# Regional Synthesis

**Status and Trends of Land Change in the Western United States—1973 to 2000**
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# Land-Cover Trends in the Western United States—1973 to 2000

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## Introduction

Land-cover change is a pervasive phenomenon, brought about by both human and natural alteration of landscapes. Studying land-cover change is important because it helps explain (1) the types of changes that are occurring, (2) the rates at which they are occurring, and (3) the places where specific land-cover changes are occurring on the landscape. Understanding the spatial, temporal, and thematic dynamics of land-cover change facilitates research and development of hypotheses about the major drivers and consequences of change, helps define future scenarios, and is useful in understanding impacts on other ecosystem resources.

Land-cover change in the western United States is an important part of the overall story of the West. Humans have been using and altering the landscape for centuries to take advantage of resources provided by nature. For example, Native Americans in the Klamath Mountains in northern California regularly set fires for specific land-management purposes such as improving hunting conditions or promoting growth of certain species that are useful for food and cordage materials (Lewis, 1993). In general, Native American practices are believed to have been an important component of historical fire regimes and vegetation dynamics (Anderson, 2005; Fry and Stephens, 2006). Today (2012), fire management continues to be a major component and driver of land-cover change in the western United States.

From the dense redwood forests of the Coast Ranges in Washington, Oregon, and California, to the lava fields and sagebrush-steppe communities of the Snake River Plain in Idaho, to the "Sky Islands" in Arizona and New Mexico, land cover in the West is as diverse as in any other part of the country. A complex mosaic of landscapes, characterized by abrupt changes in geology, topography, soils, and climate, and also their associated floral and faunal communities, results in a collection of ecoregions that exhibit dramatic variability in land-cover characteristics. Ecoregions—that is, areas that are similar in their biotic-, abiotic-, terrestrial-, and aquatic-ecosystem components, with humans considered as part of the biota (McMahon and others, 2001)—serve as useful entities for studying regional land-use/land-cover change, as they can encapsulate both the similarities and differences in the range of potential land-use/land-cover changes that are likely to occur regionally (Gallant and others, 2004).

To provide estimates of change on an ecoregion-by-ecoregion basis, a temporal- and spatial-sampling framework was employed, using U.S. Environmental Protection Agency's Level III Ecoregions for the United States (Omernik, 1987; U.S. Environmental Protection Agency, 1997) as the spatial stratification. A random sample of $10 \times 10$ km sample blocks was selected for most ecoregions ($20 \times 20$ km sample blocks were employed for two ecoregions). Within each sample block, land use/land cover was mapped for five study dates—1973, 1980, 1986, 1992, and 2000—using Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus imagery, in addition to aerial photographs obtained from the National Aerial Photography Program and National High Altitude Program. The minimum mapping unit for all study dates was a $60 \times 60$ m pixel.

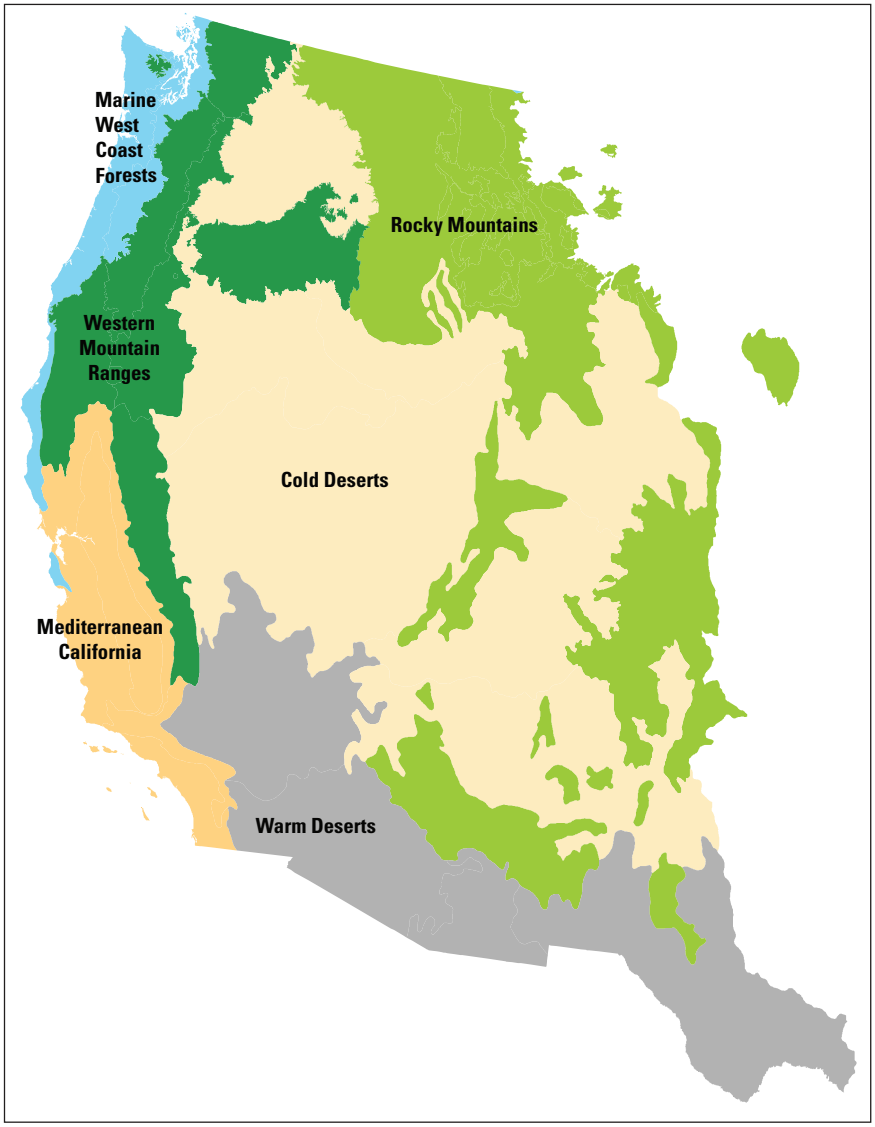
After the data from the 1992 National Land Cover Dataset (Vogelmann and others, 2001) was reviewed and, if necessary, modified, areas of land-use/land-cover change were identified manually. Upon completion of the mapping, results were compiled and statistical estimates, with corresponding standard errors, were derived (see appendix 4 for a full description of project methodology; see also, Loveland and others [2002] and Stehman and others [2003]).

## Regional Synthesis

The U.S. Geological Survey completed an assessment of 30 ecoregions in the western United States (fig. 1*A*). The 30 ecoregions, which span approximately 2,707,515 $km^2$ (1,045,373 $mi^2$), extend from the Rocky Mountains to the Pacific Coast and from the Canadian to the Mexican border. The ecoregions vary greatly in size, the largest being the Central Basin and Range Ecoregion (approximate area, 343,169 $km^2$) and the smallest being the Willamette Valley Ecoregion (approximate area, 14,458 $km^2$).


**Figure 1.** *A*, Map of all 30 Western United States ecoregions, showing land-use/land-cover classes from 2001 National Land-Cover Database (Homer and others, 2004); note that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. *B*, Map showing six main Western United States ecoregion groups, modified from U.S. Environmental Protection Agency's (1997) Level II Ecoregions for western United States. Within each ecoregion group, individual ecoregions share many similar physical and biological characteristics. *C*, List of six main Western United States ecoregion groups depicted in figure 1*B*; also listed are individual ecoregions included in each ecoregion group, as well as ecoregion abbreviations used in figure 1*A*.

*B*




*C*

**EXPLANATION**

**Marine West Coast Forests Ecoregions**

CR – Coast Range Ecoregion
PL – Puget Lowland Ecoregion
WV – Willamette Valley Ecoregion

**Rocky Mountains Ecoregions**

ANMM – Arizona/New Mexico Mountains Ecoregion
CRK – Canadian Rockies Ecoregion
MRK – Middle Rockies Ecoregion
MVFP – Montana Valley and Foothill Prairies Ecoregion
NRK – Northern Rockies Ecoregion
SRK – Southern Rockies Ecoregion
WUM – Wasatch and Uinta Mountains Ecoregion

**Western Mountain Ranges Ecoregions**

BM – Blue Mountains Ecoregion
C – Cascades Ecoregion
ECSF – East Cascades Slopes and Foothills Ecoregion
KM – Klamath Mountains Ecoregion
NC – North Cascades Ecoregion
SN – Sierra Nevada Ecoregion

**Mediterranean California Ecoregions**

CCV – Central California Valley Ecoregion
SCCCOW – Southern and Central California Chaparral and Oak Woodlands Ecoregion
SCM – Southern California Mountains Ecoregion

**Cold Deserts Ecoregions**

ANMP – Arizona/New Mexico Plateau Ecoregion
CBR – Central Basin and Range Ecoregion
CLMP – Columbia Plateau Ecoregion
CLRP – Colorado Plateaus Ecoregion
NBR – Northern Basin and Range Ecoregion
SRB – Snake River Basin Ecoregion
WB – Wyoming Basin Ecoregion

**Warm Deserts Ecoregions**

CD – Chihuahuan Deserts Ecoregion
MA – Madrean Archipelago Ecoregion
MBR – Mojave Basin and Range Ecoregion
SBR – Sonoran Basin and Range Ecoregion

**Figure 1.**—Continued

For purposes of discussion, the 30 Western United States ecoregions have been divided into six main groups,[1] within which the ecoregions share many similar physical and biological characteristics: the Marine West Coast Forests Ecoregions, the Rocky Mountains Ecoregions, the Western Mountain Ranges Ecoregions, the Mediterranean California Ecoregions, the Cold Deserts Ecoregions, and the Warm Deserts Ecoregions (fig. 1*B*).

The Western United States ecoregions consist primarily of five land-use/land-cover classes (grassland/shrubland, forest, agriculture, developed, and barren); six other land-use/land-cover classes (water, wetland, mining, mechanically disturbed, nonmechanically disturbed, and ice/snow) are also present but in smaller amounts. Grassland/shrubland and barren land are most common in the arid-southwest and interior-desert ecoregions, whereas forest dominates ecoregions in the Pacific Northwest and Rocky Mountains. Agriculture and developed are found to some degree in nearly all ecoregions but are concentrated mainly in a relatively few high-density ecoregions (fig. 1*A*).

Studying the 30 Western United States ecoregions has revealed several unique land-cover-change histories. The dominant patterns and trajectories of change have been associated with urbanization, wildfire, forest cutting for

[1] These six main groups of ecoregions are based on the U.S. Environmental Protection Agency's Level II Ecoregions for the western United States (Omernik, J.M., 1987; Commission for Environmental Cooperation, 1997; U.S. Environmental Protection Agency, 1997), with the following exceptions: (1) the Level II Western Cordillera Ecoregion was subdivided into the Rocky Mountains Ecoregions and the Western Mountains Ranges Ecoregions, (2) the Arizona/New Mexico Mountains Ecoregion was included in the Rocky Mountains Ecoregions, and (3) the Madrean Archipelago Ecoregion was included in the Warm Deserts Ecoregions.

timber production, and shifts in agricultural production. However, these land-cover-change histories are expressed uniquely from ecoregion to ecoregion. For example, rates of forest cutting varied dramatically between the Coast Range, Klamath Mountains, and Sierra Nevada Ecoregions, owing to their local (and regional) biological and physical characteristics, as well as their land-management practices (Sleeter and others, 2010). Likewise, the rates of land-cover change in developed land were similar across such dramatically different ecoregions as the Mojave Basin and Range, Puget Lowland, and Central California Valley Ecoregions. Thus, behind each ecoregion emerges a unique story of change that can be related to each land-cover class and which is largely associated with each ecoregion's distinct resource base and socioeconomic conditions.

