crucial knowledge for defining strategies for sustainable development.

In addition to improving our knowledge of how human and natural systems interact (a long-term research endeavor), in the short run we also need to develop approaches for monitoring and forecasting human impacts on forested ecosystems. Criteria and indicators for social and biological components of forested ecosystems are at the core of current sustainability initiatives. At present, these indicators measure vectors of change and their consequences in isolation, and little work has been done to develop synthetic indicators that can monitor the underlying processes of change at appropriate scales. This paper examines the definition and use of indicators of change in forest conditions and how they might be adapted to monitor processes of change. In particular, we examine the two principle vectors of change in forested ecosystems, land use and timber management, and how these changes might be adequately monitored. We find generally that broad-scale indicators of sustainability may, at best, be devoid of information; at worst they may mislead. The paper discusses challenges for measuring forest conditions, especially in a way that connects human actions with ecological consequences.

Vectors of Change

While human populations have many direct and indirect effects on the structure and function of forested ecosystems, land use and timber harvesting and management summarize a majority of significant impacts. These vectors of change have been applied to nearly every acre of the South (with the possible exception of some small inaccessible swamp areas). Furthermore, land use and timber management are vectors that continue to be in flux, and they will shape the future landscape of the South. Tracking these two powerful forces of change should provide useful aggregate information on the sustainability of forested ecosystems in the South and elsewhere.

Land Use

Forests can be viewed as a residual land use in the South. Do nothing with land in this region, and it will become wooded. Much of today's forests originated in this manner, reverting to forest either after a timber harvest or after an agricultural practice was abandoned. Alternatively, forestation can be viewed as an active investment, and over the past couple of decades, forests originating from tree planting have expanded considerably. These two definitions of stand origin provide endpoints on the broad spectrum of actual forest uses.

Tracking overall timberland area in the South provides one measure or indicator of the persistence of forests in the South. Timberland area peaked in the South in the mid-1960s at about 209 million acres. Between the '60s and '70s, the amount of timberland declined to about 200 million acres, as land was converted mainly to agricultural uses and then leveled off (Powell et al. 1993). This stability, however, masks some countervailing changes. Over the last 15 years, timberland area has declined somewhat in the southeastern portion of the South (the states from Virginia to Florida) but has increased in the southcentral region (the remaining states).

To the extent that most forestland is a residual land use, it is important to understand what has happened with other land uses in the region as well. That is, in most cases it is not the value of forests that determines whether land becomes forested. Rather, it is the relative value of nonforest uses of land. Agriculture is the other dominant use of land in the South (measured here after excluding Texas and Oklahoma, because they can distort proportions) where cropland accounted for about 58 million acres in 1992 (Census of Agriculture). This is a decline of nearly 10 percent since 1982, due mainly to policies that have aimed to reduce the pool of cropland in the United States, especially on marginal lands. Policies in the agricultural sectors will likely continue to have direct impact on the area that becomes or remains forested in the South.

In the South (again exclusive of Texas and Oklahoma), roughly 56 percent of land is timberland and 18 percent is cropland. The remaining 26 percent is split into roughly thirds between grassland pasture, urban and other miscellaneous land uses. Urban land use is especially relevant to concerns regarding ecosystem sustainability. These areas represent the most substantial human footprints on lands. In these areas, dominated by impervious surface and high densities of human populations, ecosystem structure is greatly simplified and ecosystem function clearly disrupted. Roughly 25 million acres of land were in urban use in 1992. Percentage gain in urban area has been substantial, but over the last thirty years, the resulting percentage reduction in rural land use has been relatively small because of its large share of the landscape.

On the surface, the amount of timberland in the South indicates stability in forested ecosystems, with some countervailing declines in cropland and expansion in urban areas. The result is "no-net-loss" of forested area. But does the area of timberland completely illuminate changes in forest condition in this or any other region? Clearly not. The area of forestland may be stable while the age and species distribution of forests change dramatically. The ownership profile of forests may also shift over time portending changes in management intent, and forest productivity may increase or decrease in response to various forces.

