13. Land Use and Land Cover Change

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Key Messages

1. **Choices about land-use and land-cover patterns have affected and will continue to affect how vulnerable or resilient human communities and ecosystems are to the effects of climate change.**
2. **Land-use and land-cover changes affect local, regional, and global climate processes.**
3. **Individuals, organizations, and governments have the capacity to make land-use decisions to adapt to the effects of climate change.**
4. **Choices about land use and land management provide a means of reducing atmospheric greenhouse gas levels.**

In addition to emissions of greenhouse gases from energy, industrial, agricultural, and other activities, humans affect climate through changes in how we use land (such as growing food, cutting trees, or building cities) and what we put on the land (such as planting grain crops and new trees or pouring concrete) (Loveland et al. 2012). For example, cities are warmer than the surrounding countryside because of the greater extent of paved areas in the cities, which affects how water and energy are exchanged between the land and the atmosphere, and how exposed the population is to extreme heat events. Decisions about land use and land cover can therefore affect, positively or negatively, how much our climate will change, and what kind of vulnerabilities that humans and natural systems will face as a result.

The impacts of changes in land use and land cover cut across all regions and sectors of the National Climate Assessment. Chapters addressing each region discuss land use and land cover topics of particular concern to specific regions. Similarly, chapters addressing sectors examine specific land use matters. In particular, land cover and land use are a major focus for sectors such as agriculture, forestry, rural and urban communities, or Native American lands. By contrast, the key messages of this chapter are national in scope and synthesize the findings of other chapters regarding land cover and land use.

Land uses and land covers change over time in response to evolving economic, social, and biophysical conditions (Lebow et al. 2012). Many of these changes are set in motion by individual landowners and land managers and can be quantified from satellite measurements, aerial photographs, and on-the-ground observations (Loveland et al. 2002). Over the past few decades, the most prominent land changes within the U.S. have been the amount and kind of forest cover due to logging practices and development in the Southeast and Northwest, and to urban expansion in the Northeast and Southwest.

Because humans control land use and, to a large extent, land cover, individuals, organizations, and governments can make land decisions to adapt to and/or reduce the effects of climate change. Adaptation options include varying the local mix of vegetation and concrete to reduce heat in cities, or elevating homes to reduce exposure to sea level rise or flooding. Land use and land-cover related options for reducing the speed and amount of climate change include expanding forests to accelerate removal of carbon from the atmosphere, modifying the way cities are built and organized to reduce energy and motorized transportation demands, and altering agricultural management practices to increase carbon storage in soil. The term "mitigation" is often used for these kinds of activities that can reduce future climate change.

Despite this range of climate change response options, there are two main reasons why private and public landowners may not choose to modify land uses and land covers for climate adaptation or mitigation purposes. First, land decisions are influenced not only by climate but also by economic, cultural, legal, or other considerations. In many cases, climate-based land-change efforts to adapt to or reduce climate change meet with resistance because current practices are deeply entrenched in local economies and cultures. Second, certain land uses and land covers are simply difficult to modify, regardless of desire or intent. For instance, the number of homes constructed in floodplains or the amount of irrigated agriculture can be so deeply rooted that they are difficult to change, no matter how much those practices might impede our ability to respond to climate change.

Recent Trends

In terms of land area, the U.S. remains a predominantly rural country, even as its population increasingly gravitates towards urban areas. In 1910, only 46% of the U.S. population lived in urban areas, but by 2010 that figure had climbed to more than 81% (U.S. Census Bureau 1995, 2012). Even with those large population shifts, in 2006 (the most recent year for which these data are available) more than 80% of the land cover in the lower 48 states was still dominated by shrub/scrub vegetation, grasslands, forests, and agriculture (Fry et al. 2011; Homer et al. 2007). Forests and grasslands, which include acreage used for timber production and grazing, account for more than half of all U.S. land use by area (Table 1) (Nickerson et al. 2011). Agricultural uses account for about 20% of our surface area. Developed or built-up areas covered only about five percent of the country's land surface, with the greatest concentrations of urban areas in the Northeast, Midwest, and Southeast. This apparently small percentage of developed area belies its rapid expansion and does not include development that is dispersed in a mosaic among other land uses (like agriculture and forests). In particular, low-density housing developments (suburban and exurban areas) have rapidly expanded throughout the U.S. over the last 60 years or so (Brown et al. 2005; Hammer et al. 2009; Solecki and Rosenzweig 2012). Areas settled at suburban and exurban densities (1 house per 1 to 40 acres on average) now cover more than 15 times the land area of areas settled at urban densities (1 house per acre or less).

