Chapter 4

Land Resources

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The land resources of the United States have experienced significant changes since the 2010 Resources Planning Act (RPA) Assessment, and continual change is expected in most landscapes because of both natural and human actions. This chapter summarizes recent trends of land use and land cover across the conterminous United States and presents future projections to 2070 based on RPA scenarios. We begin by highlighting the key findings from a supporting RPA analysis of historical changes in the land base and evaluating how recent land cover changes affect landscape patterns including forest fragmentation. We then summarize land use projections under future scenarios and evaluate projected changes in impervious and tree covers and landscape patterns. Geographic regions reported in this chapter generally follow the RPA regions (as shown in figure 2-1 in the Introduction Chapter), except that the States of Alaska and Hawaii are not included. Later chapters provide more information about the condition and health of forests, rangeland, and other specific land resources.

Key Findings

- Developed lands continue to encroach on natural ecosystems and agricultural areas, with about half of new developed lands converting from forest or rangeland.
- Developed lands are projected to continue to expand in all scenarios, although less than projected in the 2010 RPA Assessment. The expansion of developed lands varies across regions and is projected to be larger under high socioeconomic growth scenarios and smaller under hotter climate futures.
- Forest land area increased slightly over the past decades, mostly at the expense of pasture and crop land areas. This trend is expected to shift to decreasing forest area under all scenarios, although at lower rates than projected by the 2010 Assessment.
- Forest cover fragmentation slowed over the past decade but continues overall and is expected to continue into the future for the western and southeastern subregions, while decreasing slightly in the north and central subregions.
- Changes in unfragmented forest land cover are more dynamic in private forests of the South, while changes in the West are slower and concentrated in public lands.
- Most forest lands remain in “natural” landscapes, but an increasing proportion is expected to be in “interface” landscapes near developed or agriculture use in the future.
- Economic and regional factors tend to be more important drivers of land use area changes than changes in climatic conditions.

Historical Land Use and Land Cover

- ❖ According to National Resources Inventory data, developed lands had the largest net increase of all land uses from 1982 to 2012—with forest and agriculture (crop and pasture) lands contributing about equally to new developed land—while crop lands had the largest decrease. Forest gains from other land uses (primarily from converted pasture) exceeded forest losses to other land uses (mostly to developed), resulting in a slight net increase in forest land area.
- ❖ Developed land area expanded at an increasing rate from 1982 to 1997, then continued to expand at a decreasing rate until 2012.
- ❖ Changes in the U.S. land base differ depending on whether land use or land cover is being examined. After 2000, changes in land use and land cover across the conterminous United States were broadly similar for agriculture and developed land, but less so for forest land. The differences in forest change between land use data and land cover data were mostly due to temporary losses of forest cover (canopy disturbances such as harvest or wildfire) that did not change the forest land use.

Maintaining productive forests and rangelands requires monitoring of those resources and analysis of change in relation to society's changing needs and expectations as well as a changing climate (see the sidebar Forest Carbon Land Base). Changes in U.S. forests and rangelands affect their associated resources, underscoring the importance of monitoring and examining trends in land use and land cover. Because the RPA Assessment is a multi-resource assessment where social, economic, and biological dimensions are all important, both land use and land cover perspectives are considered. This section summarizes the key findings from a recent RPA Assessment of land resources across the conterminous United States (Nelson et al. 2020) and describes the data used for the future projections of land resources later in this chapter. The RPA land base analyses use data from four primary sources: the U.S. Department of Agriculture, Forest Service Forest Inventory and Analysis Program (FIA) (land use in Burrill et al. 2018); the USDA Natural Resources Conservation Service National Resources Inventory (NRI) (non-Federal land use in USDA 2015); the National Land Cover Database (NLCD) (land cover in USGS 2019a, b, c, d); and the U.S. Census Bureau (USCB) (human demographics in U.S. Census Bureau 2017a, b). In general, gross change for a given category of land use or cover refers to area transitions to (gross loss) or from (gross gain) another category. Net change refers to the difference between the area in a category at different times. Net percent change is calculated as the ratio of net area change to the area at the first time.

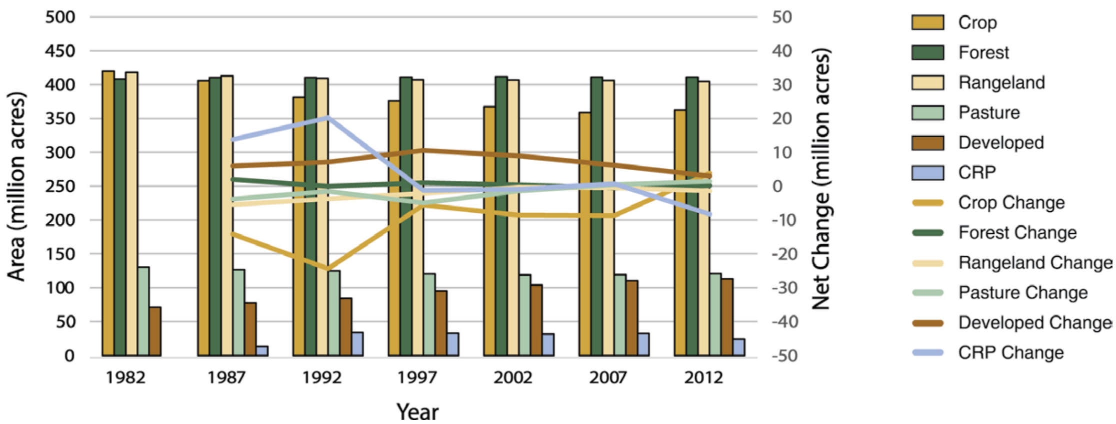
Land use refers to the social and economic intent for which land is used, while land cover refers to the vegetation, exposed land surfaces, water, and artificial structures covering the land surface at a given time (Coulston et al. 2014). Land use classes often incorporate both past use and intended future use, in addition to current conditions, while land cover classes relate to conditions only at a specific time (e.g., the instant at which satellite imagery is acquired). For example, substantial loss of tree canopy (e.g., due to wildfire, wind, or harvest) results in temporary loss of forest cover during the subsequent changes from bare ground to grass and shrub, but ultimately the area is again classified as forest cover when trees attain sufficient height and cover. However, the forest land use of that same disturbed area does not change because no permanent land use change occurred. Many inconsistencies between land classifications relate to differences in the temporal framework of definitions and observations. Therefore, the choice of one land classification system over another depends on the specific resource question being asked, the data available to address the question, and the timeframe of the analysis.

In this report we use two complementary USDA inventories (FIA and NRI) to represent current and projected future land use conditions. These inventories are based on statistical samples of plots, precluding their use for spatially explicit analyses such as landscape pattern assessment for which land cover data (NLCD) are better suited. Each of the following sections refers specifically to "land use" or "land cover" depending upon which data were used. While it is sometimes possible to compare estimates of land cover and estimates of land use, such comparisons often reveal only the definitional or temporal differences between data sources. In some cases, both types of data have been integrated to improve the interpretation of results.

National Resources Inventory on Non-Federal Land

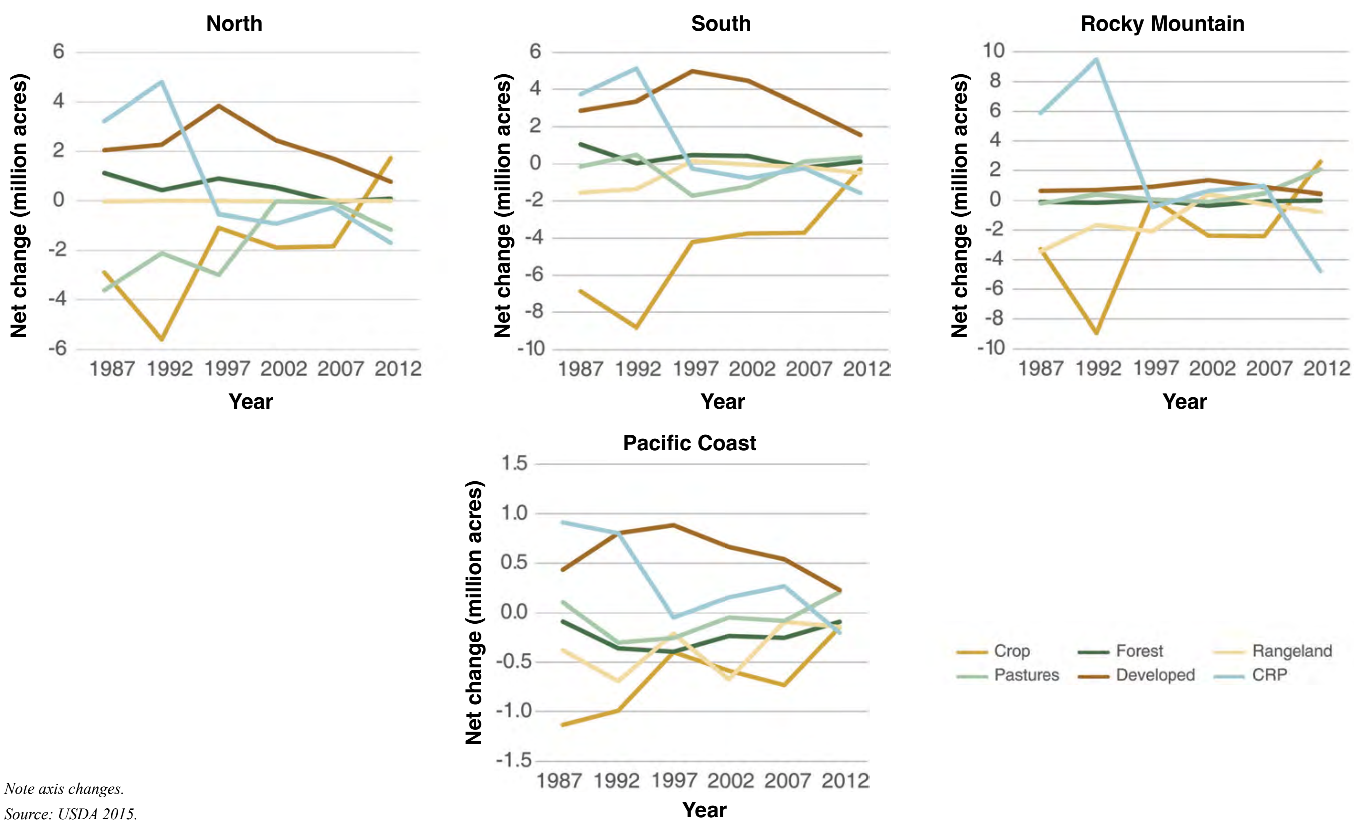
NRI estimates of land use status and trends are based on 5-year reports spanning a 30-year period (1982, 1987, 1992, 1997, 2002, 2007, 2012). The 2017 NRI Report was published after completion of RPA analyses of land use status and future projections. Results for NRI 2017 are generally similar to 2012 but are not included here. Forest land use comprised the largest share of non-Federal land in 2012 (411 million acres, 26.8 percent), followed closely by rangeland (405 million, 26.4 percent) (Nelson et al. 2020). Between 1982 and 2012, there were net losses of crop, pasture, and rangeland area, and net gains of forest, developed, and Conservation Reserve Program (CRP) area (figure 4-1). There was no CRP area in 1982 because CRP enrollments began in 1986. Crop land had the largest area decline (approximately 57 million acres), while developed land had the largest increase (approximately 42 million acres). While forest land area had only a slight increase during this period, there was significant gross change (i.e., forest area converted both to and from other uses). The largest loss of forest land was the approximately 18 million acres converted to developed land, and the largest gain in forest was the approximately 20 million acres converted from pasture. Net loss in rangeland was caused predominately by conversions to crop, developed, and pasture lands, but losses were partially offset by conversions to rangeland from crop, pasture, and forest lands. These cumulative changes result from periodic net changes which emphasize different types of transitions over time at the scale of both the conterminous United States (figure 4-1) and RPA regions (figure 4-2).

Figure 4-1. NRI area trends in land use classes (bars) and 5-year net change in land use classes (lines) in the conterminous United States from 1982 to 2012.



Source: USDA 2015. (Adapted from Figure 3 in Nelson et al. 2020.)

Figure 4-2. NRI trends in 5-year net area change in land use classes from 1987 to 2012 by RPA region.



Note axis changes.

Source: USDA 2015.

Forest Carbon Land Base

The forest land base of the United States offers many ecosystem services. One important service is the removal of carbon dioxide (CO_2) from the atmosphere. As part of the United States' commitment to the United Nations Framework Convention on Climate Change (UNFCCC), estimates of emissions and removals of CO_2 and other greenhouse gases are reported annually, not only for forest but across all land use categories and sectors of the economy in the National Inventory Report (NIR) (US EPA 2020). The land use definitions used in the NIR follow the Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories (see Eggelston et al. 2006). These land use definitions differ from those used in this chapter. The purpose of this sidebar is to describe recent trends in the forest land base used for United States carbon reporting.

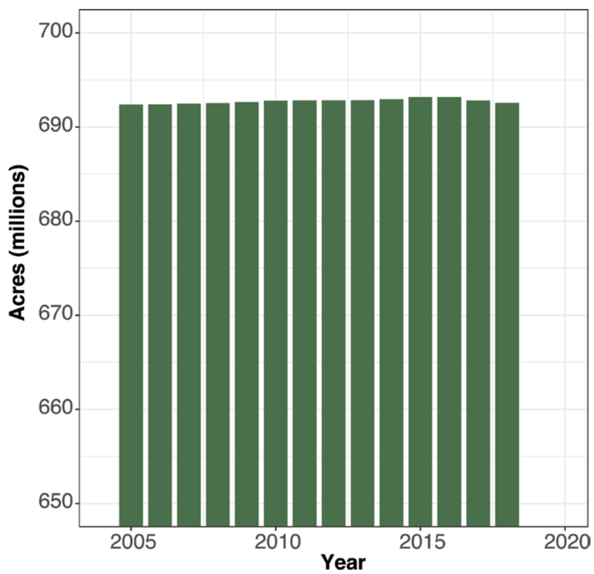
United States forests (including Alaska and Hawaii) and the harvested wood products obtained from them offset the equivalent of 11 percent of CO_2 emissions from other sectors each year (see the Forest Resources Chapter for carbon projections). Forest information is reported as part of the Land Use, Land Use Change, and Forestry chapter of the NIR, following IPCC good-practice guidelines. There are two important practices related to the reported forest land use information: only managed lands are considered (97 percent of all forest land is considered managed; Ogle et al. 2018), and land converted to forest is tracked separately from "forest remaining forest" for a period of 20 years after conversion (Eggelston et al. 2006). After that 20-year period, the converted land may be considered as forest remaining forest. Adhering to those practices results in estimates of the forest land base that differ from other estimates in this report.

The information contained in the NIR, along with projections of CO_2 emissions and reductions, inform the nationally determined contribution (NDC) for the United States under the Paris Agreement. NDCs for each country articulate efforts to reduce national emissions and adapt to the impacts of climate change. The United States accounts for emissions reductions in the land sector with 2005 as the base year. The data, methods, and models used to estimate emissions and removals are applied consistently over the entire UNFCCC reporting period (from 1990 until two years before the present), facilitating proper accounting. In 2023, the most recent estimates of land sector emissions and removals will be subtracted from the estimates in the base year 2005 to determine the contribution of the land sector and the land use categories within it to the U.S. NDC. This means that estimates of the forest land base and the carbon stocks and changes on that land base are of critical importance.

Since 1990, the area of forest remaining forest has been relatively stable at approximately 692 to 693 million acres. Losses that occurred through the 1990s were generally offset by gains in forest remaining forest from 2005 to 2016 (figure 4-3). In 2017 and 2018, there were losses in forest remaining forest of approximately 0.4 and 0.3 million acres respectively (figure 4-4). The dominant transitions into and out of forest involved the grassland, cropland, and settlement land uses. Since 1990, 79 million acres of grassland and 11 million acres of cropland have been converted to forest land. These gains were offset during that period by forest losses of 41 million acres to grassland, 8 million acres to cropland, and 35 million acres to settlement. The annual conversion rate of grassland to forest has sharply declined since 2013 from a peak of about 3 million acres per year to 2.45 million acres per year, while reciprocal conversion remained relatively stable at about 1.5 million acres per year (figure 4-4). The rate of forest conversion to settlement increased from 1990 to 2005 and has been relatively stable since then at approximately 1.4 million acres per year (figure 4-4).

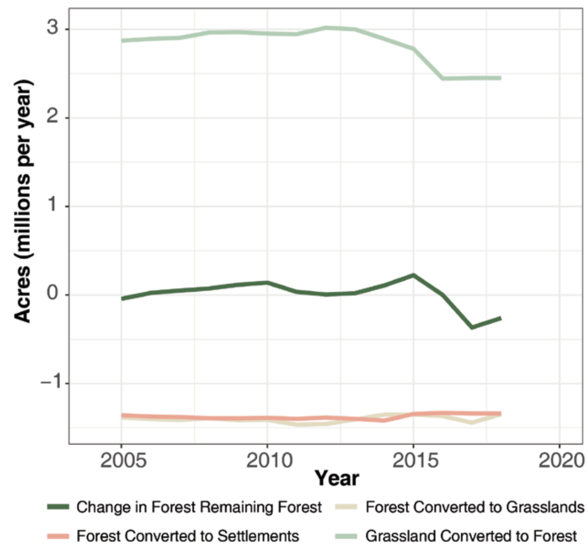
The amount of forest and trends in land use conversion have a direct impact on the amount of CO_2 the forests of the United States sequester and store (Domke et al. 2020a). Since the 1990s, the land use trends that support the NIR have changed (US EPA 2020). Future shifts in land use will influence the CO_2 sequestration and carbon storage capacity that forest land currently provides. The amount of forest area as well as disturbance dynamics, harvesting for fiber, and forest growth defines the sequestration potential of U.S. forests (Domke et al. 2020b). Understanding the range of potential future shifts in land use, disturbance, harvest, and growth can inform policy discussion on emission reduction targets (Coulston et al. 2015, Wear and Coulston 2019).

Figure 4-3. Area of U.S. "forest remaining forest" from 2005 to 2018.



Source: Domke et al. 2020a.

Figure 4-4. Key land use transitions affecting the area of "forest remaining forest" 2005 to 2018.



Source: Domke et al. 2020a.