The crux of the problem of developing a good indicator of forest sustainability is to measure something that proxies for the relative scarcity of the actual conditions of interest. The amount of timberland, however, may be flawed as an indicator of forest extent when we are concerned with measuring specific services rendered from forest, for example, the relative scarcity of certain ecological or wildlife values. The capacity to grow trees in an area not used for something else (the definition of timberland) may not be a good measure of the extent and especially the condition of forested ecosystems. A better indicator would be one that weights forested areas by factors that account for the effects of disturbance regimes or landscape structure on the production of specific ecosystem services. In the case of wildlife, for example, we need to augment measures of forested area to account for the effects that human presence may have on its habitat values. To explore this idea further, we examine the spatial distribution of human populations in the South and construct a measure of timberland that adjusts for potential effects of human presence on ecological function.

Influence of Human Populations

One way to account for human influence on the condition of a forest is to consider the population density in the vicinity of the forest. Forestland may occur in areas that range from practically no human presence to nearly urban conditions, and we posit that most ecological or habitat values of forest areas are inversely related to human population density. For example, Pye et al. (1997) find a strong relationship between population density and the average size of forest patches within southeastern counties. Average patch size decreases as population density increases. Patch size serves as an indicator of two types of ecological values. First, smaller patches mean more edge habitat and less interior forest habitat in the same area of forest. Second, average patch size is directly related to forest fragmentation. Reduced connectivity indicates barriers to species dispersal and in some cases to species persistence. Population density may therefore provide a proxy for fragmentation within forested areas.

Population has grown substantially in the South over the past 40 years. The U.S. Census indicates that population increased 84 percent, from 452.5 million in 1950 to 782.0 million in 1990. This population growth has not, however, been evenly distributed (Figure 1). Rather, it has been focused in certain areas, most notably Florida, other coastal areas, and the "Piedmont Crescent" from Raleigh, North Carolina to Birmingham, Alabama. In parts of these areas population has doubled or even tripled over this 40-year span. In contrast, other portions of the South, most notably a large area stretching from the Mississippi Delta to southeastern Georgia, experienced population declines over the same period, fueled largely by labor-saving technological change in agriculture.

