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# 2 Framing the Future in the Southern United States

## *Climate, Land Use, and Forest Conditions*

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The Intergovernmental Panel on Climate Change (IPCC) has concluded, with 90% certainty, that human or “anthropogenic” activities (emissions of greenhouse gases, aerosols and pollution, land-use/land-cover change) have altered global temperature patterns over the past 100–150 years (IPCC 2007a). Such temperature changes have a set of cascading, and sometimes amplifying, effects on the entire global climate system, including the water cycle, cryosphere, hurricane intensity, and sea level. This chapter develops a set of scenarios for exploring potential climate and resource effects futures in the Southern United States.

The term global warming refers to an increase in average atmospheric temperature, but this definition masks much seasonal and regional variability, such as that which has been observed in

the Southern United States. Temperature observations in the Southern United States have fluctuated, but generally indicate a cooling trend in the second half of the twentieth century, especially in the late spring–early summer period (Portmann et al. 2009). Many studies have hypothesized the reasons for this cooling trend (Misra et al. 2012), including pollution increases, reforestation, irrigation, urban land cover variations, and the use of pesticides. Nevertheless, recent climatological analysis suggests that the cooling trend has abated and that an upward temperature trend is emerging (Tebaldi et al. 2012). Precipitation has also shown wide year-to-year variability with rainfall increasing about 10% for Georgia, Alabama, and Florida (Karl et al. 2009). Indeed, rainfall is quite variable across the region and is very much influenced by large-scale driving variables such as hurricanes and El Niño and La Niña events.

Concerns about climate change have prompted the development of general circulation models (also known as climate models) to predict how changes in atmospheric greenhouse gases (e.g., carbon dioxide and methane), solar output, orbital parameters, vegetation, and other factors might affect climate variables such as temperature, cloud formation, and precipitation. The climate models have limitations, one of which is the inability to project alternative futures, compromising their usefulness as a tool for examining future climates given their economic, social, technology drivers—factors that may hold substantial influence over how climate is expressed in ecological systems and may directly influence the structure of future forests.

These issues led the IPCC to develop additional models (under different greenhouse gas and societal scenarios) using a range of physical assumptions and parameterizations. The IPCC commissioned a special report to generate storylines of greenhouse gas emissions, set within four broad descriptions of future economic, demographic, political, environmental, and technological change (Nakicenovic et al. 2000). The *A1 storyline* describes a future of very rapid economic growth with a global population that peaks in mid-century, and then decreases. Modifications to A1 include the *A1B storyline*, which assumes future technology provides a balance in energy sources. The *A2 storyline* describes a continuously increasing global population and economic growth that is more regionally oriented; that is, with less market integration and trade among countries. Population growth for the *B1 storyline* is the same as A1, but the economic future for B1 is rapid change toward a service and information economy, with a strong emphasis on clean and resource-efficient technologies. The *B2 storyline* describes a growing population and intermediate economic growth, but a preference for national solutions over global integration. Another limitation of these climate models is that their scale is on the order of 50–150 km, making “downscaling” a temperature or precipitation projection to local and regional areas neither trivial nor error free; some of these issues have been addressed by ensembling techniques and various statistical or dynamic downscaling approaches (Winkler et al. 2011a).

In this chapter, we describe and provide land-use and climate-change projections using methods developed for the Southern Forest Futures Project (SFFP; Wear and Greis 2012, in press), as well as climate change projections using a climate model ensemble and a statistical downscaling approach. Most subsequent chapters utilize a set of discrete futures described by the SFFP, some use model averages provided by the ensembles, while a few use both sources. Projections served two purposes: (1) they characterize a range of possible land use and climate futures for the Southern United States; and (2) they provide a common frame of reference and common variables for chapter authors to use in their interpretations, modeling, and other analyses.

## DEVELOPING THE ENSEMBLE OF CLIMATE MODELS

Monthly temperature and precipitation predictions for 2000–2060 were created for each county in 17 states (Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Missouri, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia). Each monthly prediction is an ensemble, or average, of multiple simulations from four climate models—a subset of models described in Maurer et al. (2007): CGCM3 (Flato

and Boer 2001), CCSM3 (Collins et al. 2006), HadCM3 (Gordon et al. 2000), and GFDLCM2.1 (Delworth et al. 2006). Individual ensembles were created for three IPCC greenhouse gas emissions storylines: B1, A1B, and A2.

Global climate model output from the CMIP3 multi-model dataset (Meehl et al. 2007) were downscaled as described by Maurer et al. (2007). The downscaling used a bias-correction/spatial-downscaling method (Wood et al. 2004), which generated gridded fields of precipitation and surface air temperature over the conterminous United States and portions of Canada and Mexico using quantile-mapping of observations from 1950 to 1999 (Adam and Lettenmaier 2003) and an interpolation of monthly bias-corrected climate-model anomalies onto a fine-scale grid of historical climate data that produced a monthly time series at each 1/8-degree grid cell (~140 km<sup>2</sup> per grid cell). Quantile mapping corrects for model bias using the empirical transformation of Panofsky and Brier (1968). A correction function is calculated by matching the distributions of the simulated data with the observed data by quantile. This correction function is then used to correct the data in the validation period (e.g., Boé et al. 2007). The 1/8-degree downscaled output was averaged for all simulations for each combination of a given climate model and emissions storyline. The resulting averages for the four climate models were then averaged for each emissions storyline. Finally, the resultant ensemble 1/8-degree fields were used to generate county-level data using nearest-neighbor interpolation. Changes in monthly temperature and precipitation were calculated by differencing the 2001 to 2010 period from the 2051 to 2060 period.

Statistical downscaling allows production of long periods of climate scenarios for multiple locations in a manner much more computationally efficient than using nested high-resolution models (i.e., dynamical downscaling). However, statistical downscaling approaches have several common limitations. These limitations include: (1) underestimation of extremes unless approaches are used to adjust the variance, (2) the assumption of stationarity between large-scale and local climate in the future, and (3) the creation of individual climate predictants (i.e., temperature, humidity, precipitation) that may be physically inconsistent with one another (Winkler et al. 2011b). The users must remain vigilant to the potential effects of these limitations on the results of statistical downscaling.

## DEVELOPING THE CORNERSTONE FUTURES

We examined alternative scenarios affecting southern forests developed for the SFFP (Wear and Greis 2012, in press) to provide a mechanism for considering and preparing for changes in southern forests and the benefits they provide. Because any single projection of global (or regional) biological, physical, and social systems has a high probability of being incorrect, the SFFP constructed a range of possibilities that describe the forces influencing forests. This set of six future scenarios, labeled “Cornerstone Futures,” provides a foundation for many of the analyses in this book. Each Cornerstone Future is a comprehensive and coherent (internally consistent) combination of varying climatic, demographic, and economic changes in the South; simulating these changes allowed us to forecast likely impacts on the amount and characteristics of forests. In this section, we describe the land-use and forest forecasts that are coupled with climate, demographic, and economic changes as a foundation for analysis. Forecasts were derived from simulations using the assessment system (USFAS) developed originally for the Resources Planning Act (RPA) 2010 Assessment (U.S. Department of Agriculture Forest Service 2012b) and provided forecasts based on broad economic, timber market, demographic, and climate futures (Wear and Greis in press).

The USFAS provided the modeling framework for our analysis and we considered driving factors in terms of the inputs from this model (Figure 2.1). Market futures were driven by price forecasts, with prices increasing as timber products became scarcer and decreasing as supply increased. Land-use models within the USFAS were driven by population and income projections. The effects of climate variables on projections of forest conditions were manifest in forest-type distributions and forest productivity. Although based on IPCC storylines, the RPA scenarios also contain data and detail relevant to conditions in the United States—specifically climate and socioeconomic

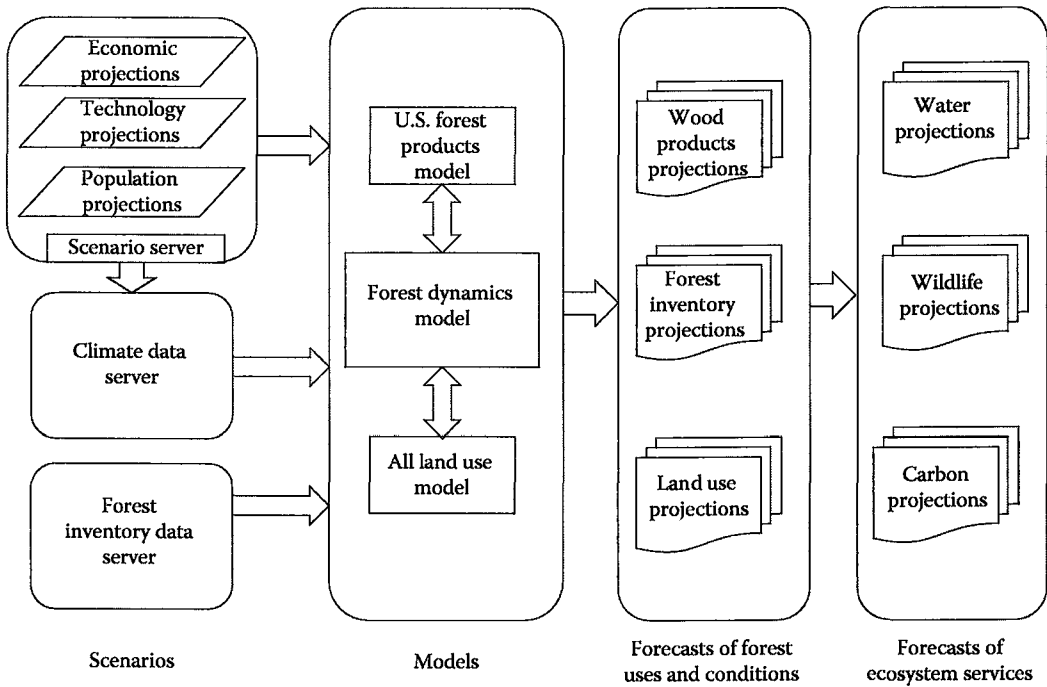


FIGURE 2.1 General schematic of the U.S. Forest Assessment System (USFAS).

projections, downscaled to the county level (U.S. Department of Agriculture Forest Service 2012a). Because the USFAS had originally been designed to develop the RPA assessment, we began by evaluating whether the existing RPA scenarios were adequate for addressing the issues of the SFFP. Note that the RPA adopted a version of A1 (A1B) because of its assumptions about energy futures (high demand for woody biomass) and dropped B1 because of data compatibility issues; A1B, A2, and B2 were evaluated.

For each of the IPCC storylines, the 2010 RPA scenarios provide unique forecasts of population and economic growth, downscaled to U.S. counties through 2060. The storylines were used as input to emissions modeling systems; their outputs were used as inputs to run models that generated alternative climate forecasts. The RPA analyses paired the results from three climate models with the storylines, resulting in nine potential climate futures. The climate-model data were downscaled using a statistical approach to the 0.5 arc minute and then aggregated to the county scale (Coulson et al. 2010). For the A1B and A2 storylines, the climate models are MIROC3.2, CSIRO MK3.5, and CGCM3; for the B2 storylines, they are the HadCM3, CSIRO MK2, and CGCM2.

The climate-model projections were generated as changes from simulated historical monthly averages (1961 to 1990) for each climate model (Joyce et al. in press; Price et al. 2011). Basing forecasts on the simulated values was intended to correct for differential biases of the climate models at the fine scale used for the analysis. Change forecasts were then applied to historical data to generate projections. Monthly average daily maximum and minimum temperatures, precipitation, along with other variables not considered in the SFFP analysis were generated to 2100 (compared to 2060 for the SFFP).

To summarize, the RPA scenarios provided a set of climate futures defined by three general circulation models for each of three storylines. Within USFAS, land-use models defined changes in forest area (and other uses) produced by the economic variables from the storylines as well as timber and crop prices (Wear 2011). Forest-dynamics models forecasted changes in forest conditions produced by harvesting, which in turn was influenced by the economic variables (Polyakov et al. 2010), and changes associated with aging, disturbance, and climate (Wear et al. 2013).

Two other important forces of change—forest harvesting and the potential impacts of wood-based energy on other wood products markets—were also evaluated. The USFAS addressed alternative scenarios for wood production in two ways. The first approach was to apply alternative projections of prices for forest products to forecast changes in harvesting. This “price exogenous” approach, although simple, allowed the USFAS to simulate increasing and decreasing scarcity in markets without specifically addressing market dynamics and wood-products demand structures. The second approach was to incorporate explicit models of market demands for various forest products, which for the RPA scenarios was the forest-products model that was developed by Ince et al. (2011) to simulate specific market futures associated with bioenergy/wood products markets for the A1B, A2, B2, and other storylines. The forest-products model was chosen for the RPA scenarios because it can incorporate demands for all classes of U.S. wood products within a global marketing framework (Raunika et al. 2010) and can be driven by variables taken from the same storylines.

In developing the Cornerstone Futures, we used exogenous price forecasts, in particular, three “price exogenous” scenarios: constant timber prices, increasing prices (plus 1% per year), and decreasing prices (minus 1% per year). Increasing prices reflect an increasing scarcity of timber products and therefore can be applied to two possible futures: a shortage in available timber supplies or an increased demand to satisfy existing uses or emerging uses such as bioenergy. Decreasing prices reflect decreasing scarcity consistent with a contraction in demands for products (such as pulpwood for paper production) or a rapid expansion in supplies derived from intensive management. We used the 1% increase and decrease rates (Figure 2.2) to bookend the analysis of markets because they are consistent with real price growth over the expansionary phase of southern timber markets from the 1980s through the 1990s. This approach allowed us to examine a broad range of market futures without explicit consideration of sources of demand growth or decline.

For our initial set of Cornerstone Futures, therefore, we started with the nine RPA scenarios for forecasts of climatic and socioeconomic conditions, and then applied the three alternative timber market scenarios. None of the resulting 27 initial possibilities was considered more likely than the other—they all were considered plausible. Each likely contained some unique insights into future resource uses and conditions; nevertheless, in the interest of practicality and clarity, we selected a smaller subset for detailed analysis and discussion as well as for use in the chapters of this book.

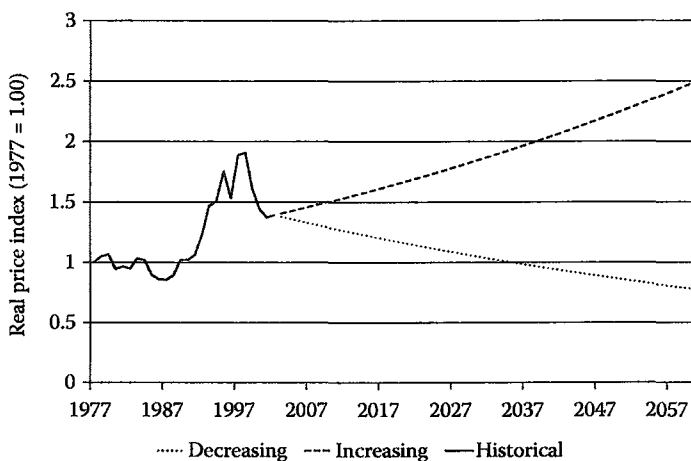


**FIGURE 2.2** Historical and projected real price index for timber products in the southern United States. (From Timber Mart South for historical data, 2010 Resources Planning Act assessment total product output charts.)

