Ecoregion and Scenario Framework

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Chapter 2. Ecoregion and Scenario Framework

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2.1. Introduction

The current and projected changes in LULC are key components for this assessment of carbon and GHG stocks and fluxes (Zhu and others, 2010). Mapping of the baseline (1992–2005) LULC conditions (chap. 3) provided a spatial foundation for the wall-to-wall assessment of carbon stocks and GHG fluxes in various ecosystems (chap. 1). The development of a range of potential future LULC projections together with corresponding climate-change projections allowed for an evaluation of potential future carbon sequestration capacities and vulnerabilities as influenced by these projected drivers. This chapter provides an overview of methods used to construct the alternative LULC scenarios and descriptions of the distinguishing characteristics of each of the ecoregions used for the assessment.

2.2. Definition of Terms

The framework for projected changes in LULC and land management for three future scenarios from 2005 through 2050 are presented in this chapter. LULC classes used for this assessment are described in detail in chapter 3. To maintain consistency with the overall assessment, we present results of the land use scenario downscaling process consistent with the broad ecosystem types used to assess regional-scale carbon dynamics. These ecosystems include forests, grasslands/shrublands, agricultural lands, and wetlands. Urban development was modeled as a separate LULC class but was collapsed into the "other" category. Urban areas with significant tree cover were considered in carbon modeling, as noted in chapter 1.

Changes in land use (conversions) are associated with the conversion of lands from one use type to another. Typical conversions include changes between forest and agricultural lands (afforestation and deforestation) and conversions to development (for example, urbanization). Land management practices, such as timber harvesting, are captured as changes in land cover where it is assumed that logged areas no longer meet the definition of a forest cover classification. Areas of forest logging are accounted for through the use of a temporary mechanical disturbance category, where the specific areas remain until the next temporal period (5 years for scenarios) before being reassigned to the forest class. As a result, forest land use is considered a land use class, consisting of areas ranging from mature forest to areas where logging has recently occurred and trees may not be present or have only recently been replanted. In the following sections, we present projections of changes in forest cover, forest use, and forest management (mechanical disturbance of forest land or logging). For some ecoregions and scenarios, we also present the gross conversions associated with deforestation and afforestation where those changes were important to regional-scale land use dynamics.

2.3. Spatial Domain Used for the Assessment

This assessment is organized by seven level II ecological regions (ecoregions) that cover the Eastern United States; the ecoregions were adapted from the ecoregion frameworks of the EPA (U.S. Environmental Protection Agency, 2013a) and for the purposes of this assessment are as follows: (1) Mixed Wood Shield, (2) Atlantic Highlands, (3) Mixed Wood Plains, (4) Central USA Plains (5) Southeastern USA Plains, (6) Ozark, Ouachita-Appalachian Forests, and (7) Mississippi Alluvial and Southeast USA Coastal Plains (includes the Everglades and the Texas-Louisiana Coastal Plain level II ecoregions for analysis of this assessment; fig. 1–1). All the assessment models were parameterized, and the results were calibrated and reported based on these ecoregions. In this report, the term region is often used in a general sense, depending on the context, whereas the term ecoregion refers to the EPA ecoregion hierarchy (U.S. Environmental Protection Agency, 2013a). The major terrestrial and aquatic ecosystems are analyzed within these ecoregions. The use of the ecoregions and the NLCD's LULC classes chosen for the ecosystems in this assessment suggest that the reported results are meaningful within the defined ecoregion and ecosystem boundaries and may not be directly comparable with other national- or regional-level estimates because of the different boundary definitions. Further discussion of the ecoregions and ecosystems may be found in Zhu and others (2010).

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The EPA ecoregion framework was used to capture regionally unique processes and landscape potential (Omernik, 1987; U.S. Environmental Protection Agency, 2013a). Ecoregions represent areas with similar patterns of biotic, abiotic, aquatic, and human land-use characteristics and have proven to be a useful framework for collecting and synthesizing information about LULC change (Gallant and others, 2004). Ecoregions as defined by the EPA are hierarchical at four spatial scales (levels I, II, III, and IV) for the conterminous United States. The 1999 version of level III ecoregions (U.S. Environmental Protection Agency, 1999) was used as the base map for the assessment. Based on this version of the EPA 1999 framework, a further modified version consisting of seven level II ecoregions was developed to serve as the framework for this assessment (fig. 1–1). Condensed versions of the ecoregion descriptions are included in the following sections.

2.3.1 Mixed Wood Shield

The Mixed Wood Shield ecoregion covers the northern parts of Minnesota, Wisconsin, and Michigan in the United States and contains the Northern Minnesota Wetlands and the Northern Lakes and Forests level III ecoregions (fig. 1–1). Although there are some minor areas of bedrock exposure, this is a glaciated region, and most areas are covered with glacial drift. The broad landforms are mostly smooth to irregular plains with a few areas of hills.

The ecoregion has a severe midlatitude humid continental climate, marked by warm summers and very cold winters, with no pronounced dry season. The mean annual temperature ranges from 2 to 6 degrees Celsius (°C); the mean summer temperature is about 16 °C; and the mean winter temperature ranges from –10 to –12 °C. The frost-free period ranges from less than 100 days to near 160 days in lake-moderated areas. The mean annual precipitation ranges from about 500 to 960 millimeters (mm) within the region (Wiken and others, 2011).

The subboreal vegetation includes northern coniferous forests, northern hardwood forests, boreal hardwood-conifer forests, swamp forests, and peatlands. Changes in stand densities and forest composition from hardwood and conifers to successional species that have occurred during the past 150 years have been affected by land use history and management (Albert, 1995; Zhang and others, 2000; Schulte and others, 2007). From the mid-1800s through the early 1900s, there was intense logging, repeated slash-and-burn fires, and a short period of attempted settlement or agricultural use of cutover lands and then abandonment. As forests recovered, mixed coniferous forests transformed into hardwood (especially aspen)-dominated forests; aspen has proven to be an early successional species with strong post-disturbance sprouting ability (Friedman and Reich, 2005). Fire suppression policies also represent a major change from the natural disturbance history in this region.

