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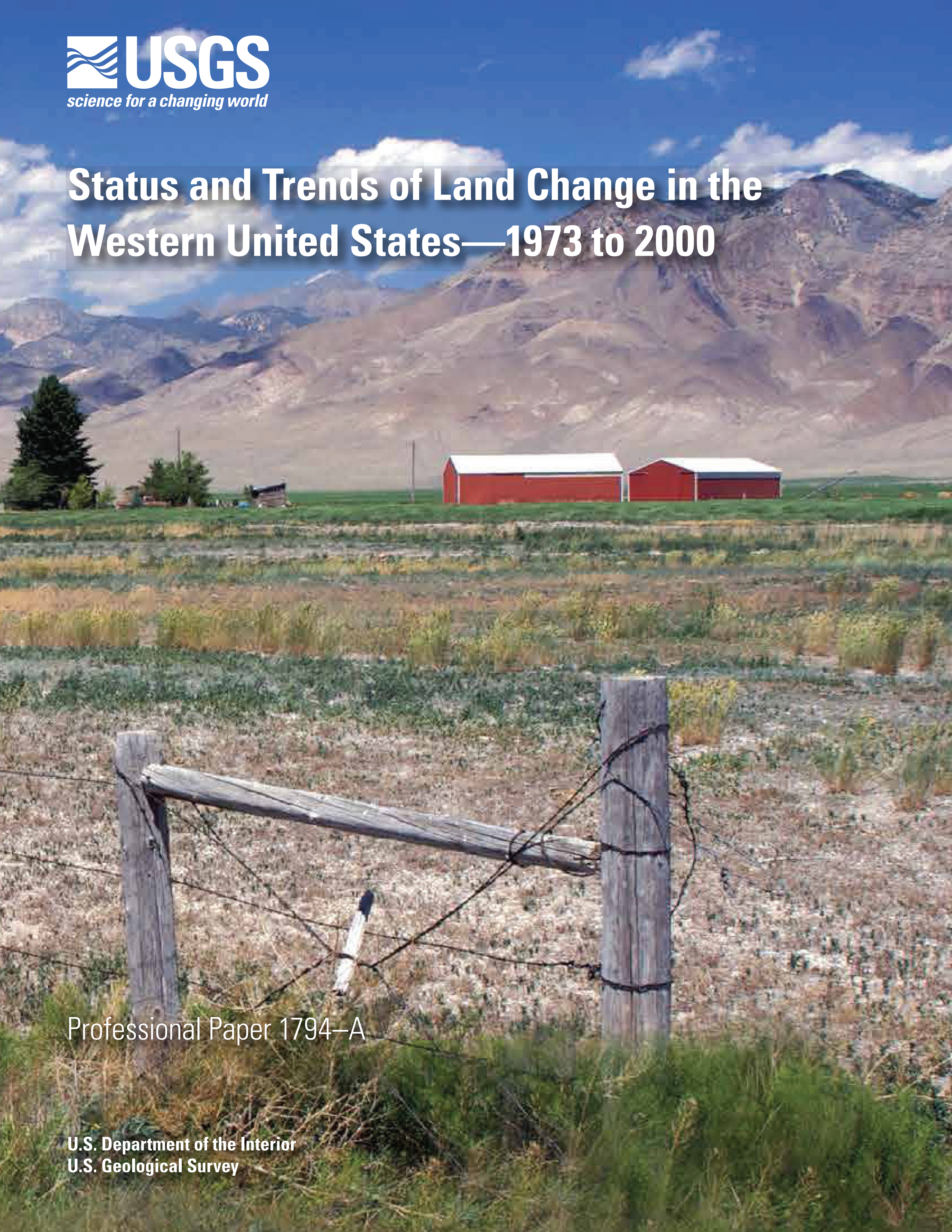
Status and Trends of Land Change in the Western United States—1973 to 2000



Professional Paper 1794–A

U.S. Department of the Interior
U.S. Geological Survey

Status and Trends of Land Change in the Western United States—1973 to 2000

Edited by Benjamin M. Sleeter, Tamara S. Wilson, and William Acevedo

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Cover:
Farm in Little Lost River Valley near Howe, Idaho, with Lemhi Range in background. Photograph by Benjamin M. Sleeter, 2008.

Inside cover:
Grasslands of Antelope Flats, in Grand Teton National Park near Jackson, Wyoming, with Teton Range in background. Photograph by Benjamin M. Sleeter, 2008.