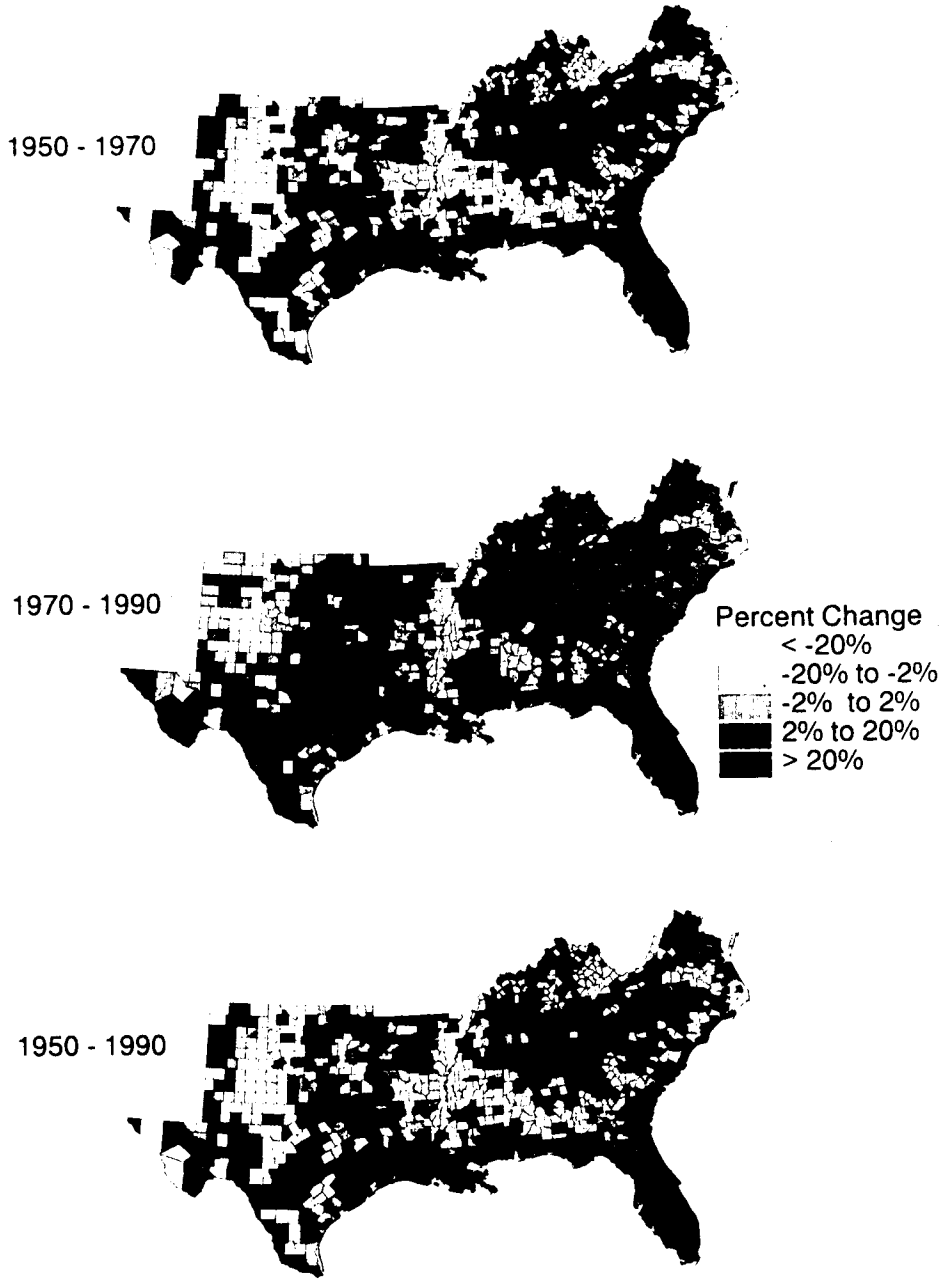

Figure 1. Percentage change in human population density for counties in the South, 1950-1990, measured for three periods.

Changes in population density do not have a proportional impact on the area of timberland within a county. To illustrate, Figure 2 charts the share of timberland in North Carolina counties as a function of population density. As expected, the function shows a negative relationship between population and timberland area. However, it indicates also that a majority of a county will still be considered timberland up to a population density of about 550 people per square mile. At even 1,000 people per square mile (the upper end of the range of population densities in North Carolina), the share of timberland is still about 32 percent. This suggests that a portion of timberland in the South is located in an essentially urban environment. In these urbanized counties, it is clear that while land may meet the physical criteria for timberland, the forest may have neither commercial timber nor ecological attributes of great value (though they may have considerable aesthetic and other environmental values).