Land cover in the Mixed Wood Shield ecoregion is dominated by forest, wetlands, and water, which account for about 87 percent of the region's area. The region has a relatively low human population compared with other regions of the Eastern United States. The economy is based primarily on forestry, recreation and tourism, hunting and fishing, and iron ore mining. Land change is driven by demand for resources such as timber, minerals, and in the lower peninsula of Michigan, some energy resource extraction from oil and natural gas. Forestry activities are the main drive of land use and land cover change in the Mixed Wood Shield ecoregion. Land change during the past 40 years shows the continued dominance of forest land cover, although this land use has declined slightly. Wetlands have been relatively stable at about 20 percent of the region's land cover since 1973. With the cold climate and thin, nutrient-poor soils in the region, agriculture is very limited compared with the adjacent Mixed Wood Plains and Central USA Plains ecoregions to the south. Agricultural lands covered about 7 percent of the region in 2000, a relatively stable land use since the early 1970s. Where there is agriculture, it is generally in small areas; the most common products are hay and grain crops, beef and dairy cattle, and potatoes.

2.3.2. Atlantic Highlands

The Atlantic Highlands ecoregion covers forested upland areas in Pennsylvania, New Jersey, New York, Connecticut, Massachusetts, Vermont, New Hampshire, and Maine in the northeastern United States (fig. 1–1). This is a cool, humid, forested, and formerly glaciated region that is relatively sparsely populated compared with adjacent regions. It has higher elevations and more rugged topography than most adjacent ecoregions and contains iconic mountain ranges and elevated plateau areas of the Northeast, including the White, Green, Taconic, Berkshire, Adirondack, Catskill, and Pocono Mountains, the Hudson Highlands, and the Allegheny Plateau. Elevations reach more than 1,900 meters (m) at Mount Washington in New Hampshire. The Atlantic Highlands ecoregion contains the Northern Appalachian and Atlantic Maritime Highlands (includes the northern Appalachian Plateau and uplands) and North Central Appalachians level III ecoregions (U.S. Environmental Protection Agency, 2013a).

The Atlantic Highlands ecoregion has a severe midlatitude humid continental climate, marked by warm summers and cold, snowy winters. The mean annual temperature ranges from about 1 to 8 °C, varying by elevation and latitude. The frost-free period ranges from less than 50 days at high elevations to near 180 days in low-elevation southeast areas. The mean annual precipitation ranges from about 840 mm to more than 2,000 mm on high peaks (Wiken and others, 2011).

As with climate, the vegetation of the region also varies by elevation and latitude. Forest types are transitional in a broad zone between the boreal forests to the north in Canada and the broadleaf deciduous forests to the south (Braun, 1950; Goldblum and Rigg, 2010). Forest types include northern hardwoods, northern hardwoods-spruce, and northeastern

spruce-fir forests in the north and Appalachian oak forests in the south (Kuchler, 1964). To the south and at low elevations, northern hardwood forests give way to transition hardwood forests
with more oaks, hickories, and pines on dry sites and northern hardwoods and hemlock on mesic and north-facing slopes.

The economy of the Atlantic Highlands ecoregion today is based primarily on forestry, tourism and recreation, hunting and fishing, and some small-scale farming. Forestry activities for paper and pulp production, sawlogs, and biomass chipping are important, especially in the part of the region that is covered by Maine, and some high-quality hardwoods are harvested in the Pennsylvanian forests (Napton and others, 2003). Forest management is influenced by the varied land ownership patterns in the region. Private forest land dominates the region, from large corporate land holdings in Maine to small individual holdings in southern areas.

During the past few decades, the area of forest land cover in the region has started to decline, a trend seen in other parts of the Northeastern and Eastern United States (Drummond and Loveland, 2010; Jeon and others, 2012). Forest cover has decreased by nearly 3 percent since 1973 (Sleeter and others, 2013).

Agricultural lands are the second largest class of land cover in the Atlantic Highlands ecoregion, covering about 9 percent of the region. With its cold climate and stony soils, agriculture is limited in most parts of the Atlantic Highlands ecoregion compared with the adjacent Mixed Wood Plains ecoregion. The most common products are dairy cattle, hay and silage crops, apple orchards, and nursery stock. Similar to the Mixed Wood Shield ecoregion, the Atlantic Highlands ecoregion also has a relatively low human population compared with other regions in the Eastern United States. The area covered by developed land increased from 1.9 percent of the region in 1973 to 2.4 percent in 2000 (Sleeter and others, 2013).

2.3.3. Mixed Wood Plains

The Mixed Wood Plains ecoregion covers an area of glaciated, rolling to level terrain with mixed land cover that extends across parts of Minnesota, Wisconsin, Iowa, Illinois, Michigan, Indiana, Ohio, Pennsylvania, New York, New Jersey, Connecticut, Massachusetts, Vermont, New Hampshire, and Maine (fig. 1–1). The ecoregion is characterized by a land cover mosaic of agricultural lands, forest, wetlands, and glacial lakes. This is in contrast to the Mixed Wood Shield and Atlantic Highlands ecoregions to the north where soils are more nutrient-poor and mostly lacking in agricultural lands and in contrast to the nutrient-rich Central United States Plains and Temperate Prairies ecoregions to the south and west where landscapes are dominated by agricultural land use. The Mixed Wood Plains ecoregion contains the North Central Hardwood Forests, Driftless Area, Southern Michigan/Northern Indiana Drift Plains, Northeastern Coastal Zone, Erie Drift Plain, Maine/New Brunswick Plains and Hills, and Eastern Great Lakes and Hudson Lowlands level III ecoregions (U.S. Environmental Protection Agency, 2013a).

The Mixed Wood Plains ecoregion has been glaciated and includes a wide variety of deep glacial and marine deposits with a few areas of bedrock outcrops. The terrain includes flat lake plains, rolling till plains, outwash plains, hummocky stagnation moraines, a less-glaciated dissected plateau in the Driftless Area (that is, with only some patchy pre-Illinoian glacial drift), and some low to high hills, especially in New England.

The Mixed Wood Plains ecoregion has a severe midlatitude humid continental climate, marked by warm summers and cold, snowy winters. There is some maritime influence in coastal areas and lake-effect influence near the Great Lakes. The mean annual temperature ranges from 4 to 10 °C. The frost-free period ranges from 110 to 170 days. Mean annual precipitation ranges from about 600 mm in the far west to more than 1,250 mm in wetter parts of the east (Wiken and others, 2011).