## FINAL SET OF FUTURES

To begin defining the set of Cornerstone Futures to be used for detailed analysis, we conducted USFAS land-use, forest-condition, and timber-harvesting simulations for the initial set of 27 alternative futures and applied measures of total forest land, biomass in forests, and other variables to compare the resulting forecasts. This process was complicated because the alternative futures had different rankings based on which variable was used to construct the ranking—for example, the same future might forecast the biggest loss of forest land and only a moderate level of future biomass loss (estimated as growing stock volumes).

*Timber prices*—We started by dropping the set of futures with constant prices. In every comparison, these futures yielded forecasts that were intermediate between futures with increasing and decreasing prices, meaning that the increasing and decreasing price futures bracketed the constant price futures for all variables evaluated. This step reduced the number of alternative futures to 18.

*Biomass volume and land use*—We next used two highly aggregate metrics to compare forecasts across the remaining futures: total volume of biomass by broad forest types and total area of forest land (Wear et al. in press).

Total inventory volume follows a broad range of trajectories across futures. Increases are only expected for the B2 storyline with low prices (resulting in lower harvesting), which predicts the lowest urbanization (relatively low population growth and moderate income growth). All other futures would result in biomass expansion through 2030 or 2040, followed by decreases. The future with the lowest biomass in 2060 is predicted using the A1B storyline (moderate population growth and high income growth) combined with high timber prices. Softwood volumes would increase to 2030 but then either level off (A1B/high prices) or increase through 2060, with the highest rate of increase for B2/low prices. Hardwood volumes are projected to decrease after 2030 for all futures except B2/low prices, with the largest decrease for A1B/high prices.

Forest area is forecasted to decrease in response to the economic/population forecasts from all the storylines and both the timber price futures (by construction, land use is not directly responsive to climate). Low population and income growth reduces urbanization and conversion of forest land. In addition, high timber prices discourage deforestation. Therefore, the B2 storyline (moderate income growth) coupled with high prices would yield the smallest loss of forest land by 2060, and the A1B storyline (rapid economic growth) coupled with low prices would yield the largest loss. With the storyline held constant, low prices would yield more forest loss than high prices. Because the A2 storyline is intermediate to the A1B/high forest loss and B2/low forest loss and is also intermediate in the biomass volume forecasts (for all climate projections), it was dropped from the analysis.

The range of outcomes for these two variables suggested inclusion of four futures for consideration. A high economic growth/increasing timber price future (A1B/high price) and a low growth/decreasing price future (B2/low price) bracket the projections of total forest biomass. For forest area change projections, the brackets are a low economic growth/increasing timber price future (B2/high price), which could reflect less globalization (more isolated nation economies) and increasing U.S. scarcity of wood products in the face of less trade; and a high growth/decreasing price (A1B/low price) future, which could reflect a shift in timber production offshore to support global economic growth (or simply a decline in the demand for forest products). These became the initial set of four Cornerstone Futures.

Although the timber-price and storyline effects overshadowed the effects of climate variation (Wear et al. in press), we decided not to eliminate climate variation from consideration because we wanted to account for spatial variations that may be masked by the aggregate outcomes. Accordingly, we introduced climate variation by assigning a climate model to each of the four cornerstones identified previously: MIROC3.2 to A1B/high prices, HadCM3 to the B2/low prices, CSIROMK3.5 to the A1B/low prices, and CSIROMK2 to the B2/high prices. These climate models were selected to provide a variety of spatial expressions of the climate projections (MIROC3.2 A1B, for example, is

generally warmer than the others, but these differences do not significantly affect the projections of aggregate forest conditions).

A review of these four Cornerstone Futures indicated that forest-investment forecasts, a key element in the development of southern forests since the 1950s, failed to respond with fluctuations in market futures. We therefore expanded our scope to address the effects of forest planting in a way that was consistent with our modeled changes in timber markets. To accomplish this, we augmented USFAS with a simple model that assumes replanting of all current plantations as well as a specified portion of other harvested forests. These assumptions were derived from historical rates of planting for each of the 13 states and from consultations with professional foresters on the likely path of future planting. The planting rates adopted for these baseline assumptions are more moderate than the aggressive expansion of plantations in the 1990s, and more closely reflect the economic conditions and trends of the 2000s. Because planting rates are tied to harvesting (which controls the availability of forests for planting) and to land-use changes, the area projected for planting was assumed to vary somewhat across simulated futures. We adjusted this baseline projection approach to introduce broader variation in the planting rate and to reflect the assumptions about future timber markets. The result was two additional futures. For the first, we increased planting rates in harvested areas by 50% from base rates for the MIROC3.2-A1B/high price future, therefore yielding higher planting rates than the other Cornerstone Futures but not as high as was experienced in the 1990s—we concluded that this would be plausible in light of observed nursery capacity and forest management. For the second, we decreased planting rates by 50% from base rates for the HadCM3-B2/low price future, therefore yielding a very moderate increase in forest plantations that would level off after about 2030.

## SUMMARY

Cornerstones A through D are defined by the matrix formed by intersecting low and high population and income forecasts with increasing and decreasing timber price futures as described in the preceding:

- *Cornerstone A:* High population/income growth along with increasing timber prices and baseline rates of post-harvest tree planting.
- *Cornerstone B:* High population/income growth along with decreasing timber prices and baseline rates of post-harvest tree planting.
- *Cornerstone C:* Low population/income growth along with increasing timber prices and baseline rates of post-harvest tree planting.
- *Cornerstone D:* Low population/income growth along with decreasing timber prices and baseline rates of post-harvest tree planting.

In developing these four Cornerstone Futures, we used baseline rates of tree planting from data collected by the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service. Two other Cornerstones were developed that either augment planting rates by 50% of Cornerstone A (Cornerstone E), where economic growth is strong and timber markets are expanding; or by decreasing rates by 50% of Cornerstone D (Cornerstone F), where economic growth is reduced and timber markets are declining.

- *Cornerstone E:* High population/income growth along with increasing timber prices and high tree planting rates.
- *Cornerstone F:* Low population/income growth along with decreasing timber prices and low tree planting rates.

The six Cornerstone Futures define a broad range of potential future conditions within which forests might develop. They describe a range of futures identified as important driving factors—wood

products markets, bioenergy, land uses, and climate changes—in a process that began with solicitation of input in a series of public meetings and ended with refinement by a panel of recognized natural resource experts. They address bioenergy and wood-products markets in a qualitative fashion—through exogenously defined trajectories of timber prices—that captures a broad range of market conditions. And they address land use and climate change in a detailed and spatially explicit way through projections of population, income, temperatures, and precipitation downscaled to the county level. The next step in the analysis was to evaluate these Cornerstone Futures using the models contained in the U.S. Forest Assessment System.

## LAND-USE MODELS

Land-use patterns define both the extent of human presence on a landscape and the ability of land to provide a full range of ecosystem services. The future sustainability of forests in the South has been and will continue to be largely influenced by the dynamics of land use. And as the regional population grows, so too will the area of developed uses. The pattern of these developments, returns from the various products of rural land, and the inherent productivity of the land will determine the distribution of forest, crop, and other rural land uses—therein lies the structure and function of terrestrial ecosystems (Chen et al. 2006; Wear 2002).

The USFAS forecasts land use based on the RPA econometric land-use models developed by Wear (2011) to reflect variations in land-use patterns and biophysical capabilities across the U.S. regions. The land-use model for the South addresses changes in all uses of land for all of the 13 states in the SFFP analysis area (with the exception of central and western Texas and Oklahoma, where the land-use model developed for the Rocky Mountain/Great Plains region was applied) and is driven by population and income growth along with the prices of timber products.

Each land-use model has two major components: (1) changes in county-level population and personal income, which are used to simulate future urbanization; and (2) allocations of rural land among competing uses, which likely result from predicted urbanization and rural land rents. Output from both components is based on land-use data from the 1987 and 1997 National Resource Inventories (U.S. Department of Agriculture Natural Resources Conservation Service 2009) to ensure that forecasted land-use changes are generally consistent with observed urbanization intensities and rural-land-use changes (see Wear 2011).

We examine how land use could respond to the economic and population forecasts associated with the Cornerstone Futures. Our forecasts use empirical models to address the Cornerstone Futures and to examine some specific questions about alternative land-use futures. Land-use forecasts play a central role in USFAS (Wear in press), with the information developed in this chapter providing one of the inputs to the USFAS forest-dynamics model, which in turn generates forecasts of southern forest conditions, which are described subsequently.

## FOREST CONDITIONS MODELS

Within the forest-dynamics model of the USFAS (Figure 2.1), the future of every plot in the FIA inventory was projected in a multiple stage process (Wear et al. 2013). The harvest-choice model assigned a management intensity choice (no harvest, partial harvest, or final harvest) based on timber prices (from the forest products module) and then on condition of the plot (Polyakov et al. 2010). The age of each plot was determined for the next period, and if harvested, the plot was determined to be naturally regenerated or planted. Forecasted climate (including temperature and precipitation) was assigned and forest conditions on the plot were inferred based on the harvest/no harvest decision, age, and climate selection.

Planting probabilities were derived from the frequency of observed planting on harvested plots, calculated for each forest type in each state using the most recent inventory period and were adjusted to reflect the assumptions of each Cornerstone Future as described earlier.

To incorporate forest market data, we adopted a simplified process that specifies a price trajectory for each Cornerstone Future and provides input both on individual plot-harvesting decisions and on the overall supply of timber. Consistent with theory, higher prices yielded more harvesting and larger timber supplies; lower prices yielded smaller timber supplies. Harvest-choice models, based on empirical analysis, were consistent with harvesting behavior observed in the late 1990s and early 2000s.

Projections of forest area from the land-use module also fed into the forest dynamics module and the projection of future market conditions. Changes forecasted at the county level for nonfederal land were based on National Resource Inventory data (U.S. Department of Agriculture 2009) and were used to rescale the area represented by each plot in the county.

The assignment of future plot conditions involved a resampling of historical plot records called whole-plot imputation (Wear et al. 2013): selecting a historical plot with comparable conditions to represent the conditions of the future plot location. The selected historical plot was as close as possible to the original plot location to allow for orderly changes in conditions. For example, if plot conditions were forecasted to be warmer, the resampling algorithm would first look within the same survey unit to find a historical plot with similar temperature increases. Finding none, the algorithm would extend the search to adjacent units until an appropriate match is found. This process was repeated for every time step (or interval between measurements or projections) to generate plot forecasts over time. The inventory forecast was completed by coupling the plot forecast with the land-use forecasts, which were applied to adjust the area represented by each nonfederal plot within each county (through the plot expansion factor described in the previous paragraph).

The forest-dynamics model was based on several probabilities, including probabilistic harvest-choice, forest-investment, and forest-transition models that were implemented with random draws from probability distributions, and a whole-plot imputation that was based on a random selection of a subset of historical plots (with replacement). This meant that forecasts could vary from one run of the forest-dynamics model to the next. The forecasts for the 50-year simulation in this chapter are based on 26 runs, one of which was selected as representative based on the central tendency across several variables. The full suite of 26 runs, providing information about the uncertainty of the forecasts, was used whenever confidence intervals were needed.

The time step of the simulation depended on the FIA inventories that underlay much of the modeling (Huggett et al. in press). Because starting years and time step varied from state to state, the forecast periods were staggered across the region; for example, a time step of 6 years starting in 2007 for one state compared to 6 years starting in 2008 for its neighbor. For reporting across the region, we selected 10-year intervals, each beginning with a zero-ending year (e.g., 1990), and then attached forecasts from the nearest year to the referenced decade—identical to how FIA assigns years for aggregate inventories (Smith et al. 2009).

## VARIATION ACROSS THE CORNERSTONE FUTURES

Figure 2.3 shows the six Cornerstone Futures in a diagram that emphasizes their key variables. Cornerstones A through D are defined by the matrix formed by intersecting RPA/IPCC storylines A1B and B2 with increasing and decreasing timber price futures. Cornerstones E and F depart from these four by either augmenting the planting rates in Cornerstone A (E) or by decreasing the planting rates in Cornerstone D (F).

Storylines vary in their projections of population density. A2, the storyline not used within the Cornerstone Futures, yields the highest population growth with an 80% increase from 2006 to 2060. The lowest population growth is associated with B2 (40%) and A1B is bracketed by the two (60%). Because urbanization is also fueled by income levels, A1B, with its strong economic growth, actually results in the most urbanization and highest losses of forest area (described in the following); B2 results in the lowest urbanization and forest losses.

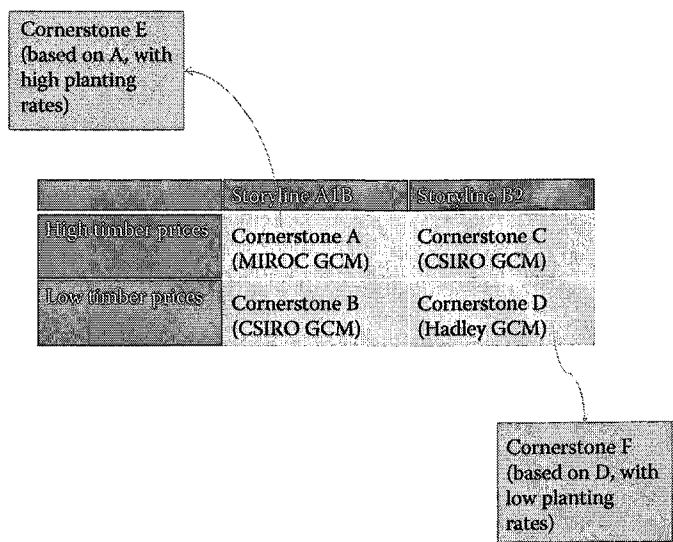


**FIGURE 2.3** The six Cornerstone Futures defined by permutations of storylines from the 2010 Resources Planning Act (RPA) assessment, three general circulation models (GCMs), and two timber price futures; and then expanded by evaluating increased and decreased forest planting rates.