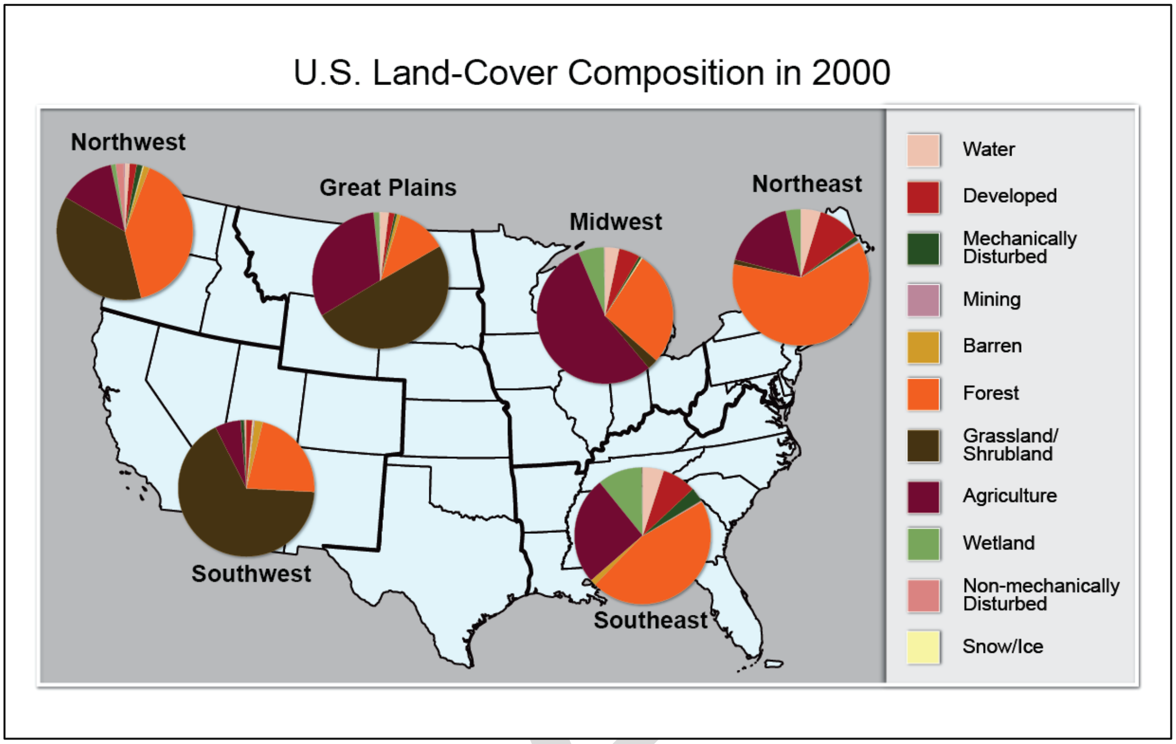

Figure 13.1. U.S. Land-Cover Composition in 2000

Caption: Map shows regional differences in land cover. These patterns affect climate and will be affected by climate change. They also influence the vulnerability and resilience of communities to the effects of climate change (Figure source: USGS Earth Resources Observation and Science (EROS) Center. Data from USGS Land Cover Trends Project).

Despite these rapid changes in developed land covers, the vast size of the country means that total land-cover changes in the U.S. may appear deceptively modest. Since 1973, satellite data show that the overall rate of land-cover changes nationally has averaged about 0.33% per year. Yet this small rate of change has produced a large cumulative impact. Between 1973 and 2000, 8.6% of the area of the lower 48 states experienced land-cover change, an area roughly equivalent to the combined land area of California and Oregon (Loveland et al. 2012).

These national-level annual rates of land changes mask considerable geographic variability in the types, rates, and causes of change (Loveland et al. 2002). Between 1973 and 2000, the Southeast region had the highest rate of change, due to active forest timber harvesting and replanting, while the Southwest region had the lowest rate of change. Satellite observations also tend to underestimate urban development, especially where settlement occurs at low densities. Other analyses show that suburban and exurban areas increased fivefold in size between 1950 and 2000 (Brown et al. 2005).

Table 13.1. Circa-2001 land-cover statistics for the National Climate Assessment regions of the United States (Homer et al. 2007), and overall United States land-use statistics—circa 2007 (Nickerson et al. 2011).

Land Cover Class	Northeast	Southeast	Midwest	Great Plains	Southwest	Northwest	Alaska	Hawaii	United States	Land Use Class (ca 2007)	United States (ca 2007)
Agriculture	10.9%	23.0%	49.0%	29.7%	5.0%	10.0%	0.0%	4.0%	18.60%	Cropland	18.0%
Grassland, Shrub/Scrub, Moss, Lichen	3.4%	7.8%	2.9%	50.5%	65.7%	42.8%	44.9%	33.3%	39.2%	Grassland, Pasture, and Range	27.1%
Forest	52.4%	38.7%	23.7%	10.7%	19.9%	37.7%	22.4%	22.0%	23.2%[1]	Forest	29.7%[1]
Barren	0.8%	0.3%	0.2%	0.5%	3.7%	1.5%	7.7%	11.2%	2.6%	Special Use[2]	13.8%
Developed, Built-Up	9.6%	7.7%	8.0%	4.0%	2.7%	3.0%	0.1%	6.7%	4.0%	Urban	2.7%
Water, Ice, Snow	14.9%	7.3%	10.4%	1.9%	1.7%	3.2%	18.5%	21.7%	7.4%	Misc-ellaneous[3]	8.7%
Wetlands	8.0%	15.2%	5.8%	2.7%	0.7%	1.3%	6.4%	0.3%	5.0%		

[1] Definitional differences, such as the special uses distinction in the USDA Economic Research Service land use estimates, make direct comparisons between land use and land cover challenging. For example, forest land use (29.7%) exceeds forest cover (23.2%). Forest use definitions include lands where trees have been harvested and may be replanted, while forest cover is a measurement of the presence of trees.

[2] Special uses represent rural transportation, rural parks and wildlife, defense and industrial, plus miscellaneous farm and other special uses.