Although once mostly forested, because the region stretches from near the edge of the Great Plains grasslands in the west to coastal New England in the east, the historical vegetation of the Mixed Wood Plains ecoregion is varied. In Minnesota, Iowa, and Wisconsin, a forest and savanna transition zone includes small patches of prairie, oak savannas, and maple-basswood forests on mesic sites (Braun, 1950; Kuchler, 1964). In south-central Wisconsin, pine barrens with jack pine (*Pinus banksiana*) and scrub oaks were common in the sandy, droughty outwash and lake plains, along with areas of wet conifer swamps and peatlands (Curtis, 1959). In the central section of the Mixed Wood Plains from Lake Michigan to Lake Ontario, there are beech-maple forests with some oak-hickory forests on drier sites. Further east, in southern New England and the lower Hudson Valley of New York, Appalachian oak and northeastern oak-pine forests occur, with several forest species at the northern limits of their range.

The economy of the Mixed Wood Plains ecoregion continues to be diverse, based on manufacturing and technology, finance, health research and services, education, agriculture, forestry, fishing, and tourism. LULC reflects some of this diversity with its mixed uses. Land use is dominated slightly by agricultural lands, accounting for about 40 percent of the region in 2000, whereas forest cover was nearly as extensive at 37 percent of the region. Agricultural lands have decreased since 1973 and tend to be a more dominant part of the landscape in the western half of the ecoregion, in Minnesota, Iowa, Wisconsin, and Michigan. The most typical agricultural activities center around dairy and beef cattle, hay and silage crops, corn, oats, soybeans, fruit orchards and vineyards, and nursery stock. Forests, however, are similar to other parts of the Northeastern and Eastern United States, and have been declining in the past few decades (Drummond and Loveland, 2010; Jeon and others, 2012). Forest land is more dominant in the New England part of the region, especially in the Maine/New Brunswick Plains and Hills ecoregion of Maine, which was about 70 percent covered in forest in 2000.

2.3.4. Central USA Plains

The Central USA Plains ecoregion is an area of glaciated, flat-to-gently-rolling plains that extends across parts of Wisconsin, Illinois, Indiana, Michigan, and Ohio (fig. 1–1). The ecoregion is characterized by LULC that is dominated by agricultural lands. It is one of the largest areas of the Eastern United States with suitable relief and soils for cropland (Hart, 1968). This is in contrast to the Mixed Wood Plains to the north that has a bimodal mix of agricultural lands and forests and to the nonglaciated Southeastern USA Plains and Ozark, Ouachita-Appalachian Forests ecoregions to the south and east that are more densely forested and have more irregular or hilly landforms. The Central USA Plains ecoregion includes the Southeastern Wisconsin Till Plains, Huron/Erie Lake Plains, Central Corn Belt Plains, and Eastern Corn Belt Plains level III ecoregions (U.S. Environmental Protection Agency, 2013a)

The Central USA Plains ecoregion has a severe midlatitude humid continental climate, marked by warm to hot summers and cold winters. The mean annual temperature ranges from approximately 7 °C in the north to 13 °C in the south. Temperatures are moderated in areas near the Great Lakes. The frost-free period ranges from 150 to 200 days. Mean annual precipitation varies from about 700 mm to 1,140 mm (Wiken and others, 2011). Tornados are not uncommon in late spring and early fall.

The historical vegetation of the Central USA Plains ecoregion ranged from mostly prairies and savannas in the west to various forest types and some savanna mosaics to the east. A large part of the region consists of the eastern extent of the Prairie Peninsula region (Transeau, 1935; Geis and Boggess, 1968). In southeast Wisconsin, northern Illinois, and parts of Indiana and western Ohio, a forest and savanna transition zone included small patches of prairie, oak savannas, and beech-maple forests on mesic and eastern sites (Braun, 1950; Kuchler, 1964; Albert, 1995). The savannas contained a tallgrass prairie mosaic along with bur oak (*Quercus macrocarpa*) and other woody species.

Economic restructuring in the steel and other manufacturing sectors resulting from a decline in the heavy manufacturing industry in the area caused job losses and economic decay in parts of the Central USA Plains ecoregion in the late 20th century. The economy of the region today is still based primarily on manufacturing, agriculture, and financial and other services. The ecoregion is dominated by agriculture, although the extent of agricultural lands has decreased in response to increased demands for urban land uses (Sleeter and others, 2013). The most typical agricultural activities center on cash grain farming primarily of corn and soybeans, with some wheat and oats. Also important in the region are dairy and beef cattle, hogs, poultry, and hay and silage crops; these farms are on the small and truck farming scales. Dry beans and sugar beets are grown in the Saginaw Lake Plain of Michigan. Although forests only cover about 11 percent of the region, they cover only slightly more land than developed land, which covered slightly less than 11 percent of the region in 2000. Forest land has seen relatively small but consistent declines since 1973, a declining trend similar to other parts of Eastern United States (Drummond and Loveland, 2010). Most of the loss in forest land area is a result of conversion to developed land, with some conversion of forests to agricultural lands in certain areas.

2.3.5. Southeastern USA Plains

The Southeastern USA Plains ecoregion is the largest level II ecoregion in the Eastern United States, covering the inner coastal plains, Piedmont areas, and interior low plateaus in parts of 22 States. The ecoregion is characterized by a land cover mosaic of forest, pasture, cropland, and developed land. The region is generally not as arable as the more nutrient-rich Central USA Plains ecoregion to the north or the Great Plains region to the west. However, there are several parts of the Southeastern USA Plains that are better suited to agriculture than the bordering Ozark, Ouachita-Appalachian Forests ecoregion, which is typically hilly. The Southeastern USA Plains ecoregion contains the East Central Texas Plains, South Central Plains, Piedmont, Northern Piedmont, Southeastern Plains, Interior Plateau, Interior River Valleys and Hills, and Mississippi Valley Loess Plains level III ecoregions (U.S. Environmental Protection Agency, 2013a).

The Southeastern USA Plains ecoregion is mostly unglaciated except for a few areas in the northern fringes, in Iowa, Missouri, Illinois, Indiana, and New Jersey. The ecoregion has landforms consisting mostly of smooth to irregular plains with some areas of open hills. There are also areas of karst plains, dissected plateaus and tablelands, and some steep slopes and ravines. Elevations in the region range from sea level along Chesapeake Bay to more than 800 m on high hills of the inner Piedmont.