Census Bureau Urban Area and Population

More than 80 percent of the U.S. population lived in urban areas in 2010, an increase from 75 percent in 1990 (Nelson et al. 2020). Census-defined urban area also expanded during that time, increasing from 2.1 percent (47 million acres) to 3.0 percent (68 million acres) of total land area, with larger increases occurring within the most urbanized counties. States with the largest urban area in 2010 were Texas (5.6 million acres), California (5.3 million acres), and Florida (4.7 million acres). States with the largest percentage of urban land in 2010 were New Jersey (39.8 percent), Rhode Island (38.7 percent), and Massachusetts (38.0 percent). The largest area of urban land growth from 1990 to 2010 occurred in Texas (1.9 million acres), Florida (1.8 million acres), and Georgia (1.4 million acres), while the largest percentage growth in urban land occurred in Nevada (128.6 percent), Delaware (91.4 percent), and North Carolina (87.8 percent). The expansion of urban area has driven the expansion of the wildland-urban interface (see the sidebar Wildland-Urban Interface).

National Land Cover Database

RPA analyses of forest cover include the NLCD woody wetlands class and the three NLCD upland forest classes. For general comparisons with the non-Federal statistics cited above, forest land cover comprised the largest share of non-Federal land in 2011 (416 million acres, 27.6 percent), followed by crop land (309 million, 20.5 percent) (Nelson et al. 2020). Between 2001 and 2011, there were net losses of crop, pasture, and forest lands, and net gains of shrub, grass, developed, and other (water, barren, herbaceous wetland) lands. Considering both non-Federal and Federal lands, forest comprised the largest share of land cover in the RPA North and South Regions in 2011, while shrub was the dominant land cover in the Rocky Mountain and Pacific Coast Regions (Nelson et al. 2020). Forest cover change from 2001 to 2011 was dominated by gains and losses from or to grass and shrub covers, for both Federal and non-Federal ownerships within all four RPA regions. Most of the net land cover changes from 2001 to 2011 occurred in non-Federal ownerships, which comprised more than three-fourths of the total area of the conterminous United States. Developed land had the largest percent net change (an increase) in all RPA regions, almost all on non-Federal land, while patterns of land cover transitions on Federal lands varied substantially among RPA regions.

Comparing Land Use and Land Cover Transitions

After 2000, changes in land use and land cover on non-Federal land in the conterminous United States were broadly similar for both agriculture and developed land, but less so for forest land. The differences in forest change between land use data (NRI) and land cover data (NLCD) were mostly due to temporary changes in forest cover (canopy disturbances) that did not change the forest land use. Because there is no rangeland class in NLCD, the NLCD shrub and grass classes are often used as surrogates for rangeland. However, portions of the NLCD shrub, grass, and barren cover classes are (regenerating) forest land use, while a portion of NLCD grass cover is pasture land use. The fact that those cover and use classes partially overlap prevents direct comparisons of land cover area and change with land use area and change (Nelson et al. 2020). The sidebar Protected Forest Area is an example of an analysis that is relatively insensitive to differences between land use and land cover.

The status and trends of FIA forest land area were recently updated in a supporting RPA report (Oswalt et al. 2019). Comparisons of FIA data with NRI and NLCD data during common periods showed that the average annual rates of FIA forest land use change between 2001 and 2011 were 0.26 percent from forest to nonforest and 0.34 percent from nonforest to forest for all ownerships across the RPA North and South Regions, resulting in a slight net gain in forest land use (Nelson et al. 2020). FIA data were insufficient to estimate change in the RPA Rocky Mountain and Pacific Coast Regions. According to NRI data, non-Federal lands experienced average annual rates of forest change between 2002 and 2012 of 0.18 percent from forest to nonforest and 0.19 percent from nonforest to forest, resulting in negligible net change in non-Federal forest land use. Thus, both land use datasets (FIA, NRI) reveal similar trends in forest land use area. In a general comparison, forest land cover between 2001 to 2011 experienced average annual rates of forest cover change across all ownerships of 0.46 percent from forest to nonforest and 0.17 percent from nonforest to forest, resulting in a net loss of NLCD forest cover (Nelson et al. 2020). For the RPA North and South Regions, the average annual net loss of forest cover was 0.28 percent. These land cover trends in the two eastern RPA regions differ slightly from land use trends, due mostly to differences in how forest canopy disturbances are classified (Nelson et al. 2020).

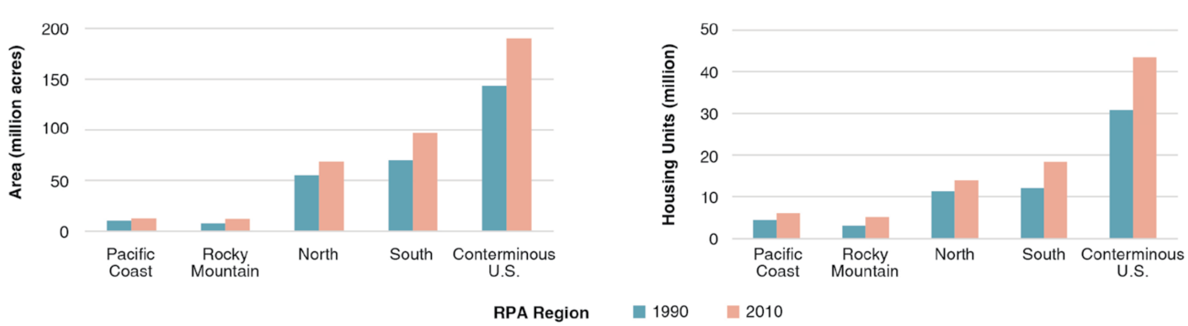
Wildland-Urban Interface

The wildland-urban interface (WUI), defined as the area where houses are in or near wildland vegetation, combines both land use (residential) and land cover (forest, grass, shrub) to identify an environment of unique interest to natural resource managers (Radeloff et al. 2005). Housing development in forested and other naturally vegetated ecosystems is of particular interest because housing development is increasing faster than population (Bradbury et al. 2014) and can have significant ecological effects (Pejchar et al. 2015). When native vegetation is lost and fragmented by houses and associated infrastructure, nonnative species are introduced, pollution increases, zoonotic diseases are transmitted, and wildfires become more common, challenging, and costly (Hansen et al. 2005, Bar-Massada et al. 2014, Syphard et al. 2017).

Tracking the extent of the WUI provides insights into ecological conditions and management concerns in residential areas with wildland vegetation (Zipperer et al. in press).

Radeloff et al. (2018) mapped WUI extent and change from 1990 to 2010 across the conterminous United States using decennial Census data (number of housing units) and land cover data (wildland vegetation coverage) to determine where housing is intermixed with, or adjacent to wildland vegetation. WUI environments were widespread in 2010, covering more than 190 million acres (10 percent of total area) and containing 43.4 million housing units (33 percent of all housing units) (figure 4-5). From 1990 to 2010, the WUI area grew by 46.8 million acres (33

Figure 4-5. Total area (left) and number of housing units (right) in the wildland-urban interface of the conterminous United States in 1990 and 2010.



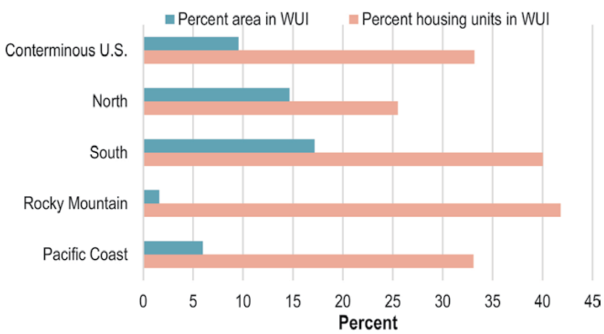
Source: Radeloff et al. 2017.

percent), an area larger than that of Washington State, and the number of housing units in the WUI increased by 41 percent. In 2010, the WUI contained 43 percent of the 29.2 million new housing units built between 1990 and 2010. There are striking regional differences in the percent of total area and total number of housing units in the WUI (figure 4-6) and growth rates (figure 4-7).

WUI extent, growth, and rates of increase are all of interest to land managers. Extent and growth indicate the need for natural resource managers, such as those who work to reduce wildfire risk, to engage in outreach to new WUI residents, while growth rates are a key concern to managers of changing forest and residential environments. The number of WUI homes and the amount of WUI area are consistently larger in the RPA North and South Regions, where forested areas have a long history of housing development. In those regions, the WUI is a relatively larger portion of total region area. The South Region is notable for extensive and prevalent WUI area, as well as relatively high rates of growth. In the western regions, smaller WUI areas experienced rapid growth from 1990 to 2010, particularly in the number of housing units. The Rocky Mountain Region had the smallest WUI area, but it contained 42 percent of all housing units in that region and experienced the fastest growth of both WUI area and housing units from 1990 to 2010. When compared to the eastern regions, the relatively higher western growth rates resulted from relatively smaller absolute gains.

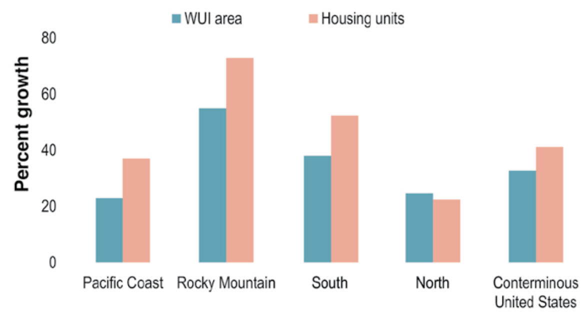
Forest land comprises a major share of the WUI area. The FIA forest land in 2013 (USDA Forest Service 2020) was evaluated in terms of its WUI status in a recent assessment of WUI research needs (Mockrin et al. in press). In 1990, that forest land occupied nearly 70 million acres (49 percent) of the total WUI area, and the WUI contained 10 percent of the nation’s forest land. Over the next two decades, the percent of total WUI area that was forest land did not change much, but WUI expansion increased the share of the nation’s total forest land area found in WUI environments. By 2010, forest land occupied 90 million acres (51 percent) of the total WUI area and the WUI contained 14 percent of total forest land. Across all years, approximately 85 percent of the forest land in the WUI was in the “low housing density intermix” WUI class, which represents the least developed WUI areas. The majority (80 percent) of the forest land in these WUI areas was privately-owned, typically individual- or family-owned forests, while 16 percent was in private corporate ownership. In 2010, just over one-quarter of the national total of 306 million acres of individual- or family-owned forest land area was in the WUI.

Figure 4-6. Percent of total area and percent of total housing units in the wildland-urban interface in 2010, by RPA region.



Source: Radeloff et al. 2017.

Figure 4-7. Percent growth in wildland-urban interface area and number of housing units from 1990 to 2010, by RPA region.



Source: Radeloff et al. 2017.

Protected Forest Area

Protected forests help to conserve the natural functioning of forests while preserving irreplaceable landscapes (Ervin 2003). The Protected Areas Database of the United States (PAD-US; Conservation Biology Institute 2016) maps the known protected areas (held in fee-simple ownership), along with the status of each protected area according to guidelines developed by the International Union for the Conservation of Nature (IUCN; Dudley and Stolton 2008). According to Nelson et al. (2020), 95 percent of the total protected forest area is held in either Federal or State ownership, of which 38 percent is in the RPA Rocky Mountain Region, 29 percent in the North Region, 17 percent in the Pacific Coast Region, and 16 percent in the South Region. For this report, protected forest area estimates in the conterminous United States were updated to the year 2016 for forest cover (USGS 2019d) and forest land use (Burrill et al. 2018). In addition to the seven IUCN protection categories, a de facto protection category included Federal- and State-owned area that has not yet been assigned to an IUCN category. Most public lands both satisfy the IUCN definition of the Sustainable Use category (VI) and approximate the Habitat Management areas category (IV) for some threats such as invasive plant occurrence (Riitters et al. 2018), justifying use of the de facto category for public lands not currently assigned.

Comprising over 30 percent of the total forest area (table 4-1), publicly owned and protected forest area may be the Nation's largest planned land use. Approximately 14 percent of total forest area occurred in a designated IUCN category, and an additional 18 to 20 percent had de facto protection. Wilderness areas contained the largest shares of protected forest area, while the smallest shares were contained in nature reserves, national parks, and natural monuments. While the area of protected forest depends on the definition of forest as land cover (NLCD) or land use (FIA), the shares of total forest area in each of the seven IUCN protection categories is similar for both cases.

Table 4-1. Protected forest cover and forest land use area in the conterminous United States, circa 2016.

	Forest area		Percent of total IUCN protected forest area	
Item	**NLCD forest cover**	**FIA forest land use**	**NLCD forest cover**	**FIA forest land use**
IUCN protection category[a]	million acres		percent	
Ia Nature reserve	1	1	1.2	1.3
Ib Wilderness area	25	33	33.5	34.2
II National park	7	8	8.8	8.4
III Natural monument	1	2	1.6	2.5
IV Habitat management	15	16	18.1	16.6
V Protected landscape	14	18	17.0	18.8
VI Sustainable use	16	17	19.7	18.2
All IUCN protection categories	79	96	100	100
De facto protection[b]	106	140		
No protection[c]	390	449		
Total forest area[d]	575	685		
Percent with IUCN protection	13.7%	14.0%		
Percent with de facto protection	18.5%	20.4%		

FIA = Forest Inventory and Analysis. IUCN = International Union for the Conservation of Nature. NLCD = National Land Cover Database.

[a] *IUCN protection category definitions source: https://www.iucn.org/theme/protected-areas/about/protected-area-categories.*

[b] *Federal and State ownership not yet assigned to an IUCN category.*

[c] *Not in Federal or State ownership and not yet assigned to an IUCN category.*

[d] *Totals may differ slightly from elsewhere in this report. Entries may not sum to column totals because of rounding.*

Excludes District of Columbia.

Sources: USGS 2019d; Burrill et al. 2018; Conservation Biology Institute 2016.

Historical Forest Fragmentation and Landscape Context

- Driven by a 2.6 percent net loss of forest cover area from 2001 to 2016, fragmentation increased in all RPA regions over a wide range of spatial scales. However, the rate of forest cover loss and fragmentation decreased after 2006 in all regions.
- In both 2001 and 2016, 88 percent of forest cover area was in landscapes dominated by “natural” land covers (forest, grass, shrub, water, wetland, or barren cover), while 31 percent was in “interface” landscapes containing at least 10 percent of developed or agriculture land cover.
- From 2001 to 2016, the loss of forest cover area was highest within landscapes dominated by developed land cover (9 percent), but the total forest area occurring in developed-dominated landscapes increased by 18 percent as those landscapes expanded to include additional forest area. The loss of forest cover area was lowest in agriculture-dominated landscapes (1 percent), but the total forest area in agriculture-dominated landscapes decreased by 5 percent as those landscapes contracted to exclude additional forest area.
- Most of the gross changes (loss and gain) of core (unfragmented) forest cover occurred on private land in the RPA South Region, while most of the net loss occurred on public land in the Pacific Coast and Rocky Mountain Regions.
- Most of the forest-nonforest cover edge in the vicinity of fragmented forest land in 2016 was associated with shrub or grass land in the Rocky Mountain and Pacific Coast Regions and with developed or agriculture land in the North and South Regions.

The preceding section described the land base in terms of the area of individual resource components such as forest and agriculture lands. Another component of the land base is the landscape, that is, the type and spatial arrangement of the resources that are contained in a given area. For example, a forested landscape contains mostly forest land area, while a forest-developed interface landscape contains substantial forest and developed land areas. Such landscape patterns influence the locations and types of forest changes that occur, as well as the ecological effects of those changes and the social values placed on them in different circumstances. Using land cover maps from 2001 to 2016, this section addresses several aspects of forest landscape patterns, including forest fragmentation and the anthropogenic context of forests. To improve interpretation of the findings, key results from the analysis are integrated with forest land use information from the Forest Inventory and Analysis (FIA) database circa 2016, and with forest canopy disturbance information (Schleeweis et al. 2020) from 2000 to 2010.

Land Cover Change

Overall changes in land cover area are a necessary baseline for evaluating landscape pattern changes over time. The previous section described the land cover area changes from 2001 to 2011 that were reported by Nelson et al. (2020). With the release of the 2016 National Land Cover Database (NLCD) which was used for this landscape pattern analysis, Homer et al. (2020) provided a detailed analysis of land cover area changes across the conterminous United States from 2001 to 2016. To supplement the information in Nelson et al. (2020), a brief update of land cover area changes sets a baseline for landscape pattern changes from 2001 to 2016.

The landscape patterns described in this section depend primarily on three generalized cover types: forest (including the NLCD upland forest and woody wetland classes), agriculture (including crop and pasture classes), and developed (which includes most of the impervious road surfaces as well as urban classes). From 2001 to 2016, there were net gains of developed cover area and net losses of forest cover area in all RPA regions, while the agriculture cover area increased in the western regions (Pacific Coast and Rocky Mountain) and decreased in the eastern regions (North and South; table 4-2). Unlike the two western regions, forest losses that occurred in the two eastern regions in the early 2000s were partially offset by later gains. Over all regions, the 5-year net gains in developed cover and losses in forest cover became smaller over time, and agriculture losses that occurred earlier in the timeframe were balanced by later gains such that the 15-year net change was relatively small.

Forest Cover Fragmentation

Forest fragmentation was assessed by measuring forest area density (FAD), which indicates “how much forest is surrounded by how much other forest,” and is specifically the proportion of a neighborhood surrounding a given forest location that also has forest cover (Riitters et al. 2002). The interpretation of FAD is straightforward: if forests are not fragmented then FAD equals 1.0 for all forest locations and neighborhood sizes, and FAD decreases as fragmentation increases. Fragmentation is therefore relative to a completely forested condition, and deviations from that baseline arise from natural (and endemic) fragmentation as well as anthropogenic fragmentation. Riitters and Robertson (2021) summarized results across the conterminous United States using NLCD data for 2001, 2006, 2011, and 2016 (USGS 2019a, b, c, d), documenting increased fragmentation from 2001 to 2016 over a wide range of neighborhood sizes. This report highlights the status and trends of "interior" forest cover for a 38-acre neighborhood size, where a forest location is considered "interior" if the FAD value in its neighborhood is at least 0.9 (i.e., if the neighborhood is at least 90 percent forested; McIntyre and Hobbs 1999). Note that the same definition of interior forest was applied to forest land use projections in the later section on Projected Forest Fragmentation and Landscape Context but with a different neighborhood size.

The net change of interior forest area does not necessarily equal the net change of total forest area because interior forest change occurs at the neighborhood scale and total forest area change occurs at the pixel scale (Riitters and Wickham 2012). The interior status of a given location can change "directly" when that location itself changes, or "indirectly" when neighboring locations change. Thus, direct change refers to the gain or loss of forest at that location, while indirect change results from forest gains or losses in the neighborhood of persistent forest.