The overall spatial change—that is, the amount of land area that changed at least one time over the 27-year study period—in the western United States was 5.8 percent. Whereas land-cover change across the entire western United States was relatively low, considerable ecoregional variability exists in the estimates of change (table 1). The highest changing ecoregion in terms of overall spatial change (as percent of ecoregion area) was the Puget Lowland Ecoregion, where an estimated 28.0 percent of the ecoregion underwent some form of change. The lowest changing ecoregion was the Chihuahuan Deserts Ecoregion, with an estimated 0.5 percent change.

In general, ecoregions where timber harvesting is common experienced the highest rates of land-cover change, whereas ecoregions that have the lowest rates of change were generally associated with deserts in the arid Southwest. In ecoregions where urbanization and agricultural land use were most common, the rates of change tended to be more modest. The Marine West Coast Forests Ecoregions had the highest average amount of change, at 24.2 percent, largely a result of intensive timber harvesting (table 1). The Rocky Mountains Ecoregions and the Western Mountain Ranges Ecoregions had an estimated 6.9 percent and 10.8 percent change, respectively. The Mediterranean California Ecoregions had an estimated 10.1 percent change, mainly a result of a mix of urbanization, shifts in the locations of agricultural production, and disturbances from fire. Land-cover change in the western desert ecoregions was lowest, with 3.2 percent change in the Cold Deserts Ecoregions and 1.7 percent change in the Warm Deserts Ecoregions (table 1). And yet, even within these groups of ecoregions, considerable geographic variability of change exists (fig. 2).

Change in forested ecoregions in the western United States was due largely to a mix of timber harvesting and disturbances from wildfire, and both of these processes were influenced by land-ownership and -management practices (fig. 3). The fact that a large proportion of land in forested ecoregions consisted of publicly managed, protected areas, which include conservation as a primary management objective, resulted in reduced levels of ecosystem disturbance caused by timber harvesting. However, because public lands were harvested less frequently than private lands, they also were prone to large, crown-disturbing fires made larger by the buildup of fuels. Changes in grassland/shrubland, agriculture, and developed land-cover classes were the other primary types of changes. Although agricultural land use intensified in some regions, resulting in the conversion of grassland/shrubland to cropland, it deintensified in other regions, primarily as a result of implementation of federal policies.

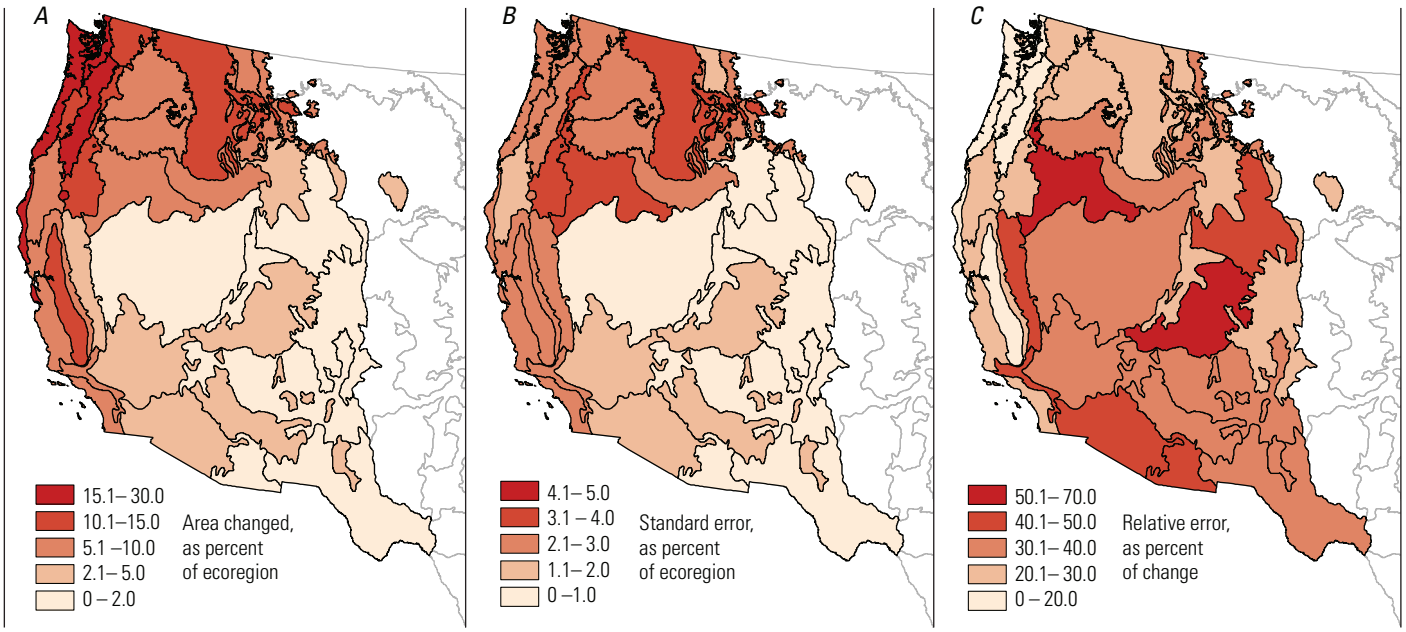



**Figure 2.** Maps showing (*A*) overall spatial change as percent of ecoregion area, (*B*) standard error as percent of ecoregion area, and (*C*) relative error as percent of change, for all 30 Western United States ecoregions over entire study period (1973–2000).

**Table 1.** Overall spatial change in each Western United States ecoregion (in square kilometers and as percent of ecoregion) for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

| Ecoregion | Ecoregion area ($km^2$) | Overall spatial change [margin of error] | |
|---|---|---|---|
| | | ($km^2$) | (% of ecoregion) |
| **Marine West Coast Forests Ecoregions** | | | |
| Coast Range Ecoregion | 57,338 | 14,641 [2,226] | 25.5 [3.9] |
| Puget Lowland Ecoregion | 18,009 | 5,041 [553] | 28.0 [3.1] |
| Willamette Valley Ecoregion | 14,458 | 2,090 [428] | 14.5 [3.0] |
| Totals | 89,805 | 21,772 [1,626] | 24.2 [1.8] |
| **Rocky Mountains Ecoregions** | | | |
| Northern Rockies Ecoregion | 162,746 | 22,539 [6,373] | 13.8 [3.9] |
| Middle Rockies Ecoregion | 90,160 | 7,974 [3,097] | 8.8 [3.4] |
| Canadian Rockies Ecoregion | 18,494 | 1,397 [449] | 7.6 [2.4] |
| Southern Rockies Ecoregion | 138,854 | 1,444 [431] | 1.0 [0.3] |
| Wasatch and Uinta Mountains Ecoregion | 44,176 | 888 [345] | 2.0 [0.8] |
| Montana Valley and Foothill Prairies Ecoregion | 64,658 | 5,252 [2,619] | 8.1 [4.1] |
| Arizona/New Mexico Mountains Ecoregion | 108,432 | 3,806 [1,586] | 3.5 [1.5] |
| Totals | 627,520 | 43,300 [6,937] | 6.9 [1.1] |
| **Western Mountain Ranges Ecoregions** | | | |
| Cascades Ecoregion | 46,787 | 11,520 [1,730] | 24.6 [3.7] |
| North Cascades Ecoregion | 30,421 | 3,200 [1,190] | 10.5 [3.9] |
| Blue Mountains Ecoregion | 65,461 | 4,275 [1,453] | 6.5 [2.2] |
| Eastern Cascades Slopes and Foothills Ecoregion | 57,329 | 6,943 [2,010] | 12.1 [3.5] |
| Klamath Mountains Ecoregion | 47,791 | 4,081 [1,079] | 8.5 [2.3] |
| Sierra Nevada Ecoregion | 53,413 | 2,645 [1,359] | 5.0 [2.5] |
| Totals | 301,201 | 32,664 [2,910] | 10.8 [1.0] |
| **Mediterranean California Ecoregions** | | | |
| Southern and Central California Chaparral and Oak Woodlands Ecoregion | 102,110 | 9,872 [3,009] | 9.7 [3.0] |
| Central California Valley Ecoregion | 45,983 | 5,910 [1,434] | 12.9 [3.1] |
| Southern California Mountains Ecoregion | 17,871 | 906 [439] | 5.1 [2.5] |
| Totals | 165,965 | 16,688 [3,057] | 10.1 [1.8] |
| **Cold Deserts Ecoregions** | | | |
| Columbia Plateau Ecoregion | 90,059 | 8,270 [2,416] | 9.2 [2.7] |
| Northern Basin and Range Ecoregion | 110,039 | 6,430 [4,254] | 5.8 [3.9] |
| Snake River Basin Ecoregion | 66,063 | 5,618 [2,011] | 8.5 [3.0] |
| Wyoming Basin Ecoregion | 128,914 | 2,372 [1,124] | 1.8 [0.9] |
| Central Basin and Range Ecoregion | 343,169 | 4,979 [2,505] | 1.5 [0.7] |
| Colorado Plateaus Ecoregion | 129,617 | 3,426 [2,694] | 2.6 [2.1] |
| Arizona/New Mexico Plateau Ecoregion | 192,869 | 2,380 [1,298] | 1.2 [0.7] |
| Totals | 1,060,730 | 33,475 [6,269] | 3.2 [0.6] |
| **Warm Deserts Ecoregions** | | | |
| Mojave Basin and Range Ecoregion | 130,922 | 3,474 [1,864] | 2.7 [1.4] |
| Sonoran Basin and Range Ecoregion | 116,364 | 2,992 [1,600] | 2.6 [1.4] |
| Madrean Archipelago Ecoregion | 40,536 | 575 [305] | 1.4 [0.8] |
| Chihuahuan Deserts Ecoregion | 174,472 | 822 [389] | 0.5 [0.2] |
| Totals | 462,294 | 7,863 [2,196] | 1.7 [0.5] |
| All Western United States ecoregions | 2,707,515 | 155,762 [11,584] | 5.8 [0.4] |