Most of the Southeastern USA Plains ecoregion has a mild midlatitude humid subtropical climate, marked by hot and humid summers and mild winters. The northernmost areas are somewhat cooler, located along the boundary of severe midlatitude humid continental climates with colder winters. The mean annual temperature ranges from 10 °C in the north in Illinois to 21 °C in the far southwest in Texas. The frost-free period ranges from 160 days in the north to 300 days near the Gulf of Mexico in the south. Mean annual precipitation ranges from about 680 mm in the dry southwest to more than 1,650 mm in wet parts of the south (Wiken and others, 2011). Precipitation is fairly evenly distributed throughout the year, falling as rain from frontal storms in fall, winter, and early spring and from convective thunderstorms or tropical storms and hurricanes in the warm late spring and summer months. Droughts occasionally affect the region.

The historical vegetation of the Southeastern USA Plains ecoregion was varied because of its latitudinal extent and the diverse landscape elements and ecosystems contained within the ecoregion. A mixed oak and oak-hickory-pine forest covered much of the Piedmont and parts of the upper coastal plains. Longleaf pine (*Pinus palustris*) was one of the most ecologically important tree species in the Southern United States, and covered an extensive area, although today only a small fraction of the longleaf pine ecosystem remains (Earley, 2004). In the interior plateaus and far western parts of the ecoregion, oak-hickory forests were sometimes intermixed with prairies. In the Interior Plateau ecoregion in Tennessee and Kentucky, oak-hickory forest with some areas of bluestem prairie, cedar glades, and some mixed mesophytic forest were predominant ecosystems (Kuchler, 1964; Griffith and others, 1997; Wood and others, 2002). In the East Central Texas Plains ecoregion, the landscape was originally covered by post oak (*Quercus stellata*) savanna vegetation, in contrast to the more open prairie to the west and to the pine forests to the east.

Although forest is the most extensive land cover class in the Southeastern USA Plains ecoregion, it accounts for less than half of the area of the region, which has some variation in forest resource lands and areas with different historical trends. Overall, forest land cover has been declining for at least the past four decades (Drummond and Loveland, 2010). However, the ecoregion is one of the most important timber production regions of the United States; pine plantation forestry is an important driver of land change in parts of the region, with tree cutting and regrowth cycles accounting for substantial amounts of land conversion. Private land ownership dominates the forests of the Southeastern USA Plains ecoregion, consisting primarily of small, nonindustrial properties of individual ownership, but there are also some larger corporate land holdings. Agricultural lands accounted for an estimated 31 percent of the region in 2000 (Sleeter and others, 2013), a decrease from 33 percent in 1973, part of a long-term regionwide decline affected by multiple driving forces and government policies (Drummond and Loveland, 2010; Sleeter and others, 2013).

Developed land is the third largest cover type in the Southeastern USA Plains ecoregion and the class with the largest net gain (Sleeter and others, 2013). Developed land covered approximately 10 percent of the region in 2000, an increase from 7.5 percent in 1973. Although parts of the Southeastern USA Plains ecoregion were still relatively rural by the middle of the 20th century, other areas of the region were poised for expansive growth. In the northeast, as part of the megalopolis between New York City, New York, and Washington, D.C., the Northern Piedmont ecoregion experienced growth in urban, suburban, and exurban land covers at the expense of farms and forest from the New Jersey suburbs to Washington (Auch and others, 2012). Further south, Piedmont population growth exceeded the national average each decade after 1960, and developed land increased from less than 12 percent to more than 16 percent of the region by 2000 (Napton and others, 2010).

2.3.6. Ozark, Ouachita-Appalachian Forests

The Ozark, Ouachita-Appalachian Forests ecoregion consists of two separate areas that make up most of the unglaciated forested mountains and upland plateaus in the Central and Eastern United States (fig. 1–1). The ecoregion is characterized by high elevations, high-relief terrain, high-gradient streams, and vegetation and includes some of the most diverse temperate forests in the world (Stephenson and others, 1993). About two-thirds of the ecoregion land cover of the ecoregion is forested, and one-quarter is agricultural lands. The Ozark, Ouachita-Appalachian Forests ecoregion contains the Ouachita Mountains, Ozark Highlands, Arkansas Valley, Blue Ridge, Ridge and Valley, Southwestern Appalachians, Central Appalachians, Boston Mountains, Western Allegheny Plateau level III ecoregions (U.S. Environmental Protection Agency, 2013a)

The Ozark, Ouachita-Appalachian Forests ecoregion is almost entirely unglaciated except for a few small areas in the northeastern fringes, in New York, Pennsylvania, and New Jersey. The ecoregion includes landforms consisting mostly of high hills and low mountains, with some open high hills and plains with hills. The ecoregion has higher elevations and more relief than the adjacent Southeastern USA Plains ecoregion. Elevations in the region range from about 95 m in the south to more than 2,035 m at Mount Mitchell in North Carolina, the highest point in the United States east of the Mississippi River.

Most of the Ozark, Ouachita-Appalachian Forests ecoregion has a severe midlatitude humid continental climate, with warm summers and cold winters. High elevations record the coldest temperatures in the region. The south is characterized by a mild midlatitude climate, marked by hot and humid summers and mild winters. The mean annual temperature ranges from 7 °C at the high elevations in the north to 17 °C at the low elevations in the southern and southwestern areas. The frost-free period ranges from 125 days to 245 days. Mean annual precipitation ranges from about 900 mm in the dry valleys to more than 2,500 mm on the high mountain peaks of the south (Wiken and others, 2011).

Vegetation in the Ozark, Ouachita-Appalachian Forests ecoregion historically varied because of the latitudinal extent of the ecoregion and the diversity of landscape elements and ecosystems. Appalachian oak, mixed mesophytic, oak-hickory, and oak-hickory-pine forests were the primary natural forest types (Kuchler, 1964). The region contains one of the richest temperate broadleaf forests in the world, with a high diversity of flora and fauna. Within the Appalachian oak forests, there is a wide variety of oak, hemlock, cove hardwood, and pine communities.