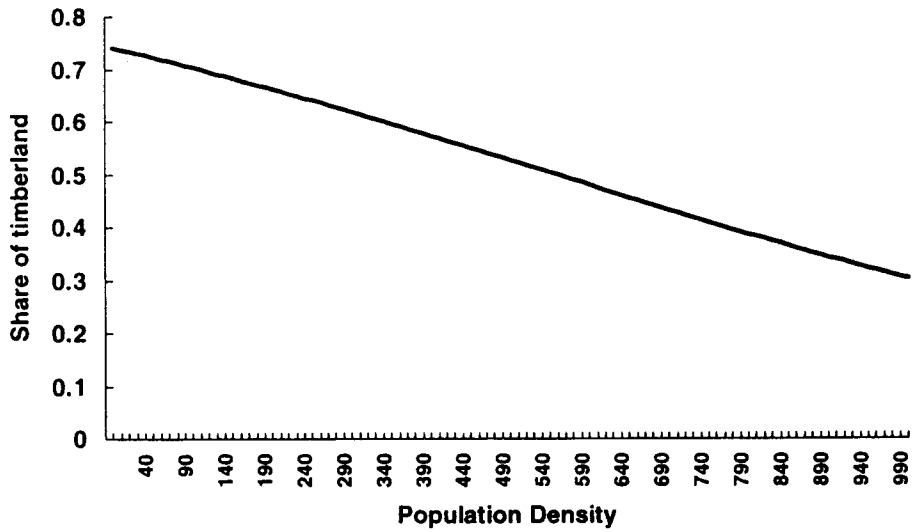

Figure 2. The share of a county classified as timberland as a function of population density. Relationship is defined using a logistic regression and controlling for the share of land in agricultural use. For the displayed relationship, the share of cropland is held constant at 15 percent.

To fully develop these effects of human population density on forest areas requires some weighting for human presence. Ideally, this would be based on research regarding the effect of population density on specific ecological functions. Here we demonstrate the potential effects of human presence on forests by constructing an ad hoc index that weights North Carolina forest by an

inverse function of a county's population density based generally on the relationship between population density and average patch size. The function is scaled by assuming that forests in rural areas with population densities of 9 people per square mile (the minimum population density in the state) are not impacted by human presence. These areas receive a weight of 1.0. At the upper end of the scale (1,000 people per square mile) we assume that forestland is so fragmented that it loses all of its ecological or habitat value. These areas receive a weight of zero. We estimate the weights for intermediate densities using an exponential function motivated by the log-log relationship between patch size and population density:

$$weight = e^{-0.005 * population\ density}$$

Figure 3 summarizes the implications of this adjustment scheme by comparing measured timberland with weighted timberland for the three most recent forest inventories of North Carolina (1974, 1983 and 1992). Weighting timberland area by population density reduces effective timberland area by an average of about 35 percent across these surveys. More importantly, the weighted measure indicates a different pattern of change when compared with raw timberland. Raw timberland declined between 1974 and 1983 at about -0.6 percent per year, but then increased slightly between 1983 and 1992 (+0.2 percent per year). In contrast, population weighted timberland declined by -.8 percent per year for 1974 to 1983 and -0.3 percent per year for 1983 to 1992. As a result, the ratio of effective timberland to measured timberland declined over time.

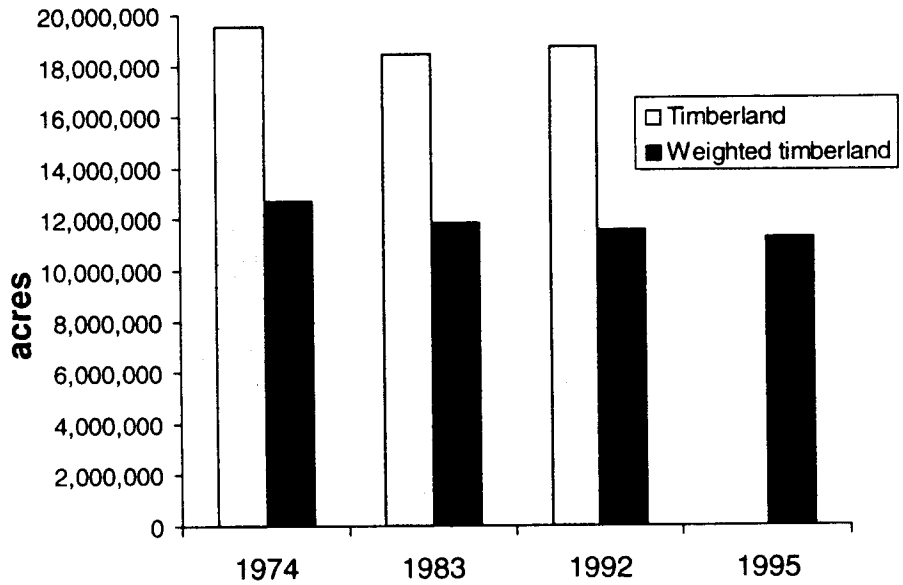

Figure 3. Raw timberland and population-weighted timberland area in North Carolina for three forest inventories (1974, 1983, 1992) and projected for 1995.