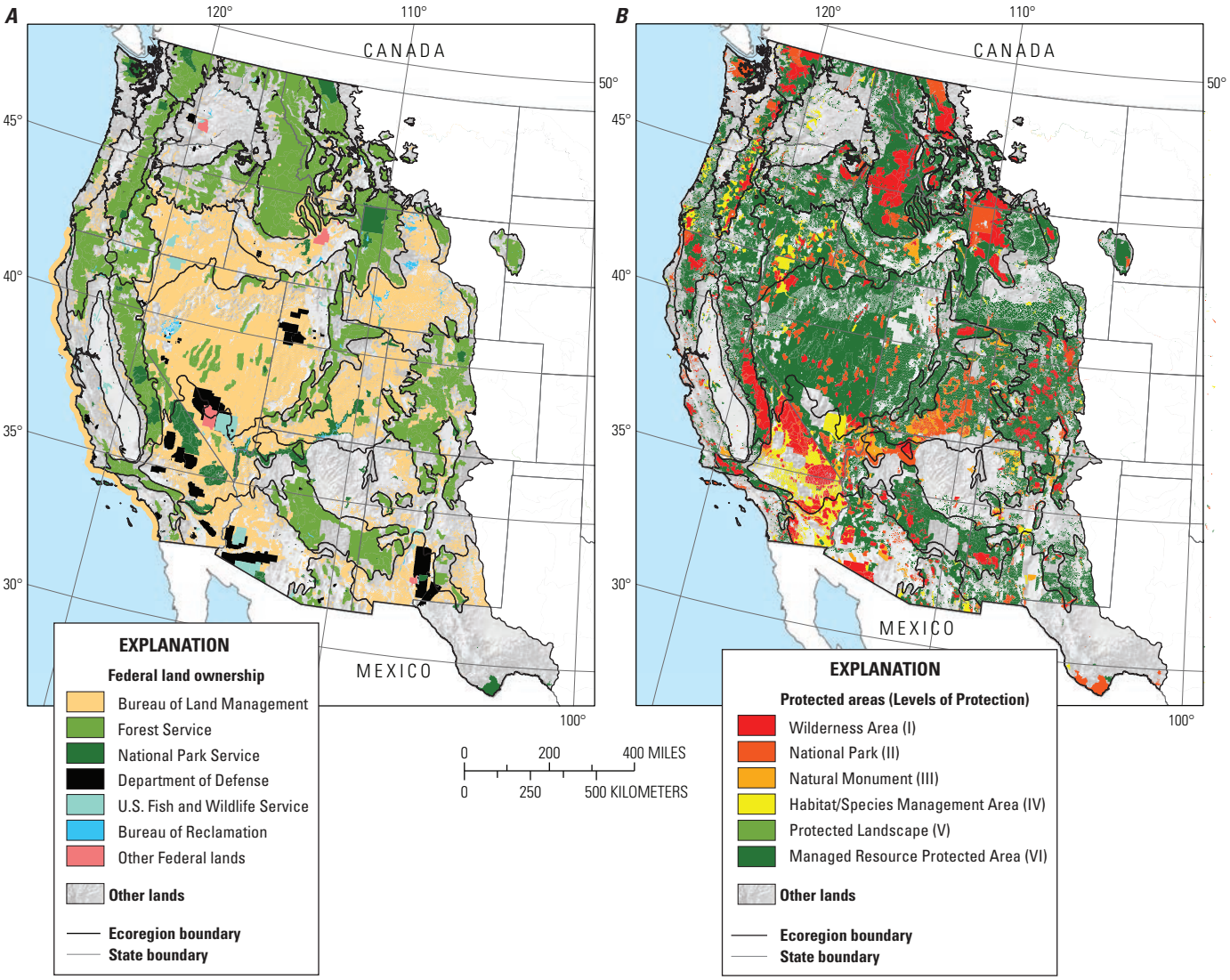



**Figure 3.** Maps showing (*A*) federal land ownership (National Atlas of the United States, 2006) and (*B*) protected areas (Conservation Biology Institute, 2010), in all 30 Western United States ecoregions. Bureau of Land Management lands offshore of California are part of California Coastal National Monument. Protected areas are based on International Union for Conservation of Nature (1994) guidelines for protected-area-management categories (see also, DellaSala and others, 2001).

The western United States is covered predominately by grassland/shrubland, which made up 59.0 percent of the ecoregions' land cover in 2000 (table 2). Furthermore, the amount of grassland/shrubland in the West remained relatively stable over the 27-year study period. Forest, the second most common land-cover class in the western United States, experienced the largest net change, declining from 29.4 percent of the ecoregions' area in 1973 to 28.1 percent in 2000 (table 2). Agriculture remained relatively stable, whereas developed land increased. Water, wetland, mining, barren, and ice/snow land-cover classes all remained stable. Table 2 presents the total areal percentages of all land-cover classes in the Western United States ecoregions for each of the five study years.

Net change is the total amount of losses in a land-cover class subtracted from the total amount of gains. Although net change provides information on how much land converted from one land-cover class to another, it can mask the total amount of land touched by change. To better understand change, gross spatial change also was measured for each land-cover class. Gross spatial change is simply the addition of gains and losses relating to a land-cover class, accounting for areas that changed in multiple time periods (fig. 4). For example, net change in forest land cover can be relatively small, even in ecoregions where timber harvest is common, because a near-equal amount of land could be regrowing into forest as is being cut for timber. Therefore, estimates of gross spatial change can have important environmental

**Table 2.** Areal percentages of land-use/land-cover classes in all 30 Western United States ecoregions for each of five study years (1973, 1980, 1986, 1992, 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[Percentages are of total area in all Western United States ecoregions. See appendix 3 for definitions of land-use/land-cover classifications]

| Land-use/land-cover class | 1973 [margin of error] (% of area) | 1980 [margin of error] (% of area) | 1986 [margin of error] (% of area) | 1992 [margin of error] (% of area) | 2000 [margin of error] (% of area) |
|---|---|---|---|---|---|
| Water | 0.8 [0.2] | 0.9 [0.2] | 0.9 [0.2] | 0.8 [0.2] | 0.8 [0.2] |
| Developed | 1.0 [0.2] | 1.1 [0.2] | 1.2 [0.2] | 1.3 [0.2] | 1.5 [0.2] |
| Mechanically disturbed | 0.4 [0.1] | 0.4 [<0.1] | 0.4 [0.1] | 0.6 [0.1] | 0.5 [0.1] |
| Mining | 0.2 [0.1] | 0.2 [0.1] | 0.2 [0.1] | 0.2 [0.1] | 0.2 [0.1] |
| Barren | 1.9 [0.5] | 1.9 [0.5] | 1.9 [0.5] | 1.9 [0.5] | 1.9 [0.5] |
| Forest | 29.4 [1.1] | 29.2 [1.1] | 29.0 [1.1] | 28.6 [1.1] | 28.1 [1.1] |
| Grassland/Shrubland | 59.0 [1.2] | 59.1 [1.2] | 58.9 [1.2] | 59.0 [1.2] | 59.0 [1.2] |
| Agriculture | 6.5 [0.5] | 6.6 [0.5] | 6.6 [0.5] | 6.3 [0.5] | 6.3 [0.5] |
| Wetland | 0.7 [0.1] | 0.7 [0.1] | 0.7 [0.1] | 0.7 [0.1] | 0.7 [0.1] |
| Nonmechanically disturbed | 0.1 [<0.1] | 0.1 [0.1] | 0.1 [0.1] | 0.4 [0.1] | 0.9 [0.3] |
| Ice/Snow | 0.1 [<0.1] | 0.1 [<0.1] | 0.1 [<0.1] | 0.1 [<0.1] | 0.1 [<0.1] |

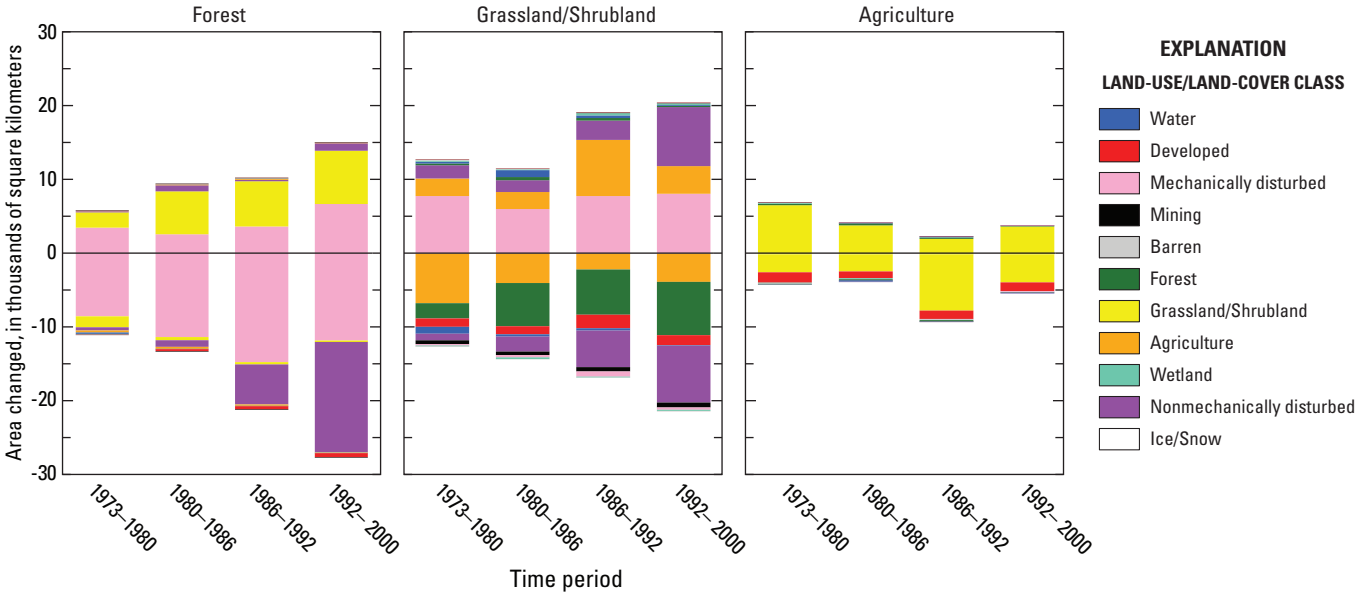



**Figure 4.** Gross changes (areas gained from, and lost to, other land-cover classes) in forest, grassland/shrubland, and agriculture land-cover classes, in all 30 Western United States ecoregions over entire study period (1973–2000). For each of these three classes, colored bars above zero axis indicate land-cover classes that lost area to that class and amounts of area lost, whereas colored bars below zero axis indicate land-cover classes that gained area from that class and amounts of area gained.

**Table 3.** Gross spatial changes and net areal changes in land-use/land-cover classes in all 30 Western United States ecoregions for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[Percentages are of total area in all Western United States ecoregions. See appendix 3 for definitions of land-use/land-cover classifications]

| Land-use/land-cover class | Gross spatial change (1973–2000) [margin of error] | | Net areal change (1973–2000) [margin of error] | |
|---|---|---|---|---|
| | ($km^2$) | (% of area) | ($km^2$) | (% change) |
| Water | 5,755 [1,954] | 0.2 [0.1] | 259 [1,069] | 1.1 |
| Developed | 12,760 [2,472] | 0.5 [0.1] | 12,785 [3,000] | 48.0 |
| Mechanically disturbed | 60,253 [5,759] | 2.2 [0.2] | 1,195 [2,128] | 10.0 |
| Mining | 2,834 [704] | 0.1 [<0.1] | 2,233 [622] | 53.4 |
| Barren | 1,016 [231] | <0.1 [<0.1] | 81 [167] | 0.2 |
| Forest | 88,707 [7,929] | 3.3 [0.3] | −33,197 [6,657] | −4.2 |
| Grassland/Shrubland | 99,285 [9,082] | 3.7 [0.3] | −1,106 [6,883] | −0.1 |
| Agriculture | 33,910 [4,987] | 1.2 [0.2] | −4,414 [4,283] | −2.5 |
| Wetland | 4,006 [1,449] | 0.1 [<0.1] | −243 [711] | −1.3 |
| Nonmechanically disturbed | 40,571 [8,342] | 1.5 [0.3] | 22,473 [7,110] | 1,124.3 |
| Ice/Snow | 77 [45] | <0.1 [<0.1] | −66 [43] | −3.4 |

considerations. Table 3 provides estimates of gross spatial change and net areal change for each land-cover class.

The five land-cover classes that had the highest gross spatial change over the entire study period (1973–2000) are as follows:

- Grassland/shrubland, 99,285 $km^2$ (margin of error, 9,082 $km^2$)
- Forest, 88,707 $km^2$ (margin of error, 7,929 $km^2$)
- Mechanically disturbed, 60,253 $km^2$ (margin of error, 5,759 $km^2$)
- Nonmechanically disturbed, 40,571 $km^2$ (margin of error, 8,342 $km^2$)
- Agriculture, 33,910 $km^2$ (margin of error, 4,987 $km^2$)

The five land-cover classes that had the largest net areal change over the entire study period (1973–2000) are as follows:

- Forest, −33,197 $km^2$ (margin of error, 6,657 $km^2$)
- Nonmechanically disturbed, 22,473 $km^2$ (margin of error, 7,110 $km^2$)
- Developed, 12,785 $km^2$ (margin of error, 3,000 $km^2$)
- Agriculture, −4,414 $km^2$ (margin of error, 4,283 $km^2$)
- Mining, 2,233 $km^2$ (margin of error, 622 $km^2$)

Another important characteristic of land-cover change is that it can vary across time in response to changing drivers of change. Overall areal change was the highest between 1992 and 2000, at 3.0 percent, and the lowest was between 1973 and 1980, at 1.6 percent. Table 4 shows estimates of net areal change in each land-cover class for each time period.