Foreword

This Professional Paper is the first multitemporal assessment of late-20th-century land change in the conterminous United States across all regions and all land-use and land-cover sectors. The work is the culmination of nearly 10 years of research and development by the U.S. Geological Survey, with support from the U.S. Environmental Protection Agency and the National Aeronautics and Space Administration, as well as university collaborators. It represents the most complete and comprehensive analysis of the rates, types, distribution, and drivers of recent changes in land use and land cover. The study bridges the gap between coarse-scale continental and global assessments and fine-scale local and regional case studies.

Land-change studies attempt to explain the “what, where, when, how, and why” of changes to the vegetation and to the use of the land. Land-change research is aimed specifically at measuring where change is occurring (and where it is not occurring); which land-use and land-cover classes are changing (and what they are changing to); how much land is changing (and how fast); and what drivers are responsible for the measured changes. The goal is not only to understand the scope of change but also to provide the information base necessary to evaluate, predict, and manage the consequences of change.

Like many key issues in climate change and ecosystem functioning, land use and land cover are both drivers and indicators of environmental quality. The National Research Council has identified the understanding of land-use dynamics as one of the grand challenges for environmental research—no other global-change parameter is so tightly intertwined with issues of past, present, and future land-use practices, weather patterns, soil and carbon dynamics, ecosystem health and diversity, economic development and policy, technology issues, human population size and distribution, and overall human health. People and their use of the land are interrelated in complex ways, and the effects of land-use and land-cover change can have a huge impact on their quality of life, on the goods and services that they can expect from the land, and on the hazards that they may face. Despite these profound consequences, the Intergovernmental Panel on Climate Change’s Third Assessment Report has cited the lack of scientific understanding about the timing, magnitude, and direction of response of ecological, social, and economic systems to the combined effects of climate change and land-use and land-cover change as a key uncertainty in determining societal vulnerabilities and predicting both regional and global impacts of climate change.

Prior to this study, only sectorally specific or spatially limited assessments and inventories had been conducted to categorize land change in the United States. These efforts often included only certain land-use and land-cover classes or ownership categories, or they were conducted over short time intervals only, and integrating these various assessments into a comprehensive and consistent national synthesis of land change was not possible. The research presented in this Professional Paper has been specifically designed to provide the first comprehensive measurement of land-cover change in the conterminous United States.

Relying on Landsat satellite imagery—the longest continuous and consistent dataset of synoptic Earth observations—the authors characterize changes across 11 primary land-use and land-cover classes spanning four time periods between 1973 and 2000. For each of these time periods and classes, estimates of change are developed for each of 84 distinct ecological regions—or ecoregions—across the conterminous United States.

The results provide useful, if not essential, information for understanding climate change, biodiversity, resource management and planning, resource security, and disaster planning. A significant conclusion is that no single profile of land-use and land-cover change exists. Numerous different, and often complex, interactions between an ecoregion’s socioeconomic drivers and its biological and physical characteristics have produced widespread regional and temporal variability in the rates, types, and total extent of land change. Among the scientific findings presented are estimates of overall forest decline in response to increased rates of disturbance, urbanization, and agricultural intensification.

This research provides a critical ecoregional to national perspective of land change in the conterminous United States. With the completion of the 1973–2000 assessment, this study lays a foundation for understanding the Nation’s land-change dynamics and makes possible a new era for analyzing the consequences of land change, as well as for modeling future land changes.

Marcia K. McNutt
Director, USGS

Preface

U.S. Geological Survey (USGS) Professional Paper 1794–A is the first in a four-volume series on the status and trends of the Nation's land use and land cover, providing an assessment of the rates and causes of land-use and land-cover change in the Western United States between 1973 and 2000. Volumes B, C, and D provide similar analyses for the Great Plains, the Midwest–South Central United States, and the Eastern United States, respectively. The assessments of land-use and land-cover trends are conducted on an ecoregion-by-ecoregion basis, and each ecoregion assessment is guided by a nationally consistent study design that includes mapping, statistical methods, field studies, and analysis. Individual assessments provide a picture of the characteristics of land change occurring in a given ecoregion; in combination, they provide a framework for understanding the complex national mosaic of change and also the causes and consequences of change. Thus, each volume in this series provides a regional assessment of how (and how fast) land use and land cover are changing, and why. The four volumes together form the first comprehensive picture of land change across the Nation.

Geographic understanding of land-use and land-cover change is directly relevant to a wide variety of stakeholders, including land and resource managers, policymakers, and scientists. The chapters that follow present brief summaries of the patterns and rates of land change observed in each ecoregion in the Western United States, together with field photographs, statistics, and comparisons with other assessments. In addition, a synthesis chapter summarizes the scope of land change observed across the entire Western United States. The studies provide a way of integrating information across the landscape, and they form a critical component in the efforts to understand how land use and land cover affect important issues such as the provision of ecological goods and services and also the determination of risks to, and vulnerabilities of, human communities. Results from this project also are published in peer-reviewed journals, and they are further used to produce maps of change and other tools for land management, as well as to provide inputs for carbon-cycle modeling and other climate change research.