Forest is the most extensive land cover class in the ecoregion, accounting for nearly two-thirds of the area of the ecoregion in 2000. The ecoregion has some variation in forest resource lands and areas with different historical trends, but overall, forest land cover has been declining here for at least the past four decades (Drummond and Loveland, 2010). Forest cover in the Ozark, Ouachita-Appalachian ecoregion decreased from 67 percent of the ecoregion in 1973 to 65 percent in 2000, the largest change in any of the land cover categories of the ecoregion (Sleeter and others, 2013). Forestry is an important driver of land change in parts of the ecoregion, with tree cutting and regrowth cycles accounting for substantial amounts of land-cover change. Agricultural lands were the second most extensive cover at 25 percent of the area in 2000. Agricultural lands have maintained this approximate areal amount since

1973 when 24 percent of the region was in agricultural lands. In general, this is one of the more unproductive ecoregions for agriculture in the Eastern United States, with some severe physical limitations of steepness or poor soils. Developed land was the third largest cover type in the Ozark, Ouachita-Appalachian Forests ecoregion and was the class with the largest net gain. Developed land covered 5.2 percent of the region in 2000, an increase from 4.4 percent in 1973.

2.3.7. Mississippi Alluvial and Southeast USA Coastal Plains

The Mississippi Alluvial and Southern USA Coastal Plains ecoregion covers the outer Atlantic and Gulf of Mexico coastal plains and the low-lying, mostly Quaternary alluvial part of the Mississippi Embayment, including the floodplains of the lower Mississippi, White, Arkansas, Ouachita, and Red Rivers. The ecoregion's land cover is characterized by a mosaic of agricultural lands, wetlands, forests, water, and developed land. The region is generally lower, flatter, and warmer than the adjacent Southeastern USA Plains ecoregion. The Mississippi Alluvial and Southern Coastal Plains ecoregion contains the Middle Atlantic Coastal Plain, Mississippi Alluvial Plain, Southern Coastal Plain, and Atlantic Coastal Pine Barrens level III ecoregions (U.S. Environmental Protection Agency, 2013a). For the purposes of the analysis for this assessment, the Southern Florida Coastal Plain level III ecoregion of the Everglades level II ecoregion has been included in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion, as has the Western Gulf Coastal Plain level III ecoregion of the Texas-Louisiana Coastal Plain level II ecoregion because of the similarities of the ecoregions.

The Mississippi Alluvial and Southern Coastal Plains ecoregion is unglaciated except for the terminal moraine and glacial outwash materials that formed Long Island, N.Y., and Cape Cod, Massachusetts. The ecoregion has landforms consisting mostly of flat plains, smooth plains, and a few irregular plains. There are also karst plains, river deltas, floodplains and low terraces, oxbows, swamps, bogs, estuaries, barrier islands, coral islands and reefs, dunes, and beaches. Elevations in the region range from sea level to about 100 m in Illinois, and relief is typically only 1 to 10 m. The region consists mostly of Quaternary sands, silts, and clays, with a few areas of Tertiary and Cretaceous-age marine terrace sediments.

Most of the Mississippi Alluvial and Southern Coastal Plains ecoregion has a mild midlatitude humid subtropical climate, marked by hot and humid summers and mild winters. The northeasternmost areas are somewhat cooler than the southern areas and are located along the boundary of severe midlatitude humid continental climates with colder winters, whereas southern Florida has a humid subtropical to tropical savanna climate with hot summers and warm winters. The mean annual temperature ranges from 11 °C in the northwest in Illinois to 25 °C in southern Florida and southern Texas. Summer heat is tempered by sea breezes in coastal areas. The frost-free period ranges from 190 days in the northeast to 365 days at the southern tip of Florida. Mean annual precipitation ranges from about 600 mm in the driest southwest part of the region in southern Texas to more than 1,760 mm along the wettest parts of the central gulf coast (Wiken and others, 2011). Precipitation is fairly evenly distributed throughout the year, falling as rain from frontal storms in fall, winter, and early spring and from convective thunderstorms or tropical storms and hurricanes in the warm late-spring and summer months. Southern areas typically have a drier winter season than the northern areas. Droughts occasionally affect parts of the region, mostly in the south.

The natural vegetation of the Mississippi Alluvial and Southern Coastal Plains ecoregion is varied due to the latitudinal extent, diverse soil textures, and the subtle but often dynamic landforms. Small differences in elevation, water-table levels, or exposure to maritime salts can greatly affect vegetation patterns. The longleaf pine forest types were diverse and have proven difficult to classify given the great variations in disturbance history, site conditions, and species composition in the gradients from xeric upland sandhill communities to more mesic and wet flatwoods and savannas (Christensen, 1988; Peet and Allard, 1993). With species-rich understories, the longleaf pine historically marked one of the country's most ecologically important forest regions, although today only a fraction of the historical extent of the forests of the ecoregion remains (Earley, 2004). Another important forest type in the Mississippi Alluvial and Southern Coastal Plains ecoregion consists of the bottomland hardwood forests of floodplains and river terraces that provide crucial habitat for a variety of fish and wildlife. The mostly oak-dominated floodplain forest covered the majority of the Mississippi Alluvial Plain ecoregion. These forests had a variable species mix that was dependent on the tolerances of the species to different periods of flooding (Sharitz and Mitsch, 1993).

The landscapes of the Mississippi Alluvial and Southern Coastal Plains ecoregion have been greatly altered from the early times of Euro-American settlement, especially with 20th century technology and energy sources. Although the large urban centers have typically diverse economies with manufacturing and technology, finance, medical, education, and service elements, many of the more rural areas of the region remain dependent on agricultural production, forestry, fish and shellfish catches, energy production, or tourism. Land cover data reflect some of the diversity and dynamism of the region's mixed uses, and there is a high overall footprint of change compared with most other ecoregions in the Eastern United States.

Agricultural lands were the most extensive cover class in the ecoregion, accounting for approximately one-quarter of the ecoregion in 2000. The most typical agricultural activities in the Mississippi Alluvial and Southern Coastal Plains ecoregion differ by area. Pasture land and hay land occur in several parts of the Mississippi Alluvial and Southern Coastal Plains ecoregion, but the traditional cash crop production is concentrated in those areas where the land is best suited to cultivation or where specialty crops, such as citrus, rice, and sugar cane, can best be grown (Hart, 1978). Most of the cropland is in those areas of rich and deep soils such as the Mississippi Alluvial Plain ecoregion, where crop production is dominated by soybeans, rice, cotton, corn, and wheat, with sugar cane in the south. Wetlands are the second most extensive land cover and are one of the distinguishing features of the ecoregion's land cover mosaic. Wetlands and surface water combined to account for nearly 36 percent of the region, with wetlands accounting for 22 percent of the area and surface water of the ecoregion, accounting for about 14 percent of the area. Forest is the third most extensive land cover class in the Mississippi Alluvial and Southern Coastal Plains ecoregion and was the largest decreasing land cover class in the ecoregion, following the consistent trend in other forests in the Eastern United States (Drummond and Loveland, 2010). Pine plantation forestry is an important driver of forest cover loss in parts of the ecoregion, such as the Carolinas, Georgia, and northern Florida, with tree cutting and regrowth cycles accounting for substantial amounts of logging. Developed land covered about 11 percent of the region in 2000, an increase from 8 percent in 1973. Although parts of the ecoregion remain relatively rural, other areas, especially in Florida and around Houston, Texas, have experienced expansive population and development growth.