It is therefore useful to examine both forms of forest change at a larger geographic scale, such as on a per-county basis (figure 4-8). There was a net loss of interior forest area in 2,054 of 3,109 counties from 2001 to 2016. Of those, 1,042 counties exhibited losses of more than 5 percent and 334 counties had losses of more than 15 percent. In forest-dominated counties, interior forest losses exceeding 5 percent were frequent in the Pacific Coast and Rocky Mountain Regions but less common in the North and South Regions, where many counties exhibited net gains of interior forest area. Large percentage changes of interior forest area were common in relatively less-forested counties, but the relatively small area of forest in those counties had little influence on national statistics. The net loss of 2.6 percent of total forest area across the conterminous United States (table 4-2) translated to an overall net loss of 6.4 percent of interior forest area, but net loss rates varied from 3 to 13 percent among RPA regions (table 4-3). Most of the net changes to interior forest area occurred before 2006, after which the rate of net loss decreased in all regions, with indications of stabilization or net gains after 2006 in the two eastern regions.

The indications of stabilization or recovery of interior forest area do not imply there were no important changes during the later time periods—only that the gross gains offset gross losses. That does not account for differences in the locations of interior forest over time, which can influence the regional sustainability of interior-dependent ecological processes. In the RPA South Region, for example, the overall net loss of interior forest area from 2001 to 2016 (3 million acres; table 4-3) resulted from gross changes (direct and indirect) involving 42.1 million acres (table 4-4). The gross gain of 19.7 million acres of interior forest (direct and indirect)

Table 4-2. Total and periodic net area change in agriculture, developed, and forest land cover from 2001 to 2016, by RPA region. Statistics for 2001 to 2011 may differ from the RPA Land Base report (Nelson et al. 2020) because the previous editions of NLCD land cover maps were updated with the release of the 2016 edition.

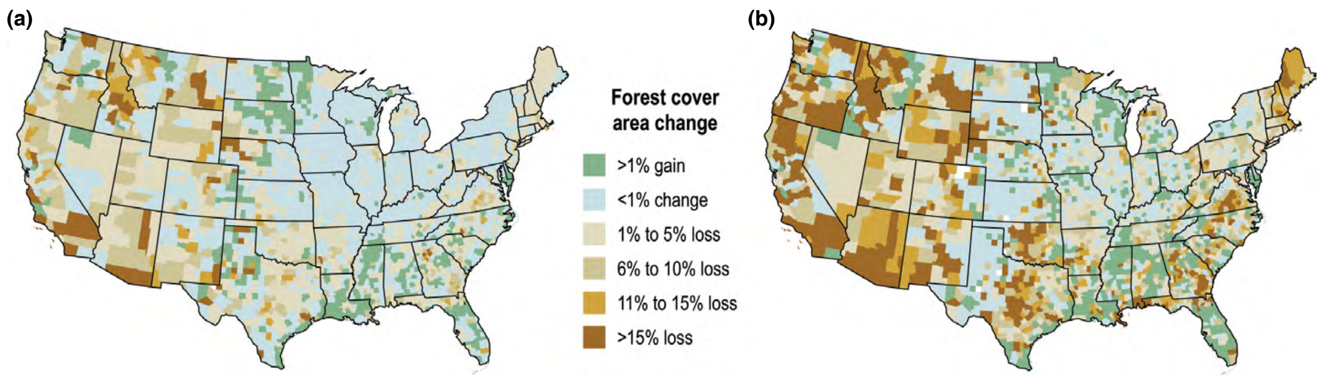
			Net change			Total net change
RPA region	**Land cover**	**Area in 2016**	**2001 to 2006**	**2006 to 2011**	**2011 to 2016**	**2001 to 2016**
		million acres	million acres	million acres	million acres	percent
Conterminous U.S.	Agriculture	450	-2.4	0.3	3.3	0.3
	Developed	106	3.4	2.2	1.5	7.2
	Forest	575	-12.0	-3.2	-0.2	-2.6
North	Agriculture	171	-0.8	-0.7	-0.2	-1.0
	Developed	38	0.9	0.6	0.3	5.2
	Forest	185	-2.2	--[a]	0.1	-1.1
South	Agriculture	128	-2.5	-0.9	0.5	-2.2
	Developed	42	1.7	1.1	0.8	9.7
	Forest	215	-4.5	0.1	1.8	-1.2
Rocky Mountain	Agriculture	128	1.0	1.9	2.8	4.6
	Developed	15	0.5	0.3	0.3	7.4
	Forest	111	-2.9	-2.2	-1.7	-5.7
Pacific Coast	Agriculture	22	-0.1	--	0.2	0.4
	Developed	11	0.2	0.1	0.1	4.6
	Forest	63	-2.5	-1.2	-0.5	-6.2

NLCD = National Land Cover Database.

[a] Value between -0.05 and 0.05.

Sources: USGS 2019a, b, c, d.

Figure 4-8. Per-county net percent change in (a) total forest cover area and (b) interior forest cover area (38-acre neighborhood size) from 2001 to 2016.



Source: USGS 2019a, d.

in the South Region during this time period implies that approximately one-fifth of that region's interior forest area in 2016 was in a different location compared to 2001. The indirect changes were relatively larger than direct changes, particularly in the North and South Regions, but less so in the Pacific Coast and Rocky Mountain Regions, suggesting that the spatial patterns of overall forest area change tended to be more dispersed in the eastern regions and more concentrated in the western regions.

To integrate forest cover and forest use data when evaluating fragmentation, measurements of FAD (forest cover) were combined with FIA field plot data (forest use in Burrill et al. 2018, Oswalt et al. 2019). This analysis used a set of plots representing 96 percent (659.3 million acres) of all FIA forest land (including woodland) in 2016; exotic and rare types of forest were excluded. Each plot location was attributed with its "core" forest status (yes or no) in 2001 and 2016, where core forest was defined as a location with FAD = 1.0 (i.e., the neighborhood is 100 percent forested) in the surrounding 11-acre neighborhood. As in previous RPA reports (e.g., USDA Forest Service 2016), this procedure differed from the analysis of "interior" forest by using a smaller neighborhood (11 acres) and a higher FAD threshold (100 percent) to obtain a better representation of fragmentation in the immediate vicinity of FIA forest plots.

In 2001, 266.7 million acres (40 percent) of the FIA 2016 forest area was classified as core forest. The loss and gain of core forest status (41.5 and 26.3 million acres, respectively) reduced the area of core forest to 251.5 million acres in 2016. In 2016, more than one-half of all core area in the conterminous United States was privately owned (140.9 million acres), and two-thirds of that area was in noncorporate private ownership (90.9 million acres). Public ownership accounted for 110.6 million acres of core area, with the Federal government owning three-fourths of that area (81.3 million acres). Consistent with the regional differences in private versus public forest land ownership (Oswalt et al. 2019), most of the western core area was publicly owned while most of the eastern core area was privately owned (figure 4-9). Most of the total gross gain and gross loss of core area occurred on privately owned land in the South Region (table 4-5). In both the North and South Regions, the losses on privately owned land substantially exceeded the gains. In contrast, two-thirds of the total net

Table 4-3. Total and periodic net change in interior forest cover area (38-acre neighborhood size) from 2001 to 2016, by RPA region.

	Interior forest area		Net change			Total net change	
RPA region	2001	2016	2001 to 2006	2006 to 2011	2011 to 2016	2001 to 2016	
	million acres	million acres	million acres	million acres	million acres	million acres	percent
Conterminous U.S.	295	276	-15.0	-3.3	-0.6	-19	-6.4
North	97	93	-3.7	--[a]	-0.2	-4	-4.0
South	100	97	-5.0	0.5	1.9	-3	-2.7
Rocky Mountain	62	54	-3.3	-2.5	-1.8	-8	-12.3
Pacific Coast	37	32	-2.9	-1.3	-0.5	-5	-12.8

[a] *Value between -0.05 and 0.05.*

Sources: USGS 2019a, b, c, d.

Table 4-4. Components of interior forest cover area (38-acre neighborhood) change from 2001 to 2016, by RPA region.

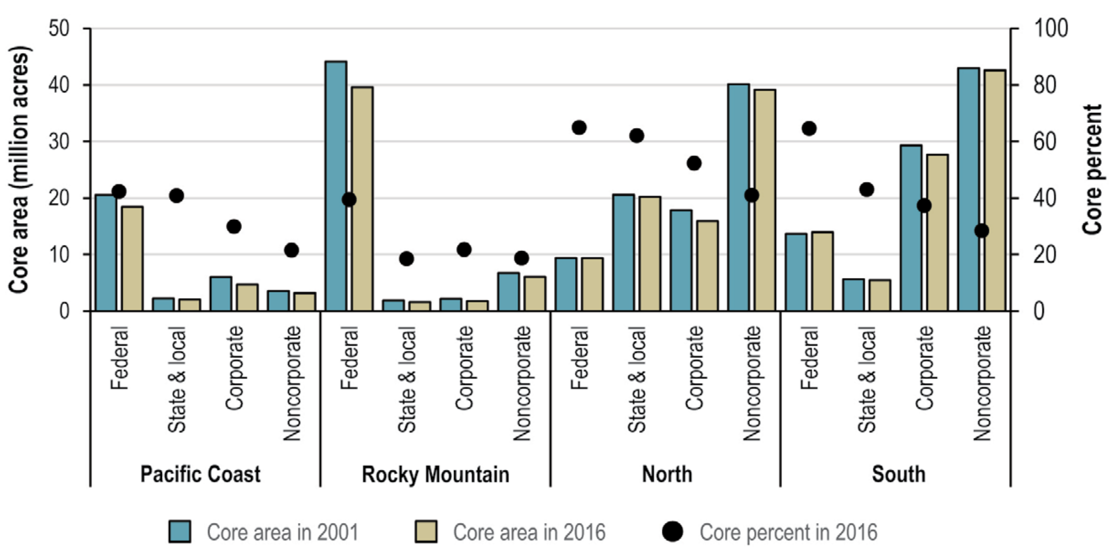
	Interior forest loss		Interior forest gain	
RPA region	Direct[a]	Indirect[b]	Direct[c]	Indirect[d]
	million acres	million acres	million acres	million acres
Conterminous U.S.	21.1	27.4	10.7	18.9
North	3.0	6.9	1.5	4.4
South	9.2	13.2	7.7	12.0
Rocky Mountain	5.0	3.7	0.3	0.9
Pacific Coast	3.9	3.5	1.1	1.6

[a] *A unit of interior forest was lost by conversion of that unit from forest to nonforest cover.*
[b] *A unit of interior forest was lost due to forest cover loss in the neighborhood of a persistent forest unit.*
[c] *A unit of interior forest was gained by conversion of that unit from nonforest to forest.*
[d] *A unit of interior forest was gained due to forest cover gain in the neighborhood of a persistent forest unit.*
Sources: USGS 2019a, d.

change of core area occurred in the Rocky Mountain and Pacific Coast Regions, typically on publicly owned lands. As a result, the conterminous United States total net change of core area was roughly the same for public and private lands.

To better understand the proximate drivers of core area loss, forest disturbance (canopy loss) attribution data from 2001 to 2010 (Schleeweis et al. 2020) was integrated with the land cover and FIA data. Each FIA plot location that changed from core to non-core status between 2001 and 2011 was attributed with one or more types of disturbance (removal, fire, and/or stress; see the Disturbances to Forests and Rangelands Chapter) that occurred in the surrounding 11-acre neighborhood. Disturbances in the neighborhood of FIA plots that changed from core to non-core status indicated that 87 percent of core area loss in the conterminous United States was associated with nearby canopy removal, while disturbances by fire or stress occurred near 21 percent of the core forest loss. (Note that multiple disturbances could have occurred near each plot.) Nearby disturbance by fire or stress was not common in the eastern forest type groups (figure 4-10); while fire or stress may occur relatively frequently in some of those eastern forest types, they are generally localized or of low enough severity not to remove the forest canopy, and therefore largely not appear in the eastern type groups. Among western forest type groups, nearby disturbance by fire was relatively common in all forest type groups except three that are typical of temperate rainforest (hemlock/Sitka spruce, redwood, alder/maple), and nearby disturbance by fire

Figure 4-9. The area of FIA forest land use in the conterminous United States with core forest cover status (11-acre neighborhood size) in 2001 and 2016, by RPA region and ownership category. The circles indicate the percentage of forest area that was core in 2016.



Sources: USGS (2019a, d); Burrill et al. (2018).

Table 4-5. Gross and net change of core forest cover status (11-acre neighborhood) for 2016 FIA forest land, by RPA region and ownership. Public ownership includes Federal and State and local. Private ownership includes corporate and noncorporate.

RPA region	Ownership	Loss	Gain	Net change
		million acres	million acres	million acres
Conterminous U.S.	Public	12.5	5.0	-7.4
	Private	29.0	21.3	-7.7
North	Public	2.3	2.0	-0.3
	Private	6.7	3.8	-2.9
South	Public	1.5	1.6	0.1
	Private	18.1	16.1	-2.0
Rocky Mountain	Public	5.5	0.6	-4.8
	Private	1.3	0.2	-1.2
Pacific Coast	Public	3.1	0.8	-2.3
	Private	2.9	1.2	-1.6

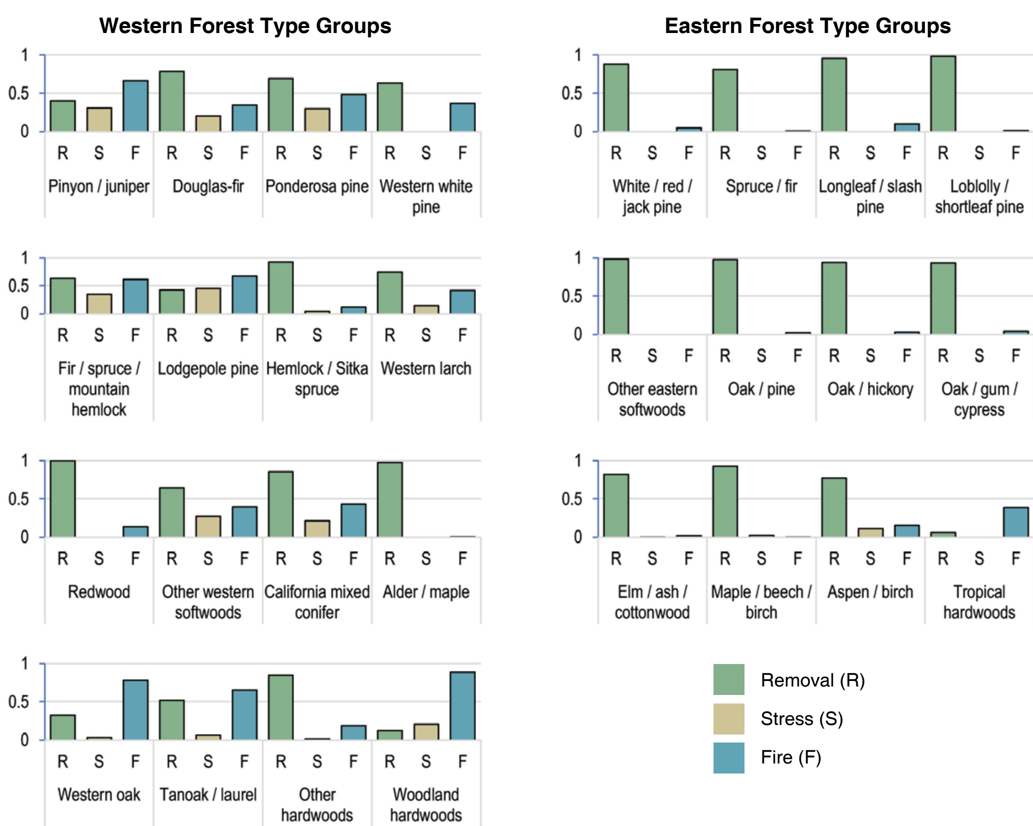
FIA = Forest Inventory and Analysis.

Sources: Burrill et al. 2018; USGS 2019a, d.

was more common than disturbance by removal in four forest type groups where timber harvesting is less common (pinyon/juniper, western oak, tanoak/laurel, woodland hardwoods) along with one forest type group that experienced extensive wildfires (lodgepole pine). Nearby stress was common in only 10 of the 28 forest type groups, mostly in the West. Because core area tends to occur in relatively remote areas where fire and stress are more common, the association of core area loss with those disturbance types was often higher than the overall exposure of all forest area to those disturbance types (see the Disturbances to Forests and Rangelands Chapter). For example, approximately 5 percent of all pinyon/juniper forest area was exposed to nearby stress from fire, but over half the loss of core area was associated with nearby fire.

An analysis to support interpretation of the potential impacts associated with fragmentation considered a larger 38-acre neighborhood and attributed each FIA plot location with the frequencies of the types of forest-nonforest "edges" in that neighborhood, as defined by the 2016 NLCD land cover map (Riitters et al. 2012). Five types of forest edge were identified: forest-developed, forest-agriculture, forest-shrub

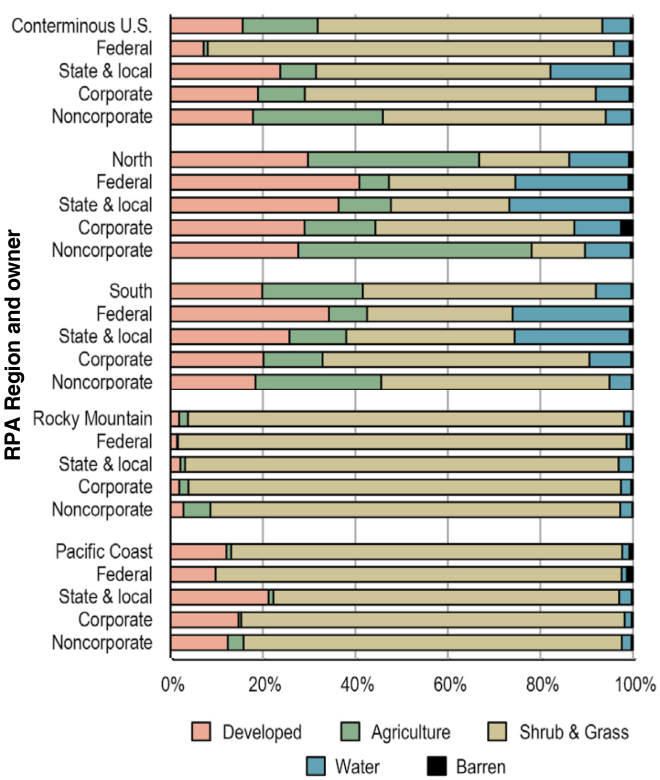
Figure 4-10. Proportion of FIA forest land area across the conterminous United States exhibiting a loss of core forest cover status—2001 to 2011. Loss associated with removal (R; green), stress (S; brown), or fire (F; blue) events within a 11-acre neighborhood, by forest type group for western forest type groups (left) and eastern forest type groups (right). The proportion of loss is on the vertical axis; the sum of proportions in a type group may be larger than 1.0 because more than one type of event can be associated with a given loss of core forest status.