To examine the potential effects of the most recent population growth in North Carolina, we weighted timberland area from the 1992 survey with population densities estimated by the Bureau of Census for 1995. The result indicates a further erosion of effective timberland. Furthermore, the forecasted loss of effective timberland is at substantially higher rate (-0.9 percent per year) than estimated for the 1983 to 1992 period (-0.3 percent per year). This provides some indication that most recent development in North Carolina may be having substantial effect on the extent of forests in the state before even accounting for the likely loss of raw timberland (though these losses might be mitigated by transitions from agricultural to forest uses).

Clearly, this is an arbitrary weighting scheme, but our intent here is to illustrate some concepts (we did however, apply some sensitivity analysis to the relationship between the endpoints and found the pattern of results quite robust to these changes). These results do suggest that an accounting for the effects of human presence on the ecological services provided by forest could lead to different findings regarding sustainability. In particular, the extent of forests may serve as a misleading indicator for the relative scarcity of the services provided by forests (recall especially that the ratio of effective to measured timberland decreased over time), and no-net-loss in timberland may mask substantial declines in the services rendered from the forests of the South. In addition, these results raise important concerns regarding the implications of the recent acceleration of population growth in North Carolina.

Timber Harvesting

Besides the expanding population of the southern landscape, timber harvesting and management is the other major vector of change influencing the condition of forestlands in the South. We generally examine what the influence of further expansion in timber harvests might be and focus especially on how an adequate indicator of consequent changes could be constructed.

The South has been called the wood-basket of the United States and with good reason. In 1992, the region produced 50 percent of the softwood and 42 percent of the hardwood timber produced in the country (Powell et al. 1993). These figures reflect the result of steady, strong growth in timber harvest from the South over the last 30 years (Figure 4). Over this period, timber production grew at a relatively steady average annual rate of 2 percent per year for softwoods and 2.2 percent per year for hardwoods. Product mix has been dominated by sawlogs (to produce lumber) and pulpwood (to produce paper products), each of which represent 40 percent of total output. The remaining 20 percent is made up of veneer logs, fuelwood and furnish for composite wood products.

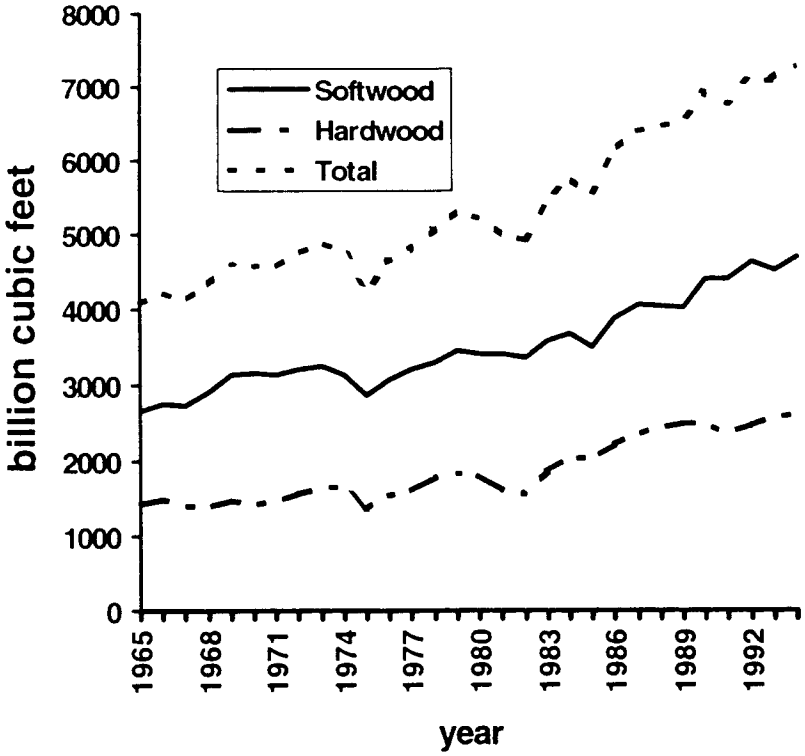

Figure 4. Total hardwood and softwood timber production from the South, 1965-1994