Historically, population density has varied across the five subregions of the South (Figure 2.4). In 2006, the Piedmont had the highest population density (about 250 people per square mile or ppsm), followed by the Coastal Plain and Appalachian-Cumberland highlands with intermediate densities (100–150 ppsm) and the Mid-South and Mississippi Alluvial Valley with the lowest densities (75 ppsm). This general trend would continue over the A1B storyline projection period, with growth

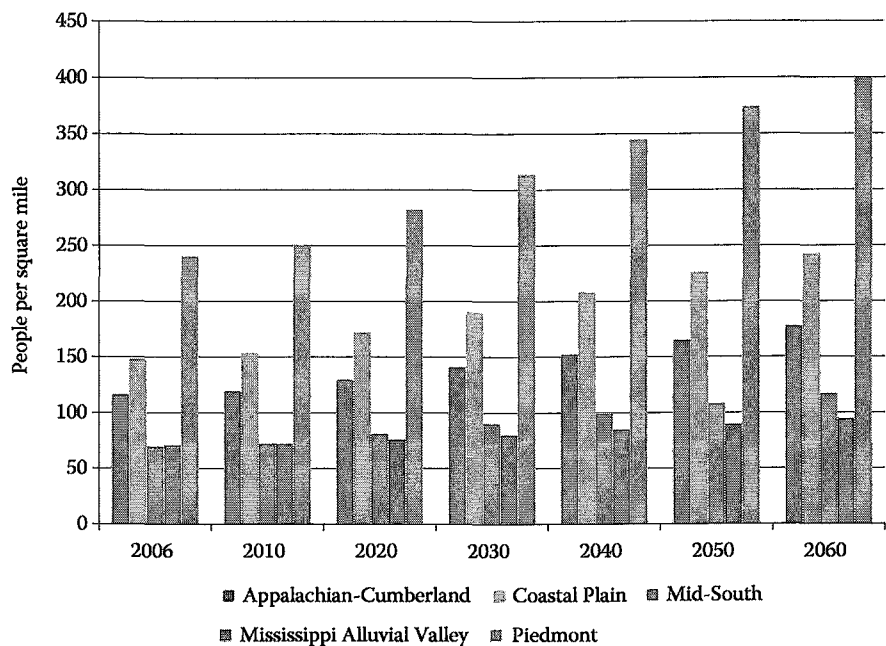


**FIGURE 2.4** Projections of population density, 2006–2060, for the five subregions of the Southern United States under storyline A1B (low population growth, high economic growth, high energy use) from the 2010 Resources Planning Act (RPA) assessment.

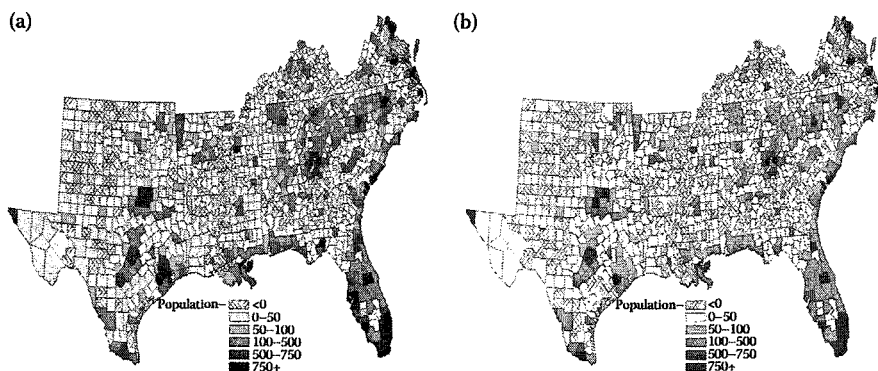


**FIGURE 2.5** Projection of population change in the Southern United States, 2010–2060, assuming the (a) A1B storyline of low population growth, high economic growth, high energy use; and (b) B2 storyline of moderate growth and energy use from the 2010 Resources Planning Act (RPA) assessment. Note that counties marked with a cross-hatch have forecasted population losses.

strongest on the Piedmont (an additional 150 ppsm). By 2060, the population density in the Coastal Plain would be as high as current population densities in the Piedmont.

Even within the subregions, population change would not be evenly spread. Forecasted population growth from 2006 and 2060 (Figure 2.5a,b) shows that several areas are expected to experience population decreases. This includes parts of the High Plains in Texas and Oklahoma, much of the Mississippi Alluvial Valley, and parts of southern Alabama and Mississippi. Population growth in the South would continue to be organized around major metropolitan centers, especially Atlanta, Miami, Houston, Dallas, Washington, Nashville (TN), Charlotte (NC), and Raleigh (NC).

Cornerstone Futures were also framed by timber market projections over the next 50 years. These projections did not account for short-run business cycles or the pattern of economic recovery from the recent recession, instead attempting to capture some broader long-run potentials for market development. Price forecasts defined by the Cornerstone Futures anticipated an orderly progression, either increasing or decreasing in real terms at 1% per year from a 2005 base. That year, prices were below their peak values from the late 1990s, especially for pulpwood-sized material.

We also held the real returns to agricultural crops constant through the period. Because future markets could depart from these assumptions, we used additional analyses to examine the sensitivity of future forest conditions to general market conditions (described in the preceding), providing a framework for evaluating forest product/bioenergy market possibilities.

## OUTLOOK FOR CLIMATE

### OUTPUT FROM ENSEMBLES

Climate projections showed that January temperatures would increase by no more than 0.5°C under the B1 ensemble, but by more than 2°C under A1B and A2. January precipitation would decrease by up to 1 mm/day in the lower Mississippi Alluvial Valley and Tennessee Valley under the B1 and A1B ensembles, with increased precipitation to the west and east. Under the A2 ensemble, the largest increase in precipitation would occur over Kentucky and Tennessee, with reduced precipitation to the west and south.

Under the A2 ensemble, July temperatures would increase as much as 3°C from western Tennessee to Oklahoma and western Texas (Figure 2.6a–c). The A1B ensemble shows temperature increases in excess of 3.5°C in the Mississippi Alluvial Valley (Figure 2.6a–c), compared to >2°C

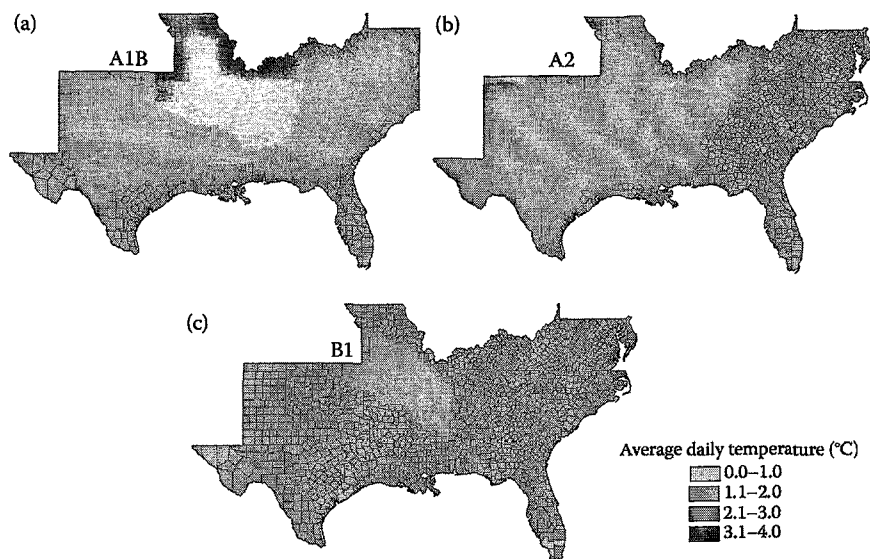


**FIGURE 2.6** Difference in July temperature in the Southern United States, comparing the 2051–2060 period to the 2001–2010 period under the (a) A1B storyline of low population growth, high economic growth, high-energy use; (b) A2 storyline of continuous population growth and high economic growth; and (c) B1 storyline of low population growth, high economic growth, and shift to a service/information economy. (Adapted from Intergovernmental Panel on Climate Change 2007b, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.)

temperature increases under the B1 ensemble (13°C). Under all three storylines, nearly all areas of the South are expected to increase by  $\geq 1^\circ\text{C}$ .

July precipitation is projected to increase from Georgia northward to Virginia, Maryland, and Delaware, ranging from 0.6 mm/day under the A2 ensemble (Figure 2.7a–c) to 0.8 mm/day under the A1B ensemble (Figure 2.7a–c). From 2051 to 2060, the ensembles predict drier conditions from the Appalachians westward and in southern Florida ( $\geq 0.8$  mm/day).

## OUTPUT FROM CORNERSTONE FUTURES

Figures 2.8 through 2.10 present graphic and map displays of precipitation data, and Figures 2.11 through 2.13 present graphic and map displays of temperature data from the Southern Forest Futures Project (McNulty et al. in press). Characterized by low population growth and high energy use/economic growth (MIROC3.2 A1B), Cornerstone A is forecasted to be dry and hot, with average annual precipitation of 912 mm and average annual temperature of  $20.22^\circ\text{C}$ . Annual precipitation expected for any southern county ranges from 103 to 4999 mm, and temperature ranges from  $-12.01^\circ\text{C}$  to  $50.24^\circ\text{C}$ . Also characterized by low population growth and high energy use/economic growth (CSIROMK3.5 A1B), Cornerstone B is forecasted to be wet and warm, with average annual precipitation of 1167 mm and average temperature of  $19.06^\circ\text{C}$ . Annual precipitation expected for southern counties ranges from 93 to 3912 mm, and temperature ranges from  $-11.21^\circ\text{C}$  to  $44.24^\circ\text{C}$ . Characterized by moderate population/income growth and energy use (CSIROMK2 B2), Cornerstone C is forecasted to be moderate and warm, with average annual precipitation of 1083 mm and average annual temperature of  $19.45^\circ\text{C}$ . Annual precipitation expected for any southern county ranges from 35 to 2641 mm, which would break the 1956 regional low of 42 mm in Texas (Burt 2007). Temperature is expected to range from  $-19.73^\circ\text{C}$  to  $45.39^\circ\text{C}$ . Also characterized by moderate population/income growth and energy use (HadCM3 B2), Cornerstone D is also forecasted to be moderate and warm, with average

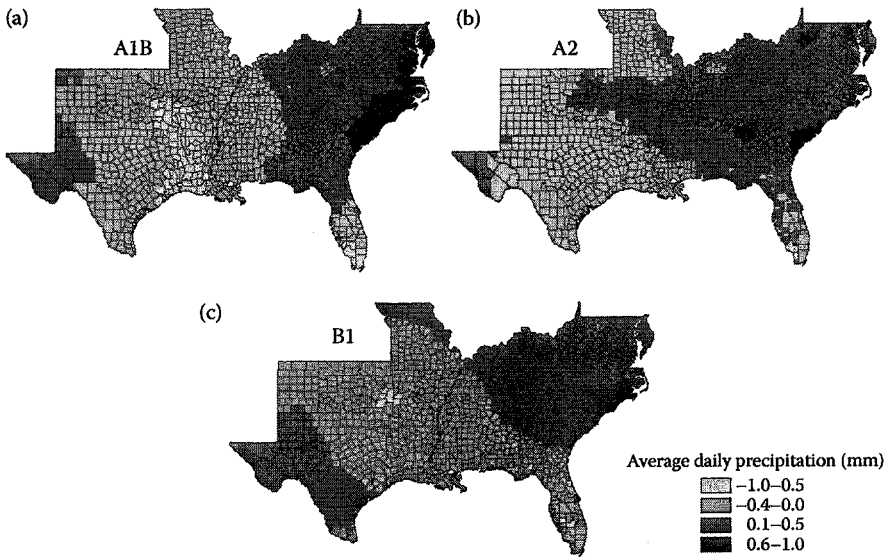


**FIGURE 2.7** Difference in July precipitation in the Southern United States, comparing the 2051–2060 period to the 2001–2010 period under the (a) A1B storyline of low population growth, high economic growth, high energy use; (b) A2 storyline of continuous population growth and high economic growth; and (c) B1 storyline of low population growth, high economic growth, and shift to a service/information economy. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.)

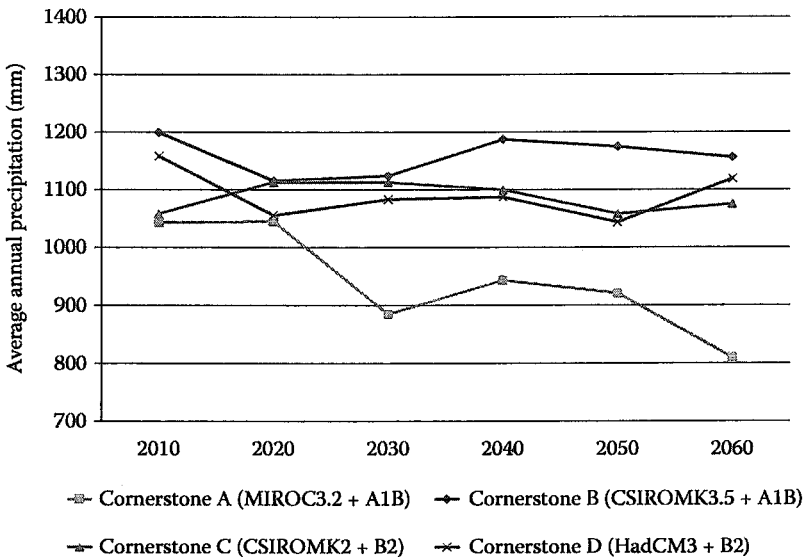


**FIGURE 2.8** Predicted annual precipitation (2010, 2020, 2030, 2040, 2050, and 2060) for the Southern United States as forecasted by four Cornerstone Futures (A through D), each of which represents a general circulation model paired with one of two emissions storylines—A1B representing low population/high economic growth, high energy use, and B2 representing moderate growth and use. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.)

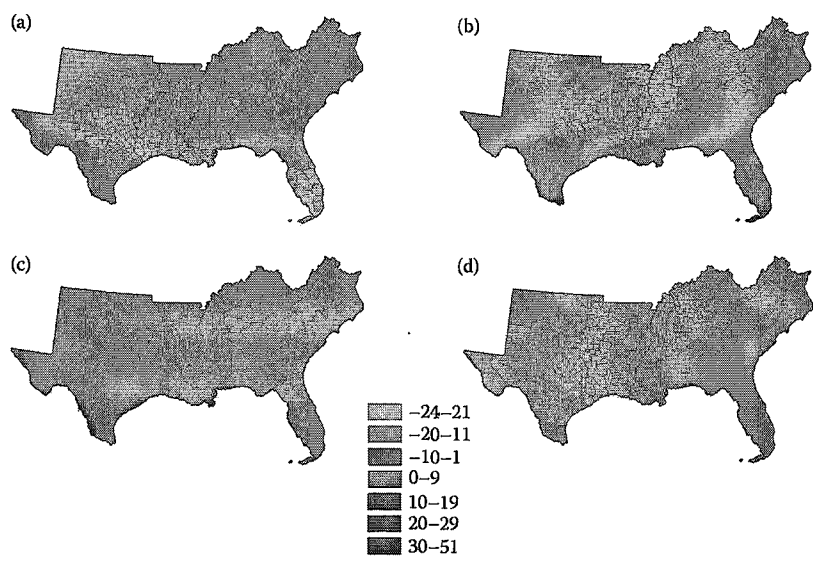


**FIGURE 2.9** Predicted change in precipitation from 2010 to 2050 for the Southern United States as forecasted by four Cornerstone Futures, each of which represents a general circulation model paired with one of two emissions storylines—A1B representing low population/high economic growth, high energy use, and B2 representing moderate growth and use: (a) MIROC3.2 A1B, (b) CSIROMK3.5 A1B, (c) CSIROMK2 B2, and (d) HadCM3 B2. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.)