Sources: USGS (2019a, c); Burrill et al. (2018).

& grass, forest-water, and forest-barren. The mean share of each type (Riitters et al. 2012) indicates their relative importance as edge where the forest is fragmented, which in turn can indicate the potential types of ecological impacts of fragmentation (e.g., Forman and Alexander 1998, Murcia 1995, Ricketts 2001). For example, nearby anthropogenic edge (farms, houses, roads, etc.) tends to increase fire ignitions (Radeloff et al. 2018) as well as occurrences of invasive forest plants (Riitters et al. 2018) (see also the Disturbances to Forests and Rangelands Chapter). Except for forest-developed edge in the Pacific Coast Region, almost all forest-nonforest edge in the two western regions is forest-shrub & grass edge (figure 4-11). Most of the forest-agriculture edge is contained in the two eastern regions, which also exhibit the largest percentages of forest-developed edge. Forest-agriculture edge is relatively more important near noncorporate private forest than public or corporate private forest. The relatively large shares of forest-developed edge in public ownerships are largely attributable to the presence of roads (a type of development) which traverse relatively less-fragmented forested landscapes (Riitters et al. 2012).

Figure 4-11. Mean shares of five types of forest cover edge within a 38-acre neighborhood of FIA forest land plots across the conterminous United States in 2016, by RPA region and ownership category.



Sources: USGS (2019d); Burrill et al. (2018).

While this analysis of forest cover fragmentation did not distinguish between natural and anthropogenic fragmentation, separate analyses of the same land cover data (Homer et al. 2020, Riitters et al. 2020) indicate that almost all forest cover losses and gains involved transitions between forest, shrub, and grass land covers. Furthermore, most forest cover gains and losses occurred in natural-dominated landscapes (see the Forest Landscape Context section below) and forest canopy losses were associated primarily with forest removal and secondarily with fire, stress, or land use conversion (see the Disturbances to Forests and Rangelands Chapter). Taken together, these findings are generally consistent with the interpretation that most forest cover loss results from pervasive forestry operations (Cohen et al. 2016, Curtis et al. 2018, Masek et al. 2008). Because losses due to forestry operations in the United States are typically followed by gains from forest regeneration, that interpretation is strengthened for the two eastern RPA regions by the balance between direct gains and losses of interior forest in each region (table 4-4). It is plausible that the relatively larger and continuing net loss of interior area in the western RPA regions (table 4-3) reflect slower regeneration following severe wildfire or stress (figure 4-10) especially on public lands (table 4-5).

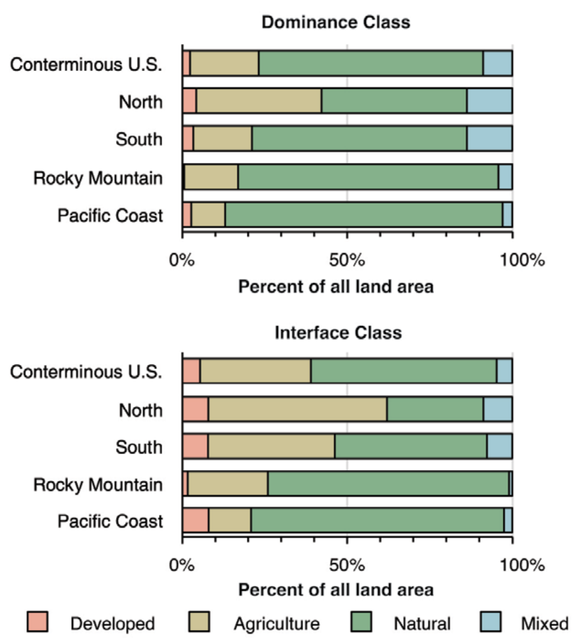
Forest Landscape Context

The anthropogenic context of land area in the conterminous United States was evaluated in terms of landscape dominance and interfaces that describe the relative importance of developed and agriculture land covers within a 162-acre neighborhood of a given location (Riitters et al. 2020). Landscape dominance identifies areas where developed, agriculture, or "natural" (i.e., all other) land covers are locally dominant (at least 60 percent of the neighborhood area), while the landscape interface identifies areas in which developed and/or agriculture land covers are a significant component of the local landscape (at least 10 percent of the neighborhood area). Using NLCD data from 2001 and 2016, developed land included the four NLCD developed classes (which incorporate most of the impervious road cover) and agriculture land included the pasture/hay and cultivated crop classes. All other NLCD cover classes were considered "natural" and the water class was excluded. Landscape dominance was classified as "developed," "agriculture," or "natural" if one of the three corresponding land cover types exceeded the 60 percent threshold value, and otherwise classified as "mixed." Similarly, landscape interface was classified as "developed," "agriculture," or "both" if the proportion of the corresponding land cover type(s) exceeded the 10 percent threshold value, and otherwise classified as "neither." The same classifications were applied in the later section on Projected Forest Fragmentation and Landscape Context, but with a different neighborhood size. In this section, landscape dominance and interface were evaluated for all land area and for forest cover area only, where the latter included the three NLCD upland forest classes and the woody wetlands class. Although the forest inventory plot data described above were not used for this analysis, the changing landscape context of FIA forest land use has been reported elsewhere (Riitters and Costanza 2019).

Most of the total land area was in the natural dominance class in 2016, but the proportion of area in each of the dominance classes varied among RPA regions (figure 4-12). The proportion of total area in developed- and agriculture-dominated landscapes was larger in the two eastern RPA regions than in the two western regions. In all regions, larger proportions of total area were contained in the developed and agriculture interface landscapes, with more than half of both the North and South Regions occurring in those landscape interfaces. Following the patterns of land cover change from 2001 to 2016 (table 4-2), there was a net gain of developed dominance and interface area in all RPA regions, and a net loss of agriculture dominance and interface area in all regions except the Rocky Mountain Region (figure 4-13). In the Rocky Mountain Region, the relatively large net losses of natural dominance and "neither" interface areas are due more to grassland conversion than forest conversion from 2001 to 2016 (Homer et al. 2020). Apart from agriculture-related changes in the Rocky Mountain Region, most of the net changes occurred in the two eastern regions.

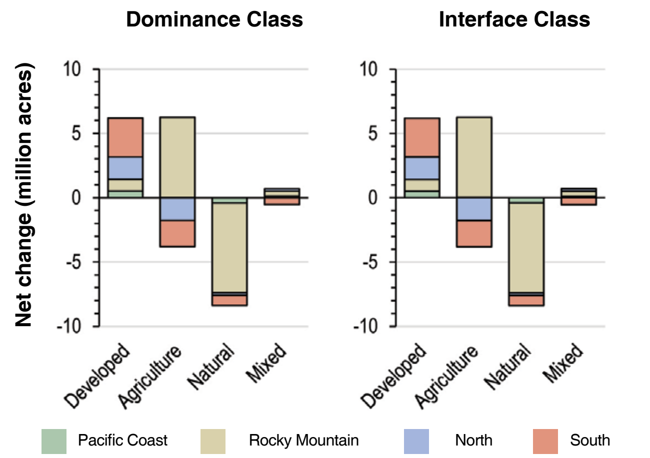
Analogous to the analysis of interior forest change, the components of forest cover change in relation to landscape context include direct changes due to forest loss and gain in each type of landscape, and indirect changes due to expansion (or contraction) of each type of landscape to include (or exclude) the persistent forest area. In both 2001 and 2016, 88 percent of total forest cover area was in landscapes dominated by "natural" land covers (table 4-6), but 31 percent was in landscapes that contained a significant share (at least 10 percent) of developed or agriculture land cover (table 4-7). From 2001 to 2016, the forest area in developed dominance and interface landscapes increased by 0.4 and 1.4 million acres, respectively, while the forest area in agriculture dominance and interface landscapes decreased by 0.8 and 6.1 million acres, respectively. The changes in the agriculture and developed landscapes were driven primarily by indirect change. For example, the net rate of forest cover loss was highest within landscapes dominated by developed land cover

Figure 4-12. Share of total land area by dominance class (top) and interface class (bottom) in 2016, by RPA region. See text for definitions of dominance and interface classes.



Source: USGS (2019d).

Figure 4-13. Net change of total land area by dominance class (left) and interface class (right) from 2001 to 2016, by RPA region. Changes of land area to or from water are not included. See text for definitions of dominance and interface classes.



Source: USGS (2019a, d).

Table 4-6. Components of forest cover area change from 2001 to 2016 in the conterminous United States by landscape dominance class.

	Forest area		Net percent change		
Dominance class	2016	Change	Total[a]	Direct[b]	Indirect[c]
	million acres		percent		
Developed	2.6	0.4	17.7	-8.7	26.4
Agriculture	17.0	-0.8	-4.7	-1.0	-3.7
Natural	508.4	-13.7	-2.6	-2.7	0.1
Mixed	46.7	-1.3	-2.8	-1.8	-1.0
Total forest area	574.7	-15.5	-2.6	-2.6	--[d]

[a] *Percent change of area from 2001.*
[b] *Forest gain minus loss in a persistent dominance class.*
[c] *Dominance class gain minus loss of persistent forest.*
[d] *Not applicable.*
Sources: USGS 2019a, d.

Table 4-7. Components of forest cover area change from 2001 to 2016 in the conterminous United States by landscape interface class.

	Forest area		Net percent change		
Interface class	2016	Change	Total[a]	Direct[b]	Indirect[c]
	million acres		percent		
Developed	33.8	1.4	4.4	-3.7	8.1
Agriculture	121.9	-6.1	-4.8	-0.9	-3.8
Neither	397.8	-10.8	-2.6	-3.1	0.4
Both	21.1	--[d]	0.1	-2.3	2.5
Total forest area	574.7	-15.5	-2.6	-2.6	--[e]

[a] *Percent change of area from 2001.*
[b] *Forest gain minus loss in a persistent interface class.*
[c] *Interface class gain minus loss of persistent forest.*
[d] *Value between -0.05 and 0.05.*
[e] *Not applicable.*
Sources: USGS 2019a, d.

(9 percent), but the total amount of forest area occurring in those landscapes increased by 18 percent as the developed lands expanded to include additional forest area. The net rate of forest loss was lowest in agriculture-dominated landscapes (1 percent), but the total forest area in those landscapes decreased by 5 percent as agricultural lands contracted to exclude additional forest area. In contrast, the locations of natural-dominated and noninterface landscapes were relatively stable and the forest change within those landscapes was driven primarily by direct forest loss and gain.

Projected Land Use

- ❖ Developed land area is projected to increase in the future, while all non-developed land uses are projected to lose area. The most common source of new developed land is forest land.
- ❖ Forest land area is projected to decrease under all scenarios, although at lower rates than projected by the 2010 Assessment.
- ❖ Higher projected population and income growth lead to relatively less forest land, while hotter projected future climates lead to relatively more forest land.
- ❖ Projected future land use change is more sensitive to the variation in economic factors across RPA scenarios than to the variation among climate projections.

Land Use Change Model

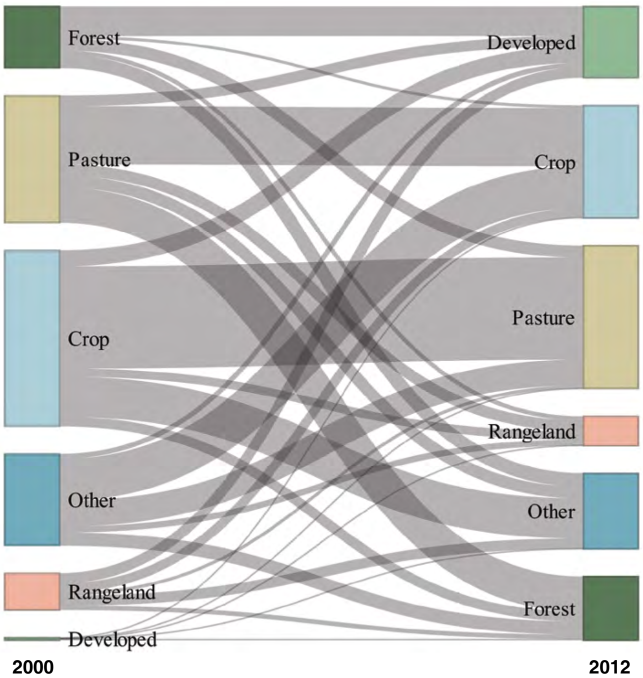
Land use change is a major driver of resource change. We projected land use change on private land for each county in the conterminous United States from 2020 to 2070 for five major land use classes: forest, developed, crop, pasture, and rangeland. The land use projections are based on the 20 RPA scenario-climate futures (four RPA scenarios and five climate projections; see the sidebar RPA Scenarios) and are therefore explicitly linked to projected climate change and socioeconomic change. Mihiar and Lewis (in review) provide details of the methods and results.

All land use change was assumed to occur on privately owned land within these land use classes; all other ownerships, as well as other NRI categories (Conservation Reserve Program, water, and other rural), were held constant throughout the projection period. Land development is assumed to be an irreversible change—developed land only gains area over time—because there were only trivial historical losses in developed area in the NRI data used to calibrate the projection models. The land use projections do not assume any significant future change in land use policy or regulations (i.e., projections are policy-neutral, based on historical land use relationships driven by future climate change as well as population and economic growth assumptions).

The future projections of land use were based on a subset of NRI data for private land only, spanning 2000 to 2012. During that time, the most active transitions occurred to/from crop and pasture lands (figure 4-14). Of the 6.7 million acres of crop land moving to other use, 67 percent of that land was placed in the Conservation Reserve Program (CRP). Likewise, 91 percent of new crop land from the other category originated from the CRP. The conversion trends of undeveloped land into developed land have changed significantly through time (figure 4-3). Approximately 1.2 million acres of undeveloped land transitioned into developed land annually in the 1980s; this amount increased to approximately 2.0 million acres per year between 1992 and 1997, but the rate of newly developed land declined thereafter (figure 4-3). Bigelow et al. (2022) found that the decline was consistent across urban and rural regions in the conterminous United States and resulted in 7.0 million acres of forest and agriculture land remaining undeveloped between 2000 and 2015. If developed land had continued to expand at the same rate observed before 2000, those 7.0 million acres of forest and agriculture use would have converted to a developed use.

The projections are based on land use transition probabilities, estimated from NRI plots with repeated observations during the years 2000 to 2012 (Mihiar and Lewis, in review). The modeling approach has three components: (a) developing empirical linkages between climate, population, income, and the value of land in production for the major U.S. land uses of agriculture (crop and pasture), forest, and developed; (b) estimating an empirical link between the net returns to each land use and the observed choice of land use across agriculture, forest, and developed conditional on the current land use allocation; and (c) using estimated transition probabilities to project future land use changes.

Figure 4-14. Gross land use change in the conterminous United States from 2000 to 2012. For land moving out of a particular land use in 2000 (bars on left), the width of the gray flows indicate the relative area moving into each new use in 2012 (bars on right).



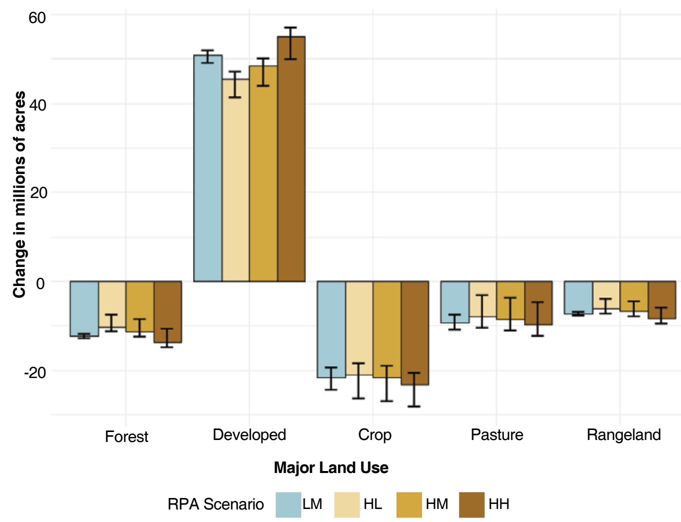
Source: USDA 2015.

Land Use Projections

Our analyses of the land use projections are stratified across several dimensions. We examine both gross and net land use change. Gross change describes all transitions of land between uses, while net change describes the change in land area after accounting for all transitions in and out of that land use. We also consider how the projections differ across the RPA North, South, Rocky Mountain, and Pacific Coast Regions. Finally, we explore the projections across the four RPA scenarios and five climate projections (see the sidebar RPA Scenarios). We examine the influence of atmospheric warming by comparing results from the lower warming-moderate growth RPA scenario (LM) to the high warming-moderate growth scenario (HM), and we examine the influence of socioeconomic growth by comparing the high warming-low growth RPA scenario (HL) to the high warming-high growth scenario (HH). In addition, the influence of future climate is examined by comparing results across the selected climate projections.

Projected trends in land use from 2020 to 2070 are consistent across RPA scenarios, indicating large net increases in developed land and moderate net declines in each of the non-developed land uses (figure 4-15). Projected declines are largest in crop use and smallest in rangeland use for each scenario. The HH scenario resulted in the largest net gain in developed land and largest net loss in forest land, while the HL scenario resulted in the smallest net gain in developed land and smallest net loss in forest land (table 4-9), suggesting that the land use change model (Mihiar and Lewis in review) is more sensitive to the variation in future economic variables (population and income) than in future atmospheric warming and climate variables (temperature and precipitation) across RPA scenario-climate futures.

Figure 4-15. Projected net land use changes from 2020 to 2070 across the conterminous United States, by RPA scenario. The range drawn within each bar represents difference in projection across climate projections.



LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

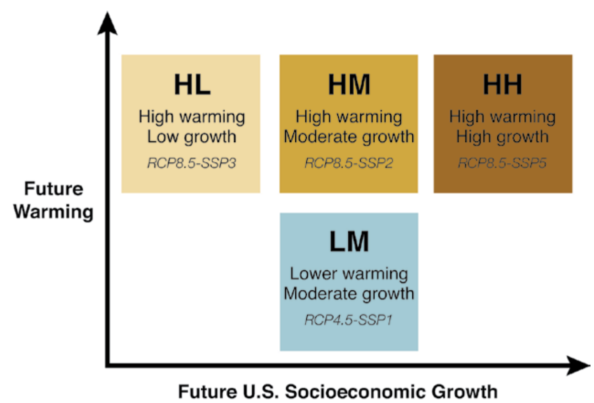
Land use projections reveal an expansion of developed land of 41.3 to 57.0 million acres across the RPA scenario-climate futures (table 4-9). However, those increases differ by RPA region (figure 4-18). The largest projected growth in developed land area is in the South Region, where approximately 18.4 (HL-hot) to 25.0 million acres (HH-wet) of new developed land is projected. The North Region has the second largest projected increase in developed land, approximately 10.6 (HL-hot) to 14.0 million acres (HH-least warm). The Rocky Mountain Region is projected to see developed land area grow between 6.4 million acres (HL-hot) and 8.9 million acres (HH-dry), and the Pacific Coast Region is projected to see developed land area grow by between 5.9 million acres (HL-hot) and 9.9 million acres (HH-least warm). These projected changes of developed land area are important to understand how future forested landscapes may evolve, because loss of forest land is projected to be the largest source of new developed land, accounting for an average of 46 percent of new developed land (table 4-10).