[3] Miscellaneous uses represent unclassified uses such as marshes, swamps, bare rock, deserts, tundra plus other uses not estimated, classified, or inventoried.

Table 13.2. Percentage net and gross land-cover change (1973-2000) for the conterminous United States National Climate Assessment regions. Net change is the percent change in the area of each land-cover type. Gross change is the percentage of the total area of the land-cover type at the first time that was modified between two periods (for example, includes increases in forest cover and decreases in forest cover).

	Northeast		Southeast		Midwest		Great Plains		Southwest		Northwest	
Land Cover Type	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross
Grassland/Shrubland	0.73	1.14	0.31	0.91	0.59	1.35	1.55	5.29	-0.28	2.51	0.35	4.58
Forest	-2.02	4.05	-2.51	7.91	-0.93	2.26	-0.71	1.50	-0.49	0.75	2.39	6.04
Agriculture	-0.85	1.48	-1.62	3.67	-1.38	2.74	-1.60	4.82	-0.37	1.73	-0.35	1.94
Developed	1.36	1.37	2.28	2.30	1.34	1.35	0.43	0.43	0.51	0.52	0.51	0.51
Mining	0.14	0.53	-0.05	0.47	0.02	0.13	0.07	0.09	0.10	0.12	0.03	0.05
Barren	0.00	0.01	-0.01	0.03	0.00	0.01	0.00	0.09	0.00	0.02	0.00	0.05
Snow/Ice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.03	0.06	0.45	0.64	0.08	0.25	0.23	0.46	0.03	0.13	-0.02	0.12
Wetland	-0.05	0.08	-0.69	1.31	-0.05	0.34	-0.13	0.40	-0.02	0.12	0.03	0.12
Mechanically Disturbed [1]	0.66	1.42	1.76	3.90	0.32	0.81	0.11	0.52	0.07	0.22	0.07	2.71
Non-mechanically Disturbed [2]	0.00	0.00	0.07	0.10	0.01	0.01	0.06	0.18	0.46	0.55	1.78	2.10

[1] Land in an altered and often un-vegetated state that, because of disturbances by mechanical means, is in transition from one cover type to another. Mechanical disturbances include forest clear-cutting, earthmoving, scraping, chaining, reservoir drawdown, and other similar human-induced changes.

[2] Land in an altered and often un-vegetated state that because of disturbances by non-mechanical means, is in transition from one cover type to another. Non-mechanical disturbances are caused by fire, wind, floods, animals, and other similar phenomena.

Projections

Future patterns of land use and land cover will interact with climate changes to affect human communities and ecosystems. At the same time, future climate changes will also affect how and where humans live and use land for various purposes.

National-scale analyses suggest that the general historical trends of land use and land-cover changes (described above) will continue, with some important regional differences. These projections all assume continued population growth, which will result in changes in land use and land cover that are spread unevenly across the U.S. Urban areas are projected to increase at the slowest rate in the Northeast region, because of the high level of existing development and relatively low rates of population growth, and at highest rate in the Northwest. In terms of area, the Northwest has the smallest projected increase in urban area (approximately 4.2 million acres), and the Southeast the largest (approximately 27.5 million acres) (Wear 2011).

Some of the projected changes in developed areas will depend on assumptions about changes in household size, and how concentrated urban development will be. Higher population density means less land is converted from forests or grasslands, but results in a greater extent of paved area. Projected growth in low-density exurban areas will result in a greater area affected by development, and is expected to increase commuting times and infrastructure costs. The areas projected to experience exurban development will have less density of impervious surfaces (like asphalt or concrete). While exurban areas have about one-third of their area covered by impervious surfaces (Bierwagen et al. 2010), urban or suburban areas are about one-half concrete and asphalt.

Projected land-use and land-cover changes will depend to some degree on rates of population and economic growth. In general, scenarios of continued high growth produce more rapid increases in developed areas of all densities and in areas covered by impervious surfaces (paved areas and buildings) by 2050 (Bierwagen et al. 2010; Wear 2011). Exurban and suburban areas are projected to expand by 15% to 20% between 2000 and 2050 (Bierwagen et al. 2010). Cropland and forest are projected to decline most under a scenario of high population and economic growth and least under lower-growth scenarios. More forest than cropland is projected to be lost in the Northeast and Southeast, whereas more cropland than forest is projected to be lost in the Midwest and Great Plains (Sohl et al. 2012). Some of these differences are due to the current mix of land uses, others to the differential rates of urbanization in these different land uses.