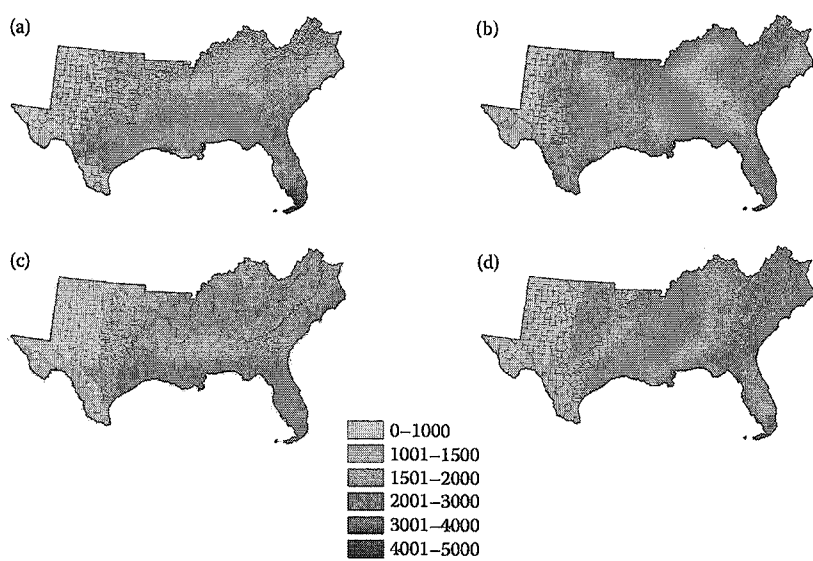


**FIGURE 2.10** Maximum precipitation from 2010 to 2060 for the Southern United States as forecasted by four Cornerstone Futures, each of which represents a general circulation model paired with one of two emissions storylines—A1B representing low population/high economic growth, high energy use, and B2 representing moderate growth and use: (a) MIROC3.2 A1B, (b) CSIROMK3.5 A1B, (c) CSIROMK2 B2, and (d) HadCM3 B2. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.)

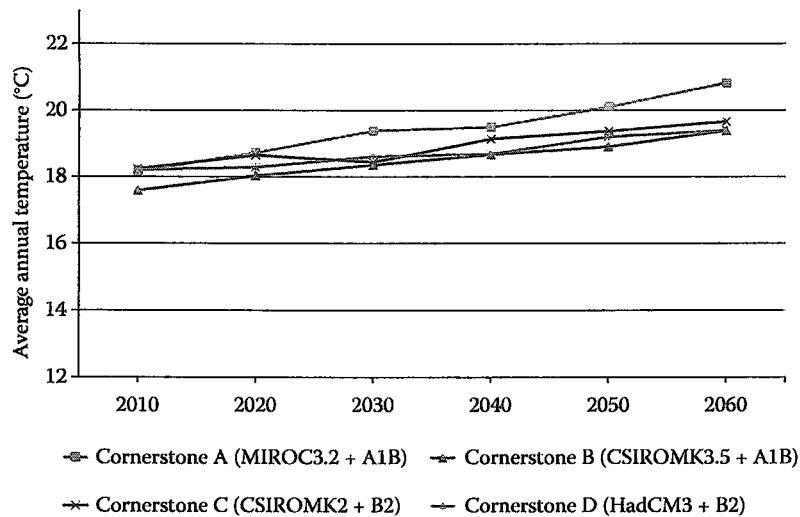


**FIGURE 2.11** Predicted annual air temperature (2010, 2020, 2030, 2040, 2050, and 2060) for the Southern United States as forecasted by four Cornerstone Futures (A through D), each of which represents a general circulation model paired with one of two emissions storylines—A1B representing low population/high economic growth, high energy use, and B2 representing moderate growth and use. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.)

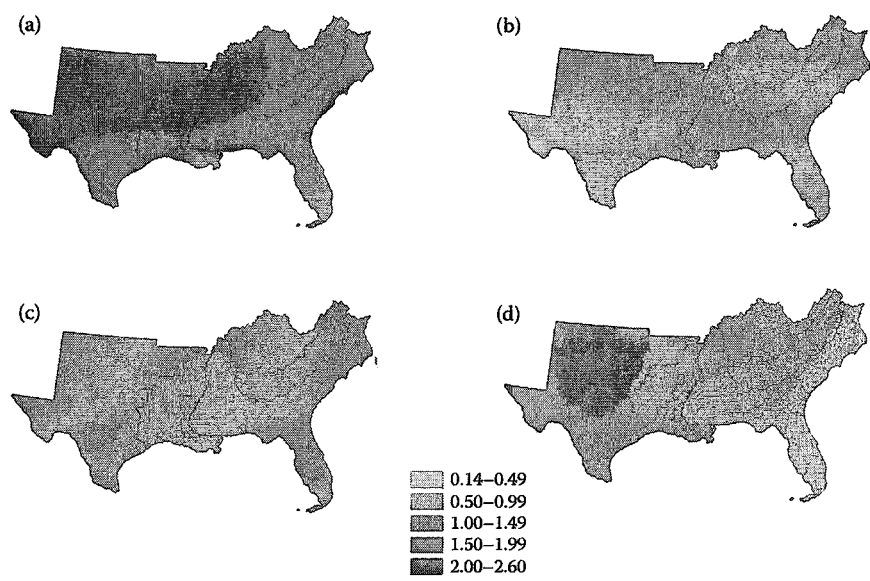


**FIGURE 2.12** Predicted change in air temperature from 2010 to 2050 for the Southern United States as forecasted by four Cornerstone Futures, each of which represents a general circulation model paired with one of two emissions storylines—A1B representing low population/high economic growth, high energy use, and B2 representing moderate growth and use: (a) MIROC3.2 A1B, (b) CSIROMK3.5 A1B, (c) CSIROMK2 B2, and (d) HadCM3 B2. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.)

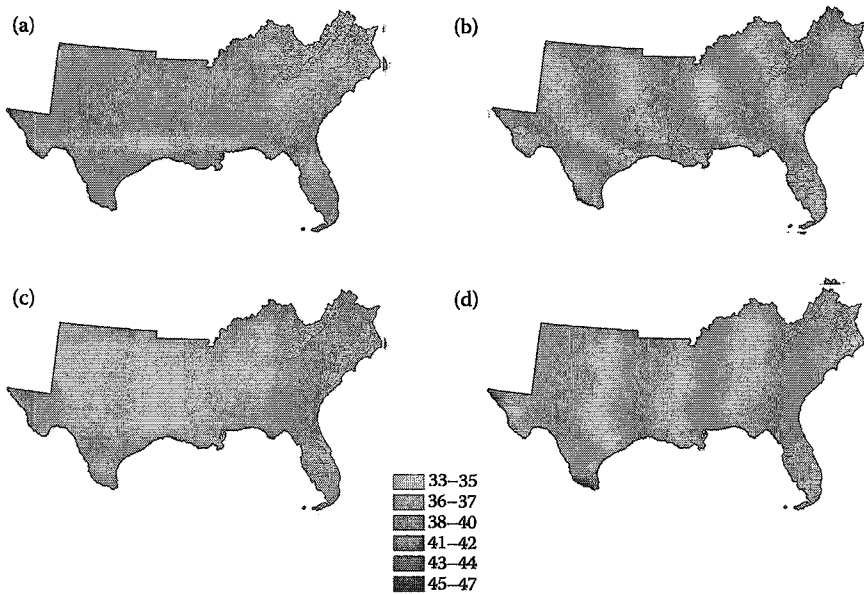


**FIGURE 2.13** Maximum air temperature from 2010 to 2060 for the Southern United States as forecasted by four Cornerstone Futures, each of which represents a general circulation model paired with one of two emissions storylines—A1B representing low population/high economic growth, high energy use, and B2 representing moderate growth and use: (a) MIROC3.2 A1B, (b) CSIRO3.5 A1B, (c) CSIRO3.2 B2, and (d) HadCM3 B2. (Adapted from Intergovernmental Panel on Climate Change 2007b. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.)

annual precipitation of 1106 mm (higher than Cornerstone C) and average annual temperature of 19.3°C (lower than Cornerstone C). Annual precipitation expected for any southern county ranges from 102 to 2708 mm, and temperature ranges from -18.7°C to 48.0°C.

Forecasted precipitation and temperature averages are not likely to be uniform throughout the South, and significant variations expected across the five subregions. The high energy use/economic growth (MIROC3.2 A1B) under Cornerstone A is predicted to result in the least decadal precipitation by 2060, with an overall average of 810 mm for all five southern subregions and a low of 525 mm in the Mid-South. This trend is expected to abate only slightly by 2090 to an average of 858 mm for all subregions and 535 mm for the Mid-South; still much drier than the historical overall average of 1136 mm.

Although also based on high-energy-use/economic-growth, Cornerstone B (CSIROMK3.5 A1B) predicts more decadal precipitation than the other Cornerstone Futures by 2060, with an overall average of 1156 mm. This trend continues into 2090, with an overall average predicted to be 1223 mm. Cornerstone B also predicts cooler decadal temperatures than the other Cornerstone Futures by 2060—with an overall average of 19.4°C—for every subregion except the Mid-South. This trend continues into 2090, with an overall average of 20.1°C for Cornerstone B, lower than all the other cornerstones for all subregions.

Cornerstone A predicts warmer decadal temperatures than the other Cornerstone Futures by 2060, with an overall average of 20.8°C for all five southern subregions. This trend continues into 2090, with an overall average of 21.8°C, ahead of all the other cornerstones for all subregions.

Electing to use discrete Cornerstone Futures with different climate futures prevented us from isolating the effects of climate versus population, land use, or other driving forces behind the scenario. Evaluating these secondary and tertiary effects using the same factorial analysis that went

into the development of the Cornerstone Futures, which were based on emissions storylines and climate models, was beyond the capacity of the Futures Project. However, forest forecasts for the full factorial were the basis for the selection of the Cornerstone Futures and are described in detail in Wear et al. (in press).

## OUTLOOK FOR LAND USE

Land-use forecasts indicate a range of results for the Cornerstone Futures (Figure 2.14a–d). Urbanization would add between 29 and 42 million acres of developed uses by 2060, with losses of varying degrees accruing for all other land uses. The Cornerstone Futures are in general agreement about predicted changes for range and pasture use, but not for cropland and forest area. Predicted losses range from about 11 million acres (6.5%) to about 22 million acres (13.1%) for forest uses, and from about 5 million acres (6%) to about 16 million acres (19%) for cropland uses.

### URBAN LAND USES

By model construction, urbanization forecasts are driven exclusively by population and income and are not influenced by the future trajectory of timber or agricultural prices. Cornerstones A and B (with the A1B storyline) predict the same higher rates of income and population growth. The result would be an expansion in urban uses of about 43 million acres (about 143%) by 2060 from the 1997

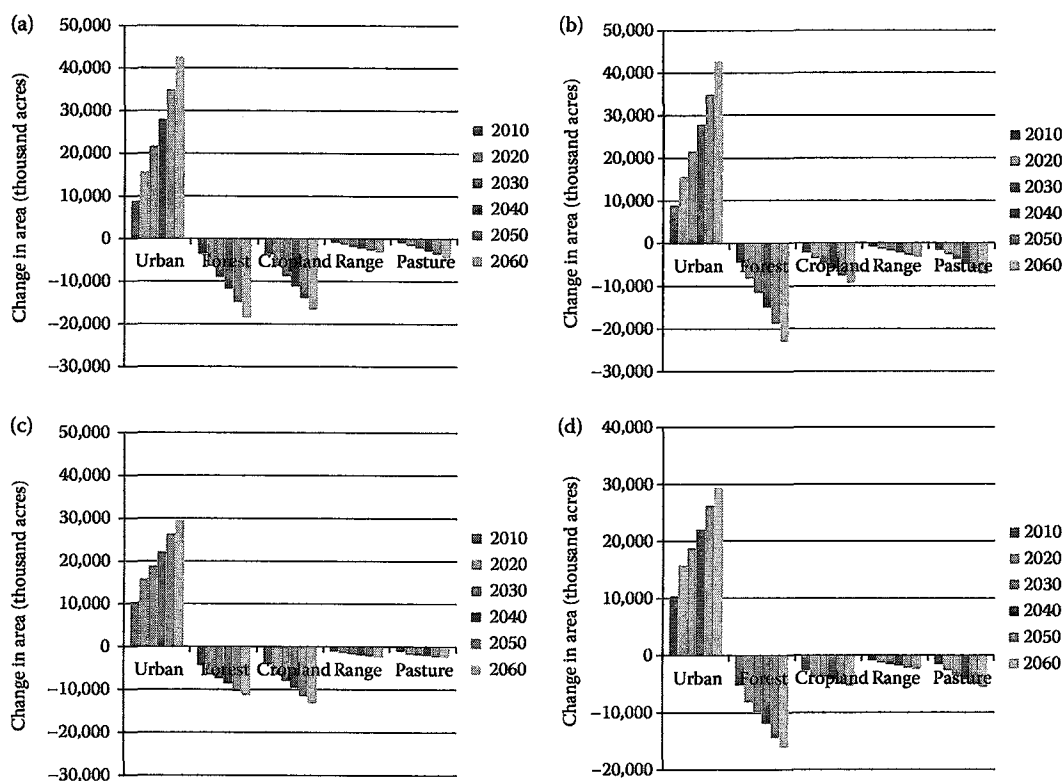


**FIGURE 2.14** Changes in urban, forest, cropland, range, and pasture land uses in the Southern United States under each of four Cornerstone Futures: (a) large urbanization gains with increasing timber prices, (b) large urbanization gains with decreasing timber prices, (c) moderate urbanization gains with increasing timber prices, and (d) moderate urbanization gains with decreasing timber prices.

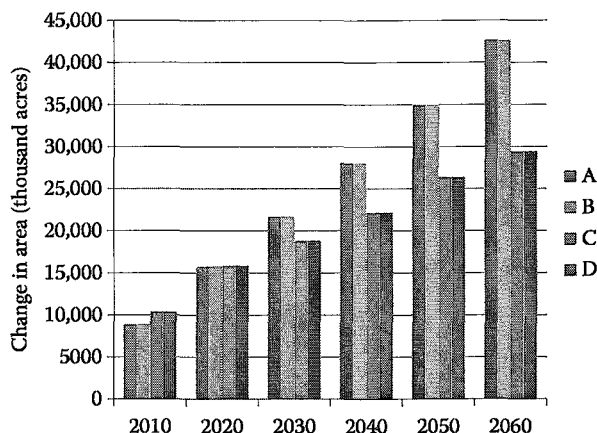


**FIGURE 2.15** Change in urban land uses for the Southern United States, 1997–2060, under four Cornerstone Futures: (A) large urbanization gains with increasing timber prices; (B) large urbanization gains with decreasing timber prices; (C) moderate urbanization gains with increasing timber prices; and (D) moderate urbanization gains with decreasing timber prices.

base of about 30 million acres (Figure 2.15). Cornerstones C and D (with the B2 storyline) predict lower rates of income and population growth, with a resulting gain in urban uses of about 30 million acres (98%).