RPA Scenarios

The RPA Assessment uses a set of scenarios of coordinated future climate, population, and socioeconomic change to project resource availability and condition over the next 50 years. These scenarios provide a framework for objectively evaluating a plausible range of future resource outcomes.

The 2020 RPA Assessment draws from the global scenarios developed by the Intergovernmental Panel on Climate Change to examine the 2020 to 2070 time period (IPCC 2014). The RPA scenarios pair two alternative climate futures (Representative Concentration Pathways or RCPs) with four alternative socioeconomic futures (Shared Socioeconomic Pathways or SSPs) in the following combinations: RCP 4.5 and SSP1 (lower warming-moderate U.S. growth, LM), RCP 8.5 and SSP3 (high warming-low U.S. growth, HL), RCP 8.5 and SSP2 (high warming-moderate U.S. growth, HM), and RCP 8.5 and SSP5 (high warming-high U.S. growth, HH) (figure 4-16). The four 2020 RPA Assessment scenarios encompass most of the projected range of climate change from the RCPs and projected quantitative and qualitative range of socioeconomic change from the SSPs, resulting in four distinct futures that vary across a multitude of

Figure 4-16. Characterization of the 2020 RPA Assessment scenarios in terms of future changes in atmospheric warming and United States socioeconomic growth. These characteristics are associated with the four underlying Representative Concentration Pathway (RCP) – Shared Socioeconomic Pathway (SSP) combinations.



Source: Langner et al. (2020).

Figure 4-17. Characteristics differentiating the 2020 RPA Assessment scenarios. These characteristics are associated with the four underlying Representative Concentration Pathway (RCP) – Shared Socioeconomic Pathway (SSP) combinations.

RPA Scenario (RCP-SSP)	Global Temperature Rise	U.S. Population Growth	U.S. Economic Growth Rate	Bioenergy Demand	Energy Sector Focus	Global Energy Usage	International Trade Openness
LM Lower warming Moderate growth *RCP4.5-SSP1*	Lower	Medium	Medium-High	High	Renewables	Low	Medium
HL High warming Low growth *RCP8.5-SSP3*	High	Low	Low	Low	Fossil fuels	Medium	Low
HM High warming Moderate growth *RCP8.5-SSP2*	High	Medium	Medium	Medium	Mixed	Medium	Medium
HH High warming High growth *RCP8.5-SSP5*	High	High	High	High	Fossil fuels	High	High

characteristics (figure 4-17), and providing a unifying framework that organizes the RPA Assessment natural resource sector analyses around a consistent set of possible world views. The Scenarios Chapter describes how these scenarios were selected and paired; more details are provided in Langner et al. (2020).

The 2020 RPA Assessment pairs these four RPA scenarios with five different climate models that capture the wide range of projected future temperature and precipitation across the conterminous United States. An ensemble climate projection that averages across the multiple model projections is not used because of the importance of preserving individual model variability for resource modeling efforts. The five climate models selected by RPA represent least warm, hot, dry, wet, and middle-of-the-road climate futures for the conterminous United States (table 4-8); however, characteristics can vary at finer spatial scales. Although the same models were selected to develop climate projections for both lower and high-warming futures, distinct climate projections for each model are associated with RCP 4.5 and RCP 8.5. The Scenarios Chapter describes how these climate models were selected. Joyce and Coulson (2020) give a more extensive explanation.

Throughout the RPA Assessment, individual scenario-climate futures are referred to by pairing RPA scenarios with selected climate projections. For example, an analysis run under "HL-wet" assumes a future with high atmospheric warming and low U.S. population and economic growth (HL RPA scenario), as well as a wetter climate for the conterminous United States (wet climate projection).

Table 4-8. Five climate models selected to reflect the range of the full set of 20 climate models in the year 2070. Each model was run under RCP 4.5 and RCP 8.5, providing a range of different U.S. climate projections.

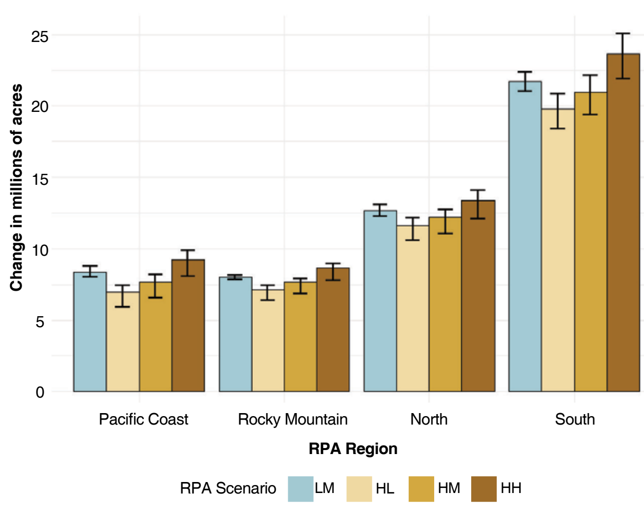
	Least warm	Hot	Dry	Wet	Middle
Climate model	MRI-CGCM3	HadGEM2-ES	IPSL-CM5A-MR	CNRM-CM5	NorESM1-M
Institution	Meteorological Research Institute, Japan	Met Office Hadley Centre, United Kingdom	Institut Pierre Simon Laplace, France	National Centre of Meteorological Research, France	Norwegian Climate Center, Norway

RCP = Representative Concentration Pathway.

Source: Joyce and Coulson 2020.

Over the 50-year period from 2020 to 2070, we project a total net forest land loss of between 7.6 and 15.0 million acres (table 4-9). When averaging results across RPA scenario-climate futures, approximately 91 percent of current forest land is projected to remain in forest use by 2070 (table 4-10). Most of the gross forest loss (19.8 to 26.0 million acres) is projected to convert to developed land (table 4-11), which is assumed to be a permanent change, followed by conversions to pasture, crop, and rangeland (table 4-11). When averaging results across RPA scenario-climate futures, we project about 25.3 million acres of new forest land will be added from conversions out of pasture land (17.4 million), crop land (2.4 million acres), and rangeland (5.5 million acres) (table 4-10). Transitions between forest and pasture lands are the most common and account for the largest area of gross forest change. Only conversions from forest to developed and pasture to forest show significant variation in projection across RPA scenario-climate futures (table 4-11). The remaining conversion types are not sensitive to scenarios or climate projections, varying by less than 1.0 million acres across scenarios and climate projections.

Figure 4-18. Projected net developed land use change from 2020 to 2070, by RPA region and RPA scenario. The range drawn within each bar represents difference in projection across climate projections.



LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

Table 4-9. Projected net land use change from 2020 to 2070 by RPA scenario and climate projection.

	LM scenario					HM scenario				
	Climate projection					Climate projection				
	Least warm	Hot	Dry	Wet	Middle	Least warm	Hot	Dry	Wet	Middle
Land use	million acres (percent)					million acres (percent)				
Forest	-13.0 (-3.2%)	-11.9 (-2.9%)	-11.9 (-2.9%)	-12.5 (-3.0%)	-12.6 (-3.1%)	-12.5 (-3.0%)	-8.6 (-2.1%)	-11.8 (-2.9%)	-11.9 (-2.9%)	-12.1 (-3.0%)
Developed	51.8 (53.1%)	49.1 (50.4%)	50.7 (51.9%)	51.6 (52.8%)	50.7 (51.9%)	50.2 (51.3%)	43.9 (45.0%)	49.0 (50.2%)	50.1 (51.3%)	48.9 (50.1%)
Crop	-20.6 (-5.8%)	-20.4 (-5.7%)	-23.4 (-6.5%)	-24.4 (-6.8%)	-19.5 (-5.4%)	-19.2 (-5.3%)	-26.9 (-7.5%)	-19.7 (-5.5%)	-23.2 (-6.5%)	-19.3 (-5.4%)
Pasture	-10.6 (-8.9%)	-9.7 (-8.1%)	-7.8 (-6.5%)	-7.6 (-6.4%)	-10.9 (-9.7%)	-11.1 (-9.3%)	-3.7 (-3.1%)	-9.5 (-7.9%)	-8.0 (-6.7%)	-10.3 (-8.6%)
Rangeland	-7.6 (-1.9%)	-7.1 (-1.8%)	-7.6 (-1.9%)	-7.1 (-1.7%)	-7.8 (-1.9%)	-7.5 (-1.8%)	-4.6 (-1.1%)	-8.0 (-2.0%)	-6.9 (-1.7%)	-7.3 (-1.8%)

	HL scenario					HH scenario				
	Climate projection					Climate projection				
	Least warm	Hot	Dry	Wet	Middle	Least warm	Hot	Dry	Wet	Middle
Land use	million acres (percent)					million acres (percent)				
Forest	-11.3 (-2.8%)	-7.6 (-1.9%)	-10.7 (-2.6%)	-10.8 (-2.6%)	-11.0 (-2.7%)	-15.0 (-3.7%)	-10.8 (-2.6%)	-14.3 (-3.5%)	-14.5 (-3.5%)	-14.5 (-3.5%)
Developed	47.1 (48.3%)	41.3 (42.4%)	46.1 (47.3%)	47.0 (48.2%)	46.0 (47.2%)	57.0 (58.3%)	49.8 (51.1%)	55.6 (57%)	57.0 (58.3%)	55.3 (56.6%)
Crop	-18.4 (-5.1%)	-26.4 (-7.3%)	-19.0 (-5.3%)	-22.5 (-6.3%)	-18.6 (-5.2%)	-20.8 (-5.8%)	-28.3 (-7.9%)	-21.3 (-5.9%)	-24.9 (-6.9%)	-20.8 (-5.8%)
Pasture	-10.6 (-8.8%)	-3.3 (-2.7%)	-9.0 (-7.5%)	-7.5 (-6.2%)	-9.8 (-8.2%)	-12.3 (-10.3%)	-4.8 (-4.1%)	-10.6 (-8.9%)	-9.2 (-7.7%)	-11.4 (-9.5%)
Rangeland	-6.8 (-1.7%)	-4.0 (-1.0%)	-7.4 (-1.8%)	-6.3 (-1.6%)	-6.6 (-1.6%)	-9.0 (-2.2%)	-5.9 (-1.5%)	-9.5 (-2.3%)	-8.4 (-2.1%)	-8.7 (-2.2%)

LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

Note: Differences with values calculated from table 4-11 are due to rounding.

Table 4-10. Projected gross land use change from 2020 to 2070, averaged over all RPA scenarios and climate projections.

		2070 land use (million acres)					
		Forest	Developed	Crop	Pasture	Rangeland	2020 total
2020 land use (million acres)	**Forest**	372.1	23.2	3.6	8.7	2.2	409.8
	Developed	-	97.7	-	-	-	97.7
	Crop	2.4	10.6	270.1	71.7	4.0	358.8
	Pasture	17.4	8.1	59.4	28.3	6.2	119.4
	Rangeland	5.5	8.8	3.9	1.5	382.5	402.2
	2070 total	**397.4**	**147.6**	**336.9**	**110.6**	**395.2**	**-**
	Mean 50-year net change	-12.4 (-3.0%)	50.7 (+51.9%)	-21.8 (-6.1%)	-9.2 (-7.7%)	-7.3 (-1.8%)	-

Note: The mean net changes shown here are not strictly comparable to values shown in tables 4-9 and 4-11.

Change of forest to developed land ranges from 19.8 million acres (HL-hot) to 26 million acres (HH-least warm) across RPA scenario-climate futures (table 4-11). Largely because of these losses to developed land, these RPA scenario-climate futures are also responsible for the overall smallest (34.4 million acres) and largest (40.5 million acres) gross losses of forest land. Gross gains of forest land are lowest under HH-middle (24.9 million acres) and highest under HM-hot (26.5 million acres), with most gains coming from pasture land across all scenario-climate futures.

The projections for crop to forest land transitions are relatively stable across RPA scenarios (table 4-11). However, under the higher warming RPA scenarios (i.e., HL, HM, and HH), the largest difference in gross change of crop to forest area is projected between the least warm and hot climate projections. We project approximately 0.5 million acres of additional forest area converting from crop land when comparing the least warm to the hot projections. We also project about 0.4 million acres of additional forest area converting from crop land under the HM scenario relative to the LM scenario, both using the hot climate projection. These results suggest that higher atmospheric warming results in more forest land and less crop land across the United States.

Pasture to forest land transitions account for the greatest amount of new forest land in the future, between 17.2 and 18.2 million acres, following a similar pattern to that of crop to forest land transitions (table 4-11). When comparing results using the hot climate projection, we project 1.0 million acres of additional forest from pasture land under the HM scenario relative to LM. When comparing results across climate projections under the HM scenario, we project 0.9 million additional acres converting to forest from pasture for the hot climate projection relative to the least warm projection. Our land use projections indicate that hotter future temperatures may lead to more forest land and less pasture land.

The projected reductions in forest land area, which occur on private lands under all RPA scenarios, differ by RPA region although losses are always highest under the HH-least warm scenario-climate future (figure 4-19). Projected forest land losses are largest in the South Region—between 4.6 million (HL-hot) and 9.2 million acres (HH-least warm).

Table 4-11. Projected gross forest land change from 2020 to 2070, by RPA scenario and climate projection.

	LM scenario					HM scenario				
	Climate projection					Climate projection				
	Least warm	Hot	Dry	Wet	Middle	Least warm	Hot	Dry	Wet	Middle
Gross forest loss	million acres					million acres				
Forest to developed	24.0	22.8	23.4	23.8	23.4	23.4	20.7	22.8	23.3	22.9
Forest to crop	3.6	3.6	3.5	3.5	3.6	3.6	3.6	3.6	3.5	3.6
Forest to pasture	8.7	8.7	8.7	8.7	8.7	8.7	8.8	8.7	8.7	8.7
Forest to rangeland	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Gross forest gain										
Crop to forest	2.3	2.4	2.5	2.5	2.3	2.3	2.8	2.4	2.5	2.3
Pasture to forest	17.3	17.2	17.6	17.4	17.2	17.3	18.2	17.2	17.5	17.2
Rangeland to forest	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5

	HL scenario					HH scenario				
	Climate projection					Climate projection				
	Least warm	Hot	Dry	Wet	Middle	Least warm	Hot	Dry	Wet	Middle
Gross forest loss	million acres					million acres				
Forest to developed	22.3	19.8	21.7	22.2	21.8	26.0	22.9	25.2	25.8	25.2
Forest to crop	3.6	3.6	3.6	3.5	3.6	3.6	3.6	3.6	3.5	3.6
Forest to pasture	8.7	8.8	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
Forest to rangeland	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Gross forest gain										
Crop to forest	2.3	2.7	2.4	2.5	2.3	2.3	2.7	2.4	2.4	2.3
Pasture to forest	17.4	18.2	17.2	17.5	17.2	17.3	18.2	17.1	17.4	17.1
Rangeland to forest	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5

LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

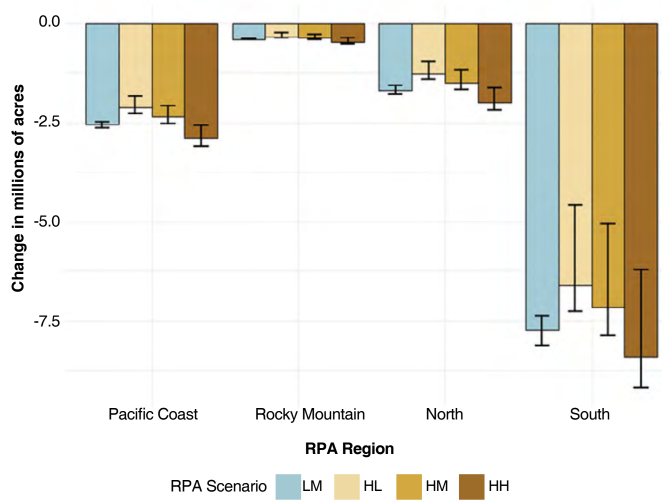
Notes: There are no transitions from developed to forest land. The sum of the rounded gross changes shown here may differ from the net changes shown in table 4-9.

The Pacific Coast Region is projected to lose between 2.5 million (LM-wet) and 3.1 million (HH-least warm) acres of forest land area, and the North Region is projected to lose between 1.6 million (LM-dry) and 2.2 million (HH-least warm) acres. The Rocky Mountain Region is projected to lose less than 0.5 million acres under all RPA scenario-climate futures. The large projected losses in the South Region can be explained by both the large initial base of forest area and the large projected gains in developed land area, mostly deriving from forest land. The small projected forest losses in the Rocky Mountain Region are explained by its much smaller initial base of forest area, and by the projection that rangeland is the dominant source of new developed land in this region.

To examine the impact of future atmospheric warming on future land use change, we compared the lower warming LM and high warming HM RPA scenarios (table 4-9), where warming varies across scenarios but economic growth is similar. The average net increase in developed land area is 52.0 percent across the five climate projections under the LM scenario, while the corresponding average is 49.6 percent under the HM scenario, a difference of 2.4 percent. The difference between the LM and HM scenarios suggests that a future with higher atmospheric warming avoids a moderate amount of new development to the benefit of non-developed land uses. Slight differences in socioeconomic projections between LM and HM may also play a role in the differing outcomes for land development found in our projections. However, an analysis where socioeconomic projections were held constant also found lower development rates associated with a higher warming future (Mihiar and Lewis in review). Avoided-development under the HM scenario primarily affects forest land, resulting in approximately 1.2 million acres of additional forest by 2070. The higher warming future also benefits pasture land, with projections for the HM scenario resulting in 0.8 million acres more pasture land than the LM scenario.

To examine the impact of economic growth on future land use change, we compared the low growth HL and high growth HH RPA scenarios (table 4-9), where economic growth varies across scenarios, but atmospheric warming remains constant. The influence of economic growth, represented by population and income projections, on new developed land far surpasses the influence of future warming described above when comparing the LM and HM scenarios. The average net expansion of developed land area (across the five climate projections) is 46.7 percent under the HL scenario, while the corresponding average is 56.3 percent under the HH scenario—a difference of 9.4 percent. Forest land is projected to be 3.5 million acres lower under the HH scenario than the HL scenario, and crop and pasture lands are also projected to be lower

Figure 4-19. Projected forest land net change from 2020 to 2070, by RPA region and RPA scenario. The range drawn within each bar represents difference in projection across climate projections.



LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

under the HH scenario (by 2.2 million and 1.6 million acres, respectively). Our results suggest that scenarios assuming higher atmospheric warming reduce the projected expansion of developed land area, while scenarios assuming higher growth in population and income have the opposite impact. This result is supported by an extensive analysis of the impact of climate on land use change conducted by Mihiar and Lewis (in review).

This analysis projected 50-year net land use changes that are significantly different from the projected 50-year net changes reported in the 2010 RPA Assessment. In particular, the 2010 RPA Assessment projected an average increase in developed land area between 39 and 69 million acres from 2010 to 2060, while we project an increase in development ranging from 43.9 to 57.0 million acres from 2020 to 2070. Similarly, the 2010 RPA Assessment projected a 50-year average loss in forest land ranging from 16 to 34 million acres by 2060, whereas we project a 50-year loss in forest area ranging from 10.7 to 15.0 million acres by 2070. The difference in projected developed land area change is likely due to the declining annual rate of new developed land which began around the year 2000 (figure 4-3). The 2010 RPA Assessment projections were based on NRI data from 1987 to 1997 and did not reflect the declining annual rate after 2000.

Projected Tree and Impervious Cover Change

❖ Projections of tree and impervious cover were generally consistent among three representative scenarios which all indicated an increase in impervious cover and a slight increase in tree cover nationally.

Tree and impervious cover change alongside changes in land use. Tree cover is one of the simplest proxies for assessing the amount of forest and its associated benefits, for example moderating climate, reducing building energy use and atmospheric carbon dioxide (CO_2), providing wood products, improving air and water quality, mitigating rainfall runoff and flooding, providing wildlife habitat, enhancing human health and social well-being, and lowering noise impacts (Nowak and Dwyer 2007). Air pollution removal by conterminous United States trees and forests in 2010 was estimated at 19.2 million tons, with health effects valued at $6.8 billion (Nowak et al. 2014). These pollutants are: carbon monoxide (CO); nitrogen dioxide (NO_2); ozone (O_3); lead (Pb); sulfur dioxide (SO_2) and particulate matter (PM), which includes particulate matter less than 10 microns (PM_{10}) and particulate matter less than 2.5 microns ($PM_{2.5}$) in aerodynamic diameter. A critical question related to forest sustainability is how tree cover is likely to change given projected land use changes. By estimating the potential change in tree cover across the conterminous United States, forest management plans can be developed to provide desired levels of tree cover and forest benefits for current and future generations.

Impervious surfaces (such as roads and buildings) change alongside land and tree cover change. Impervious surfaces provide essential services to society, but they can also negatively impact the environment through increased air temperatures and heat islands (Heisler and Brazel 2010, Oke 1989). These environmental changes consequently affect building energy use, human comfort and health, ozone production, and pollutant emissions. In addition, impervious surfaces significantly affect urban hydrology (e.g., stream flow, water quality) (National Research Council 2008, US EPA 1983).

The projected land use changes in the 20 RPA scenario-climate futures (see the sidebar RPA Scenarios, above) were used to estimate changes in tree and impervious cover between 2020 and 2070. The baseline amount of 2020 tree and impervious cover in each land cover class of every county in the conterminous United States was calculated using the 2016 USDA Forest Service Tree Canopy Cover (TCC) dataset (USDA Forest Service 2019) and the NLCD 2016 Percent Developed Imperviousness (PDI) dataset (MRLC 2021). Because the 2001 NLCD tree canopy cover data underestimates tree cover (Nowak and Greenfield 2010), we applied similar photointerpretation (PI) methods to 4,000 random points across the conterminous United States to estimate tree and impervious cover within RPA land use classes and compare them with TCC estimates. There was no statistically significant difference between PDI and PI values for impervious cover; however, the TCC data underestimated PI tree cover by an average of 10.8 percent (table 4-12). An adjustment factor (table 4-12) was used to adjust tree cover for each TCC pixel estimate. Adjusted tree cover, hereafter referred to as tree cover, was then calculated for each RPA land cover class in each county of the conterminous United States.

For projections, the tree canopy cover estimated from the 2016 data was used as the 2020 base tree cover estimate. For each subsequent decade from 2030 to 2070, the projected area of each land use class was multiplied by the county-specific percent tree and impervious cover of the corresponding land cover class to estimate the tree and impervious cover in each county. If a county was missing a land cover class in 2020, the cover values from a neighboring county were used. This process assumed that the average tree and impervious covers in 2020 for each land cover class at the county level remain constant through time, with the land use class area changing through time (Nowak et al. 1996).

Three of the 20 RPA scenario-climate futures were selected for mapping and analysis of projected cover changes:

- **Average scenario (HM-wet).** The national average tree cover increase was closest to the average change among all RPA scenario-climate futures.
- **Maximum scenario (HL-hot).** The scenario had the highest average increase in tree cover.

Table 4-12. Comparison of USDA Forest Service tree canopy cover and photo-interpreted percent tree canopy cover estimates by RPA land use class.

Land use class	2016 TCC	2016 PI	Difference[a]	Adjustment factor[b]
Forest	58.9	75.4	-16.5	0.401
Developed	16.1	31.6	-15.5	0.185
Crop	2.2	8.0	-5.8	0.059
Pasture	14.2	25.6	-11.4	0.132
Other	2.6	10.9	-8.3	0.085
Water	0.4	5.6	-5.2	0.052
All classes	21.8	32.7	-10.8	na

AF = adjustment factor; NLCD = National Land Cover Database; PI = photo-interpreted; TCC = tree canopy cover.

[a] *Difference in percent tree cover (TCC minus PI). All differences are significant at alpha = 0.05.*

[b] *Adjustment factor used to adjust TCC tree cover estimates; AF = -difference / (100 - NLCD tree cover).*

- **Minimum scenario (HH-middle).** The scenario had the lowest average increase in tree cover.

Projected changes in tree and impervious cover were summarized by State, RPA region, and ecoregion (i.e., forest, desert, grassland) (Nature Conservancy 2018).

Projected Tree Cover Change

While the national average tree cover did not change much among the three scenarios, there were regionally consistent differences in tree cover change (figure 4-20). The overall projected national increase in tree cover between 2020 and 2070 in the average scenario was 0.02 percent. Areas projected to have tree cover increases were in central Florida, California, Texas, and Oklahoma; eastern Washington, Colorado, and Arkansas; southern Minnesota, Wisconsin, and Michigan; northern Missouri; western New York, Ohio, Kentucky, and Tennessee; and Illinois and Indiana. Tree cover loss was projected in New England; much of the Southeastern United States; northern Minnesota, Wisconsin, Idaho, and Louisiana; southern Missouri; eastern Texas, Oklahoma, and Kansas; and western Arkansas, Washington, and Oregon (figure 4-20).

Counties that had the largest projected increases in tree cover were typically in the RPA South Region. The counties with the largest decreases in tree cover were all city-based counties in Virginia (table 4-13), which are all much smaller than the typical U.S. county and tend to build out with the developed land use within their boundaries by 2070. Overall, the States with the largest projected increases in tree cover were Delaware (+0.9 percent), Indiana (+0.9 percent), and Illinois (+0.7 percent); greatest reductions in tree cover

Figure 4-20. Tree cover change for three RPA scenarios from 2020 to 2070.

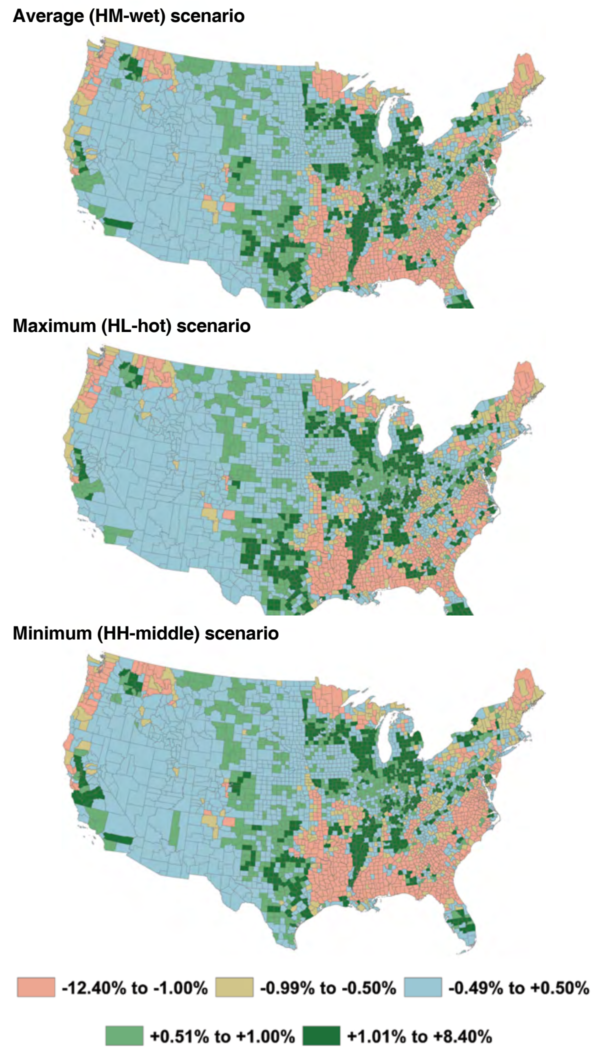


Table 4-13. Top five counties in the conterminous United States with the greatest projected increases and decreases in tree cover from 2020 to 2070 for the average, maximum, and minimum scenarios.

Average scenario HM-wet		Maximum scenario HL-hot		Minimum scenario HH-middle	
County	Change (percent)	County	Change (percent)	County	Change (percent)
		Projected increases			
Tunica, MS	+6.3	Desha, AR	+8.4	Tunica, MS	+5.8
Quitman, MS	+6.0	Tunica, MS	+7.3	Quitman, MS	+5.5
Desha, AR	+5.7	Arkansas, AR	+7.2	Jefferson, WV	+5.3
Dyer, TN	+5.7	Monroe, AR	+6.9	Dyer, TN	+5.2
Cross, AR	+5.2	Cross, AR	+6.8	Boone, AR	+4.8
		Projected decreases			
Petersburg city, VA	-7.6	Petersburg city, VA	-7.9	Danville city, VA	-8.6
Danville city, VA	-8.6	Danville city, VA	-8.8	Newton, TX	-9.4
Emporia city, VA	-11.1	Emporia city, VA	-11.0	Emporia city, VA	-10.8
Franklin city, VA	-12.0	Franklin city, VA	-12.0	Franklin city, VA	-11.6
Buena Vista city, VA	-12.4	Buena Vista city, VA	-12.3	Buena Vista city, VA	-12.1

HM = high warming-moderate U.S. growth; HL = high warming-low U.S. growth; HH = high warming-high U.S. growth.

were in Georgia (-1.3 percent), Maine (-1.1 percent), and Virginia (-1.1 percent). The North (+0.15 percent) and Rocky Mountain (+0.14 percent) Regions exhibited overall increases in projected tree cover while the Pacific Coast (-0.3 percent) and South (-0.24 percent) Regions exhibited decreases in projected tree cover (table 4-14). The grassland (+0.44 percent) and desert (+0.21 percent) ecoregions had projected increases in tree cover while the forest ecoregion (-0.30 percent) exhibited projected decreases in tree cover (table 4-15).

Table 4-14. Tree cover in 2020 by RPA region (percent of total area) and projected changes in tree cover in 2070 for the average, maximum, and minimum scenarios.

RPA region	2020	2070 for scenario:			Change for scenario:		
		Average HM-wet	Maximum HL-hot	Minimum HH-middle	Average HM-wet	Maximum HL-hot	Minimum HH-middle
	%	%	%	%	%	%	%
North	39.7	39.9	39.9	39.8	0.15	0.17	0.10
South	45.9	45.7	46.0	45.5	-0.24	0.05	-0.41
Rocky Mountain	17.9	18.0	18.0	18.0	0.14	0.13	0.14
Pacific Coast	34.0	33.9	34.0	33.9	-0.03	-0.02	-0.03
Conterminous U.S.	32.7	32.7	32.8	32.6	0.02	0.10	-0.04

HM = high warming-moderate U.S. growth; HL = high warming-low U.S. growth; HH = high warming-high U.S. growth.

Table 4-15. Tree cover in 2020 by ecoregion (percent of total area) and projected changes in tree cover in 2070 for the average, maximum, and minimum scenarios. Ecoregions are sorted by decreasing percent change for the average scenario.

Ecoregion	2020	2070 for scenario:			Change for scenario:		
		Average HM-wet	Maximum HL-hot	Minimum HH-middle	Average HM-wet	Maximum HL-hot	Minimum HH-middle
	%	%	%	%	%	%	%
Grassland	15.1	15.5	15.6	15.5	0.44	0.47	0.42
Desert	15.0	15.2	15.2	15.2	0.21	0.19	0.23
Forest	49.0	48.7	48.9	48.6	-0.30	-0.14	-0.40
Conterminous U.S.	32.7	32.7	32.8	32.6	0.02	0.10	-0.04

HM = high warming-moderate U.S. growth; HL = high warming-low U.S. growth; HH = high warming-high U.S. growth.

Projected Impervious Cover Change

While the average tree canopy cover did not change much, with some areas gaining tree cover and other areas losing tree cover, impervious cover was projected to increase throughout most of the conterminous United States from 2020 to 2070 (figure 4-21). The overall projected increase in impervious cover in the average scenario was 0.46 percent, 23 times greater than the net percent increase in tree cover (0.02 percent). Areas that exhibited the greatest projected increases in impervious cover were in the more densely populated regions of the United States.

Counties that had the largest projected increases of impervious cover were in California and Virginia (table 4-16). Less than 1 percent of counties were projected to have a decrease in impervious cover and the average decrease was negligible in those counties. Overall, the States with the largest projected increases in impervious cover were Delaware (+1.9 percent), California (+1.2 percent), and New Jersey (+1.0 percent). The Pacific Coast Region exhibited the largest overall increase in projected impervious cover (+0.87 percent), followed by the South (+0.62 percent), North (+0.50 percent), and Rocky Mountain (+0.18 percent) Regions (table 4-17). The forest ecoregion had the largest projected increase in impervious cover (+0.61 percent), followed by the grassland (+0.30 percent) and desert (+0.26 percent) ecoregions (table 4-18).

Discussion

The projections of tree and impervious cover across the conterminous United States were generally consistent among the average, maximum, and minimum scenarios. All scenarios showed an increase in impervious cover and

Table 4-16. Top five counties in the conterminous United States in terms of greatest projected increases and decreases in impervious cover from 2020 to 2070 for the average, maximum, and minimum scenarios.

Average scenario HM-wet		Maximum scenario HL-hot		Minimum scenario HH-middle	
County	**Change (percent)**	**County**	**Change (percent)**	**County**	**Change (percent)**
Projected increases					
Santa Clara, CA	+14.2	Santa Clara, CA	+10.6	Stanislaus, CA	+19.7
Stanislaus, CA	+13.8	Franklin city, VA	+10.2	Santa Clara, CA	+18.7
Franklin city, VA	+9.9	Stanislaus, CA	+9.1	Franklin city, VA	+9.6
Buena Vista city, VA	+9.1	Buena Vista city, VA	+9.0	Bowie, TX	+9.2
Emporia city, VA	+8.1	Emporia city, VA	+8.2	Buena Vista city, VA	+8.7
Projected decreases					
Daniels, MT	-0.0015	Judith Basin, MT	-0.0015	Daniels, MT	-0.0015
Hall, TX	-0.0022	Greeley, NE	-0.0023	Greeley, NE	-0.0018
Sheridan, KS	-0.0023	Sheridan, KS	-0.0024	Hall, TX	-0.0019
Greeley, NE	-0.0024	Hall, TX	-0.0032	Sheridan, KS	-0.0023
Floyd, IA	-0.0051	Floyd, IA	-0.0051	Floyd, IA	-0.0046

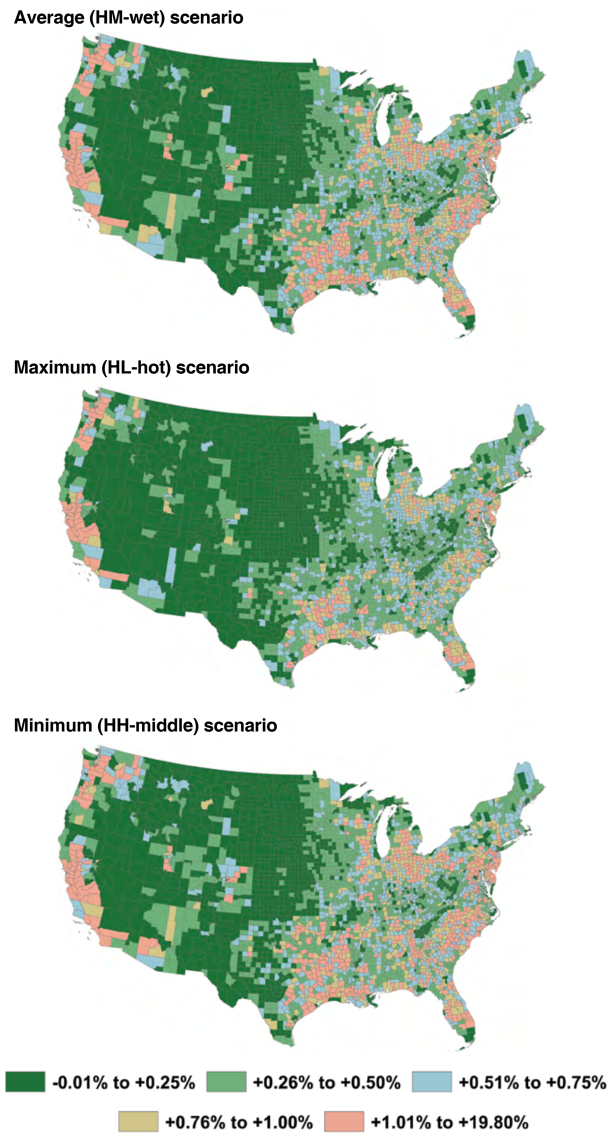
HM = high warming-moderate U.S. growth; HL = high warming-low U.S. growth; HH = high warming-high U.S. growth.

Table 4-17. Impervious cover in 2020 by RPA region (percent of total area) and projected changes in impervious cover in 2070 for the average, maximum, and minimum scenarios.