## Grassland/Shrubland Land-Cover Class

Although grassland/shrubland was the most common land-cover class across the West (fig. 5), very little net change (−1,106 $km^2$) occurred between 1973 and 2000 (table 3). This amounts to a loss of 0.1 percent of the grassland/shrubland in the western United States. However, the relatively small amount of net change masks substantial fluctuations involving the conversion of lands into, and out of, grassland/shrubland. Conversions from grassland/shrubland to other classes totaled an estimated 65,341 $km^2$, whereas conversions to grassland/shrubland accounted for an estimated 64,235 $km^2$. The amount of total land area that changed to or from grassland/shrubland was 99,285 $km^2$ (table 3), meaning that 3.7 percent of the western United States experienced conversion into, or out of, grassland/shrubland during the 27-year study period. Table 5 shows Western United States ecoregions that had greater than 2.5 percent net change in grassland/shrubland.

Changes in grassland/shrubland are associated with several land-change processes. A large amount of the gross areal change in grassland/shrubland was the result of capturing the intermediate stage (usually grassland/shrubland) of forest regrowth after disturbance events such as clearcutting or wildfire. Following such events, forests typically take several years before emerging as areas that can be once again classified as forest land-cover class. The largest grassland/shrubland conversion was associated with regeneration of forest after clearcutting. An estimated 29,949 $km^2$ of land changed from mechanically disturbed to grassland/shrubland, whereas 21,312 $km^2$ changed from grassland/shrubland directly back to forest.

Natural disturbances, specifically wildfire, also have a direct impact on grassland/shrubland. Several areas in the

**Table 4.** Net areal changes in land-use/land-cover classes in all 30 Western United States ecoregions during each of four time periods and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Land-use/land-cover class | Net change [margin of error] (km²) | | | |
|---|---|---|---|---|
| | 1973–1980 | 1980–1986 | 1986–1992 | 1992–2000 |
| Water | 820 [1,110] | 178 [1,772] | −1,481 [842] | 742 [603] |
| Developed | 3,204 [1,138] | 2,432 [621] | 3,677 [1,129] | 3,472 [815] |
| Mechanically disturbed | −2,396 [1,376] | 2,572 [1,267] | 4,881 [1,513] | −3,862 [1,608] |
| Mining | 548 [193] | 500 [200] | 528 [218] | 657 [301] |
| Barren | 3 [54] | 6 [110] | −59 [99] | 131 [79] |
| Forest | −5,328 [1,574] | −3,984 [2,275] | −11,105 [2,783] | −12,779 [5,582] |
| Grassland/Shrubland | 165 [2,611] | −2,731 [2331] | 2,357 [4,085] | −897 [4,694] |
| Agriculture | 2,958 [1,640] | 616 [894] | −6,673 [2,144] | −1,314 [1,799] |
| Wetland | −367 [455] | −167 [1,021] | 307 [387] | −16 [293] |
| Nonmechanically disturbed | 409 [1,957] | 584 [2,166] | 7,572 [3,981] | 13,907 [7,166] |
| Ice/Snow | −15 [9] | −6 [6] | −4 [8] | −41 [27] |

**Table 5.** Net areal changes and gross spatial changes in grassland/shrubland land-cover class for Western United States ecoregions that had greater than 2.5 percent net change in grassland/shrubland class for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Net areal change (1973–2000) [margin of error] | | Gross spatial change (1973–2000) [margin of error] | |
|---|---|---|---|---|
| | (% of ecoregion) | (km²) | (% of ecoregion) | (km²) |
| Middle Rockies Ecoregion | 4.6 [2.6] | 4,146 [2,348] | 6.6 [2.9] | 5,950 [2,626] |
| Central California Valley Ecoregion | −3.9 [1.9] | −1,782 [860] | 9.9 [2.1] | 4,552 [962] |
| Northern Basin and Range Ecoregion | −2.6 [3.3] | −2,841 [3,589] | 5.5 [3.9] | 6,060 [4,249] |
| Southern and Central California Chaparral and Oak Woodlands Ecoregion | −2.7 [1.3] | −2,746 [1,326] | 5.6 [1.0] | 5,732 [1,058] |
| Eastern Cascades Slopes and Foothills Ecoregion | 2.7 [1.7] | 1,531 [986] | 7.1 [2.7] | 4,095 [1,559] |

West that are dominated by grassland/shrubland experienced high rates of fire. This was especially common in the Northern Basin and Range, Southern and Central California Chaparral and Oak Woodlands, Snake River Basin, and Middle Rockies Ecoregions. These ecoregions accounted for 75 percent of fire-related disturbance on grassland/shrubland.

Changes in grassland/shrubland also were frequently associated with conversions to and from agriculture. Changes associated with agriculture were common in the Columbia Plateau, Snake River Basin, Central California Valley, Southern and Central California Chaparral and Oak Woodlands, and Montana Valley and Foothill Prairies Ecoregions. An estimated 16,662 km² converted from grassland/shrubland to agriculture, whereas 16,116 km² converted from agriculture to grassland/shrubland. Some areas experienced conversions in both directions as marginal lands rotated into and out of production in response to regional climate variability and federal farm policy, such as the Conservation Reserve Program.

Urbanization was the primary cause of change from grassland/shrubland to developed. These conversions were most common in the Mojave Basin and Range, Southern and Central California Chaparral and Oak Woodlands, and Colorado Plateaus Ecoregions. In total, an estimated 5,496 km² of grassland/shrubland converted to developed between 1973 and 2000.

## Forest Land-Cover Class

In 2000, forest accounted for 28.1 percent of the western United States (table 2). Western forests are highly diverse, from oak-studded (*Quercus* sp.) valleys and pinyon pine–juniper (*Pinus* sp. and *Juniperus* sp., respectively)

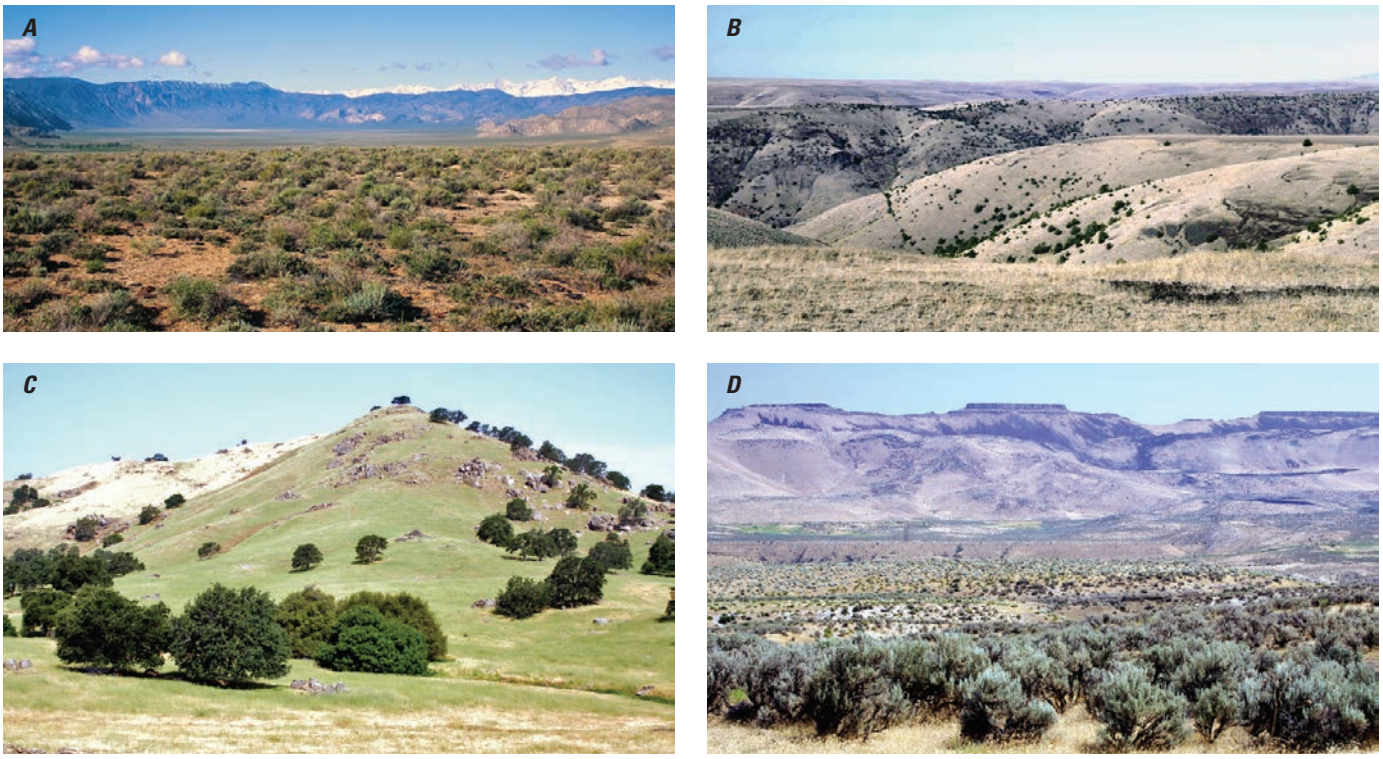



**Figure 5.** Areas of grassland/shrubland in western United States. *A*, Shrubland in northeastern Inyo County, east-central California, in Central Basin and Range Ecoregion. In distance to east are White Mountains, along California–Nevada border. *B*, Grassland in Gilliam County, northern Oregon, in southern part of Columbia Plateau Ecoregion. *C*, Grassy hills east of Porterville, located in Tulare County, central California, in Southern and Central California Chaparral and Oak Woodlands Ecoregion. *D*, Mixed grasses and shrubs north of Glenns Ferry, located in Elmore County, southwestern Idaho, in Snake River Basin Ecoregion.

woodlands in drier climates and at lower elevations, to the coniferous forests in the Sierra Nevada, the Cascade Range, and the Rocky Mountains (fig. 6). Each forest type supports a unique suite of habitat, resources, and land-use potential. Although forest is not the most common land cover in the West, changes in the forest class dominate land-cover change in the region.

Between 1973 and 2000, an estimated net decline of 4.2 percent (33,197 km$^2$) occurred in western United States forest land cover (table 3), with losses totaling 73,677 km$^2$ and gains totaling 40,480 km$^2$. However, net change masks the overall forest land-use/land-cover dynamics; gross spatial change is a better indicator of just how much the forest land-cover class changed over the 27-year study period. Gross spatial changes in forest land affected 3.3 percent of the total area in the western United States (table 3), whereas 11.1 percent of all western United States forests were touched by change at least once during the study period. Table 6 shows Western United States ecoregions that had at least 10 percent of their land area impacted by forest change.

Changes in forest land cover, which were concentrated in the ecoregions of the Pacific Northwest, can occur for many reasons. In the West, forest change consisted of forest cutting and regrowth for timber production, disturbance and regrowth following wildfire, conversion of forest land for urban and agricultural uses, and conversion from agriculture back to forest. Timber production and wildfire were the most common drivers of land-cover change in the forest class.

High rates of forest land-cover change in Western United States ecoregions were linked primarily to forestry, also known as silviculture, which is characterized by the cutting and regrowth of trees for lumber and other wood-related products. In this study's classification scheme, forest harvesting was mapped as a change from the forest class to the mechanically disturbed class. In rare cases, a mechanically disturbed state associated with the removal of wooded vegetation for rangeland improvement (for example, the chaining of pinyon pine–juniper woodland for grazing) was also captured. Between 1973 and 2000, an estimated 46,745 km$^2$ of forest were mechanically disturbed.