Urbanization is highest in areas experiencing the highest population growth; for the South, this is at the periphery of urban centers (Figure 2.16). For Cornerstones C and D, gains in urban uses are expected to be widespread, with the exception of a few areas of decreasing populations (such as the Mississippi Alluvial Valley and southwestern Alabama). For Cornerstones A and B, urbanization would spread out across an even broader area, highlighting the linkage to income.

The amount of urban growth is expected to vary across the five subregions of the South (Figure 2.17 for Cornerstones A and B). Under Cornerstones A and B, almost 18 million of the 43 million

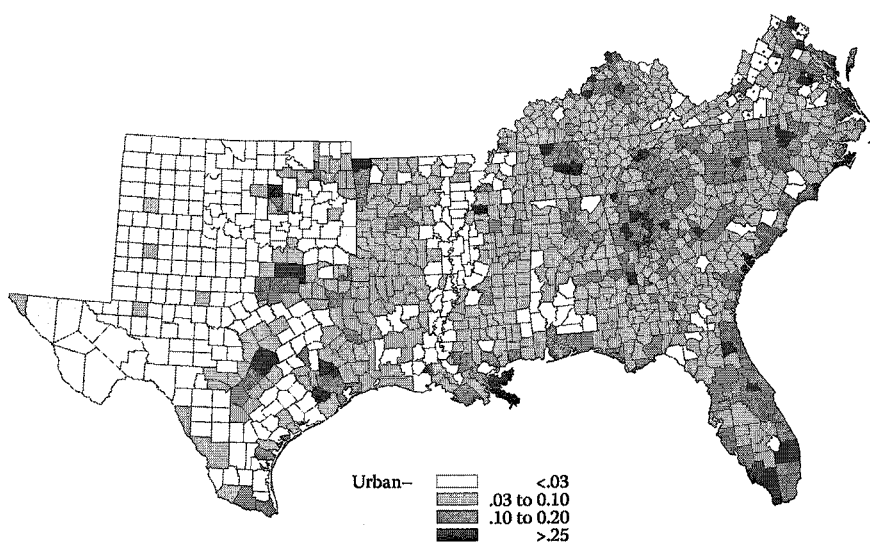


**FIGURE 2.16** Changing urban land uses in the Southern United States, 1997–2060, based on an expectation of large urbanization gains with decreasing timber prices (Cornerstone C).

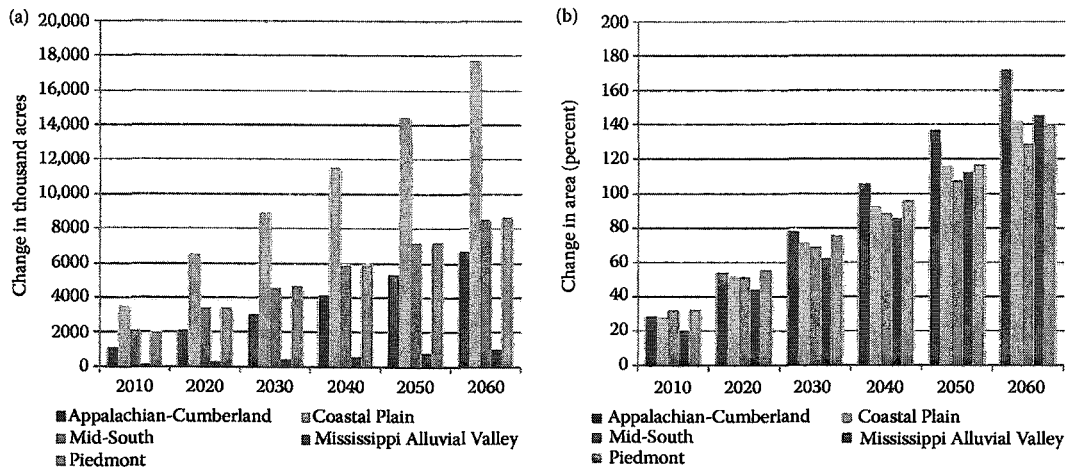


**FIGURE 2.17** Changing urban area in the five subregions of the Southern United States, 1997–2060, expressed in (a) acres and (b) percent; and based on an expectation of large urbanization gains, either with increasing timber prices (Cornerstone A) or with decreasing timber prices (Cornerstone B).

acres of additional urban area would be on the Coastal Plain. The Piedmont and Mid-South would add about 9 million acres each, the Appalachian-Cumberland highlands would add about 7 million acres, and the Mississippi Alluvial Valley would have a comparatively small increase. The rate of growth would be highest for the Appalachian-Cumberland highlands (175%) because of its relatively small 1997 urban base; the fastest growing areas are central-northern Kentucky (an area bordered by Lexington, Louisville, and Cincinnati), and, in Tennessee, near Nashville and Knoxville. Growth rates for the other four subregions range from 125% to 140%.

## FOREST LAND USES

Unlike urban land uses, the amount of forest land in the South depends on timber prices as well as the more dominant population- and income-growth drivers of urbanization. All Cornerstone Futures predict losses, but with varying degrees of loss. The biggest loss is projected to be 23 million acres (13%) by 2060 for Cornerstone B, which is based on high economic growth (storyline A1B) and decreasing timber prices (Figure 2.18). At the other end of the spectrum is a projected loss of about 11 million acres (7%) for Cornerstone C, which is based on low economic growth (storyline B2) and increasing timber prices. Comparing forecasts for Cornerstones A and B with those for Cornerstones C and D shows a 5-million acre difference between a future of increasing timber prices and a future of decreasing prices, confirming that the effects of the economic/population storyline dominate the effects of timber prices.

Forest losses would be especially high in a few areas. For all Cornerstone Futures, losses are expected to be concentrated in the Piedmont from northern Georgia through North Carolina and into parts of Virginia, as Figure 2.19 shows for Cornerstone C (selected because it is bracketed by the other Cornerstone Futures). Other areas of concentrated forest losses would be the Atlantic Coast, along the Gulf of Mexico, and in parts of eastern Texas outside of Houston. The income-fueled development in Cornerstones A and B would spread low-intensity forest losses across a broader area (Figure 2.20).

Under Cornerstone B, forest losses are forecasted to be highest in the Coastal Plain, at about 12 million acres, and lowest in the Mississippi Alluvial Valley and the Mid-South (Figure 2.21a,b). Percentage losses would be highest in the Piedmont (21%), followed by the Appalachian-Cumberland highlands (13%) and the Coastal Plain (11%).

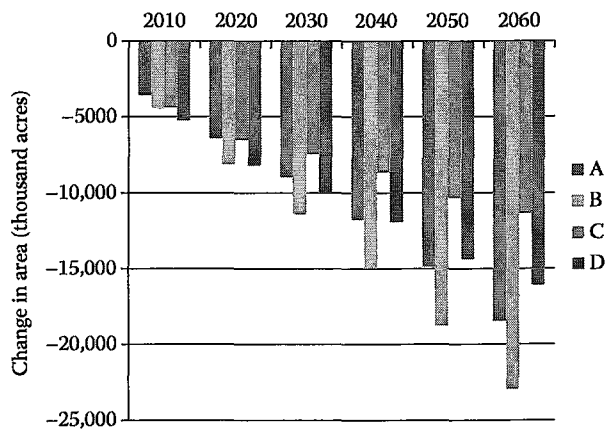


**FIGURE 2.18** Changing forest land uses for the Southern United States, 1997 to 2060, under four Cornerstone Futures: A, large urbanization gains with increasing timber prices; B, large urbanization gains with decreasing timber prices; C, moderate urbanization gains with increasing timber prices; and D, moderate urbanization gains with decreasing timber prices.

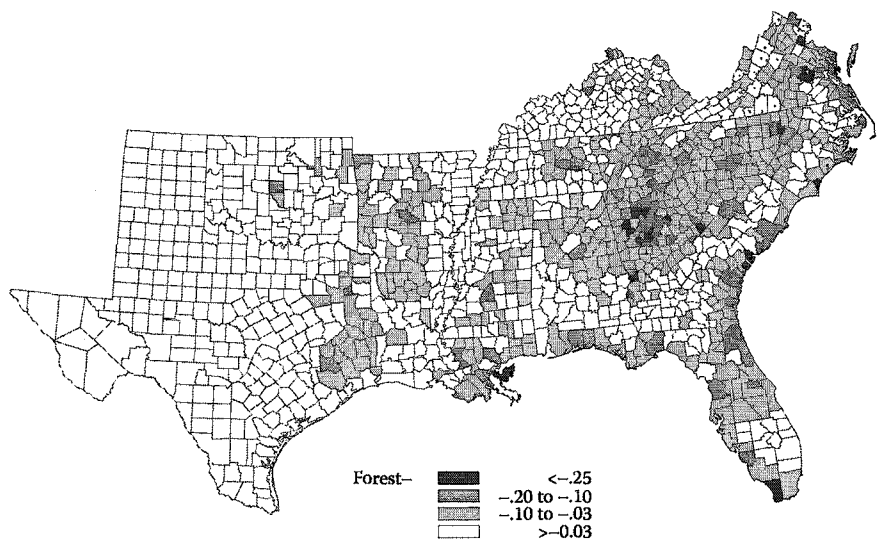


**FIGURE 2.19** Changing forest land uses in the Southern United States, 1997 to 2060, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B).

**OTHER LAND USES**

*Cropland*—As with forest area, the change in cropland area would depend on the economic conditions defined by each alternative future. However, unlike forest area, which is dominated by urbanization patterns (driven by the A1B storyline), cropland is more heavily influenced by timber prices. Losses would range from about 16 million acres under the high economic growth (A1B) of Cornerstone A with increasing timber prices, to only about 5 million acres under the lower economic growth (B2) of Cornerstone D with decreasing timber prices. The difference in crop loss

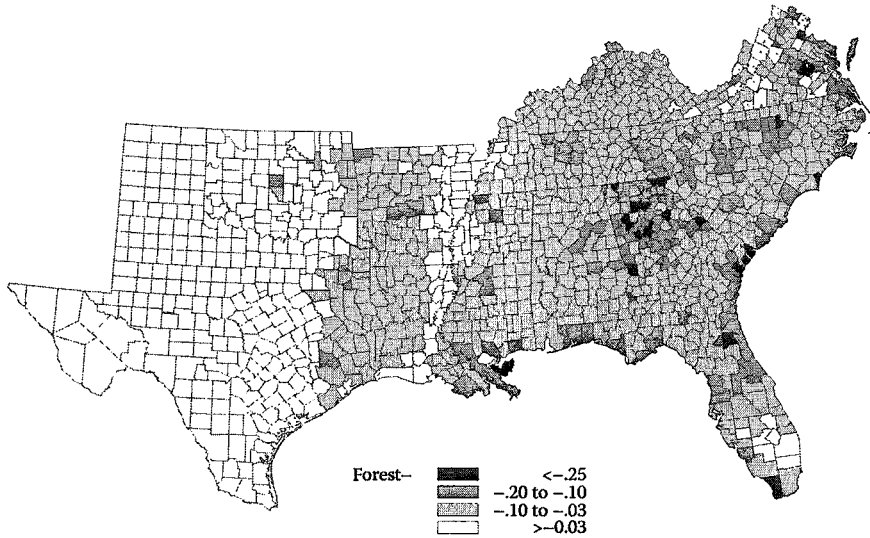


**FIGURE 2.20** Changing forest land uses in the Southern United States, 1997 to 2060, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B).

between storylines A1B and B2 (holding price futures constant) would be about 3 million acres. The difference between increasing and decreasing price futures (holding storylines constant) would be about 8 million acres.

Cornerstone D, which predicts the lowest levels of cropland loss, shows especially high levels of loss in North Carolina, southern Florida, central Kentucky and Tennessee, and the area in Texas bordered by Dallas, Houston, and Austin. Under Cornerstone A, crop losses would be highest, spreading across broader areas of North Carolina, Tennessee, and Kentucky; and with additional losses in southeastern Georgia and the coastal areas of Texas and Louisiana. Among the five southern subregions, the highest percentage loss of cropland would be in the Piedmont (28% under Cornerstone B and 51% under Cornerstone A), followed by large areas in the Coastal Plain and the Appalachian-Cumberland highlands.

*Pasture*—The pattern of pasture losses across the Cornerstone Futures would be similar to forests, with the highest losses forecasted under Cornerstone B (about 7 million acres) and the lowest under Cornerstone C. Similar to the pattern of cropland forecasts, pasture area change is more heavily affected by timber price projections than by the economic growth forecasts.

Pasture losses for all the Cornerstone Futures would be concentrated in three broad zones: the first stretching from northern Georgia to northern Kentucky and including a large area of Tennessee, the second in Peninsular Florida, and the third including the Ozark-Ouachita Highlands and the Cross Timbers section of eastern Texas and Oklahoma. Variations across the five southern subregions would be substantial. As with forests and crops, the Piedmont would experience the largest percentage loss, about 25% for Cornerstone B, followed by the Appalachian-Cumberland highlands (15%), Coastal Plain (11%), and Mid-South (9%).

*Rangeland*—By construction, forecasts of change in range area are limited to Texas and Oklahoma and only reflect the effects of urbanization (not being sensitive to fluctuations in timber prices). Rangeland would decrease by about 2.5 million acres under Cornerstone Futures C and D and about 3.2 million acres under Cornerstones A and B, with losses concentrated in the urbanizing Cross Timbers section of eastern Texas and Oklahoma—especially around Dallas and Austin—and along the border with Mexico.

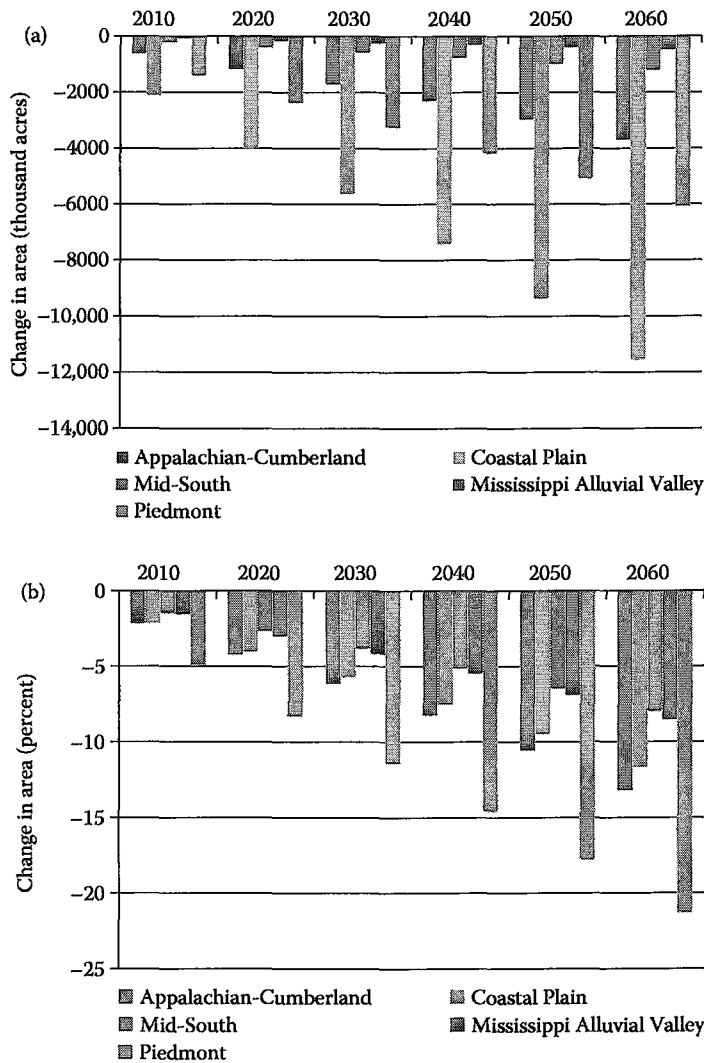


**FIGURE 2.21** Changing forest area by southern subregion, 1997 to 2060, expressed in (a) acres and (b) per cent; and based on an expectation of large urbanization gains with decreasing timber prices (Cornerstone B).