The recent history of timber harvesting in the South is and future harvesting will be heavily influenced by activities in other parts of the country. For example, harvest reductions on federal lands in the West have had a discernable impact on the markets supplied by southern lumber (Murray and Wear in press). Trade policy with Canada on softwood lumber has also likely had an effect. Therefore, any forecast of timber production in the South needs to be set in the context of the other regions of North America. To do this, we rely on forecasts of total timber production in the South generated by the national RPA timber market model (Haynes 1995). Then to fully develop local consequences of these changes, we simulate the spatial distribution of harvests using a detailed southern timber market model called SERTS (Abt et al. 1993). SERTS provides detailed forecasts of timber harvests by subregion of the South.

National timber market forecasts indicate that any future increase in U.S. production would come from the South. Softwood harvest is expected to

increase 24 percent over the next 30 years (a rate of +0.7 percent per year) and hardwood production is expected to increase even more, by about 39 percent (+1.1 percent per year) over the same time period (Haynes 1995). This rate of increase could lead to substantial changes in forest structure if spread evenly across the entire landscape. However, it appears that change will be concentrated in certain areas so that these impacts will be heavily focused on a portion of the southern landscape.

An analysis based on forecasts generated by the SERTS model indicates that the location of softwood production could shift in two important ways. First, production would increase substantially in the southeastern coastal plain where timber harvesting and management are already the most intensive. Second, timber production would expand to the north with large increases, especially in Tennessee and Arkansas, but also in Virginia. These increases in production offset losses in two other large regions. One is the western coastal plain from southern Texas to middle Mississippi. The other is the Piedmont Crescent region from Raleigh to Birmingham.

Increased production from the southeastern coastal plain and northern South reflect two different responses to increased demand for forest products. The first is increased investment and intensified management forecast for the coastal plain. This expansion at the intensive margin of forestry is likely justified because of the very strong demand for pulpwood in an area with extensive pulping capacity. The pulp and paper industry cannot easily shift capacity elsewhere because of high capital costs and environmental regulations so that investors can justify more intensive forest management. In this region, we expect that forest type diversity might decline (though age class diversity would likely increase) as plantation area expands. Of course, this depends on the extent to which plantation pine replaces natural pine or other forest types and the ecological differences between these groups.

The other type of market response exhibited in this forecast is an expansion at the extensive margin which involves extending the distance over which timber is procured. Increased production from northern reaches of the South, especially Tennessee and Arkansas would feed softwood lumber markets which have much more mobile capital than the pulp and paper sector. The biological consequences of this type of expansion might be different. We would anticipate that increased harvesting might lead to some increased tree planting, but not to the same extent as in the coastal plain—i.e., the returns to investment would not be as great. Natural regeneration would likely be the preferred approach. As a result, we could expect a much more land-extensive forestry with more area disturbed per unit of harvest in this area.