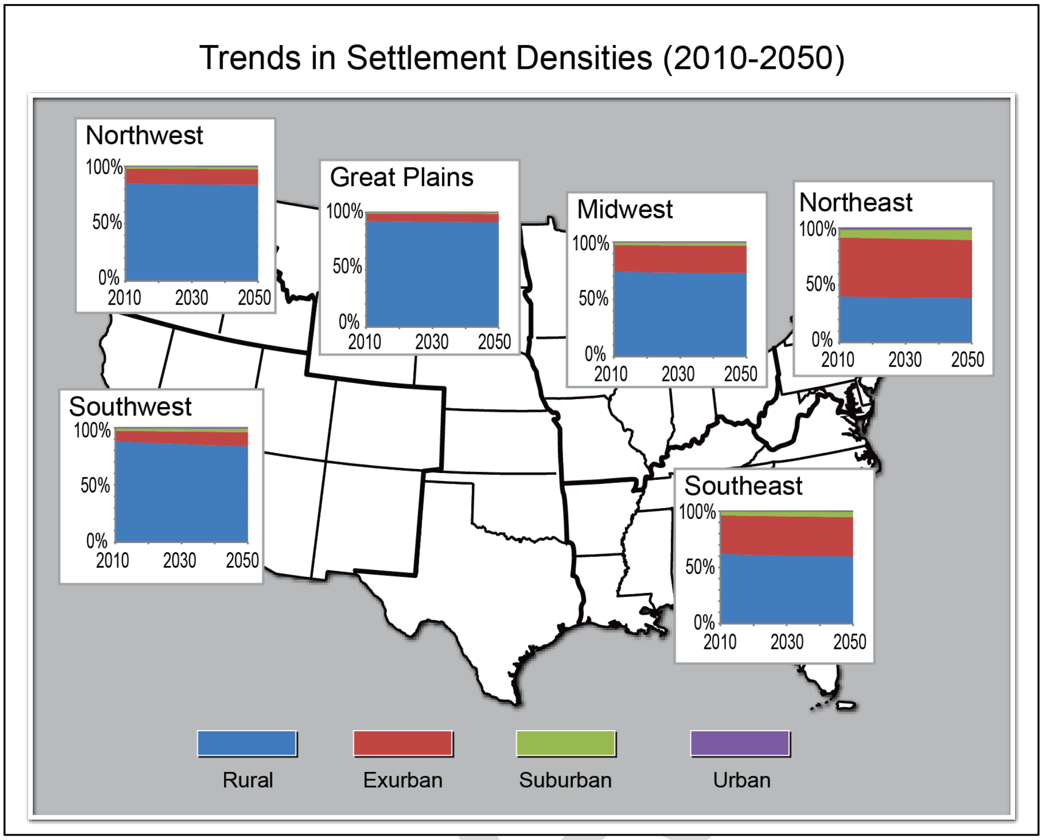

Figure 13.2: Trends in Settlement Densities (2010-2050)

Caption: Projected percentages in each housing-unit density category for 2050 compared with 2010, assuming demographic and economic growth consistent with the high-growth emissions scenario (A2 scenario). Data source: U.S. EPA Integrated Climate and Land Use Scenarios.

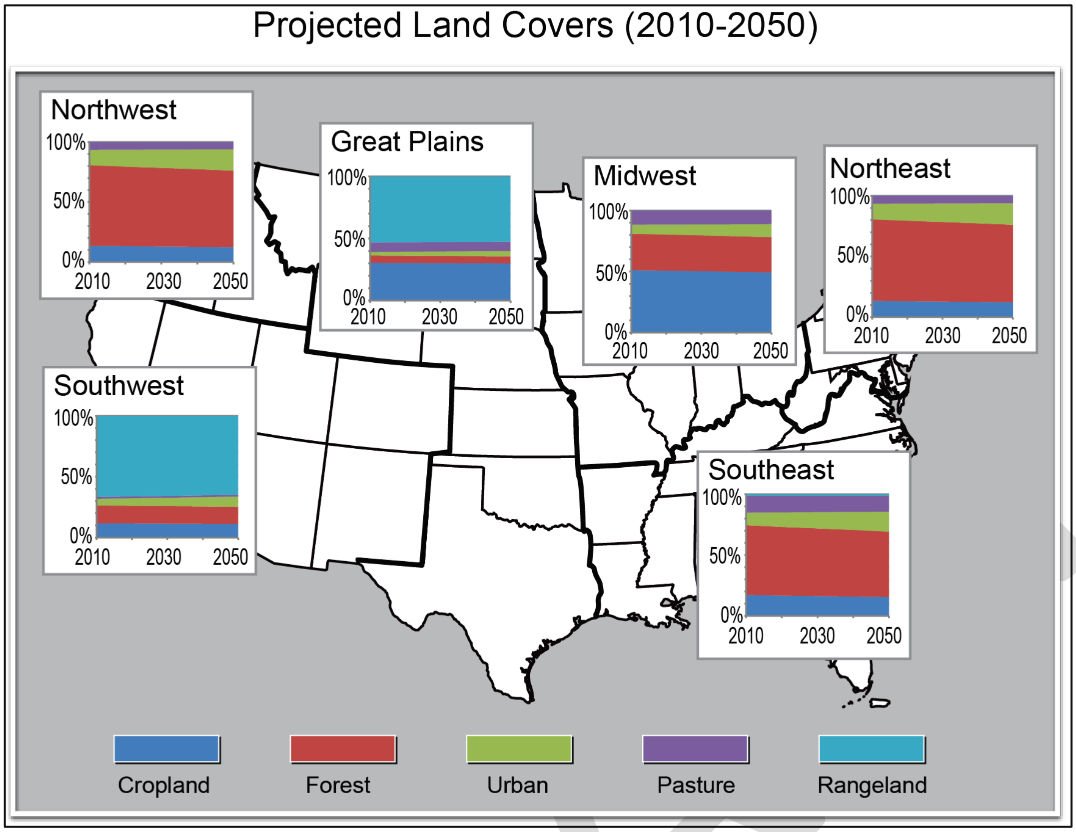

Figure 13.3. Projected Land Covers (2010-2050)

Caption: Projected percentages in each land-cover category for 2050 compared with 2010, assuming demographic and economic growth consistent with the high-growth emissions scenario (A2 scenario) (Data source: Wear et al., 2011)

Effects on Communities and Ecosystems

Choices about land-use and land-cover patterns have affected and will continue to affect how vulnerable or resilient human communities and ecosystems are to the effects of climate change.