OUTLOOK FOR FOREST CONDITIONS

FOREST AREA

Forecasts of forest area change were derived from the land-use analysis described in the preceding. The land-use analysis (Wear, in press) only considered nonfederal land consistent with the National Resources Inventory design and started from a baseline of 1997; we updated the basis to 2010 and extended the analysis to all forested land based on FIA data.

All Cornerstone Futures predict decreases in forest area with losses ranging from 4 to 21 million acres (2–10%) by 2060, the result of population- and income-driven urbanization and of changes in the relative price of timber products (Figure 2.22). The smallest loss of forest area is forecasted for Cornerstone C, which would have the lowest population and income growth resulting in lowest urbanization, and increasing timber prices resulting in shifts of some rural land toward forest uses. The largest loss of forest area is forecasted for Cornerstone B, where population growth would be

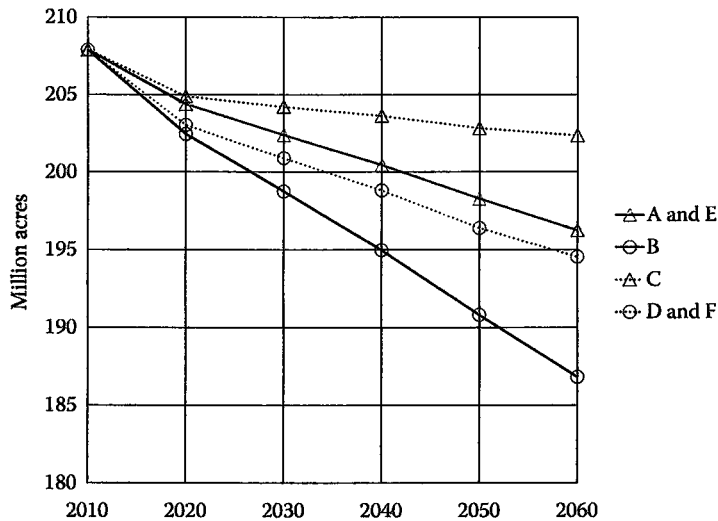


**FIGURE 2.22** Forecasted total forest area in the Southern United States, 2010–2060, by Cornerstone Future (A representing large urbanization gains with increasing timber prices, B representing large urbanization gains with decreasing timber prices, C representing moderate urbanization gains with increasing timber prices, D representing moderate urbanization gains with decreasing timber prices, E representing large urbanization gains with increasing timber prices and increased planting, and F representing moderate urbanization gains with decreasing timber prices and decreased planting). Cornerstones A and E share a land-use model, as do Cornerstones D and F. The figure shows the overlapping trajectories for these.

moderate but income growth would be strong (resulting in high urbanization), and timber prices would decrease (resulting in shifts of forest land to agricultural uses). Figure 2.22 also shows that price effects dominate the projection of forest area, with the highest forest loss predicted for the Cornerstone Futures associated with decreasing prices (B, D, and F); the three Cornerstone Futures with the lowest forest loss would have increasing prices (A, C, and E).

Forest area change would also vary across the five management types: planted pine (*Pinus* spp.), natural pine, mixtures of oak (*Quercus* spp.) and pine, upland hardwood, and lowland hardwood. The upland and lowland hardwood types are forecasted to make up 51–53% of all forests in 2060, a decrease from about 54% in 2010 (Figure 2.23a,b). Changes, however, would be most profound among the softwood types (planted pine, natural pine, and oak-pine). These forest dynamics are heavily influenced by management for forest products, which in turn is driven by timber market conditions and by the rate of forest planting.

*Planted pine*—Of the five management types in the South, only planted pine is forecasted to increase in spite of overall decreases in forested area. The South now contains 39 million acres of planted pine (about 19% of total forest area), the culmination of an upward trend that started in the 1950s. Our projections of planted pine were driven by urbanization, timber prices, and planting rates (Figure 2.24a).

Cornerstone E, characterized by a relatively high level of urbanization as well as high timber prices and planting rates, would produce the largest expansion in planted pine (though at rates lower than those experienced in the 1990s) and yield an increase of 28.2 million acres by 2060 (about 560,000 acres per year). Under this Cornerstone, 34% of forests would be planted pine in 2060. Conversely, Cornerstone F, characterized by a relatively low level of urbanization as well as low timber prices and planting rates, would yield the smallest gain in planted pine area with an increase of 7.8 million acres by 2060 (24% of forest area). The remaining Cornerstone Futures have projections that are intermediate to these results. They cluster around the forecast for Cornerstone D with

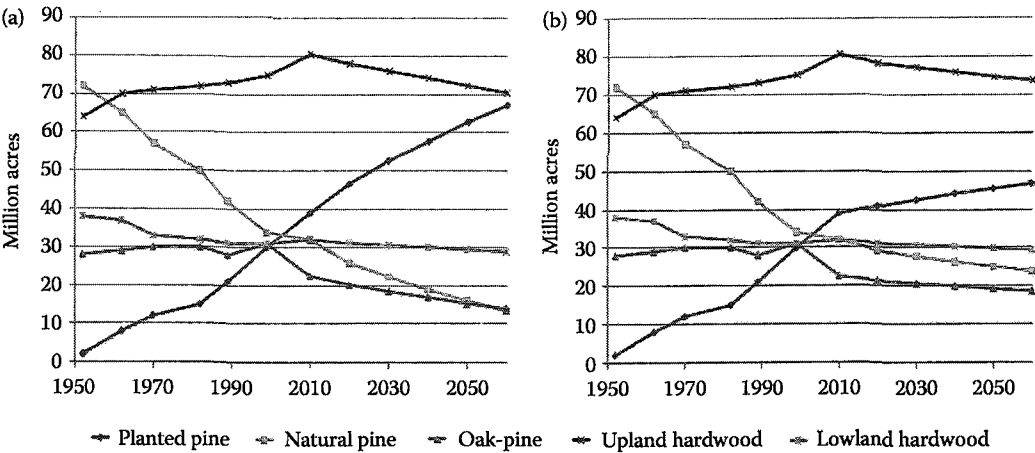


**FIGURE 2.23** Forecasted forest area in the Southern United States by management type, 1952–2060, for (a) Cornerstone E, which is characterized by high urbanization, high timber prices, and more planting; and (b) Cornerstone F, which is characterized by low urbanization, low timber prices, and less planting.

its lower timber prices and slower urbanization: a gain of 16.8 million acres (about 0.3 million acres per year) with planted pine comprising 28% of the forest acreage in 2060.

*Natural pine*—Forecasted losses in the area of naturally regenerated pine forest types mirror the gains in planted pine forests and are therefore related, albeit inversely, to the condition of forest products markets (Figure 2.24b). The largest predicted decrease in natural pine—a loss of 58% from 31.5 million acres in 2010 to 13.5 million acres in 2060—is associated with Cornerstone E, which would have the highest planting rates. The smallest decrease would occur with Cornerstone F, with its lower timber prices and planting rates, but losses would still be substantial: 7.6 million acres or 25%. Regardless of the Cornerstone Future evaluated, naturally regenerated pine types are forecasted to decrease, continuing a trend that has dominated forest type dynamics since the 1960s.

*Oak-pine*—The area of the oak-pine management type would also decrease for all Cornerstone Futures, with a similar pattern of change but smaller acreage and percent changes than is forecasted for natural pines (Figure 2.24c). As with natural pine, oak-pine is more heavily influenced by timber market conditions than by urbanization rates. Oak-pine decreases would range from 8.5 million acres (38%) for Cornerstone E to 3.9 million acres (17%) for Cornerstone F.

*Upland hardwood*—At more than 80 million acres in 2010, upland hardwoods are the predominant management type in the South, more than double the area of the next largest type. Upland hardwoods are forecasted to decrease for all Cornerstone Futures (Figure 2.24d), and variations in forecasts are associated more with the rate of urbanization than with timber market futures. The three Cornerstone Futures that predict the lowest upland forest loss are associated with lower urbanization (C, D, and F), and the three that predict the highest loss are associated with the higher urbanization forecasts (A, B, and E). Loss of upland hardwood forests would range from 5.9 million acres (about 8%) for Cornerstone C to 11.2 million acres (14%) for Cornerstone B. For Cornerstone E, which is also characterized by high timber prices but with even higher rates of planting, the projected total area of planted pine forest would be nearly equal to upland hardwood forests in 2060, as the stimulating effects of price and planting on the pine type combine with the depressing effects of urbanization on the hardwood type.

*Lowland hardwood*—The area of lowland hardwood forests is also more sensitive to the rate of urbanization and less sensitive to forest products markets than the softwood types. For this management type (Figure 2.24e), forecasts indicate losses ranging from 1.7 (5%) to 4 million acres (12%) from a base of 32 million acres in 2010. The relative ranking of predicted change across

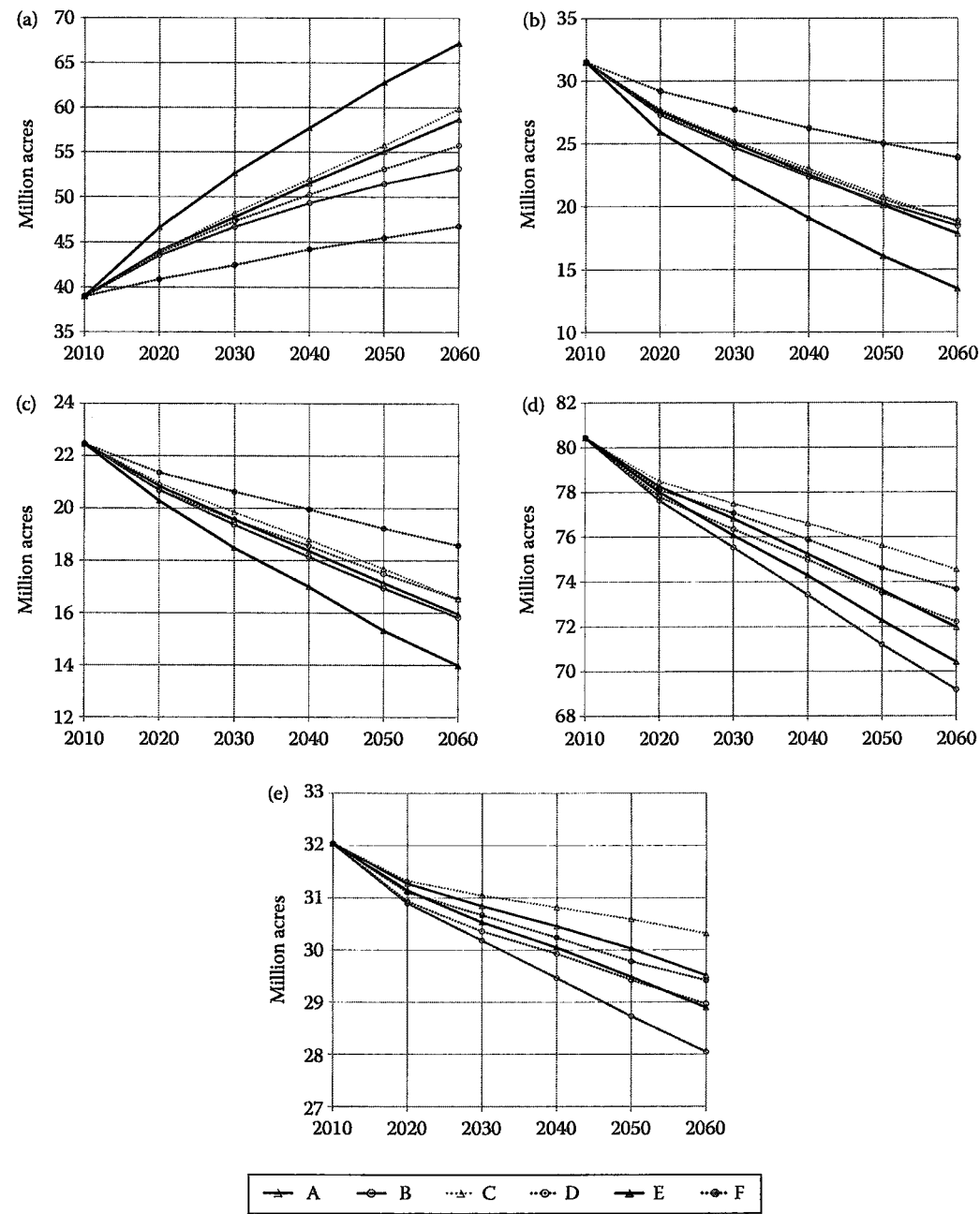


**FIGURE 2.24** Forecasted forest area in the Southern United States under six Cornerstone Futures, 2010–2060, for (a) planted pine, (b) natural pine, (c) oak-pine, (d) upland hardwood, and (e) lowland hardwood management types.

Cornerstone Futures is identical to the forecasts for upland hardwood types. Lowland forests would lose proportionally less area than the other natural pine, oak-pine, and upland hardwood.