Forest harvest was the top-ranked land-cover conversion across the West in each of the first three time periods (1973–1980, 1980–1986, and 1986–1992), and it ranked as the second leading land-cover conversion (11,895 km$^2$) between 1992 and 2000. Regrowth back to forest resulted either in the direct conversion from mechanically disturbed to forest


**Figure 6.** Forested areas in western United States. *A*, Forest along Trinity River, northwestern California, in Klamath Mountains Ecoregion. *B*, Dense forest and forest understory outside of Olympia, western Washington, in Puget Lowland Ecoregion. *C*, Low-density oak woodland in Southern and Central California Chaparral and Oak Woodlands Ecoregion. *D*, Forest regrowth in Gifford Pinchot National Forest, southwestern Washington, in Cascades Ecoregion.

**Table 6.** Gross spatial changes in forest land-cover class for Western United States ecoregions that had at least 10 percent change to and from forest class for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Gross spatial change (1973–2000) [margin of error] | |
|---|---|---|
| | (% of ecoregion) | (km²) |
| Puget Lowland Ecoregion | 26.6 [3.1] | 4,665 [544] |
| Coast Range Ecoregion | 24.9 [4.5] | 14,289 [2,568] |
| Cascades Ecoregion | 23.9 [3.3] | 11,172 [1,561] |
| Northern Rockies Ecoregion | 11.8 [3.5] | 19,274 [5,638] |
| Willamette Valley Ecoregion | 11.5 [3.0] | 1,657 [440] |
| North Cascades Ecoregion | 10.2 [3.9] | 3,101 [1,189] |
| Eastern Cascades Slopes and Foothills Ecoregion | 10.0 [3.5] | 5,738 [2,023] |

or in an intermediate stage in which mechanically disturbed conversion to grassland/shrubland before reverting to forest. The most rapid postharvest forest-recovery rates occurred in ecoregions that have favorable climates and other biological and physical factors, including the Coast Range and Puget Lowland Ecoregions, whereas longer successional periods were more common in drier, less productive regions.

The primary drivers of change to western United States forests were complex and included several interrelated factors. For years, countries in the Pacific Rim have imported logs from the Pacific Northwest (PNW), Japan being the largest importer. Old-growth logs are highly sought after, owing to their high ring count. Japanese mills also have been more efficient than PNW mills, capturing as much as 70 percent of the raw material, which enabled them to absorb the increased costs of import (Daniels, 2005). In the early 1990s, prices for PNW soft wood peaked, and importers began looking to other global markets, namely Canada, to fill demand. At the same time, Canada became a major exporter of wood products to the


**Figure 7.** Agricultural areas in western United States. *A*, Wheatfield harvest along border between Walla Walla and Columbia Counties, southeastern Washington, in Columbia Plateau Ecoregion. *B*, Cows in maintained pasture south of Westcliffe, located in Custer County, south-central Colorado, in Southern Rockies Ecoregion. *C*, Grapes near Paso Robles, located in San Luis Obispo County, central California, in Southern and Central California Chaparral and Oak Woodlands Ecoregion. *D*, Wheat field just south of Columbia River in Sherman County, northern Oregon, in Columbia Plateau Ecoregion.

United States. In the 1990s, tightened supplies of high-quality PNW logs resulted in soaring prices, ultimately prompting overseas importers to experiment with other tree species and their wood products. Markets in Russia, New Zealand, Canada, Chile, and Europe were developed, along with the increased use of new products such as glue-laminated beams. The Asian economic crisis of the late 1990s further reduced the demand for PNW logs as demand for new housing construction was dramatically reduced (Daniels, 2005).

The United States has passed several pieces of legislation that restrict the amount of logs that can be exported from federally owned lands. In 1974, Congress attached a rider to the U.S. Department of Interior Appropriation Act that initiated a near-total ban on unprocessed timber exports from federal lands west of the 100th meridian (Daniels, 2005). The Forest Resources Conservation and Shortage Relief Act of 1990 was passed to alleviate the effects of the reduced timber supply resulting from restrictions caused by the listing of the Northern Spotted Owl (*Strix occidentalis caurina*) on the endangered species list. The goal of the relief act was threefold, (1) to promote conservation of forest resources, (2) to ensure that United States forest resources were not exhausted, and (3) to guarantee a constant and available supply of forest resources to meet domestic needs. As a result, the only timber available for export from the PNW was from private landowners.

Domestic environmental policy also has had a profound impact on the PNW log-export market. In 1990 the Northern Spotted Owl was listed as threatened, and it was later joined by the Marbled Murrelet (*Brachyramphus marmoratus*). The Endangered Species Act also afforded protection to species of salmon (family Salmonidae) in riparian areas. These listings, which have impacted federal, state, and private lands alike, have resulted in significant timber harvest restrictions. In 1991, virtually all harvest on federal lands stopped in response to the Northern Spotted Owl controversy, and the issue was not resolved until 1993 when the Northwest Forest Plan was adopted. Between 1965 and 1988, timber sold from PNW national forests fluctuated between 3 and 4 billion board feet annually. In 1991, sales dropped to less than 1 billion board feet, a level maintained throughout the 1990s (Daniels, 2005). Douglas-fir (*Pseudotsuga menziesii*) exports to Japan dropped by 30 percent between 1989 and 1991, and, by 1992, 75 percent of PNW log exports were from private

lands (Daniels, 2005). By this time, old growth, which had all but disappeared from these areas, was only available on protected federal lands (fig. 3).

Forest change in the western United States also was strongly associated with natural disturbances caused by wildfire. In this study's classification scheme, areas affected by forest fires were mapped as a change from the forest class to the nonmechanically disturbed class. In rare cases, a nonmechanically disturbed state associated with disease from insect infestations also was mapped. Between 1973 and 2000, an estimated 22,827 km$^2$ of forest converted to nonmechanically disturbed, 24 percent (5,448 km$^2$) of which occurred between 1986 and 1992 and 66 percent (14,994 km$^2$) of which occurred between 1992 and 2000. The vast majority of mapped forest fires and infestations in the West occurred in the Rocky Mountains Ecoregions, 33 percent of which occurred in the Northern Rockies Ecoregion alone. In this ecoregion, land-use histories appear to have had relatively little effect on fire risk; rather, fires are more strongly associated with increased spring and summer temperatures and an earlier spring snowmelt (Westerling and others, 2006).

## Agriculture Land-Cover Class

Agriculture was the third most common land-cover class in the western United States, accounting for an estimated 6.3 percent of the total land area in 2000 (table 2; fig. 7). Like grassland/shrubland, agriculture was relatively stable, declining only 2.5 percent (-4,414 km$^2$) between 1973 and 2000 (table 3). This loss in agriculture land cover corresponds to the U.S. Department of Agriculture's (2004) Census of Agriculture, which estimated a loss of approximately 12,000 km$^2$ of total cropland in the western United States between 1969 and 1997 (fig. 8). However, differences between study years, as well as classification characteristics, make a one-to-one comparison between agricultural census and estimates presented here difficult. In addition, net change can mask temporal and spatial variability in the rates of change in the agriculture class. For example, between 1973 and 1986, agriculture increased from 6.5 percent to 6.6 percent of the total land area, whereas, between 1986 and 1992, agriculture declined by 4.5 percent to 6.3 percent regionwide. The total area that converted to or from agriculture between 1973 and 2000 was 33,910 km$^2$, approximately 1.2 percent of the western United States (table 3).

The most common conversion associated with agriculture was between agriculture and grassland/shrubland, which accounted for 83 percent of all agriculture gains and losses and, when gains and losses were combined, totaled 32,778 km$^2$. An additional 4,623 km$^2$ of agriculture land converted to developed land, an area roughly equivalent to 2.5 percent of the total agriculture land.

The following five ecoregions accounted for nearly two-thirds of all gross agriculture change:

- Columbia Plateau Ecoregion, 7,633 km$^2$ (margin of error, 2,360 km$^2$)
- Central California Valley Ecoregion, 5,148 km$^2$ (margin of error, 916 km$^2$)
- Montana Valley and Foothill Prairies Ecoregion, 4,170 km$^2$ (margin of error, 3,202 km$^2$)
- Southern and Central California Chaparral and Oak Woodlands Ecoregion, 2,711 km$^2$ (margin of error, 596 km$^2$)
- Snake River Basin Ecoregion, 2,407 km$^2$ (margin of error, 1,064 km$^2$)

The Conservation Reserve Program (CRP) was a strong driver of agriculture change in the western United States, although the effects of the program were limited to a few ecoregions. The CRP, which was enacted in 1985 (U.S. Congress, 1985), instituted the largest and most rapid conversion of cropland to grassland in United States history (Park and Egbert, 2008). The objectives of the CRP were to reduce soil erosion, improve water quality, create wildlife habitat, implement controls on commodity production, and provide financial support to agricultural producers (Park and Egbert, 2008). By 1992, an area equivalent to approximately 8 percent of United States farmland had been enrolled in the CRP program (Margheim, 1994). The CRP had the biggest impact in the Columbia Plateau and the Montana Valley and Foothill Prairies Ecoregions, with lesser impacts in the Snake River Basin Ecoregion. The CRP program had minimal impact in the Central California Valley and the Southern and Central California Chaparral and Oak Woodlands Ecoregions, accounting for less than one percent of total United States enrollments (U.S. Department of Agriculture, 2011).

Conversion of agriculture land to developed land accounted for an estimated 4,623 km$^2$ between 1973 and 2000. Five ecoregions accounted for 76 percent of all of the agriculture-to-developed conversion (table 7): the Southern and Central California Chaparral and Oak Woodlands Ecoregion (1,230 km$^2$), Colorado Plateaus Ecoregion (756 km$^2$), Central California Valley Ecoregion (684 km$^2$), Willamette Valley Ecoregion (347 km$^2$), and Northern Rockies Ecoregion (262 km$^2$). The period between 1973 and 1980 experienced the largest average annual conversion from agriculture to developed, at 203 km$^2$ per year. The other three time periods averaged 146 to 192 km$^2$ per year. Population growth and the demand for new developed land resulted in the direct conversion of agriculture to developed, as well as the conversion of grassland/shrubland to agriculture as displaced farmers sought out new areas to farm (Sleeter, 2009).