Decisions about land-use and land-cover change by individual landowners and land managers are influenced by demographic and economic trends and social preferences, which unfold at global, national, regional and local scales. Policymakers can directly affect land use through mandates and regulations, and/or by creating financial incentives. For example, Congress can declare an area as federally protected wilderness, or local officials can set aside portions of a town for industrial development and create tax benefits for companies to build there. However, climate factors typically play a secondary role in land decisions, if they are considered at all. Nonetheless, land change decisions may affect the vulnerabilities of households, organizations, and communities to the effects of climate change. A farmer's choice of crop rotation in response to price signals affects his or her farm income's susceptibility to drought, for example. Similarly, a developer's decision to build new homes in a floodplain may affect the new homeowners' vulnerabilities to flooding events.

The combination of residential location choices with wildfire occurrence dramatically illustrates how the interactions between land use and climate processes can affect climate change impacts and vulnerabilities. Low-density housing patterns in the U.S. have expanded, and are projected to continue to expand (Bierwagen et al. 2010). One result is a rise in the amount of construction in forests and other wild-lands (Radeloff et al. 2005; Theobald and Romme 2007) that in turn has increased the exposure of houses, other structures, and people to damages from wildfires, which are increasing. The number of buildings lost in the 25 most destructive fires in California history increased significantly in the 1990s and 2000s compared to the previous three decades (Stephens et al. 2009). These losses are one example of how changing development patterns can interact with a changing climate to create dramatic new risks. In the western U.S., increasing frequencies of large wildfires and longer wildfire durations are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt (Westerling et al. 2006). The effects on property loss of increases in the frequency and sizes of fires under climate change are also projected to increase in the coming decades because so many more people will have moved into increasingly fire-prone places (Ch. 2: Our Changing Climate; Ch. 7: Forestry).

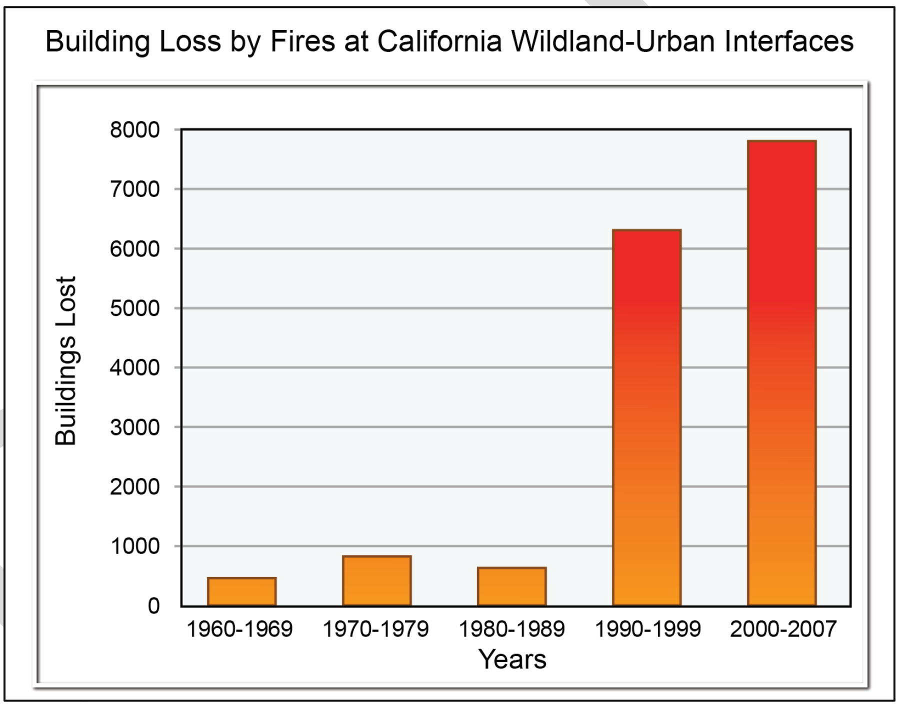

Figure 13.4. Building Loss by Fires at California Wildland-Urban Interfaces

Caption: Many forested areas in the U.S. have experienced a recent building boom in what is known as the "wildland-urban interface." Chart shows number of buildings lost from the 25 most destructive wildland-urban interface fires in California history from 1960–2007 (Redrawn from Stephens et al. 2009 with permission).

Effects on Climate Processes

Land-use and land-cover changes affect local, regional, and global climate processes.

Land use and land cover play critical roles in the interaction between the land and the atmosphere, influencing climate at local, regional, and global scales (Pielke 2005). There is growing evidence that land use and land cover interact with U.S. climate in several ways:

- Air temperature and near-surface moisture are changed in areas where natural vegetation is converted to agriculture (Fall et al. 2010; Karl et al. 2012). This effect has been observed in the Great Plains and the Midwest, where overall dew point temperatures or frequency of occurrences of extreme dew point temperatures have been increased due to converting land to agricultural use (Karl et al. 2012; Mahmood et al. 2008; McPherson et al. 2004; Sandstrom et al. 2004). This effect has also been observed where the fringes of California's Central Valley is being converted from natural vegetation to agriculture (Sleeter 2008). Other areas where uncultivated and conservation lands are being returned to cultivation, for example from restored grassland into biofuel production, have also experienced temperature shifts. Regional daily maximum temperatures were lowered by forest clearing for agriculture in the Northeast and Midwest, and then increased in the Northeast following regrowth of forests due to abandonment of agriculture (Bonan 2001).