RPA region	2020	2070 for scenario:			Change for scenario:		
		Average HM-wet	Maximum HL-hot	Minimum HH-middle	Average HM-wet	Maximum HL-hot	Minimum HH-middle
	%	%	%	%	%	%	%
North	2.2	2.7	2.6	2.7	0.50	0.41	0.52
South	1.8	2.4	2.3	2.4	0.62	0.52	0.67
Rocky Mountain	0.5	0.6	0.6	0.7	0.18	0.15	0.20
Pacific Coast	1.6	2.5	2.3	2.8	0.87	0.69	1.16
Conterminous U.S.	1.4	1.8	1.7	1.9	0.46	0.37	0.51

HM = high warming-moderate U.S. growth; HL = high warming-low U.S. growth; HH = high warming-high U.S. growth.

Figure 4-21. Impervious cover change for three RPA scenarios from 2020 to 2070.



a little net growth in tree cover nationally. The scenarios also exhibited generally consistent regional variation of changes in tree and impervious cover. Impervious cover was projected to increase by an average of 0.46 percent (from 1.4 to 1.8 percent of the land base), which is a 34 percent relative increase in impervious cover. The projected increase in impervious cover was consistent with recent trends of increasing impervious cover in urban areas nationally (Nowak and Greenfield 2018) and within urban areas globally (Nowak and Greenfield 2020).

While it is likely that impervious cover will increase due to expanding human populations and associated land development, the outcome for tree cover is less certain because many interacting factors affect tree cover, including land use change, climate change, forest policies and management activities, and natural disturbances. Furthermore, these factors are themselves influenced by the natural environment and human policies and activities. Thus, the projected changes in tree cover based on projected land use changes may not be realized, depending on how those factors alter tree cover. While total tree cover area is not projected to change much, it is likely to shift among regions, with some areas gaining and others losing tree cover. By understanding these potential changes and the reasons for these changes, forest management plans can be devised to sustain healthy forests that promote human health and well-being for current and future generations.

Table 4-18. Impervious cover in 2020 by ecoregion (percent of total area) and projected changes in impervious cover in 2070 for the average, maximum, and minimum scenarios. Ecoregions are sorted by decreasing percent change for the average scenario.

Ecoregion	2020	2070 for scenario:			Change for scenario:		
		Average HM-wet	Maximum HL-hot	Minimum HH-middle	Average HM-wet	Maximum HL-hot	Minimum HH-middle
	%	%	%	%	%	%	%
Grassland	1.8	2.4	2.3	2.5	0.61	0.51	0.69
Desert	1.0	1.3	1.2	1.3	0.30	0.24	0.32
Forest	0.6	0.8	0.8	0.9	0.26	0.20	0.31
Conterminous U.S.	1.4	1.8	1.7	1.9	0.46	0.37	0.51

HM = high warming-moderate U.S. growth; HL = high warming-low U.S. growth; HH = high warming-high U.S. growth.

Projected Land Use Patterns

- ❖ Future changes to spatial patterns of land use, such as landscape dominance and natural interface area, are strongly related to projected changes in general land use area.
- ❖ New development is projected to occur near existing development, almost doubling the area of developed-dominant land.
- ❖ Projected new development increases the area of the developed-natural interface and shifts land from the agricultural-natural interface to the joint developed-agricultural-natural interface.
- ❖ Projected land use pattern changes are consistent across all 20 RPA scenario-climate futures. The RPA scenarios had a greater impact than the climate projections on future landscapes near man-made land uses, but both drivers had about the same degree of impact in less-modified landscapes.
- ❖ While overall forest land use area was projected to decrease, the share of more-contiguous forest was projected to increase in the RPA South Central, Northeast, and North Central Subregions.

Future land use changes are likely to result in landscape pattern changes, but additional analyses were needed to project changes in landscape patterns from the county-level land use projections described in the section Land Use Projections. In this section, the county-level land use projections were downscaled (disaggregated) into spatially explicit land use maps at 90 m spatial resolution (approximately 2 acres per pixel), and the future landscape patterns were measured on those maps. The downscaling applied a demand-allocation simulation method (Brooks et al. 2020) to a 2020 land use base map for the conterminous United States. For each of the 20 RPA scenario-climate futures (four RPA scenarios, five climate projections), future land use maps were simulated at decadal intervals until 2070. The simulations were repeated 20 times for each scenario-climate future, each time assuming a different degree of spatial randomness of land use changes (Brooks et al. 2020). We then measured landscape patterns on each of the 2,000 simulated future maps (20 scenario-climate futures x 5 decades x 20 simulations). Following the naming conventions of the land use projections, "developed" includes the NRI developed class, "agriculture" includes the crop and pasture classes, and "natural" includes forest and other non-developed and non-agricultural NRI classes. The simulated spatial changes were applied only on privately owned land area (Conservation Biology Institute 2016), but for consistency with overall land area totals, the public land (Federal, State, and local government) and Tribal ownerships were included in the landscape pattern analysis. This section focuses on cumulative simulated changes from 2020 to 2070 to evaluate climatic, socioeconomic, and regional differences in future landscape patterns.

The future landscape pattern around each pixel was described by one of four dominance classes and one of four interface classes (see the section Historical Forest Fragmentation and Landscape Context) within a 162-acre neighborhood. In addition, future forest fragmentation was assessed by classifying future forest pixels into "interior" and "non-interior" forest, where interior forest is defined as a forest pixel at the center of a 162-acre neighborhood that is at least 90-percent forested (Riitters and Robertson 2021). Despite using the same general methods, we do not recommend strict comparisons of landscape patterns in this section and in the section Historical Forest Fragmentation and Landscape Context due to scale differences and qualitative differences between land use and land cover.

The county-level land use projections for all scenarios indicate increases in developed land area, drawing primarily from forested and other natural lands. The future changes of landscape patterns reflect those trends, as modified by several simulated degrees of randomness which placed future land use changes either near or far from existing area of the same land use (Brooks et al. 2020). Driven by the land use projections, we expect overall increases in the area of developed-dominated landscapes and developed interfaces, and a decrease of interior forest area. Where forest and agriculture land uses are both converted to developed area, the landscapes become more heterogeneous with the local blending of developed, agriculture, and natural land.

We summarize the overall results for the conterminous United States across all simulations, followed by comparisons among subsets of simulations defined by RPA scenarios and climate projections (see the sidebar RPA Scenarios). One RPA scenario and one climate projection were selected as "base cases" and the remaining models and scenarios were compared in terms of deviations from the base cases. The base cases, chosen to reflect "middle-ground" situations, were the HM RPA scenario and the middle climate projection. All comparisons were made using median outcomes across all simulations within a given set of scenarios and/or climate projections. Projected changes among classes were summarized in terms of net changes.

National Results

Across all RPA scenarios, climate projections, and simulations, the projected trends in landscape dominance generally followed the corresponding county-level trends. Developed-dominated land area was projected to increase by a median of 47.3 million acres (95 percent) from 2020 to 2070 (table 4-19). This area was balanced primarily

Table 4-19. Projected changes in landscape dominance from 2020 to 2070 across all RPA scenarios, climate projections, and simulations. Note that the median values do not necessarily sum to zero.

Dominance class	Median change	Range of change	Relative median change
	million acres	million acres	percent
Developed	+47.3	(+32.6, +56.8)	+95.1
Agriculture	-29.4	(-35.0, -25.4)	-7.03
Natural	-19.0	(-24.3, -9.6)	-1.49
Mixed	-0.03	(-3.2, +9.6)	-0.02

by median decreases of 29.4 million acres (7 percent) of agriculture-dominated land and by 19.0 million acres (1 percent) of natural-dominated land. The land area in the "mixed" dominance class (where no one land use covers more than 60 percent of the surrounding area) was projected to increase slightly across all models and scenarios (<0.1 million acres, <0.1 percent). Figure 4-22 illustrates the distribution of simulated changes for all simulations of the RPA scenario-climate futures.

With one exception, the projected RPA regional trends in dominance class area (table 4-20) generally conformed to historical trends in land cover dominance (figure 4-13). The exception was that the historical increase in agriculture-dominated land from 2001 to 2016 in the Rocky Mountain Region was not projected to continue. While differences between land cover and use may account for some of this trajectory change in landscape dominance, the projections were consistent with the county-level land use projection models, which indicated a future decrease of agriculture land area in that region.

We also assessed projected trends in the median areas of interface classes (figure 4-23, table 4-21). Across all simulations, the median share in the developed interface class was projected to increase by 49.9 million acres (76 percent) from 2020 to 2070, comparable to the projected increase of area in developed-dominated land. Like dominance, this increase was drawn from the agriculture interface area which had a projected decrease of 45.6

Figure 4-22. Projected net area changes of four landscape dominance classes across the conterminous United States from 2020 to 2070. The bars represent the median values across all RPA scenarios, climate projections, and simulations. The violin plots indicate the distribution of simulated values, with the violin height representing the full range of values and the width representing their relative frequency.

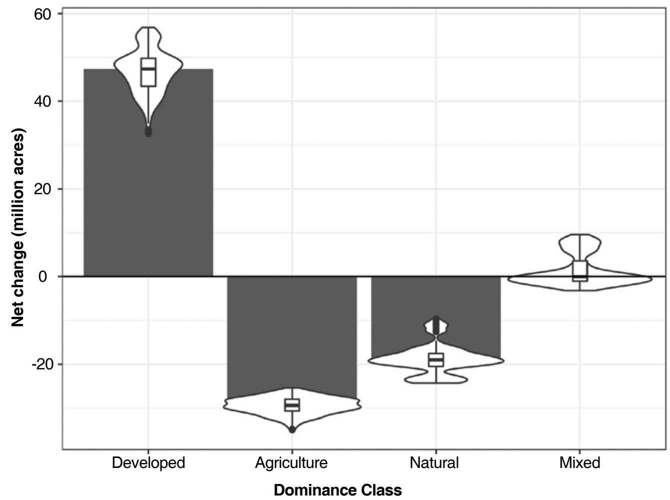


Figure 4-23. Projected net area changes of four landscape interface classes across the conterminous United States from 2020 to 2070. The bars represent the median values across all RPA scenarios, climate projections, and simulations. The violin plots indicate the distribution of simulated values, with the violin height representing the full range of values and the width representing their relative frequency.

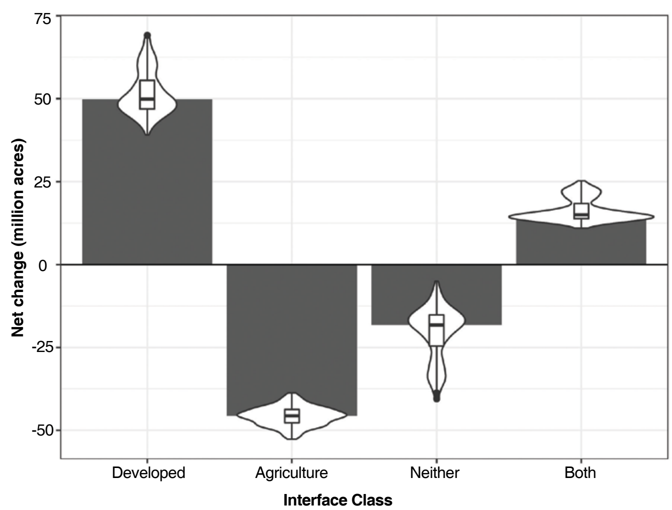


Table 4-20. Projected median change in landscape dominance area from 2020 to 2070 across all RPA scenarios, climate projections, and simulations, by RPA region. Values in parentheses indicate the range.

	Landscape dominance class (million acres)			
RPA region	**Developed**	**Agriculture**	**Natural**	**Mixed**
North	+12.4 (8.69, 14.7)	-11.4 (-12.9, -9.72)	-0.74 (-1.47, -0.09)	-0.66 (-1.29, +2.14)
South	+21.5 (16.1, 26.0)	-10.7 (-14.3, 8.63)	-8.97 (-11.2, -4.72)	-2.51 (-3.89, -1.99)
Rocky Mountain	+5.89 (2.99, 7.60)	-4.25 (-4.85, -3.68)	-3.48 (-5.04, -0.76)	+1.82 (0.94, 3.22)
Pacific Coast	+7.51 (4.89, 9.37)	-3.05 (-3.87, -2.41)	-5.76 (-7.36, -3.89)	+1.33 (0.952, 2.29)

Table 4-21. Projected changes in interface class area from 2020 to 2070 across all RPA scenarios, climate projections, and simulations. Note that the median values do not necessarily sum to zero.

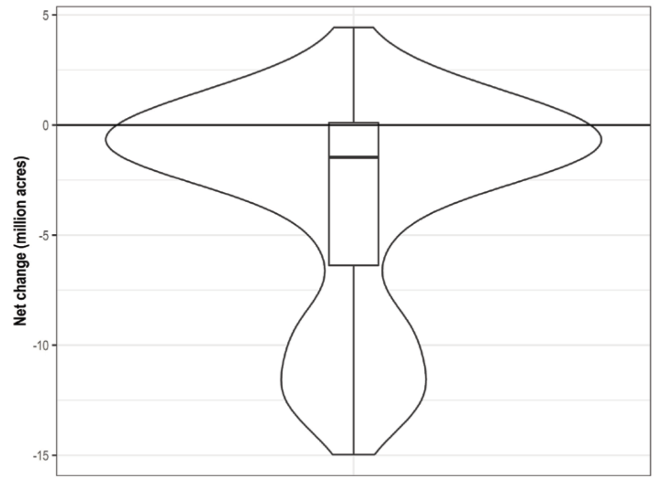
Interface class	Median change	Range of change	Relative median change
	million acres	million acres	percent
Developed	+49.9	(+39.1, +69.2)	+76.1
Agriculture	-45.6	(-52.6, -38.7)	-8.04
Neither	-18.2	(-40.5, -5.05)	-1.69
Both	+15.0	(+11.0, +25.2)	+19.6

million acres (8 percent), and non-interface area which was projected to decrease by 18.2 million acres (2 percent). The “both” interface area (where both developed and agriculture interface with natural landscapes) was projected to increase by 15.0 million acres (20 percent), which contrasts with the relatively stable share of land in the corresponding mixed dominance class. This difference is accounted for by noting that the projected decrease in agriculture interface area exceeds that of the agriculture-dominated area by more than 15 million acres. Put another way, while lands with agricultural context are generally being converted to lands with a more developed context, a considerable part of this conversion (the 15 million acres) is from non-interface land with more than 90-percent agriculture in the neighborhood to land that has at least 60-percent agriculture (i.e., remains agriculture-dominant) but now includes at least 10-percent developed land as well (i.e., becomes “both” interface).

While the values reported here are net changes across all simulations, maps of gross change (not shown here) suggest that conversion of natural land to agriculture land occurs near existing development, and that new developed land tends to be connected to existing development. Support for this interpretation is in the “long tails” in the violin plots (figure 4-23), where simulations with extremely large areas of developed interface have correspondingly small areas of non-interface land.

We assessed projected trends of interior forest area to evaluate the effects of land use change on forest fragmentation from 2020 to 2070. Over all simulations, the median projected interior forest area change was a decrease of 1.5 million acres (figure 4-24). That loss is equivalent to approximately 12 percent of the projected net forest area loss during that time (table 4-9). However, variation across the RPA scenarios and climate projections was such that over a quarter of the simulations exhibited a projected increase in interior forest, suggesting that the direction and the degree of interior area change depends on both future climate and socioeconomic trends.

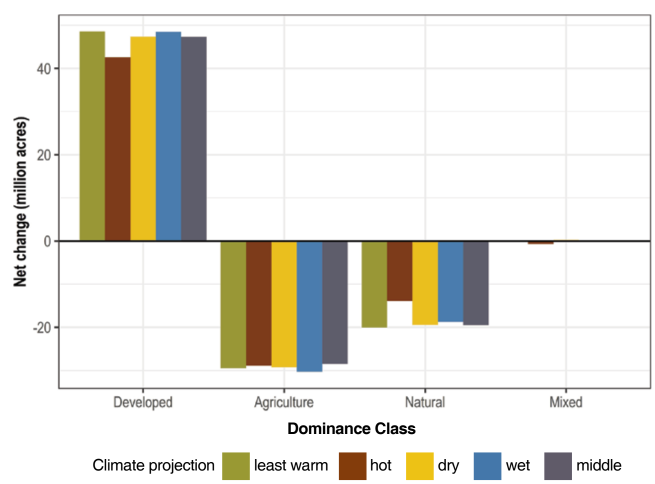
Figure 4-24. Distribution of projected changes in interior forest area from 2020 to 2070, across all RPA scenarios, climate projections, and simulations. The violin height represents the full range of values, and the width represents their relative frequency.



Climate Projection Results

To compare the main effects of the different climate projections on projected landscape patterns, we aggregated projected changes across all RPA scenarios and simulations separately within each climate projection and compared the median results of each projection with those of the middle climate projection base case. Figure 4-25 shows the effects of the different climate projection on projected future landscape dominance patterns. Impacts on each dominance class were consistent across all climate projections; however,

Figure 4-25. The effect of climate projection on landscape dominance, displayed as median projected change from 2020 to 2070.



the hot projection produced the most divergent results. In particular, the hot projection inhibited the general increase in developed-dominated land area (4.3 million fewer acres gained than the middle projection of 47.3 million acres gained), with a corresponding inhibition in the reduction of natural-dominated land (5.8 million fewer acres lost than the middle projection of 19.5 million acres lost). The difference between the hot and least warm climate projections was larger than the difference between the dry and wet projection. The wet projection resulted in the largest acceleration to reductions to agriculture-dominated land (1.8 million acres more lost than the middle projection of 28.5 million acres lost), with the balance spread across developed and natural dominant lands.

Figure 4-26 shows the effects of the different climate projections on future interface classes. As with landscape dominance, all climate projections result in the same direction of change: increasing developed interface and interface between both developed and agriculture with the natural landscape ("both"), with decreasing agriculture and neither-interface. The hot climate projection again generally projects the most divergent results, including an inhibited increase to developed interface land and a corresponding inhibited decrease to the neither interface. Also similar to their effects on landscape dominance, the difference between the hot and least warm climate projections was larger than the difference between the dry and wet projections. The hot projection reduced the projected developed interface net gain by 3.2 million acres, consistent with the effect on developed-dominated land. The wet projection resulted in the most accelerated decrease in agriculture interface land (similar to that projection's effect on agriculture dominated land): agriculture interface class area was projected to decrease

Figure 4-26. The effect of climate projection on natural interface, displayed as median projected change from 2020 to 2070.