## Developed Land-Cover Class

Developed land cover includes areas of intensive use, within which much of the land is covered with either structures or other impermeable surfaces of anthropogenic origin, or less intensive use, within which the land is covered with both vegetation and structures, including land that is

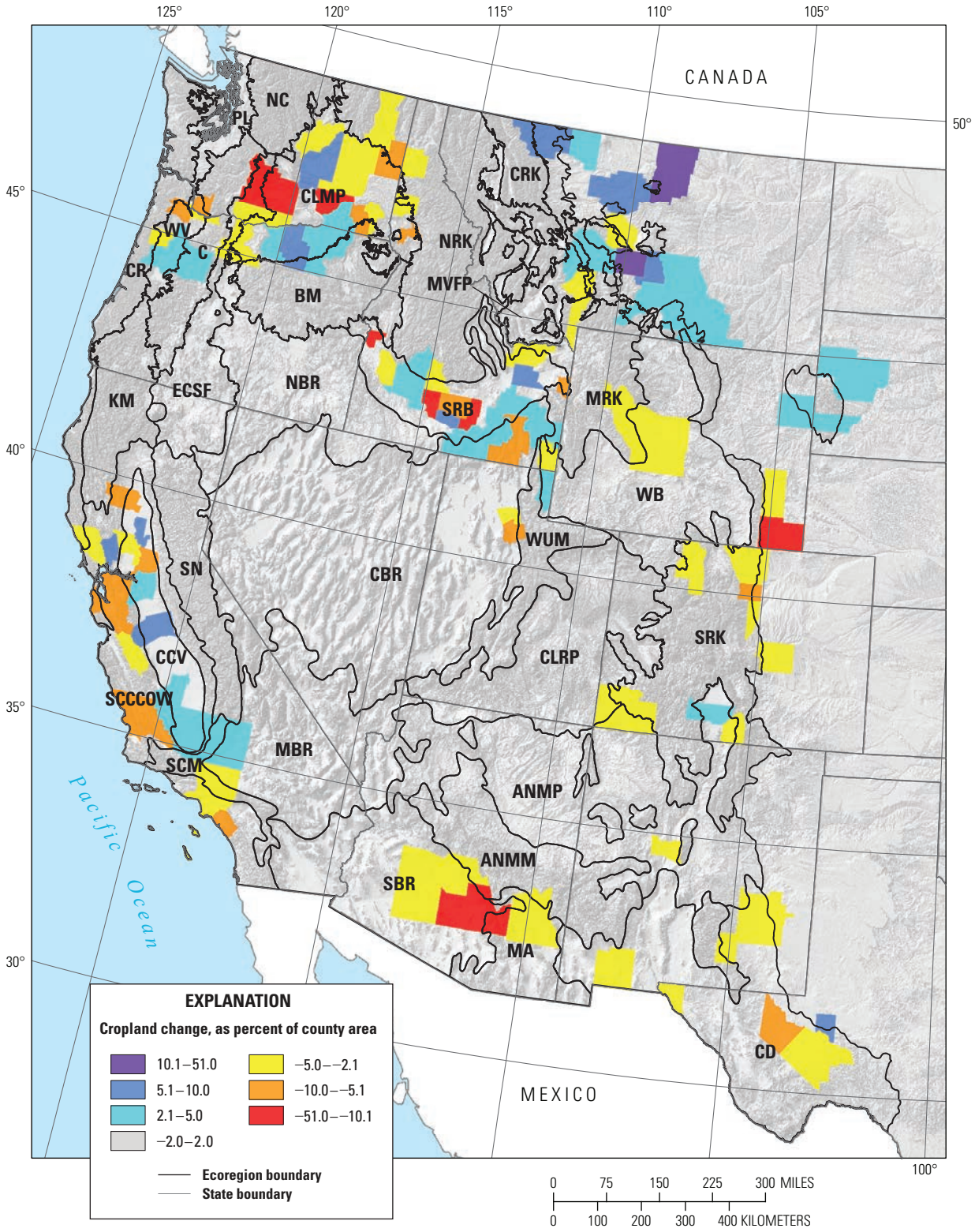



**Figure 8.** Map of counties that intersect Western United States ecoregions, showing counties whose land changed either into (positive values) or out of (negative values) cropland between 1969 and 1997. County data are based on U.S. Department of Agriculture's (2004) Census of Agriculture estimates.

**Table 7.** Sizes of new areas of developed land-cover class that converted from grassland/shrubland, agriculture, and forest classes for the 10 Western United States ecoregions that had largest net change for entire study period (1973 to 2000), as well as for all 30 Western United States ecoregions, and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Converted from grassland/shrubland class [margin of error] ($km^2$) | Converted from agriculture class [margin of error] ($km^2$) | Converted from forest class [margin of error] ($km^2$) | Net change in developed class [margin of error] ($km^2$) |
|---|---|---|---|---|
| Southern and Central California Chaparral and Oak Woodlands Ecoregion | 646 [326] | 1,230 [931] | 31 [30] | 2,234 [1,381] |
| Mojave Basin and Range Ecoregion | 1,426 [1,191] | 45 [49] | 4 [6] | 1,680 [1,329] |
| Colorado Plateaus Ecoregion | 644 [711] | 756 [1,085] | 3 [4] | 1,408 [1,795] |
| Puget Lowland Ecoregion | 30 [10] | 153 [70] | 871 [186] | 1,186 [231] |
| Central California Valley Ecoregion | 366 [181] | 684 [289] | 1 [1] | 1,129 [455] |
| Arizona/New Mexico Plateau Ecoregion | 533 [598] | 201 [293] | 5 [5] | 753 [900] |
| Northern Rockies Ecoregion | 241 [337] | 262 [361] | 205 [238] | 717 [938] |
| Central Basin and Range Ecoregion | 538 [386] | 50 [73] | 0 [0] | 649 [484] |
| Sonoran Basin and Range Ecoregion | 355 [228] | 84 [115] | 2 [2] | 481 [310] |
| Willamette Valley Ecoregion | 0 [0] | 347 [164] | 81 [41] | 454 [205] |
| All Western United States ecoregions | 5,496 [1,628] | 4,623 [1,549] | 1,717 [333] | 12,785 [3,000] |

functionally related to urban or built-up environments (for example, parks and golf courses) (fig. 9). Developed land cover increased by 48.0 percent over the study period, a net increase of 12,785 $km^2$ (table 3). Developed land accounted for 1.0 percent of the western United States in 1973 and 1.5 percent in 2000 (table 2). Owing to the unidirectional nature of change associated with development and urbanization, gross change was similar to that of net change. Developed land spanned 26,608 $km^2$ in 1973 but, by 2000, had expanded to cover 39,393 $km^2$. Between 1970 and 2000, population of the western United States experienced similar growth, increasing 62.6 percent from 72.6 to 118.1 million people (U.S. Census Bureau, 2001). Of the 392 counties that intersect the Western United States ecoregions, only 40 realized a net decline in population between 1970 and 2000 (fig. 10). Table 8 shows the ecoregions that experienced the largest increase in developed land (defined as the percentage of the ecoregion that converted to the developed land-cover class) between 1973 and 2000, the largest areal change, and the corresponding areal changes relative to their land-cover class in 1973.

Conversions to developed land were associated primarily with agriculture, forest, grassland/shrubland, and mechanically disturbed land. However, considerable spatial variability exists in the origin of new developed land. The Pacific Northwest region (that is, the Marine West Coast Forests Ecoregions and parts of the Western Mountain Ranges Ecoregions), which is dominated by dense evergreen forests, accounted for the majority of forest conversion to developed land, whereas the Mediterranean California Ecoregions, as well as the Warm Deserts Ecoregions and the Cold Deserts Ecoregions, accounted for the majority of change from grassland/shrubland to developed land. The loss of agriculture to developed land occurred in a more diverse set of ecoregions, namely the Mediterranean California Ecoregions, the Warm Deserts Ecoregions, the Cold Deserts Ecoregions, and the Marine West Coast Forests Ecoregions. Conversion to developed land from mechanically disturbed land was most common in ecoregions that already contained large areas of development.

Nearly 80 percent of all new developed land came from one of two land-cover classes, either grassland/shrubland or agriculture. However, great variability of change exists among the ecoregions. For example, in the Southern and Central California Chaparral and Oak Woodlands Ecoregion, more developed land was converted from agriculture by a 2:1 margin than from grassland/shrubland, whereas in the Colorado Plateaus Ecoregion, the margin was close to even, and in the Mojave Basin and Range Ecoregion, the margin was 35:1 in favor of grassland/shrubland. In ecoregions in which agriculture was a dominant land use, loss of agriculture to developed land was generally the most common conversion. For example, in the Central California Valley Ecoregion, conversion from agriculture to developed land occurred by a 2:1 margin over conversion of grassland/shrubland to developed land, whereas the same conversion occurred by a 3.5:1 margin in the Columbia Plateau Ecoregion and by a 6:1 margin in the Snake River Basin Ecoregion.

Conversions from grassland/shrubland to developed land accounted for 43.6 percent of all change in developed land cover, and six ecoregions accounted for approximately 70 percent of this specific conversion. Conversions from agriculture to developed land were the second most common form of change, accounting for an estimated 4,623 $km^2$ over the 27-year study period (table 7). The Southern and Central


**Figure 9.** Developed areas in western United States. *A*, New home construction in Palmdale, located in far-northern Los Angeles County, southern California, in Mojave Basin and Range Ecoregion. *B*, Industrial activity along Willamette River in Oregon City, located in Clackamas County, northwestern Oregon, in Willamette Valley Ecoregion. *C*, Oracle campus in Redwood Shores, located in San Mateo County, north-central California, in Southern and Central California Chaparral and Oak Woodlands Ecoregion. *D*, View overlooking Banning, located in Riverside County, southern California, in Southern California Mountains Ecoregion.

**Table 8.** Net areal changes in developed land-cover class (as percent of ecoregion area, as area in square kilometers, and as percent of developed land-cover class area in 1973) for the six Western United States ecoregions that had largest increase in developed class for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Net areal change [margin of error] | | Net areal change (% of developed class in 1973) |
|---|---|---|---|
| | (% of ecoregion) | ($km^2$) | |
| Puget Lowland Ecoregion | 6.6 [1.3] | 1,186 [231] | 53.8 |
| Willamette Valley Ecoregion | 3.1 [1.4] | 454 [205] | 33.4 |
| Central California Valley Ecoregion | 2.5 [1.0] | 1,129 [455] | 37.7 |
| Southern and Central California Chaparral and Oak Woodlands Ecoregion | 2.2 [1.4] | 2,234 [1,381] | 33.1 |
| Mojave Basin and Range Ecoregion | 1.3 [0.6] | 1,680 [1,329] | 85.8 |
| Colorado Plateaus Ecoregion | 1.1 [1.4] | 1,408 [1,795] | 431.9 |