- Conversion of rain-fed cropland to irrigated agriculture further intensifies the impacts of agricultural conversion on temperature. Lobell and Bonfils (2007) found up to 5°C (9°F) cooling of daily maximum temperatures in California due to irrigation. Model comparisons suggest that irrigation cools temperatures directly over croplands in California's Central Valley by 5°F to 13°F, and increases relative humidity by 9% to 20% (Sorooshian et al. 2011). Observational data-based studies found similar impacts of irrigated agriculture in the Great Plains (Lobell et al. 2006; Mahmood et al. 2008).

- Both observational and modeling studies show that introduction of irrigated agriculture can impact regional precipitation (Barnston and Schickedanz 1984; DeAngelis et al. 2010; Harding and Snyder 2012a, 2012b). It has been shown that irrigation in the Ogallala aquifer portion of the Great Plains can impact precipitation as far away as Indiana and Western Kentucky (DeAngelis et al. 2010).

- Urbanization is having significant local impacts on weather and climate. Land-cover changes associated with urbanization are creating higher air temperatures compared to the surrounding rural area (Arnfield 2003; Landsberg 1970; Shepherd et al. 2002; Souch and Grimmond 2006; Yow 2007). This is known as the "urban heat island" effect (see Ch. 9: Health). Urban landscapes are also affecting formation of convective storms and changing the location and amounts of precipitation compared to pre-urbanization, (for example, Niyogi et al. 2011; Shepherd et al. 2002).

- Land-use and land-cover changes are affecting global atmospheric concentrations of greenhouse gases. The impact is expected to be most significant in areas with forest loss or gain, where the amount of carbon that can be transferred from the atmosphere to the land (or from the land to the atmosphere) is modified. Even in relatively un-forested areas, this effect can be significant. A recent USGS report suggests that from 2001–2005 in the Great Plains between 22–106 million metric tons of carbon were stored in the biosphere due to changes in land use and climate (Zhu et al. 2011). Even with these seemingly large numbers, U.S. forests absorb only 7% to 24% (with a best estimate of 13%) of fossil-fuel CO_2 emissions (see Ch. 15: Biogeochemical Cycles, "Carbon Sink" box).

Adapting to Climate Change

Individuals, organizations, and governments have the capacity to make land-use decisions to adapt to the effects of climate change.

Land-use and land-cover patterns may be modified to adapt to anticipated or observed effects of a changed climate. These changes may be either encouraged or mandated by government (whether at federal or other levels), or undertaken by private initiative. In the U.S., even though land-use decisions are highly decentralized and strongly influenced by Constitutional protection of private property, the Supreme Court has also defined a role for government input into some land-use decisions (Berke and Kaiser 2006). Thus on the one hand farmers may make private decisions to plant different crops in response to changing growing conditions and/or market prices. On the other hand, homeowners may be compelled to respond to policies, zoning, or regulations (at national, state, county, or municipal levels) by elevating their houses to reduce flood impacts associated with more intense rainfall events and/or increased impervious surfaces.

Land-use and land-cover changes are thus rarely the product of a single factor. Land-use decision processes are influenced not only by the biophysical environment, but also by markets, laws, technology, politics, and perceptions. Yet there is evidence that climate adaptation considerations are playing an increasingly large role in land decisions, even in the absence of a formal federal climate policy. Motivations typically include avoiding or reducing negative impacts from extreme weather events (such as storms or heat waves) or from slow-onset hazards (such as sea level rise).

For example, New Orleans has, through a collection of private and public initiatives, rebuilt some of the neighborhoods damaged by Hurricane Katrina with housing elevated several meters above the ground, and with roofs specially designed to facilitate evacuation (ISC 2010). San Francisco has produced a land-use plan to reduce impacts from a rising San Francisco Bay (SFBCDC 2011). A similar concern has prompted collective action in four Miami-area counties and an array of San Diego jurisdictions, to name just two examples, to shape future land uses to comply with regulations linked to sea level rise projections (ICLEI 2011; ISC 2010). Chicago has produced a plan for limiting the number of casualties, especially among the elderly and homeless, during heat waves (ISC 2010; See also Ch. 9: Health).

Reducing Greenhouse Gas Levels

Choices about land use and land management provide a means of reducing atmospheric greenhouse gas levels.

Choices about land use and land management affect the amount of greenhouse gases entering and leaving the atmosphere and, therefore, provide opportunities to reduce climate change (Ch. 15: Biogeochemical Cycles; Ch. 27: Mitigation). Such choices can affect the balance of these gases directly, through decisions to preserve or restore carbon in standing vegetation (like forests) and soils, and indirectly, in the form of land use policies that affect fossil fuel emissions by influencing energy consumption for transportation and in buildings. Additionally, as crops are increasingly used to make fuel, the potential for reducing net carbon emissions through replacement of fossil fuels represents a possible land-based carbon emissions reduction strategy, albeit one that is complicated by many natural and economic interactions that will determine the ultimate effect of these strategies on emissions (Ch. 7: Forestry; Ch. 6: Agriculture).