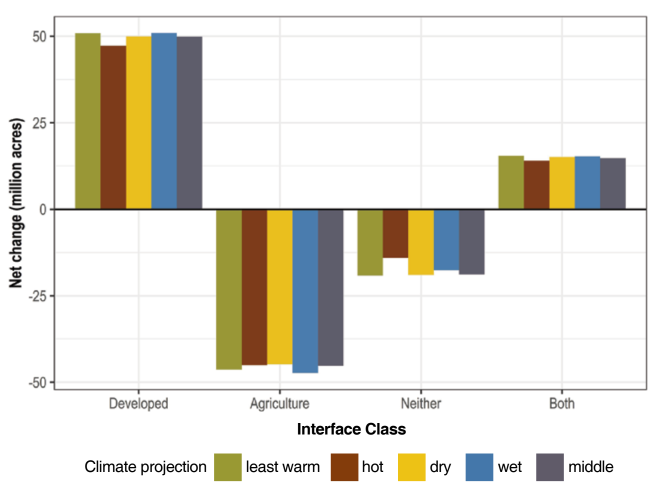
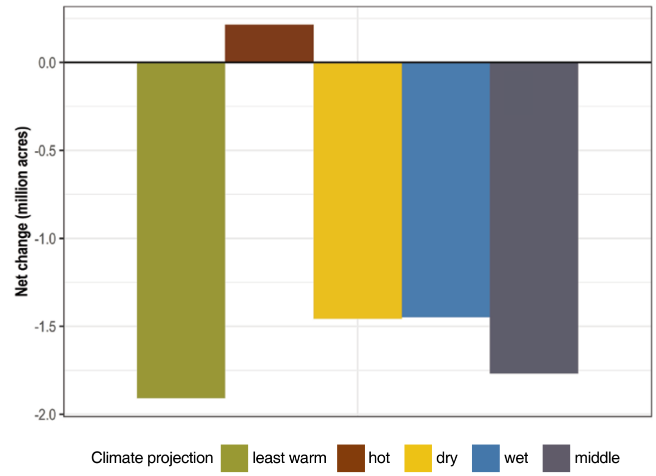


Figure 4-27. The effect of climate projection on interior forest, displayed as median projected change from 2020 to 2070.



by 2.2 million acres beyond the middle projection, with the balance spread across the other interface classes.

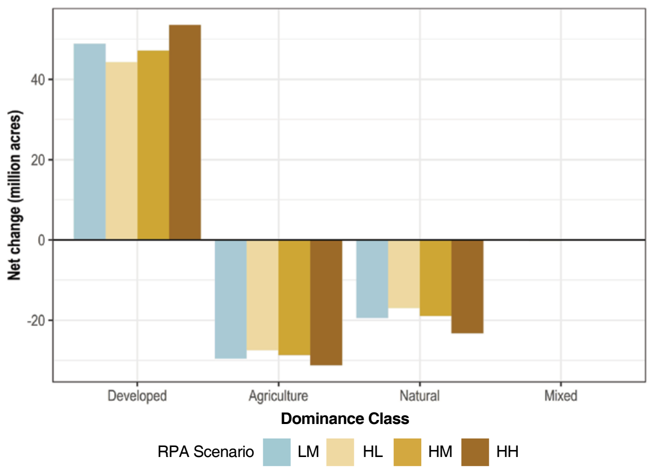
Figure 4-27 shows the effect of the different climate projections on projected future interior forest area. As with dominance and interface classes, the hot climate projection produced the most divergent results, yielding in this case a median projected increase to interior forest area. This result contrasts with a decrease of 1.8 million acres projected by the middle climate projection, as well as decreases of 1.5 million acres under the dry and wet projections, and 1.9 million acres under the least warm projection. Under the hot projection, the relatively slower increase of developed land results in relatively more remaining natural land, including interior forest. This suggests that under the hot projection, developed land is drawing from a mixture of non-interior forest and agricultural lands.

RPA Scenario Results

To compare the effects of the different RPA scenarios on projected landscape patterns for the conterminous United States, we aggregated projected changes across all climate projections and simulations separately within each RPA scenario (figure 4-14), and then contrasted the median results for each scenario with the base case (HM RPA scenario).

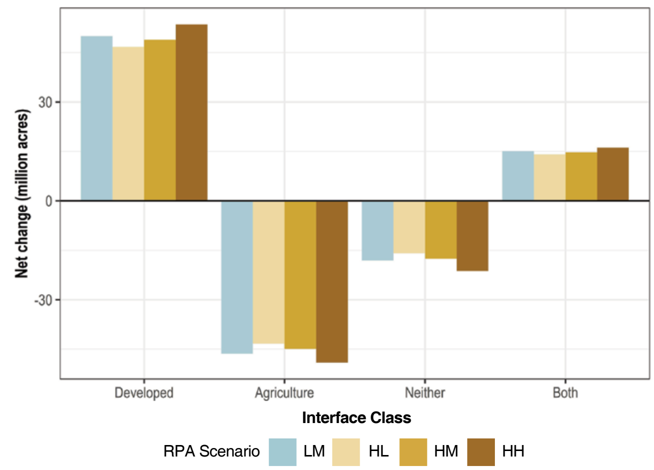
Figure 4-28 shows the effect of the RPA scenario on projected landscape dominance. The differences between high and low growth (HH and HL, respectively) had a greater effect on landscape dominance than the contrast between lower and high atmospheric warming (LM and HM, respectively). High growth was projected to increase developed-dominated land by 9.3 million acres more than the low growth scenario and 6.4 million acres above the HM base scenario. This additional

Figure 4-28. The effect of RPA scenario on landscape dominance, displayed as median projected change from 2020 to 2070.



LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

Figure 4-29. The effect of RPA scenario on natural interface, displayed as median projected change from 2020 to 2070.



LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

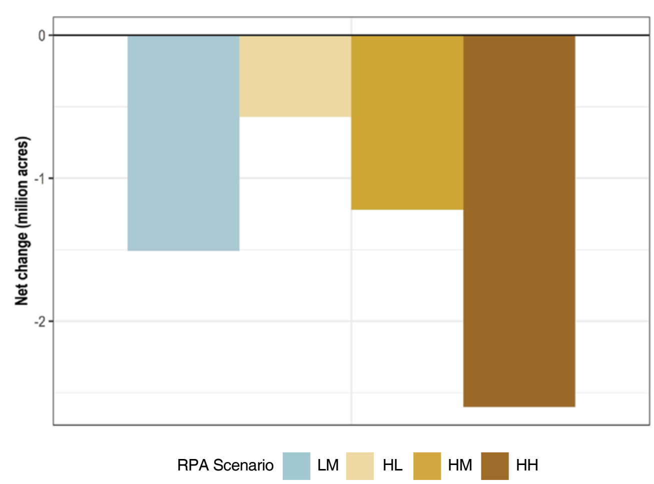
development came from agricultural and natural lands, resulting in lower projected areas for those dominance classes. The reduced projected developed-dominant land projected under the low growth scenario results in more agricultural- and natural-dominant areas. Trends for the LM scenario tended to mirror those for the HH scenario, albeit with a reduced magnitude of change relative to the HM base scenario.

Figure 4-29 shows the effect of the RPA scenario on projected interface class area. General patterns conformed to those for landscape dominance, with the main difference being an increased shift from the agriculture interface into the "both" interface class as compared to agriculture- and mixed-dominated land, respectively. This effect was more pronounced under the HH scenario, suggesting that the driver of the increased "both" interface area over the agriculture interface is economic growth (with more growth leading to more interface area containing both developed and agriculture land).

Figure 4-30 shows the effect of the RPA scenario on projected interior forest area. While the loss of interior forest area under HL is less than in other scenarios, the median interior forest area is projected to decrease across all scenarios. The loss of interior forest area from 2020 to 2070 under the HH scenario, 2.6 million acres, is over four times greater than the loss under the HL scenario (0.6 million acres). As with landscape dominance and interface classes, comparing projected results associated with the different economic growth levels (SSP) of the scenarios resulted in larger differences than the different warming levels (RCP).

Comparing the relative sensitivity of the results to RPA scenarios and climate projections, we found the former to be a stronger driver of differences in landscape dominance (compare figures 4-25 and 4-28) and landscape interface (compare figures 4-26 and 4-29) near artificially created land uses. In contrast, both drivers of change resulted in about the same degree of variation in less-modified landscapes. Taking landscape dominance as an example, the range of developed-dominated land area in 2070 is 9.2 million acres across RPA scenarios and 5.9 million acres across climate projections. For agriculture-dominated land area, the range is 3.7 million acres across RPA scenarios and 1.8 million acres across climate projections. The range for natural-dominated land area differed very little between RPA scenarios (6.3 million acres) and climate projections (6.2 million acres). While the

Figure 4-30. The effect of RPA scenario on interior forest, displayed as median projected change from 2020 to 2070.



LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

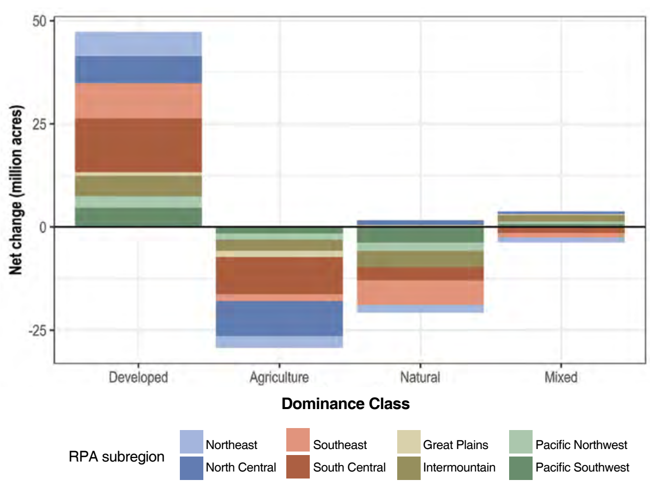
opposite result was obtained for the mixed dominance class, the magnitudes of those ranges are small in comparison to the other dominance classes (0.4 million acres for RPA scenarios versus 0.9 million acres for climate projections). Like natural-dominated land area, there is slightly more variation among climate projections than among RPA scenarios for non-interface land area and interior forest area because those conditions generally occur in less-modified landscapes.

Regional Results

Projected changes were expected to vary geographically because of regional differences in biophysical constraints on land use and in initial socioeconomic conditions. Those differences imply that regional differences are inseparable from climate projection and RPA scenario differences, which prevents identifying projection or scenario differences at the regional level. Thus, we estimated regional changes in terms of median outcomes across all simulations, by RPA subregion (figure 2-1).

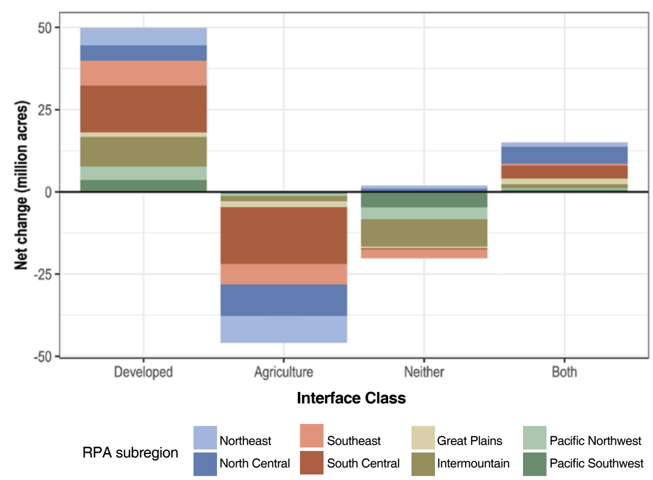
The area of developed-dominated land was projected to increase in all subregions, but the offsetting changes to other dominance classes varied among subregions (figure 4-31). Agriculture-dominated area was projected to decrease in all subregions, while natural-dominated land area was projected to decrease in all subregions except the North Central and Great Plains Subregions. The area of the mixed dominance class is projected to decrease in the eastern subregions and increase in the western subregions. The projections are generally similar to historical land cover dominance results (see the section Historical Forest Fragmentation and Landscape Context), with the exception that the historical increase of agriculture-dominated area in the Rocky Mountain Region was not projected to continue.

Figure 4-31. Projected net area change of four landscape dominance classes from 2020 to 2070, by RPA subregion. The bars represent median subregional net changes across all RPA scenarios, climate projections, and simulations.



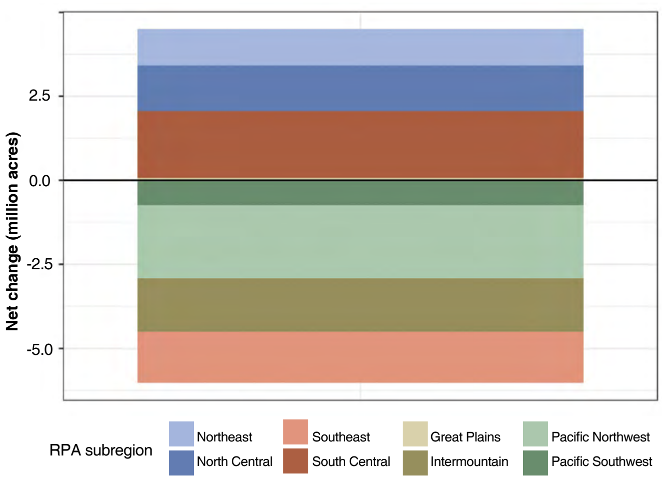
Projected trends of interface class areas were generally similar to those of landscape dominance, except for the "both" interface class as compared to mixed-dominated class (figure 4-32): the median "both" interface area increased for all subregions, whereas the Northeast, Southeast, and South Central Subregions all saw decreases to mixed-dominated land area. For changes in both dominance and interface classes, subregional differences in initial conditions (i.e., the original area of each class) largely explained subregional differences of the change (analysis not shown here). The projected changes in interface classes were generally similar to historical changes based on land cover, with the same exception to historical trends in the Rocky Mountain Region.

Figure 4-32. Projected net area change of four landscape interface classes from 2020 to 2070, by RPA subregion. The bars represent median subregional net changes across all RPA scenarios, climate projections, and simulations.



Projected changes of interior forest area were driven by the net loss of total forest area and by the locations of forest gains and losses in relation to the locations of the extant forest. Despite the overall projected loss of total forest area, the projected net change in interior forest from 2020 to 2070 varied by subregion (figure 4-33). The Southeast Subregion and the western subregions were projected to experience a decrease of interior forest area, with the largest area decrease in the Pacific Northwest Subregion. Interior forest area was projected to increase in the northern and eastern subregions, particularly in the South Central and North Central Subregions. That these subregional increases were projected despite concordant overall forest loss suggests a consolidation of contiguous forest in those subregions.

Figure 4-33. Projected net change of interior forest area from 2020 to 2070, by RPA subregion. Values shown are the medians across all RPA scenarios, climate projections, and simulations.



While these median projections are impacted by both climate and socioeconomic factors, as previously shown for the overall conterminous United States, we found no instance where such variation changed the direction of the projected subregional trends.

Management Implications

Historical patterns of land use and land cover changes are likely to continue under any future scenario, albeit at different rates than projected for the 2010 RPA Assessment. Apart from the projected increase in urban land use area, mostly deriving from land in forest and agriculture uses, the primary implication is related to the specific locations of new urban or developed land. Will future urban growth continue to expand upon the existing urban areas as our projections indicate? Or will other socioeconomic drivers such as resource scarcity or pandemics lead to a concentration within existing urban areas or to a more dispersed pattern of development? Urban densification would place additional pressures on urban forests, while the conversion of rural land would create new “urban interface” landscapes where land managers, both private and public, could face novel pressures in some areas. As more stakeholders with potentially new expectations enter conversations about land management, more emphasis could be placed on “all-lands” or “partnership” management approaches that encourage public engagement.

Our analyses of land use change considered only the value of timber commodities in valuing forest land and did not directly value other forest ecosystem services such as carbon storage, water quantity, or wildlife habitat. These values are discussed in the Forest Resources, Water Resources, and Biodiversity Chapters but were not explicitly included in our land use models. Placing additional value on those services would tend to increase the relative economic return to forest compared to other land uses that do not supply those services, which in turn would tend to increase the area of forest remaining forest.

Our current models suggest that socioeconomic drivers of land use and cover change play a more significant role than climate drivers. If so, then management actions taken in response to actual or expected climate change in a specific circumstance are unlikely to alter the fundamental economic drivers of forest land use change, unless the actual changes are so unusual or widespread that economic considerations play a smaller role in future choices of land use and cover. At the same time, climate change has the potential to become the most important driver of long-term land use changes. Our future projection models are based on historical land use and economic data from a time when climate change was arguably less important than it may become in the future. Even intense but localized disturbances such hurricanes and large wildfires have not fundamentally altered land use, nor the major drivers of land use change at regional scales. This is not to say that climate change had less import in prior decades, only that our future projections are based on data from that period. It is therefore not surprising that economic factors dominate climate factors in our future projections of the nation’s land resources. However, in the past several years there is evidence of large-scale climate-related events such as prolonged extreme drought in the Western States which could be harbingers of fundamental changes in the capacity to support some land uses over large areas. Another example is sea level rise, which has the potential to change land use dynamics over large coastal regions. With the advent of such climate-related phenomena, some areas may no longer have the capacity to support traditional land uses indefinitely, which could shift those land uses and the associated provision of ecological services to other geographic areas. While it may never be possible to adequately project all the local changes in climate, land use, and land cover that could occur, model improvements would help to better address the range of potential future impacts on the land base at both local and regional scales.

Conclusions

This chapter summarized recent trends of land use and land cover and presented future projections to 2070 based on RPA scenarios. Historical analysis of FIA data indicated that the total forest and woodland area in the conterminous United States has been relatively stable for several decades. The NRI data for only non-Federal forest land indicated a slight gain of forest area from 1982 to 2012, mostly from previously agricultural land uses. In contrast, the total area with forest cover, across all land uses, declined by approximately 3 percent from 2001 to 2016. The difference was explained in part by the loss of forest cover in areas not used as forest, and in part by the temporary loss of forest cover in areas used as forest.

While the total forest area has been relatively stable, the forest and land resources of the United States are highly dynamic over time and space. Because the spatial arrangement of the forest changes over time, the consequent changes in fragmentation and landscape context are often much larger than suggested by net area change alone. Shorter term changes such as the use of agriculture land for pasture or cultivated crops and the transitional cover of forest land use with forest, grass, or shrub covers are driven largely by economic returns to agriculture and forest management but also by temporary forest disturbances. Such changes are pervasive on privately owned land, relatively less common on public lands, and cumulatively affect a much larger total area than is indicated by net area changes over time. Over the long term, the most important lasting land use change has been and will likely continue to be the conversion of rural lands to urbanized lands, driven by increasing U.S. population and relative economic returns to development in comparison with returns to either agriculture or forest operations.

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