2.4. Temporal Domain

This assessment was conducted to estimate carbon stock and balance and their relation to LULC change and other controlling processes for baseline and future projection periods. The baseline period covers 1992 through 2005. Projections of LULC and carbon stocks and fluxes were modeled for the baseline period using observational data from the USGS and other sources (Zhu and others, 2010). The projection period extended from the end of the baseline through 2050. Annual projections of LULC and carbon stocks and fluxes were produced for the projection period across a range of scenarios and input data (for example, emission scenarios, ecosystem models, general circulation model (GCM) outputs). Whenever possible, the estimates are provided as a range of values in order to represent the spread of variability in assessment results. The ranges of values for baseline estimates were derived from the minimum and maximum of averages of model runs for 2001 through 2005. For projected future values, the ranges of values were derived from the means of the unique LULC scenarios, climate-change projections, and biogeochemical models for 2006 through 2050.

2.5. Scenario Framework

In 2000, the IPCC published the SRES (Nakićenović and others, 2000), which documented the development of a global set of GHG-emission scenarios based on an underlying set of socioeconomic conditions that were consistent with the current (at the time) scenario literature. The SRES scenarios were designed to assess the effects of alternative GHG-emission pathways on coupled human and environmental systems and evaluate future vulnerabilities on those systems under various combinations of projected change. These scenarios have been used as the basis for the IPCC third and fourth assessment reports on future projected climate change. The SRES scenarios consist of four basic narrative storylines, each of which describe alternative developments in the major drivers of GHG emissions, such as population growth, economic growth, technological change, energy use, globalization, and environmental protection. The four scenarios are oriented along two axes with either economic growth (denoted as A) or environmental protection (denoted as B) aligned along one axis and either global development (denoted as 1) or regional development (denoted as 2) aligned along the other axis; for example, the B1 scenario assumes strong environmental protection and global cooperation.

In order to explore sensitivities in the energy sector, the A1 scenario was subdivided into three subscenarios that focused on fossil-fuel use (A1FI), renewable technologies (A1T), and a balanced energy sector that did not rely on any particular energy source (A1B). Six modeling teams characterized the various scenarios, ultimately producing 40 quantified scenarios. No probability of occurrence was assigned to any one of the SRES scenarios and all should be considered equally plausible with none considered more or less preferable. Furthermore, no integrated climate-change policies, such as the emissions targets of the Kyoto Protocol (United Nations Framework Convention on Climate Change, 1998), are incorporated into any of the scenarios; therefore, the scenarios serve as reference conditions to evaluate the effects of potential mitigation actions and strategies. Since the inception of the SRES scenarios, a suite of future climate-change projections (GCM data) have also become available and correspond to the major scenarios. At the early stage of this assessment, GCM data corresponding to the B2 scenario were not available. Because this assessment required the use of both the LULC scenarios and the climate-change projection scenarios, only scenarios A1B, A2, and B1 were used in the assessment. Furthermore, although the SRES scenarios extend through 2100, this assessment only used projection data through 2050. Assumptions about the major driving forces associated with each scenario are listed in table 2–1.

2.6. Scenario Downscaling

In order to use the global scenarios, a scenario downscaling process was needed to translate the coarse-scale scenario data to fine geographic scales while maintaining consistency with the original dataset and with local data (van Vuuren and others, 2007, 2010). Land-change scenarios were developed using a modular modeling approach. A global integrated assessment model (IAM) was used to supply future projections of land use at the national scale. An accounting model was developed to refine the national-scale IAM projections and to downscale to hierarchically nested ecoregions. The ecoregion-based projections were then converted into annual maps of LULC using a spatially explicit LULC change model. The approach used for this assessment

Table 2–1. Assumptions about the primary driving forces affecting land-use and land-cover change.

[These assumptions were used to downscale scenarios A1B, A2, and B1 of the Intergovernmental Panel for Climate Change Special Report on Emission Scenarios (Nakićenović and others, 2000). Population and per-capita income projections are from Strengers and others (2004)]

Driving forces	Scenario A1B	Scenario A2	Scenario B1
Population growth (global and United States)	Medium; 8.7 billion by 2050, then declining; in the United States, 385 million by 2050	High; 15.1 billion by 2100; in the United States 417 million by 2050	Medium; 8.7 billion by 2050, then declining; in the United States, 385 million by 2050
Economic growth in the United States	Very high; per capita income $72,531 by 2050	Medium; per capita income $47,766 by 2050	High; per capita income $59,880 by 2050
Regional or global orientation	Global	Regional	Global
Technological innovation	Rapid	Slow	Rapid
Energy sector	Balanced use	Adaptation to local resources	Smooth transition to renewable
Environmental protection	Active management	Local and regional focus	Protection of biodiversity

follows the methods described in Zhu and others (2010) and more recently in Sohl and others (2012b) and Sleeter and others (2012a). The next sections review each of the major components of the scenario downscaling process.

2.6.1. Global Integrated Assessment Model

Initial quantities of projected LULC changes were formulated in a scenario named "demand" by implementing an accounting model for downscaling land-use scenarios (described in detail in Sleeter and others, 2012a). National-scale LULC projections were based on national-scale projections from the Integrated Model to Assess the Global Environment (IMAGE, version 2.2; Planbureau voor de Leefomgeving [Netherlands Environmental Assessment Agency], 2001), land-use histories, and expert knowledge. IMAGE was used to simulate future environmental change, including GHG emissions and landuse changes, for the three SRES marker scenarios (A1B, A2, B1; Strengers and others, 2004). IMAGE used a series of linked modules to project environmental consequences resulting from anthropogenic activity (Alcamo and others, 1998; Planbureau voor de Leefomgeving [Netherlands Environmental Assessment Agency], 2001). Environmental changes were projected for 17 world regions (the United States was treated as a single region) with LULC data available in a 30-foot-by-30-foot grid. IMAGE produced projections of demand for agriculture and forest harvest, which were incorporated directly into the scenario downscaling model described in Sleeter and others (2012a). Future projections of development and mining were developed through the use of proxy data (population and coal usage, respectively) from IMAGE. Land-use histories were then used to expand the scenario projections of net change in major land-use classes into comprehensive projections of gross changes between all major LULC types.