About one-third of all carbon released into the atmosphere by people globally since 1850 has come from land-cover change and management. The primary source related to land use has been the conversion of native vegetation like forests and grasslands to croplands, which in turn has released carbon from vegetation and soil into the atmosphere as carbon dioxide (CO_2) (Richter and Houghton 2011). Currently, an estimated 16% of CO_2 going into the atmosphere is due to land-related activities globally, with the remainder coming from fossil fuel burning and cement manufacturing (Richter and Houghton 2011). In the U.S., activities related to land use are effectively balanced with respect to CO_2: as much CO_2 is released to the atmosphere by land-use activities as is taken up by and stored in, for example, vegetation and soil. The regrowth of forests and increases of conservation-related forest and crop management practices have also increased carbon storage. Overall, setting aside emissions due to burning fossil fuels, the U.S. and the rest of North American land cover takes up more carbon than it releases. This has happened as a result of more efficient forest and agricultural management practices, but it is not clear if this rate of uptake can be increased, or if it will persist into the future. The magnitude of the sink can vary with weather, making it potentially sensitive to climate changes (Schwalm et al. 2012).

Opportunities to increase the net uptake of carbon from the atmosphere by the land include: increasing the amount of area in ecosystems with high carbon content (by converting farms to forests or grasslands); increasing the rate of carbon uptake in existing ecosystems (through fertilization); and reducing carbon loss from existing ecosystems (for example, through no-till farming) (Izzauralde 2012). Because of these effects, policies specifically aimed at increasing carbon storage, either directly through mandates or indirectly through a market for carbon offsets, may be used to encourage more land-based carbon storage.

The following uncertainties deserve further investigation: a) the effects of these policies or actions on the balance of other greenhouse gases, like methane and nitrous oxide; b) the degree of permanence these carbon stores will have in a changing climate (especially through effects on disturbances like fires and plant pests); and c) the possibility that increased carbon storage in one location might be partially offset by releases in another. All of these specific mitigation options present implementation challenges, as the decisions must be weighed against competing objectives. For example, retiring farmland to sequester carbon may be difficult to achieve if crop prices rise, such as has occurred in recent years in response to the fast-growing market for biofuels.

Land-use decisions in urban areas also present carbon reduction options. Carbon storage in urban areas can reach densities as high as those found in tropical forests, with most of that carbon found in soils, but also in vegetation, landfills, and the structures and contents of buildings (Churkina et al. 2010). Urban and suburban areas tend to be net sources of carbon to the atmosphere, whereas exurban and rural areas tend to be net sinks (Zhao et al. 2011). Effects of urban development patterns on carbon storage and emissions due to land and fossil fuel use are topics of current research, and can be affected by land-use planning choices. Many cities have adopted land-use plans with explicit carbon goals, typically targeted at reducing carbon emissions from the often intertwined activities of transportation and energy use. This trend, which includes both major cities, such as Los Angeles (EnvironmentLA 2011), Chicago (City of Chicago 2012), and New York City (NYCDEP 2011), and small towns, such as Homer, Alaska (City of Homer 2007), has occurred even in the absence of a formal federal climate policy.

Traceable Accounts

Chapter 13. Land Use and Land Cover Change

Key Message Process: The author team benefited from a number of relevant technical input reports. One report described the findings of a three-day workshop held from November 29 to December 1, 2011 in Salt Lake City in which a number of the chapter authors participated (Lebow et al. 2012). Findings of the workshop provided a review of current issues and topics as well as the availability and quality of relevant data. In addition, From December, 2011 through June, 2012 the author team held biweekly teleconferences. Key messages were identified during this period and discussed in two phases, associated with major chapter drafts. An early draft identified a number of issues and key messages. Based on discussions with assessment leadership and other chapter authors, the Land Use and Land Cover Change authors identified and reached consensus on a final set of four key messages and organized most of the chapter to directly address these messages. The authors selected key messages based on the consequences and likelihood of impacts, the implied vulnerability, and available evidence. Relevance to decision support, mitigation, and adaptation was also an important criterion for the selection of key messages for this cross-cutting and foundational topic.

The U.S. acquires, produces, and distributes substantial data that characterize the Nation's land cover and land use. Satellite observations, with near complete coverage over the landscape and consistency for estimating change and trends, are particularly valuable. But field inventories, especially of agriculture and forestry, provide very reliable data products that describe land cover as well as land-use change. Together, remote sensing and field inventory data as well as related ecological and socioeconomic data allow many conclusions about land use and land-cover change with very high confidence.

Key message #1/4	**Choices about land-use and land-cover patterns have affected and will continue to affect how vulnerable or resilient human communities and ecosystems are to the effects of climate change.**
Description of evidence base	The influences of climate on vegetation and soils, and thus on land cover and land use, are relatively well understood, and a number of well validated mathematical models are used to investigate potential consequences of climate change for ecosystem processes, structure, and function. Given scenarios about socioeconomic factors or relevant models, some aspects of land use and land-cover change can also be analyzed and projected into the future based on assumed climate change. A large number of studies documented in the literature address the impacts of weather events and climate variability and change on land cover and land use. During a workshop convened to review land use and land-cover change for the NCA, participants summarized various studies from different perspectives, including agriculture and forestry as well as socioeconomic issues such as flood insurance (Lebow et al. 2012). Residential exposure to wildfire is an excellent example supporting this key message, and is well documented in the literature (Radeloff et al. 2005; Stephens et al. 2009; Theobald and Romme 2007; Westerling et al. 2006).
New information and remaining uncertainties	Steadily accumulating field and remote sensing observations as well as inventories continue to increase confidence in this key message. A recent study by the EPA (Bierwagen et al. 2010) provides relevant projections of housing density and impervious surface under alternative scenarios of climate change. While there is little uncertainty about the general applicability of this key message, the actual character and consequences of climate change as well as their interactions with land cover and land use vary significantly between locations and circumstances. Thus the specific vulnerabilities resulting from the specific ways in which people, both as individuals and as collectives, will respond to anticipated or observed climate change impacts are less well understood than the biophysical