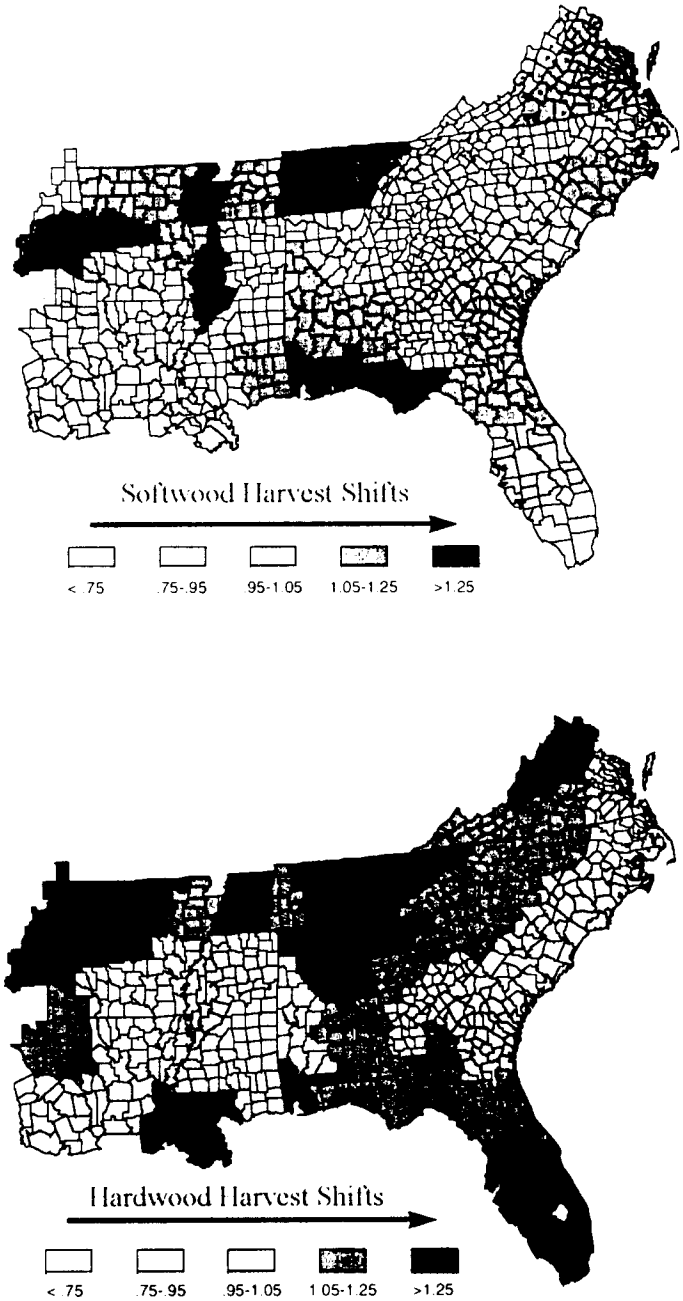

Figure 5. Changes in regional share of timber harvests by the year 2020 for softwoods and hardwoods in the South, forecast by the SERTS model.

We have demonstrated the potential hazard of using an intuitively appealing and plausible measure of forest extent: raw timberland. This measure may provide useful insights into, for example, potential carbon sequestration in forests, but it may not provide useful insights into the provision of specific habitats, etc. Aggregation across broad regions may also mask important changes. For example, no-net-loss in the South's timberland masks gains in the southcentral and losses in the southeastern subregions. Using raw timberland to indicate trends in forested habitat may also be misleading. Weighting timberland by a measure of human disturbance regimes indicates that a gain in raw timberland in North Carolina masks a loss in "effective timberland."

National assessments of timber production indicate that the South will continue to be the source of expanding national output (e.g., Haynes 1995). Increased harvesting is expected to be offset by intensified management and forest investment. A dissagregate spatial analysis of southern production indicates that expanding timber harvests may have disproportionate impact on the forested landscapes in specific parts of the South. Increasing harvest in the South would result in expanded investment and production in the southeastern coastal plain but would also require expanded production in the northern portion of the South. Here we anticipate that population growth and development coupled with increased timber harvesting will have a compounding effect on forests. It is unclear how forest owners and the structure of forested landscapes will respond, but these forecasts raise concern about forest sustainability in this region.

Spatially explicit measures of forest change provide qualitatively different insights into the potential sustainability of forests in the South. While stability might be projected for the region as a whole, specific areas may be subject to accelerated changes. For example, the measures examined here suggest that our concern regarding changes in forest structure should not be focused as much on the traditional high-production regions of the South. In these areas, we anticipate that ongoing investment will stabilize forest conditions. Rather, population growth coupled with expansion at the extensive margin of forestry suggests that change in forest structure and condition could be most substantial in a region stretching from Virginia through North Carolina, and northern Georgia to Tennessee.

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