2.6.2. Land-Use Histories

Land-use histories described the recent historical LULC changes in ecoregions of the United States. These data came primarily from the USGS Land Cover Trends Project, which provided ecoregion-based estimates on the rates, extent, and types of LULC change for multiple dates between 1973 and 2000 (Loveland and others, 2002; Sleeter and others, 2012b, 2013). Maps of land-cover change for the conterminous United States were generated through the interpretation and classification of satellite data for 2,866 sample sites, stratified by ecological region. A comparison of land-cover maps after classification was used to produce estimates of change across major classes (fig. 2–1).

USGS land cover trends data were incorporated into the construction and downscaling of the scenarios in two primary ways. First, the data were used to expand projections of net change in development, mining, and agricultural lands LULC classes into gross conversions between all primary LULC classes at the national scale. Second, the data were used to downscale proportionally these LULC conversions to ecoregions of the conterminous United States. Throughout the downscaling process, regional and sectoral experts were consulted in a series of workshops and ad-hoc consultations. The data served as a default parameter for downscaling, and experts were able to modify certain variables in order to produce regionally specific scenarios that retained consistency with the SRES scenarios. A complete description of the downscaling process can be found in Sleeter and others (2012a).

2.6.3. Mapping Scenarios of Land-Cover Change

Regional LULC scenarios, developed in the process as described above, were used as input to the Forecasting Scenarios of Land-Use Change (FORE–SCE) model (Sohl and Sayler, 2008; Sohl and others, 2012a). The FORE–SCE model produced annual, spatially explicit LULC maps from 2006 through 2050 that were consistent with the scenario assumptions and LULC proportions from the scenario downscaling process. The initial LULC map for the beginning of the simulation period was the 2005 LULC map produced from the baseline LULC modeling described in chapter 3 of this report. Suitability-of-occurrence surfaces were used to model baseline

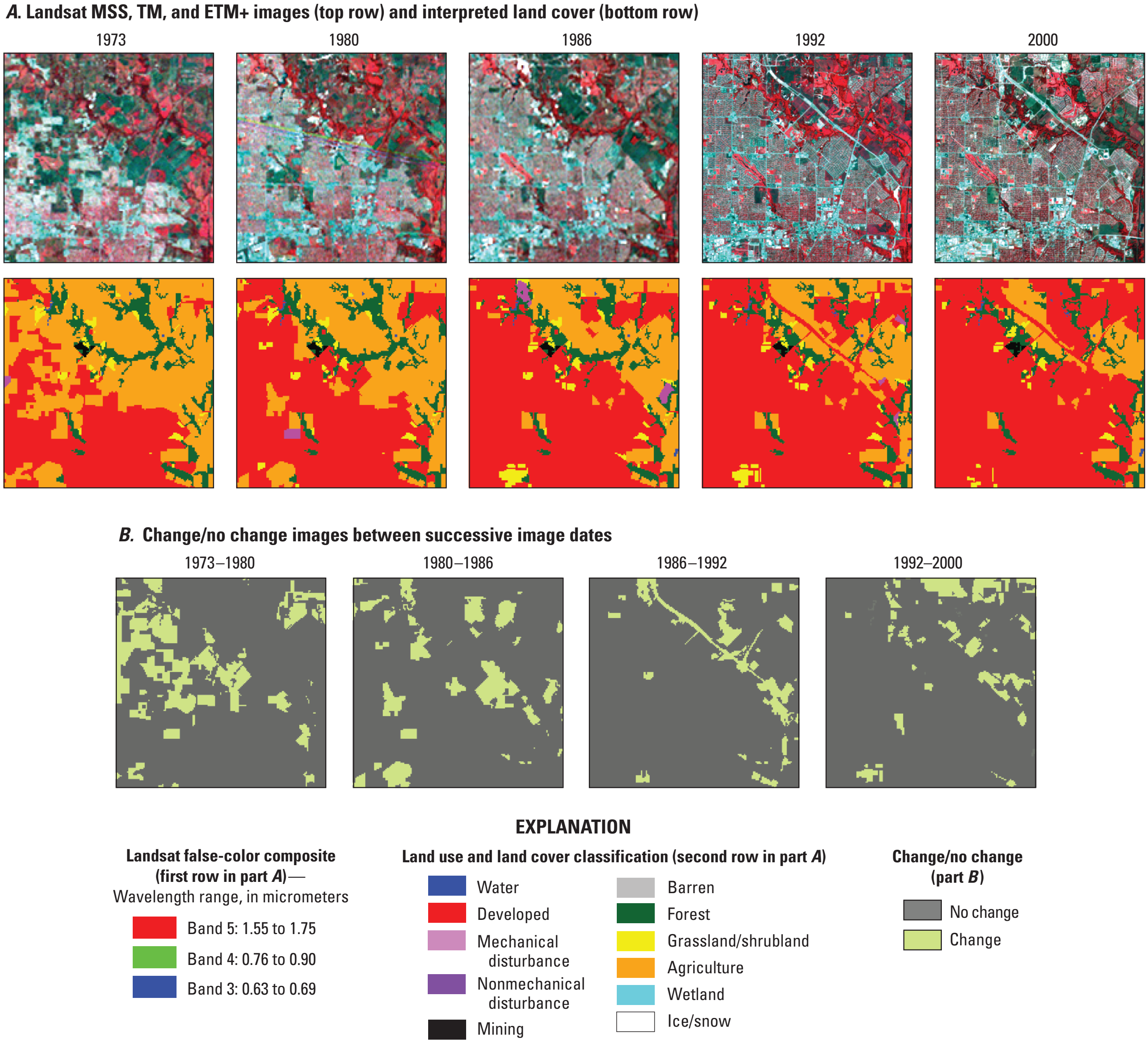

Figure 2–1. Satellite images used in the assessment of carbon sequestration and fluxes in the Eastern United States. A, Land-cover change images and B, corresponding interpretation produced from manual interpretation of Landsat data. C, Level of change for four time intervals. The example images are from the Texas Blackland Prairies level III ecoregion, which is included in the analysis of the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion. EMT+, Enhanced Thematic Mapper Plus; MSS, multispectral scanner; TM, Thematic Mapper.