	dimensions of this problem.
Assessment of confidence based on evidence	**Very High.** Observed weather and climate impacts and consequences for land cover and land use, basic understanding of processes and analyses using models of those processes, as well as substantial literature are consistent in supporting this key message.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 13. Land Use and Land Cover Change

Key Message Process: See key message #1.

Key message#2/4	**Land-use and land-cover changes affect local, regional, and global climate processes.**
Description of evidence base	The dependence of weather and climate processes on land surface properties is reasonably well understood in terms of the biophysical processes involved. Most climate models represent land-surface conditions and processes, though only recently have they begun to incorporate these conditions dynamically to represent changes in the land surface within a model run, and regional weather models are increasingly incorporating land surface characteristics. Extensive literature, as well as textbooks, document this understanding as do models of land surface processes and properties. A technical input report to the assessment (Loveland et al. 2012) summarizes the literature and basic understanding of interactions between the atmosphere and land surface that influence climate. Many studies establish and characterize these interactions at various spatial and temporal scales through remote sensing and field observations as well as large-scale experiments, including BOREAS and LBA. Examples are provided within the chapter to demonstrate that land use and land-cover change are affecting U.S. climate (Arnfield 2003; Bonan 2001; Fall et al. 2010; Landsberg 1970; Niyogi et al. 2011; Shepherd et al. 2002; Sleeter 2008; Sorooshian et al. 2011; Souch and Grimmond 2006; Yow 2007; Zhu et al. 2011).
New information and remaining uncertainties	While there is little uncertainty about this key message in general, the heterogeneity of the U.S. landscape and associated processes as well as regional and local variations in atmospheric processes make it difficult to analyze or predict the character of land use and land cover influences on atmospheric processes at all scales.
Assessment of confidence based on evidence	**Very High.** The basic processes underlying the biophysics of interactions between the land surface and atmosphere are well understood. A number of examples and field studies are consistent in demonstrating effects of land use and land-cover change on climate of the U.S.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 13. Land Use and Land Cover Change

Key Message Process: See key message #1.

Key message #3/4	**Individuals, organizations, and governments have the capacity to make land-use decisions to adapt to the effects of climate change.**
Description of evidence base	The key message is supported by well-understood aspects of land use planning and management, including the legal roles of government and citizens and management practices such as zoning and taxation. Participants in the NCA workshop (Nov 29-Dec 1, 2011 in Salt Lake City) on land use and land cover presented and discussed a number of examples showing the influences of land use decisions on climate change adaptation options (Lebow et al. 2012). The chapter describes specific examples of measures to adapt to climate change to further support this key message (ICLEI 2011; ISC 2010; SFBCDC 2011).
New information and remaining uncertainties	Experience with climate change adaptation measures involving land use decisions is accumulating rapidly. Although there is little uncertainty that land use decisions can enable adaptation to climate change, the information about climate change at scales where such decisions are made is generally lacking.
Assessment of confidence based on evidence	**Very High.** The aspects of land-use planning that can enable climate change adaptation are well understood and examples demonstrate where actions are being taken.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 13. Land Use and Land Cover Change

Key Message Process: See key message #1.

Key message #4/4	**Choices about land use and land management provide a means of reducing atmospheric greenhouse gas levels.**
Description of evidence base	The evidence base for this key message includes scientific studies on the carbon cycle at both global and local scales, and policy studies on the costs and benefits, and feasibilities, of various actions to reduce carbon emissions from land-based activities and/or to increase carbon storage in the biosphere through land-based activities. Foundational studies are summarized in the NCA Technical Input documents.
New information and remaining uncertainties	A major study by the USGS is estimating carbon stocks in vegetation and soils of the U.S., and this inventory will clarify the potential for capturing greenhouse gasses by land-use change (An early result is reported in Sohl et al. 2012). There is little uncertainty behind the premise that certain specific land uses affect the carbon cycle. There are, however, scientific uncertainties regarding the magnitudes of effects resulting from specific actions designed to leverage this linkage for mitigation. For example, uncertainties are introduced regarding the permanence of specific land-based stores of carbon, the incremental value of specific management or policy decisions to increase terrestrial carbon stocks beyond changes that would have occurred in the absence of management, and the possibility for decreases in carbon storage in another location to offset increases resulting from specific actions at a given location. Also, we do not yet know how natural processes might alter the amount of carbon storage expected to occur with management actions. There are also uncertainties regarding the political feasibilities and economic efficacy of policy options to use land-based activities to reduce the concentration greenhouse gases in the atmosphere.
Assessment of confidence based on evidence	Given the evidence base and uncertainties there is **medium** confidence that land use and land management choices can reduce the amount of greenhouse gases in the atmosphere.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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