*Regional variations*—The forecasts of forest-type dynamics vary across the subregions (Figure 2.25a–e). Forest losses would be especially concentrated in the Piedmont and Appalachian-Cumberland highlands and intensive management in the Coastal Plain would influence management

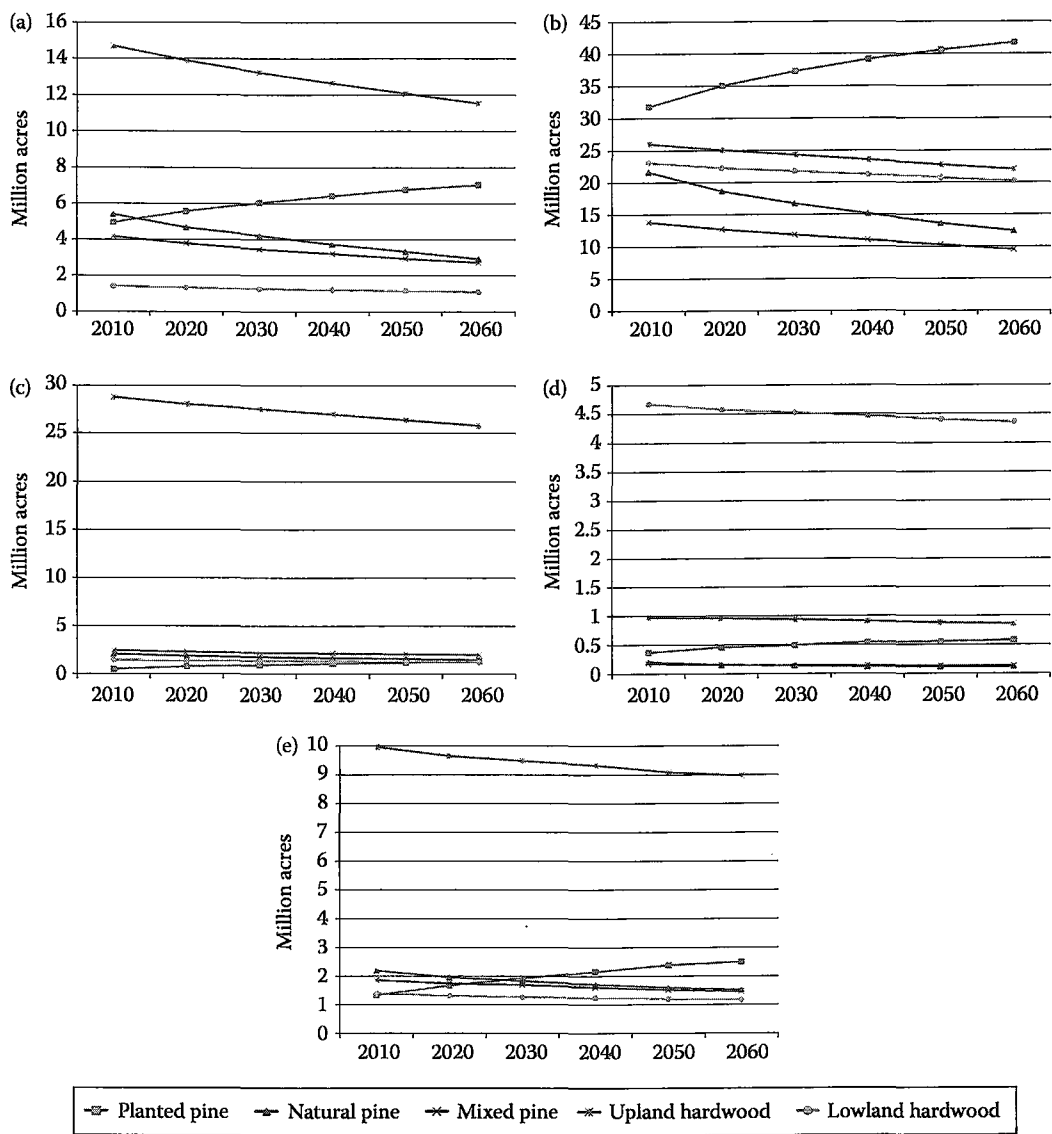


**FIGURE 2.25** Forecasted forest area in the Southern United States by management type, 2010–2060, for (a) Piedmont, (b) Coastal Plain, (c) Appalachian-Cumberland highlands, (d) Mississippi Alluvial Valley, and (e) Mid-South under Cornerstone B, which is characterized by high urbanization and low timber prices.

types differently. The Coastal Plain, with 82% of planted pine in 2010, would experience the largest growth in planted pine area, from 32 to 43 million acres. Decreases in naturally regenerated pine would be largest in the Coastal Plain as well. Upland hardwood losses would be largest in the Piedmont and in the Appalachian-Cumberland highlands, reflecting the influence of urbanization on these types. Changes in lowland hardwood types would be more evenly spread across the South.

**FOREST BIOMASS**

Of the various metrics available for measuring biomass changes for a site in a forest inventory, we opted to focus on the volume of growing stock because it is a useful index both for timber analysis

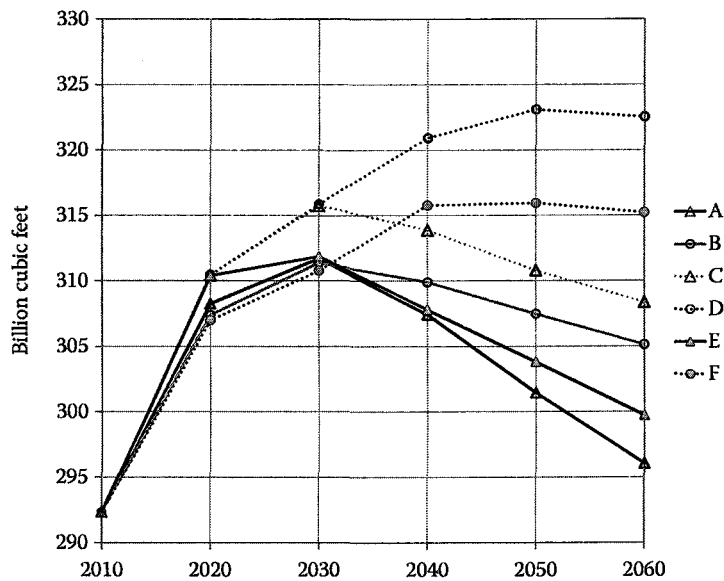


**FIGURE 2.26** Total growing stock volume in the Southern United States, 2010–2060, under six Cornerstone Futures.

and for measuring other ecosystem services. Total growing stock volumes are forecasted to change in response to both land-use changes and timber harvesting levels (Figure 2.26). From a base of about 292 billion cubic feet in 2010, inventories would increase at most by about 11% in 2060 under the low urbanization/low timber price Cornerstone D. The smallest increase in total growing stock inventories would be found with the high urbanization/high timber price Cornerstone A, with an increase in volume to 2030 and then a decrease over the remainder of the forecast period. Under this cornerstone, the volume in 2060 would be about 1% higher than values observed in 2010.

Differing patterns of change between hardwood and softwood components of the inventory are generally countervailing in their effects. Under all Cornerstone Futures, softwood growing stock inventories would increase (Figure 2.27). For the low urbanization/low timber price Cornerstone D,

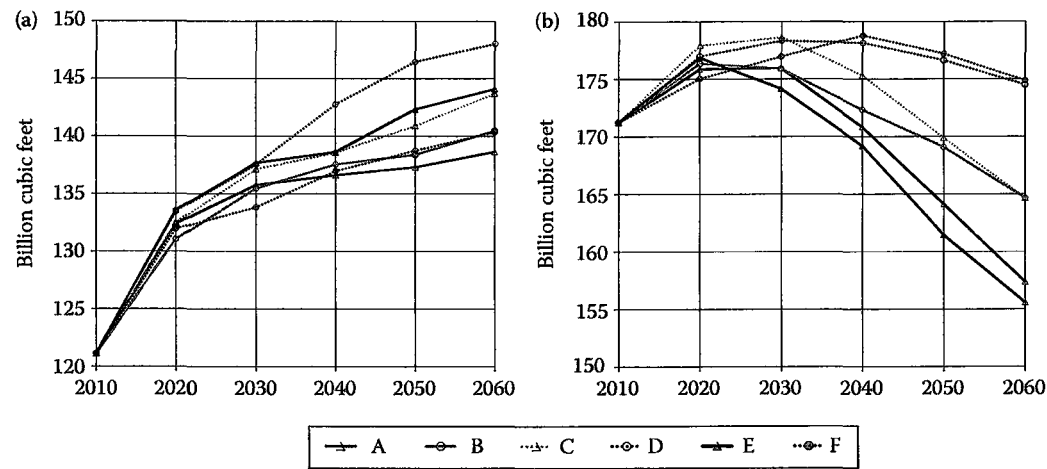


**FIGURE 2.27** Total growing stock volume in the Southern United States, 2010–2060, under six Cornerstone Futures for (a) softwoods and (b) hardwoods.

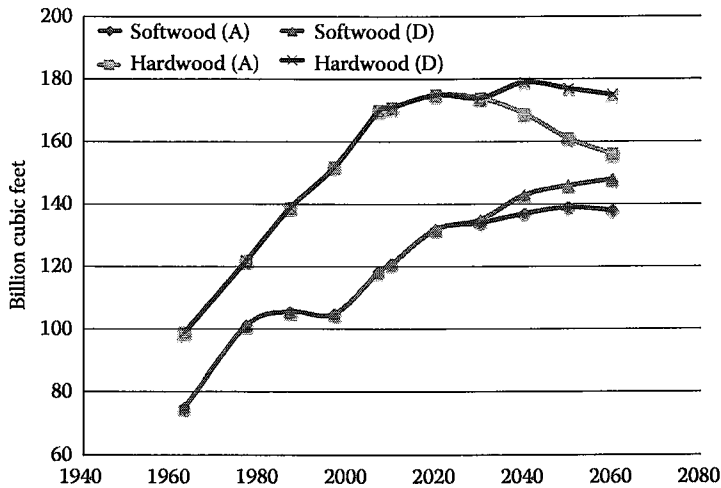


**FIGURE 2.28** Historical (1962–1999) and forecasted (2020–2060) hardwood and softwood growing stock inventories in the Southern United States, for Cornerstones A (large urbanization gains with increasing timber prices) and D (moderate urbanization gains with decreasing timber prices).

softwood inventories would increase from a base of about 121 billion cubic feet in 2010 to ≤148 billion cubic feet (37 billion cubic feet or 22%). The smallest increase would be 15% (18 billion cubic feet) for the high urbanization/high timber prices Cornerstone A.

Starting from about 171 billion cubic feet in 2010, hardwood growing stock volumes would peak somewhere between 2020 and 2040 for all Cornerstone Futures and then decrease to the year 2060 (Figure 2.27b). The most pronounced decreases would be for Cornerstones A and E, both of which have high rates of urbanization and high timber prices. Predicted declines for these Cornerstone Futures from 2010 to 2060 are in the range of 15 billion cubic feet (9%), compared to 3 billion cubic feet (2%) for Cornerstones D and F.

These predicted changes in growing stock volume depart from historical patterns of volume accumulation in the South. From 1963 to 2010 southern forests accumulated about 2.5 billion cubic feet per year or roughly 70%, with hardwoods accounting for most of this biomass accumulation (61%). Although growth is projected to continue over at least the next 10 years, growing stock volume would reach a maximum and then decrease somewhat over the following 40 years (Figure 2.28), with hardwood growing stocks decreasing, especially in response to urbanization (Cornerstone A). Softwood volumes would increase only slightly.

**FOREST CARBON**

We estimated that the carbon in southern forests in 2010 was about 12.4 billion tons stored in eight pools: down trees, standing dead trees, litter, soil organic carbon, live trees aboveground and belowground, and understory plants aboveground and belowground. Aboveground live trees and soil organic material made up 80% of the total carbon stock. Forecasts of future forest carbon stocks reflect changes in the amount of forest area and the composition of the forest inventory. However, because the model we used tracks only the carbon pool in forests and does not account for carbon transfers to agricultural and other land-use pools, our estimates are not comprehensive. Likewise, the model does not account for carbon that leaves forests as products and may remain sequestered for long periods of time in housing or other end uses (Heath et al. 2011).

Changes in forest carbon pools reflect both changes in growing stock volumes and changes in forest area (Figure 2.29). Under most Cornerstone Futures, tree carbon would peak in 2020 and then

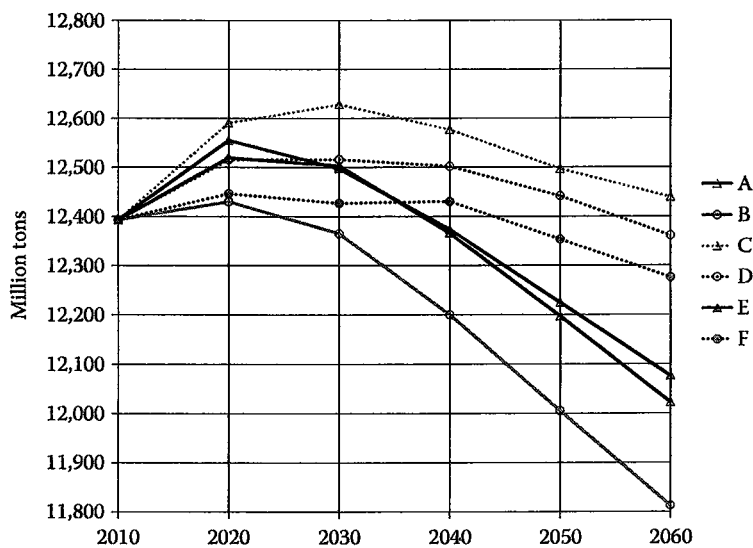


**FIGURE 2.29** Total forest carbon stock in the Southern United States, 2010–2060, under six Cornerstone Futures.

level off or decrease; the exception would be the low urbanization/high timber prices Cornerstone C, which would peak in 2030. At the extreme, the forest carbon pool in 2060 would be 5% smaller than the pool in 2010 (a net emission of about 600 million tons). Carbon would accumulate as a result of net biomass growth on forested lands, but these gains would be offset by the loss of forested land through urbanization.

The clustering of carbon forecasts in Figure 2.29 reveals the interplay of urbanization and timber prices. The forecasts with the highest amount of carbon predicted for 2060 are associated with the low urbanization Cornerstone Futures (C, D, and F). The lowest carbon forecasted is for the high-urbanization Cornerstone Futures (A, B, and E). However, within each of these triplets, the lowest carbon levels are associated with lower timber prices (Cornerstones B and F); higher timber prices and resulting intensive forest management would lead to higher carbon sequestered in the forest pool. This suggests that urbanization patterns dominate the forecasts of carbon storage and that stronger forest product markets can ameliorate carbon losses.

**FOREST COMPOSITION AND AGE CLASSES**

The USFAS was designed to replicate inventories across broad areas—for example, aggregates of at least several counties—and for broad species groupings. However, the resampling/imputation approach does provide some insights into how drivers of change may alter forest composition at a finer scale. For example, Figure 2.30 shows forest forecasts of hardwood groups for the high urbanization/low timber price Cornerstone B, which leads the other Cornerstone Futures in predicted decreases of forest area. For this cornerstone, all hardwood groups are forecasted to lose 16 million acres (14%) but not all would lose area at the same rate. Oak/hickory (*Carya* spp.) would lose about 1% compared to 10% or more for all other groups. The most substantial losses (26%) would be for the yellow poplars (*Liriodendron tulipifera*) at 4 million acres and the other hardwoods at 6 million acres. Digging a bit deeper, losses of the yellow poplar forest type are expected to be about 25% in the Coastal Plain (1.4 million acres) and the Appalachian-Cumberland highlands (1.0 million acres), compared to a more substantial loss of 34% in the Piedmont (1.6 million acres).