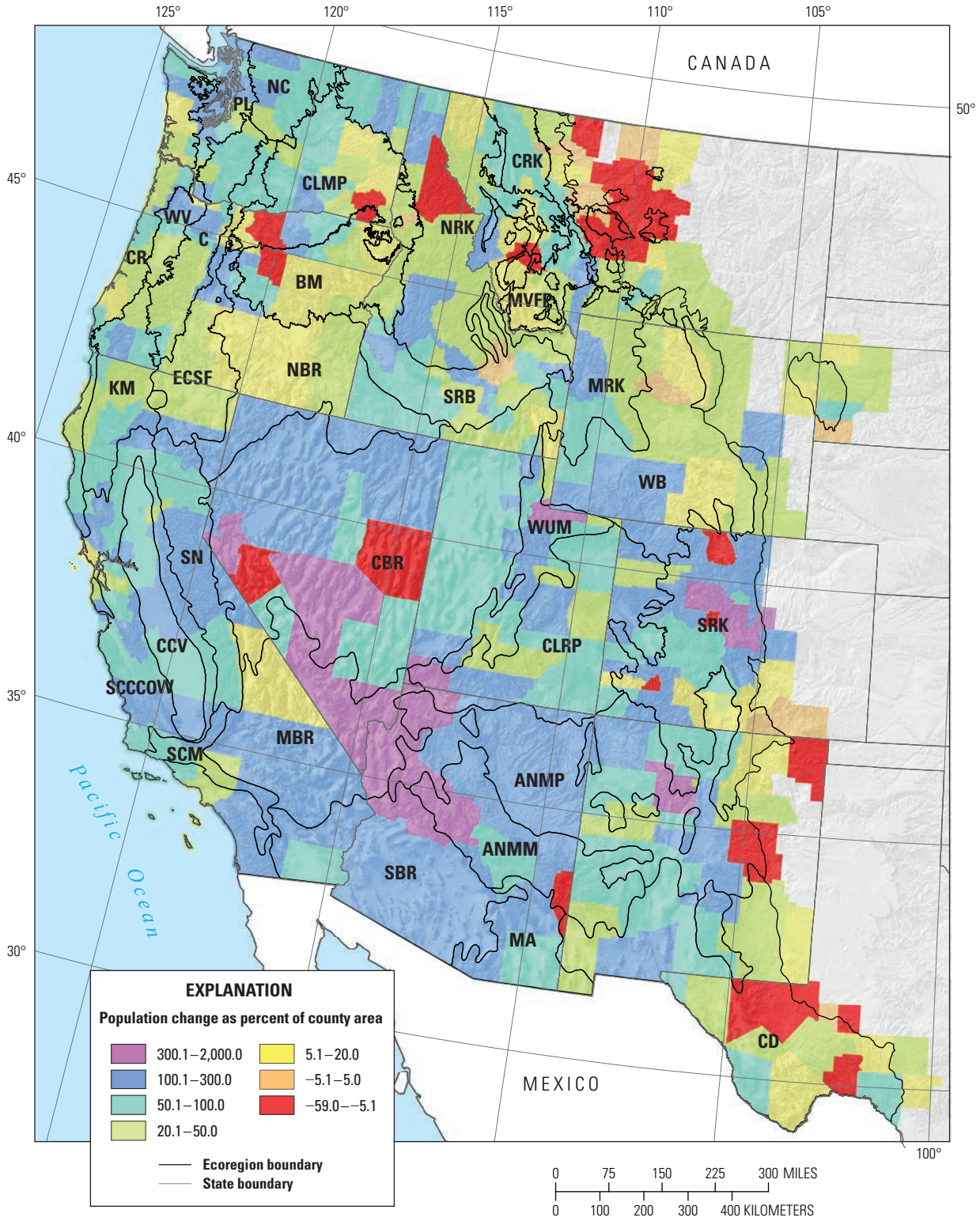



**Figure 10.** Map of counties that intersect Western United States ecoregions, showing counties that either gained (positive values) or lost (negative values) population between 1970 and 2000. Gains and losses expressed as percentage of change from 1970 population levels (U.S. Census Bureau, 2001).

California Chaparral and Oak Woodlands Ecoregion experienced the highest amount of conversion from agriculture to developed land, at 1,230 km$^2$, followed by the Colorado Plateaus, Central California Valley, Willamette Valley, and Northern Rockies Ecoregions (table 7). Conversion from forest to developed accounted for 13.7 percent of all new developed land. Approximately 87 percent of all change from forest to developed occurred in five Pacific Northwest ecoregions, the highest being the Puget Lowland Ecoregion (871 km$^2$), followed by the Coast Range (236 km$^2$), Northern Rockies (205 km$^2$), Cascades (98 km$^2$), and Willamette Valley (81 km$^2$) Ecoregions. The 10 ecoregions in the West that experienced the greatest net change in developed are shown in table 7.

Conversion from mechanically disturbed to developed often represents the capture of a intermediate land-cover stage, typically consisting of the scraping and leveling of a site and other preparations in advance of construction. The most common occurrences were in the Southern and Central California Chaparral and Oak Woodlands (301 km$^2$), Mojave Basin and Range (205 km$^2$), Puget Lowland (135 km$^2$), Central California Valley (77 km$^2$), and Central Basin and Range (61 km$^2$) Ecoregions. These five ecoregions accounted for 82 percent of all conversions from mechanically disturbed to developed.

## Transitional Land-Cover Classes

Mechanically disturbed and nonmechanically disturbed lands, referred to herein as transitional land-cover classes, played a prominent role in the story of change throughout the western United States in the 27-year study period. A mechanically disturbed state is mapped when land is in an altered and often unvegetated state, owing to disturbances by mechanical means, and, thus, is in transition from one land-cover class to another (fig. 11). For example, postharvest forest, which varied significantly throughout the West, manifested either as a rapid reestablishment of, and conversion back to, forest or as an intermediate, mechanically disturbed–grassland/shrubland state in which succession to forest occurred more slowly. Mechanical disturbances were not solely associated with forest clearing in the West. Urbanization, reservoir drawdown, infrastructure


**Figure 11.** Mechanically disturbed areas in western United States. *A*, Newly clearcut hillside in Bighorn Mountains, north-central Wyoming, in Middle Rockies Ecoregion. *B*, Clearcut area undergoing regeneration in Okanogan County, north-central Washington, in North Cascades Ecoregion. *C*, Clearcut area in Douglas County, southwestern Oregon, in Cascades Ecoregion. *D*, Mountaintop clearcut area on private land in Siskiyou County, northern California, in Klamath Mountains Ecoregion.

construction, and reoccurring vehicular disturbance of vegetation also were associated with the mechanically disturbed classification, although less frequently.

Mechanical disturbances are significant anthropogenic land-use-change events that are primarily a result of logging and, to a lesser extent, urbanization. Biological and physical factors combine to create conditions that dictate forest growth and reestablishment rates throughout the West: soil composition, geology, climate, vegetation age and diversity, and several other environmental parameters collectively determine which ecoregions are best suited to sustain a viable forest-resource base (Ryan and others, 1996; Powers, 1999).

Mechanical disturbances affected 2.2 percent (60,253 km$^2$) of the western United States over the 27-year study period. The rate of mechanical disturbance across the West escalated in each of the first three time periods, from 1,231 km$^2$ per year between 1973 and 1980 to 2,469 km$^2$ per year between 1986 and 1992, then it declined to 1,487 km$^2$ per year between 1992 and 2000. Some level of mechanical disturbance was mapped in nearly all the Western United States ecoregions between 1973 and 2000, yet the mechanical removal of forest was significantly more pervasive in certain ecoregions. The ecoregions that experienced the most logging were among the Marine West Coast Forests Ecoregions (in the Coast Range, Puget Lowland, and Willamette Valley Ecoregions), followed by the Western Mountain Ranges Ecoregions (in the Cascades, North Cascades, Eastern Cascades Slopes and Foothills, and Klamath Mountains Ecoregions) and the Rocky Mountains Ecoregions (in the Northern Rockies Ecoregion) (table 9).

Nonmechanically disturbed land reflects changes associated with wildfires, insect infestations, storms, and other natural events (fig. 12); however, the majority of nonmechanical disturbance captured in the West was associated with wildfire, with only a few cases attributed to insect- and disease-driven forest dieback. Fire has a long-established history in the West, with its abundance of fuels and its low-to-moderate levels of precipitation throughout many ecoregions (Skinner and Chang, 1996; Keeley and Fotheringham, 2001; Schoennagel and others, 2004). The vast majority of fire occurred in the Mediterranean California Ecoregions, the Western Mountain Ranges Ecoregions, and the Rocky Mountains Ecoregions, although fire has also played a role in the ecology of the Cold Deserts Ecoregions (fig. 13).

Nonmechanical disturbances affected 1.5 percent (40,571 km$^2$) of the western United States over the 27-year study period. Fifty-six percent (22,867 km$^2$) of the nonmechanical disturbances were in forest, and 38 percent (15,600 km$^2$) were in grassland/shrubland. The rate of nonmechanical disturbance across the West was 211 km$^2$ per year between 1973 and 1980 and 151 km$^2$ per year between 1980 and 1986, accelerating to 908 km$^2$ per year between 1986 and 1992 and to 1,874 km$^2$ per year between 1992 and 2000. Although nonmechanical disturbances contributed to land-cover changes in 26 of the 30 Western United States ecoregions, the Middle Rockies, Northern Rockies, Southern and Central California Chaparral and Oak Woodlands, and Northern Basin and Range Ecoregions had the largest percentages of gross change, followed by the Snake River Basin, Southern California Mountains, and Sierra Nevada Ecoregions (table 10).

Nonmechanical disturbances (fires) are usually natural events that have been and will continue to be an integral part of ecological community vitality across much of the western United States. However, the fire cycles under which native flora and fauna species have evolved naturally in the past

**Table 9.** Gross spatial changes in mechanically disturbed land-cover class for the eight Western United States ecoregions that had highest amount of gross change to and from mechanically disturbed class for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Gross spatial change (1973–2000) [margin of error] | |
|---|---|---|
| | (% of ecoregion) | (km$^2$) |
| Coast Range Ecoregion | 22.5 [4.3] | 12,887 [2,480] |
| Cascades Ecoregion | 21.1 [3.1] | 9,895 [1,471] |
| Puget Lowland Ecoregion | 20.0 [3.4] | 3,514 [590] |
| Willamette Valley Ecoregion | 10.0 [2.9] | 1,440 [420] |
| North Cascades Ecoregion | 9.8 [3.8] | 2,993 [1,171] |
| Eastern Cascades Slopes and Foothills Ecoregion | 9.3 [3.5] | 5,358 [2,026] |
| Northern Rockies Ecoregion | 6.7 [2.5] | 10,829 [3.991] |
| Klamath Mountains Ecoregion | 6.5 [2.1] | 3,124 [1,010] |

**Table 10.** Gross spatial changes in nonmechanically disturbed land-cover class for the seven Western United States ecoregions that had highest amount of gross change to and from nonmechanically disturbed class for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Gross spatial change (1973–2000) [margin of error] | |
|---|---|---|
| | (% of ecoregion) | (km$^2$) |
| Middle Rockies Ecoregion | 6.8 [3.3] | 6,165 [3,009] |
| Northern Rockies Ecoregion | 5.9 [3.3] | 9,588 [5,290] |
| Southern and Central California Chaparral and Oak Woodlands Ecoregion | 5.7 [2.3] | 5,837 [2,338] |
| Northern Basin and Range Ecoregion | 4.7 [3.9] | 5,216 [4,278] |
| Snake River Basin Ecoregion | 3.9 [2.8] | 2,580 [1,819] |
| Southern California Mountains Ecoregion | 3.7 [2.3] | 659 [415] |
| Sierra Nevada Ecoregion | 3.0 [0.8] | 1,625 [410] |


**Figure 12.** Nonmechanically disturbed areas in western United States. *A*, Fire scar in Douglas County, southwestern Oregon, in Cascades Ecoregion. *B*, Dead trees on mountainside in Valley County, central Idaho, in Northern Rockies Ecoregion. *C*, Wildfire east of Cody, located in Park County, northwestern Wyoming, in Middle Rockies Ecoregion. *D*, Dead trees resulting from insect infestation in Bighorn Mountains, north-central Wyoming, in Middle Rockies Ecoregion.

have changed with rapidly growing human populations and the implementation of fire-suppression efforts in the 20th century. For instance, the introduction of nonnative annual grasses since Eurasian settlement of the West in the 1800s has increased fire frequency because these annual species burn more frequently than the native grass and shrub species (Keeley and others, 2003; Pellant and others, 2004; Brooks and others, 2004). Grassland/shrubland fires were pervasive in the Southern and Central California Chaparral and Oak Woodlands Ecoregion and the Southern California Mountains Ecoregion, as well as in the Basin and Range ecoregions (Northern Basin and Range, Central Basin and Range, Mojave Basin and Range, and Sonoran Basin and Range Ecoregions). State- and federally mandated fire-suppression activities in the early 20th century have caused a shift towards less frequent, yet more severe, fires (Skinner and Chang, 1996). Increased forest density not only has increased the abundance of fuel sources but also has contributed to higher insect and disease attacks in many of the forested Western United States ecoregions (Oliver and others, 1996; Parker and others, 2006). Dense forests and the presence of diseased trees increase the overall fire-hazard risk, as well as the likelihood of high-severity fire events (Manley and others, 2000).

Climate has also played a role in fire regimes across the West. For instance, the effect of the El Niño/La Niña–Southern Oscillation on fire regimes is well established for the southwestern United States. El Niño events bring higher than normal winter rainfall caused by the southward displacement of the jet stream, whereas La Niña events are associated with anomalously dry winters. Available fuel load increases following higher than normal rainfall during an El Niño winter, and subsequent dry years and persistent drought deplete vegetation fuel moisture; thus, the prevalence of dry fuels creates optimal fire conditions. Ultimately, these El Niño/La Niña cycles have been shown to increase fire occurrence in the southwestern ecoregions (Swetnam and Betancourt, 1990; Swetnam and others, 1999).