LULC change. These surfaces were developed through a logistic regression process to guide the placement of patches of change for the 2006 through 2050 scenarios (see chap. 3). Each level III ecoregion was individually parameterized and modeled by applying the FORE–SCE model for each of the three SRES scenarios used in this assessment. The models of LULC from 2006 through 2050 provide downscaled spatial representations of plausible outcomes that are based on the SRES scenarios. When combined with the mapped and modeled baseline (1992 through 2005) LULC maps described in chapter 3, the baseline and modeled scenarios resulted in a continuous, consistent map database for LULC from 1992 through 2050.

2.7. Scenario Downscaling Results for the Eastern United States

The seven level II ecoregions included in this assessment cover about 3.05 Mkm^2, or approximately 38 percent of the land area of the conterminous United States and account for 82 percent of the forest area, 87 percent of the wetlands, 70 percent of the developed area, and 47 percent of the agricultural lands in the conterminous United States. Combined, level II ecoregions in the Eastern United States comprise 47 percent forest cover, 32 percent agricultural lands, 9 percent wetlands, 5 percent development, and 2 percent grasslands/shrublands (fig. 2–2).

Total overall LULC change in the Eastern United States was projected to range between 3 and 5 percent (per 5-year time period), depending on scenario. Scenarios A1B and A2 had the highest rates of change and generally were projected to experience an accelerating rate of change through the projection period. Scenario B1 remained relatively consistent at 3 to 3.6 percent change (per 5-year period) throughout the projection period. Table 2–2 provides the range of 5-year overall change projections by level II ecoregion.

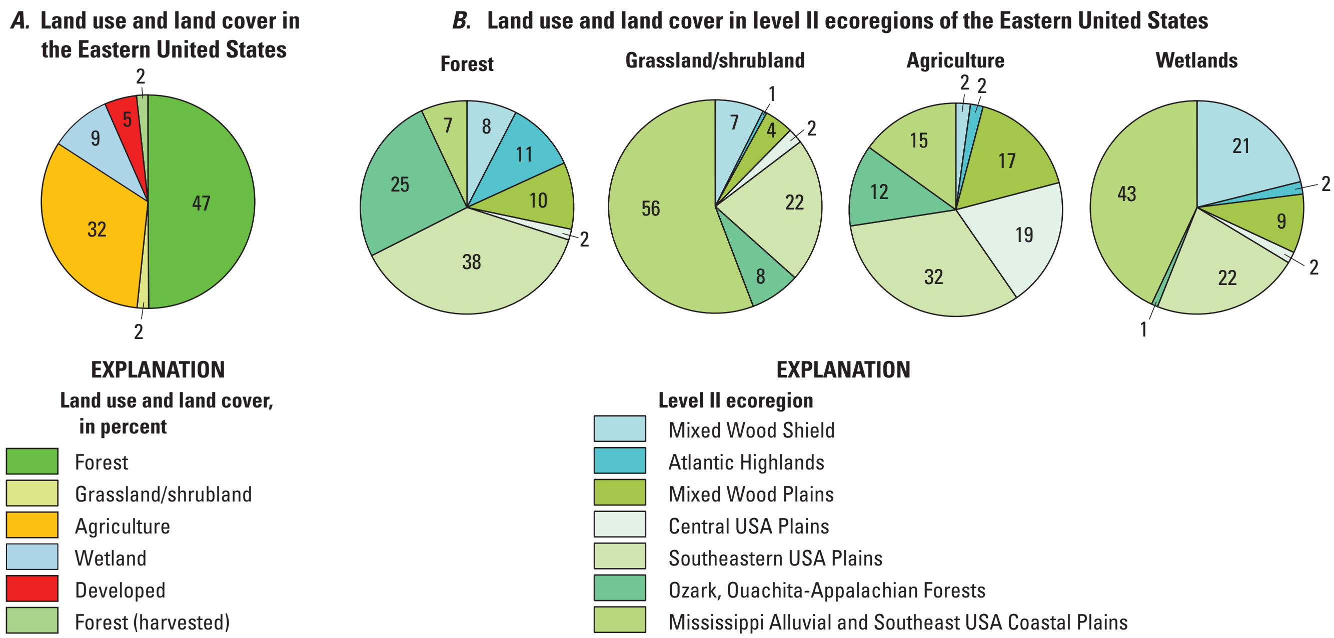

Figure 2–2. Pie charts showing *A*, total composition by land use and land cover (LULC) type and, *B*, distribution of LULC in level II ecoregions of the Eastern United States.

Table 2–2. Projected land-use and land-cover change from 2005 through 2050 in the Eastern United States.

[Values listed in the Intergovernmental Panel for Climate Change Special Report on Emission Scenarios (SRES; Nakićenović and others, 2000) columns are the percentage of each level II ecoregion that experienced a change in land use or land cover at least once between 2005 and 2050. Level II ecoregions are from U.S. Environmental Protection Agency (1999, 2013). km^2, square kilometers]

Ecoregion	Area, in km^2	Scenario A1B, as percentage change	Scenario A2, as percentage change	Scenario B1 as percentage change
Mixed Wood Shield	215,648	4.7–7.2	4.6–6.6	2.2–2.5
Atlantic Highlands	187,551	3.6–5.1	3.6–5.1	2.7–3.1
Mixed Wood Plains	388,858	1.7–2.6	1.8–2.7	0.9–1.3
Central USA Plains	239,027	0.7–1.0	0.6–0.8	0.2–0.5
Southeastern USA Plains	994,355	4.7–7.2	4.5–6.3	5.1–6.8
Ozark, Ouachita-Appalachian Forests	520,486	2.8–4.8	3.2–4.5	1.8–2.3
Mississippi Alluvial and Southeast USA Coastal Plain[1]	506,807	2.1–3.4	1.9–2.5	2.2–2.8
Eastern United States (total)	**3,052,732**	**3.2–5.0**	**3.2–4.4**	**3.0–3.6**

[1]Includes the Everglades and Texas-Louisiana Coastal Plain level II ecoregions for the analysis of this assessment.