The forecasted area of softwood species groups is shown in Figure 2.31. Loblolly/shortleaf pine (*P. echinata*/*P. taeda*) is forecasted to remain dominant, with its area roughly level through the

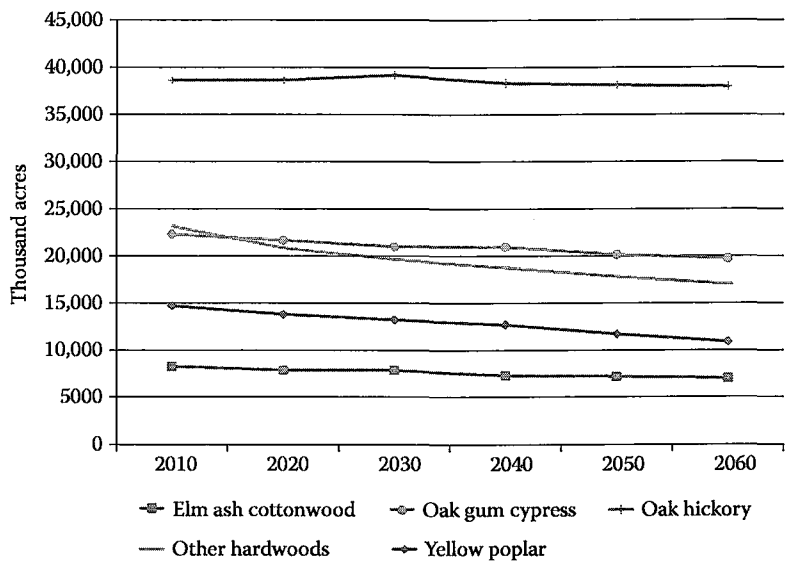


**FIGURE 2.30** Forecasts of the area of hardwood species and groups in the Southern United States, 2010–2060, under Cornerstone B, which is characterized by high urbanization and low timber prices.

forecast period. Although overall forest area is expected to decrease and softwood removals are forecasted to increase, continuation of investment in plantations would enable this group to maintain its area. Loblolly/slash pine (*P. palustris*/*P. elliotii*) is forecasted to increase slightly and oak/pine is expected to decrease. All other groups would exhibit very little change.

Another element of forest conditions that may be especially important for wildlife is the age class distribution of management types (Chapter 11). Figure 2.32a–e shows forecasts of age classes for the high urbanization/high timber prices/more planting Cornerstone E. Early-age forests are <20 years, mid-age forests are 20–70 years, and old-age forests are >70 years. Because Cornerstone E

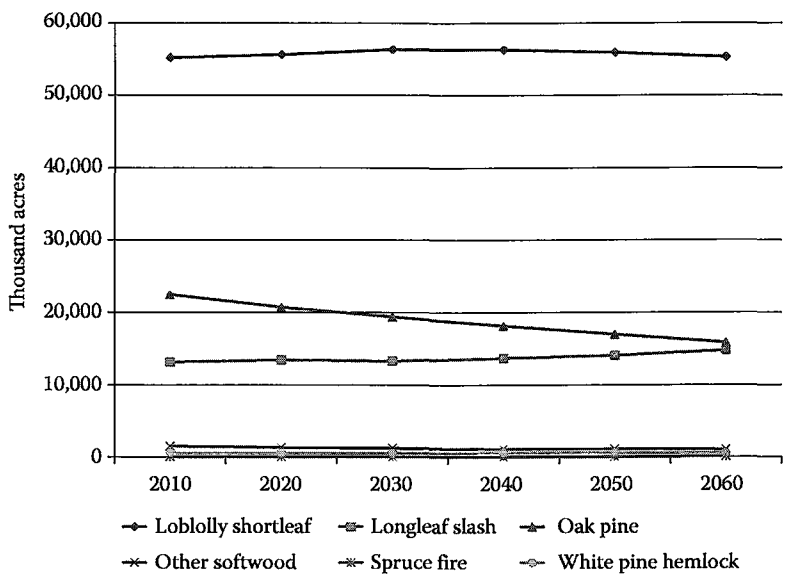


**FIGURE 2.31** Forecasts of the area of softwood species groups in the Southern United States, 2010–2060, under Cornerstone B, which is characterized by high urbanization and low timber prices.

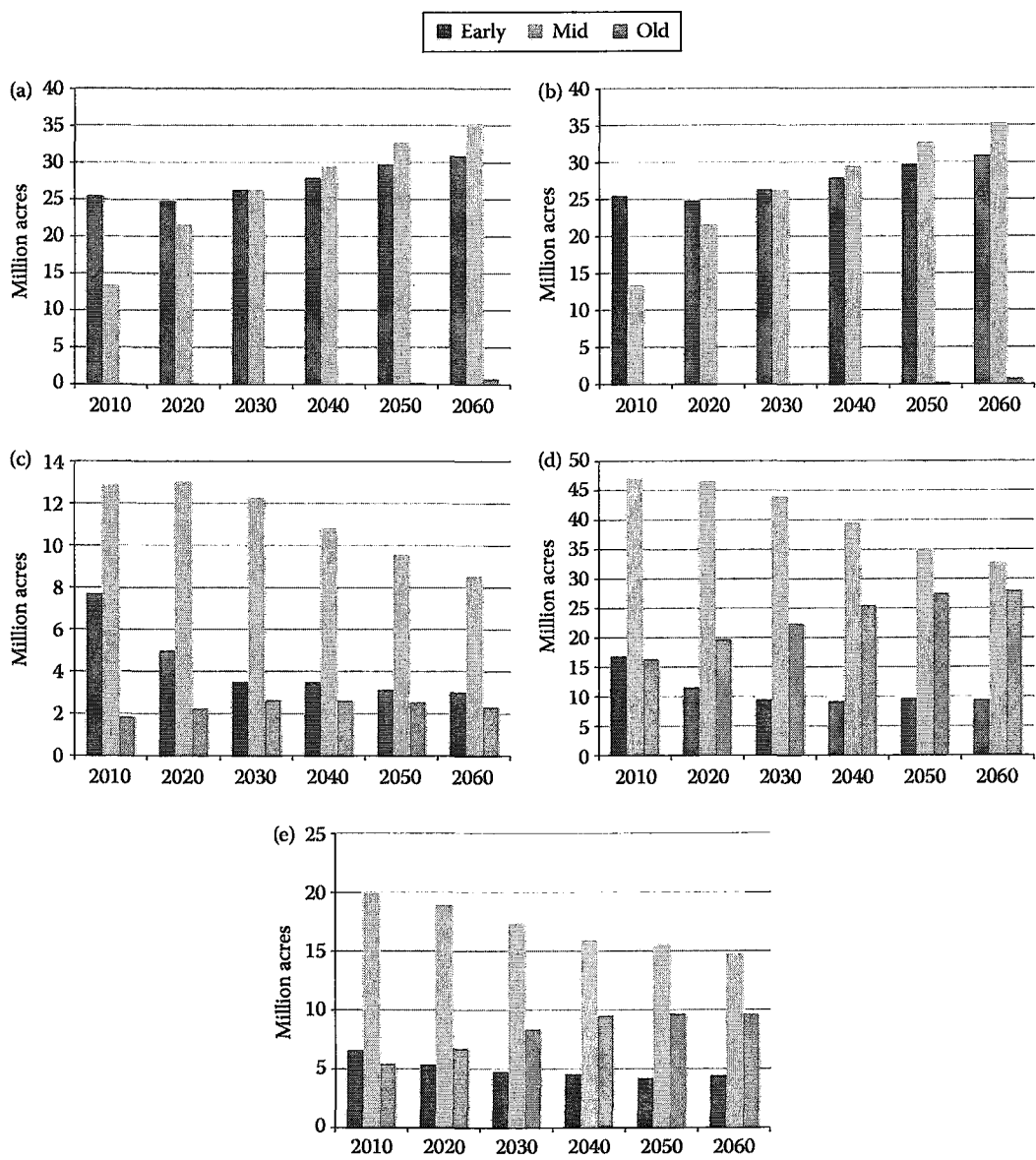


**FIGURE 2.32** Forecasts of forest age classes in the Southern United States, 2010–2060, for (a) planted pine, (b) natural pine, (c) oak-pine, (d) upland hardwood, and (e) lowland hardwood management types under Cornerstone E, which is characterized by high urbanization, high timber prices, and increased planting.

predicts the largest change in management types and the most harvesting, it is a “best” case for the production of early-age forests.

With the exception of planted pine, all management types are forecasted to experience a decrease in early-age forests throughout the forecast period for Cornerstone E. Planted pine forests are forecasted to shift their distributions toward mid-age as the rate of planting decreases from its peak in the late 1990s. Mid-age forest area would increase substantially, and early-age forest area would increase at a more moderate rate. Practically no acres of old-age forest would remain in the planted pine management type.

High harvest rates and conversion to planted pine in Cornerstone E would shift the age class distribution of the naturally regenerated pine types. The area of old-age natural pine would stay relatively constant but mid-age forests would decrease by 13 million acres (about 64%) and early-age forests would decrease by about 4.5 million acres (58%). Oak-pine would experience a similar pattern of age class changes.

In contrast to the softwoods, hardwood forecasts would experience an increase in old-age forests. For upland hardwoods, the area of mid-age forests is forecasted to decrease by 14 million acres (down from 59% in 2010 to 47% in 2060). Over this same period, old-age forests are forecasted to increase by 12 million acres (up from 20% to 40%) and early-age forests would decrease by 8

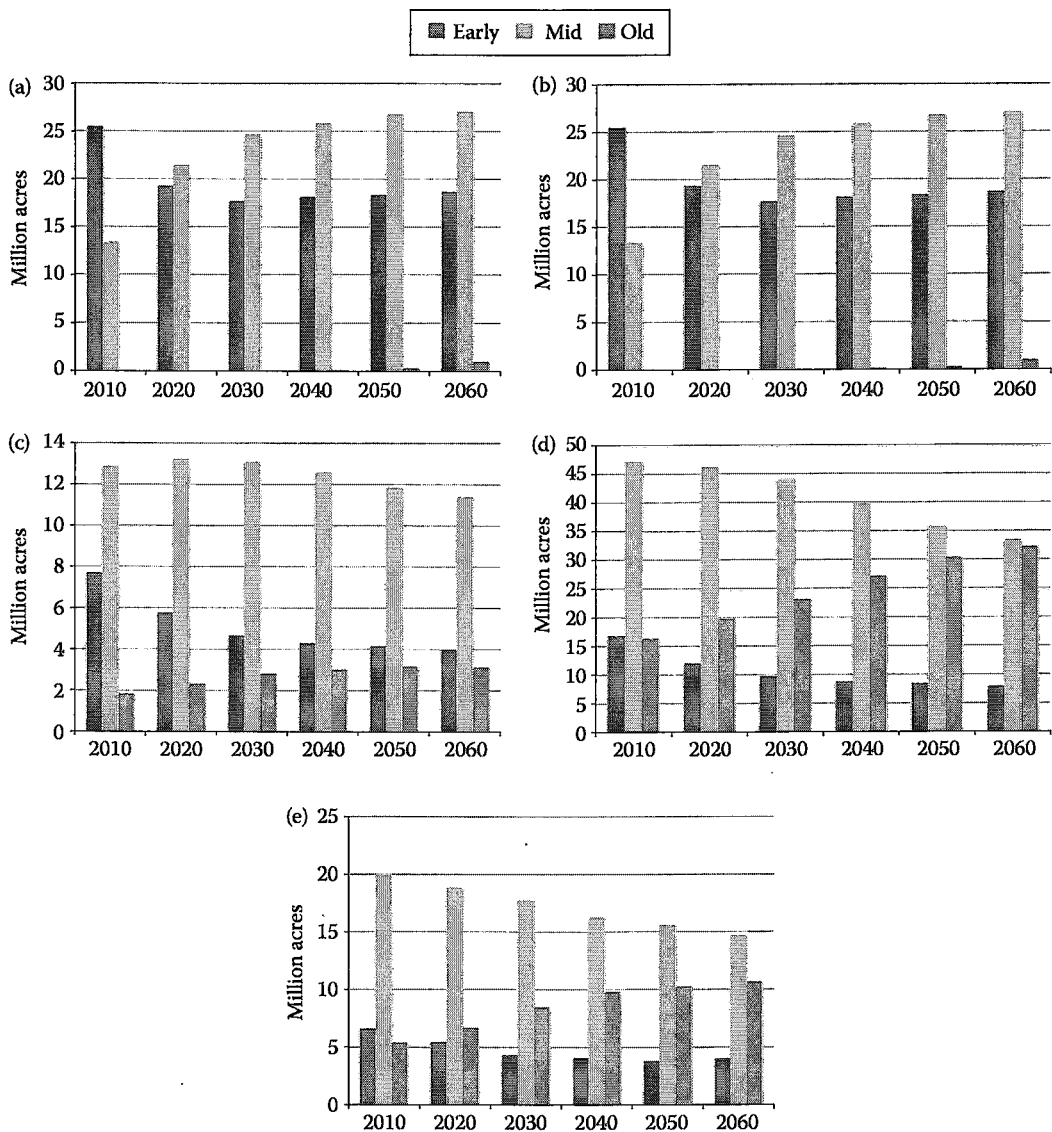


**FIGURE 2.33** Forecasts of forest age classes in the Southern United States, 2010–2060, for (a) planted pine, (b) natural pine, (c) oak-pine, (d) upland hardwood, and (e) lowland hardwood management types under Cornerstone F, which is characterized by low urbanization, low timber prices, and decreased planting.

million acres (down from 21% to 13%). Overall, the shift among age classes reveals that the early-age component of the upland hardwood type would decrease by 44% at the same time that the old-age component would increase by 71%.

The pattern of change for the lowland hardwood management type would be similar to changes in upland hardwoods, but the changes would occur at different rates. The mid-age component of lowland hardwood forests would decrease by about 5 million acres (26%), compared to an increase of about 4 million acres (77%) for the old-age component, and a decrease of about 2 million acres (33%) for the early-age component. As with the upland management type, the total area would decrease but average age would increase.

Contrary to Cornerstone E, Cornerstone F (Figure 2.33a–e) is characterized by less planting and a lower harvest rate. The forecasts for Cornerstones E and F therefore bracket all the Cornerstone Futures. For Cornerstone F, the area of early-age planted pine would decrease over time (in contrast to increases simulated under Cornerstone E), and the age class distribution would approach a stasis.

Cornerstone F would also result in less dramatic changes in area of natural pine when compared to Cornerstone E, with more stability in the early-age class, increases in the old-age class, and smaller decreases of the mid-aged class (33% less). This pattern is mirrored in the oak-pine age classes. For hardwood management types, however, the differences between Cornerstones E and F were minor. This indicates that management changes strongly influence the age structures of softwoods but have little influence on hardwoods.

## CONCLUSIONS

The SFFP describes a set of integrated social, economic, climate, and resource futures for exploring adaptation and mitigation strategies for the region's forests. Projections indicate relevant variability across the scenarios but also across space within each scenario. The six discrete Cornerstone Futures together form a broad range of plausible future conditions for the analysis of specific issues in subsequent chapters in this book. They allow for simultaneous consideration of the economic/social driving variables and the climate effect variables thereby supporting integrated analysis across various phenomena.

In contrast, some questions demanded averaged climate projections, without concurrent consideration of the socioeconomic drivers. These questions were best served by the ensembles of climate projections created for the IPCC storylines. These ensembles also demonstrate important variability across storylines and across space within storylines.

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