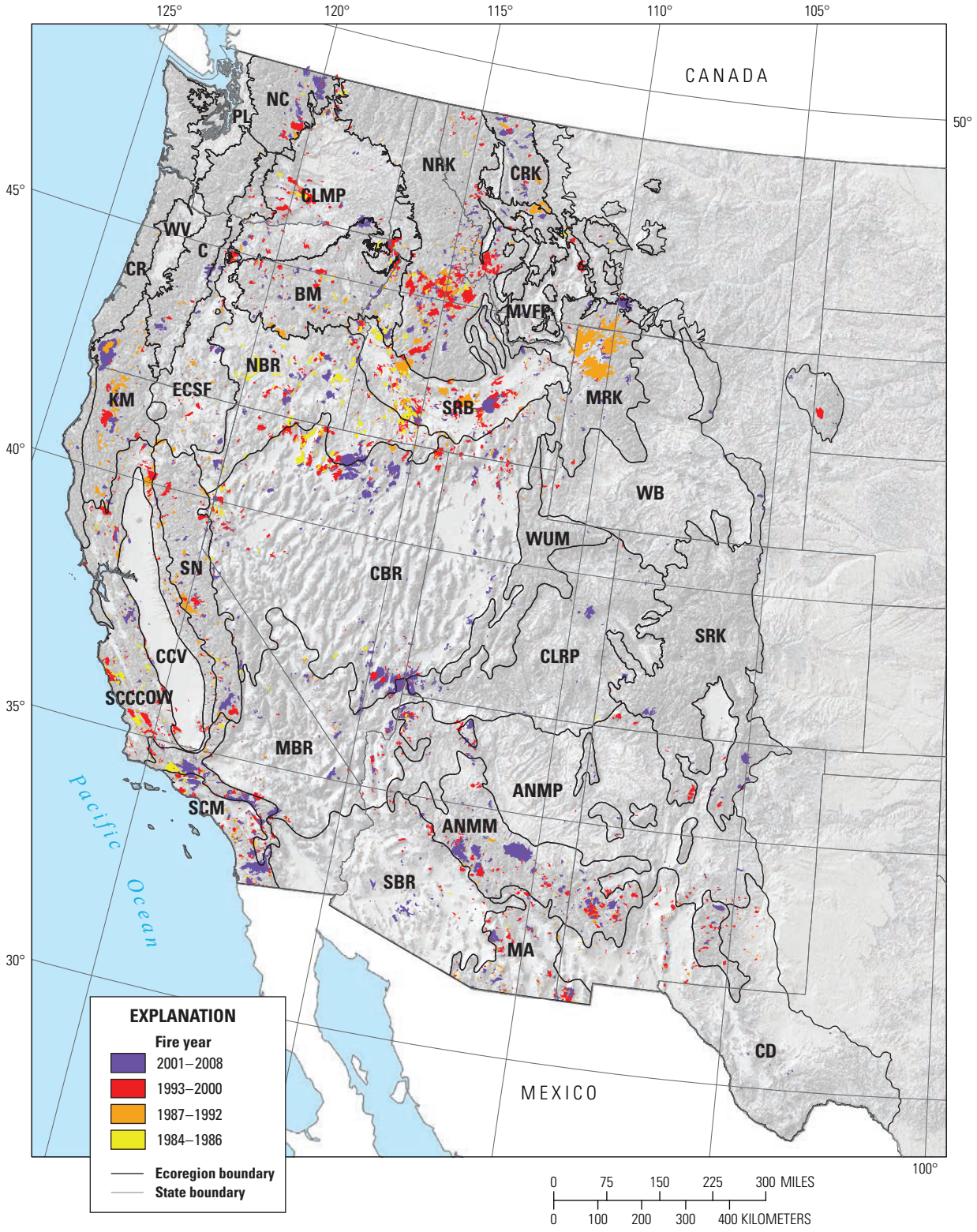



**Figure 13.** Areas of large fires in western United States between 1984 and 2008. Fire data captured by Monitoring Trends in Burn Severity project (Eidenshink and others, 2007).


**Figure 14.** Water and wetland areas in western United States. *A*, View to northeast across Emerald Bay toward Lake Tahoe, northern California, in Sierra Nevada Ecoregion. *B*, View to northwest across Crater Lake, southwestern Oregon, in Cascades Ecoregion. *C*, Coastal wetland near Coos Bay, southwestern Oregon, in Coast Range Ecoregion. *D*, Topock Marsh along Colorado River, eastern Arizona, in Mojave Basin and Range Ecoregion.

## Water and Wetland Land-Cover Classes

The water and wetland land-cover classes remained relatively stable throughout the 27-year study period. In 2000, water accounted for approximately 0.8 percent of the Western United States ecoregions, and wetlands accounted for 0.7 percent (table 2; fig. 14). Net change in both land-cover classes was less than 0.1 percent. Overall, water increased by an estimated 259 km$^2$ between 1973 and 2000, whereas wetlands decreased by 243 km$^2$ over the same time period. Water increased in three of the four time periods by an average of 86 km$^2$ per year; however, water declined at a rate of 247 km$^2$ per year between 1986 and 1992, a time period that coincides with an extended period of drought across the West. Although rare, changes in the water and wetland land-cover classes did occur in a few ecoregions; however, more than 60 percent of gross change associated with water and wetland classes occurred in only five ecoregions (Sonoran Basin and Range, Central Basin and Range, Wyoming Basin, Northern Basin and Range, and Central California Valley Ecoregions) (table 11).

## Mining Land-Cover Class

The amount of land devoted to mining increased by 53.4 percent over the 27-year study period; however, the total area in mining remained relatively small at 0.2 percent of the Western United States ecoregions (table 2). An estimated increase of 2,233 km$^2$ in mining occurred between 1973 and 2000 (table 3), with more than 60 percent of the gross change occurring in the Central Basin and Range, Mojave Basin and Range, Colorado Plateaus, Chihuahuan Deserts, and Arizona/New Mexico Mountains Ecoregions. New mining areas, as well as the expansion of existing mines, were, in general, related to the increased need for construction materials and the demand for precious metals (fig. 15).

## Other Land-Cover Classes

Barren areas—that is, areas having less than 10 percent vegetated cover (fig. 16)—accounted for 1.9 percent of the Western United States ecoregions, whereas areas of ice and

**Table 11.** Gross spatial changes in water and wetland land-cover classes for the five Western United States ecoregions that had highest amount of gross change to and from water and wetland classes for entire study period (1973 to 2000) and corresponding margin-of-error values for 85-percent confidence interval (in brackets).

[See appendix 3 for definitions of land-use/land-cover classifications]

| Ecoregion | Water class | | Wetland class | |
|---|---|---|---|---|
| | Gross spatial change [margin of error] | | Gross spatial change [margin of error] | |
| | (% of ecoregion) | (km²) | (% of ecoregion) | (km²) |
| Sonoran Basin and Range Ecoregion | 1.1 [1.1] | 1,290 [1,313] | 0.5 [0.7] | 548 [779] |
| Central Basin and Range Ecoregion | 0.3 [0.4] | 970 [1,204] | 0.2 [0.3] | 748 [1,088] |
| Wyoming Basin Ecoregion | 0.4 [0.4] | 500 [553] | 0.4 [0.2] | 471 [305] |
| Northern Basin and Range Ecoregion | 0.4 [0.3] | 414 [353] | 0.3 [0.3] | 318 [313] |
| Central California Valley Ecoregion | 0.6 [0.2] | 288 [91] | 0.7 [0.5] | 326 [231] |


**Figure 15.** Mining activities in western United States. *A*, Oil field near Coalinga, located in Fresno County, central California, in Southern and Central California Chaparral and Oak Woodlands Ecoregion. *B*, Mountaintop mining in west-central Utah, in Central Basin and Range Ecoregion. *C*, Gas well in Colorado Plateaus Ecoregion. *D*, Tailings pile in Central Basin and Range Ecoregion.


**Figure 16.** Barren areas in western United States. *A*, Mount Hood, northwestern Oregon, in Cascades Ecoregion. *B*, Lake Mead, southern Nevada, in Mojave Basin and Range Ecoregion. *C*, Stream bed along Nisqually River, in Lewis County, southwestern Washington, in Cascades Ecoregion. *D*, Lakebed near Lake Abert, along Highway 395 in south-central Oregon, in Northern Basin and Range Ecoregion.

perennial snow accounted for only an estimated 0.1 percent. The barren land-cover class most commonly consists of rocky outcrops, desert playas, and dry lakebeds. Ice and perennial snow (ice/snow land-cover class) is usually found in at the highest elevations where glaciers are common. Both of these land-cover classes remained stable over the 27-year study period (table 2).

## Summary

Taken as an aggregate of 30 individual ecoregions, land-cover change in the Western United States ecoregions was modest, with only 5.8 percent of the land cover changing at least one time between 1973 and 2000. Change was highest between 1986 and 1992 and between 1992 and 2000, with an estimated 0.4 percent change per year. The largest net change was a decline of 33,197 km$^2$ of forest land cover, which included losses to logging, fire, urbanization, and other land uses. In addition, agriculture and grassland/shrubland experienced net declines of 4,414 km$^2$ and 1,106 km$^2$, respectively, whereas developed land increased by an estimated 12,785 km$^2$. It is important to note that not all land-use/land-cover change was captured by the methodology applied for this study. For example, within-class conversions such as grassland to shrubland are not captured given the thematic resolution of the classification scheme.

Land-use/land-cover changes in the western United States are centered primarily on ecosystem disturbances resulting from logging and fire. These disturbances combined to affect 3.7 percent (100,824 km$^2$) of the Western United States ecoregions over the 27-year study period. Forest cutting for timber production was most common in the highly productive forested ecoregions of the Pacific Northwest, and it was highest during the 1980s, largely owing to favorable global economic conditions. The 1990s saw a reduction in forest cutting owing to domestic trade and environmental policy changes and a downturn in economic conditions in Asia. Although the rate of forest cutting declined, disturbances from wildfire increased substantially in the 1980s and 1990s, impacting ecoregions dominated by both forest and grassland/shrubland.

Urbanization—and the resultant expansion of developed land—was common in several Western United States ecoregions, most notably among the coastal ecoregions. The most populous ecoregion in the entire United States—the Southern and Central California Chaparral and Oak Woodlands

Ecoregion—gained the largest amount of new developed land, with an estimated 2,234 km$^2$ converting over the 27-year study period. Other ecoregions that experienced significant growth were the Central California Valley and the Mojave Basin and Range Ecoregions, where spillover from rapid growth in the neighboring Southern and Central California Chaparral and Oak Woodlands Ecoregion influenced their rates of land-cover conversions. The other ecoregion that experienced large increases in new developed land was the Puget Lowland Ecoregion, which contains the Seattle-Tacoma, Washington, metropolitan area. Urbanization also acted as a driver of change in the agriculture land-cover class. As agricultural land was converted to urban uses, farmers relocated to peripheral areas where livestock grazing was common, such as the foothills of California. Many of these areas have become popular for cultivation of nut crops, citrus, and grapes, and relocations to these areas have resulted in substantial changes to the agricultural landscape (Sleeter, 2009).

Although certain stories of land-use/land-cover change emerge for the Western United States ecoregions when viewed as a whole, the aggregate masks the temporal and ecoregional variability of change. The remaining chapters in this report, which contain summaries for each of the 30 individual Western United States ecoregions, document the rates, types, and drivers of late-20th century land-use/land-cover change in the western United States.

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