This report is only one of the products produced by USGS on land-use and land-cover change in the United States. Other reports and land-cover statistics are available online at http://landcovertrends.usgs.gov.

Acknowledgments

The U.S. Environmental Protection Agency's Office of Research and Development and the National Aeronautics and Space Administration provided initial funding to support this project.

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Adam Davis (USGS) provided extensive support in the production of figures and tables.

All photographs contained within this Professional Paper were taken by various members of the USGS Land Cover Trends research project while conducting field investigations between 1999 and 2010.

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Conversion Factors

Inch/Pound to SI	Multiply by	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
barrel (bbl), (petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Mass	
ton, short (2,000 lb)	0.9072	megagram (Mg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C=(°F-32)/1.8

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Regional Synthesis

Land-Cover Trends in the Western United States—1973 to 2000

By Benjamin M. Sleeter, Christopher E. Soulard, Tamara S. Wilson, and Daniel G. Sorenson

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 × 10 km sample blocks was selected for most ecoregions (20 × 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 × 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]).

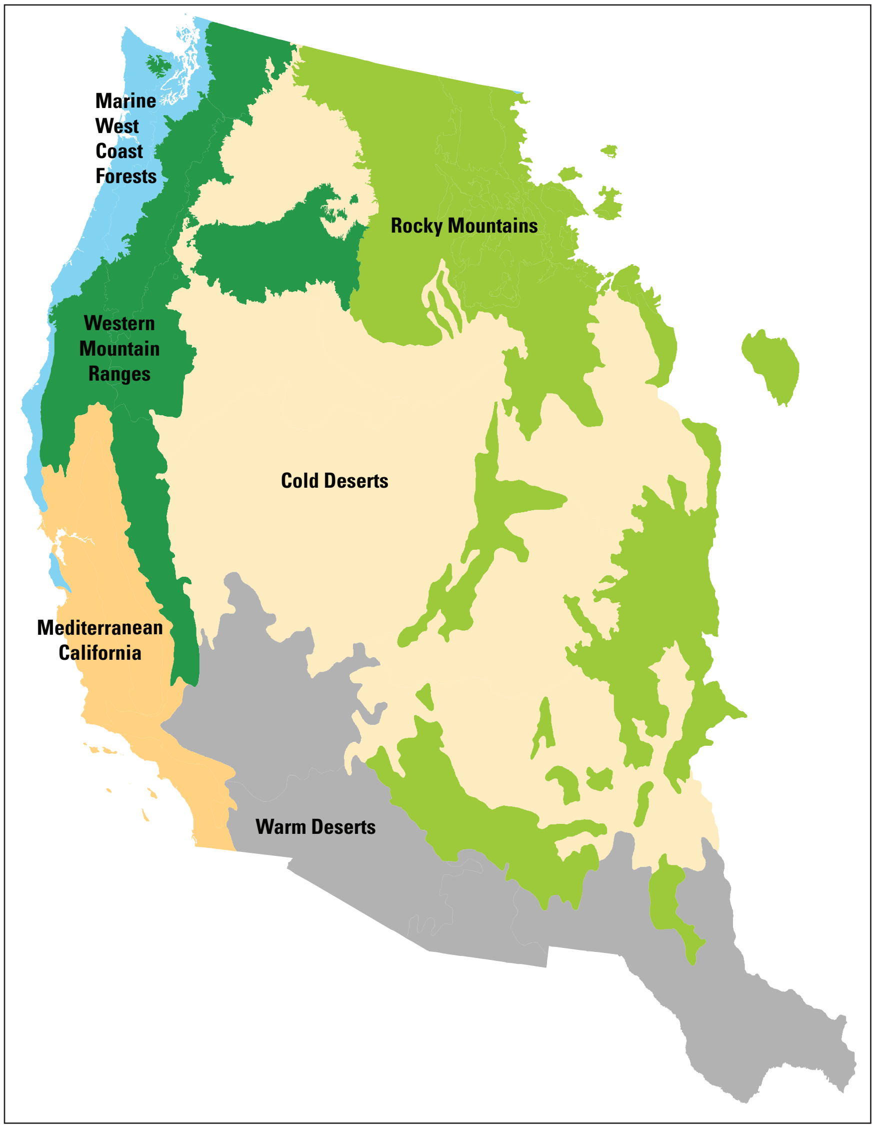
Regional Synthesis

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).

A

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.

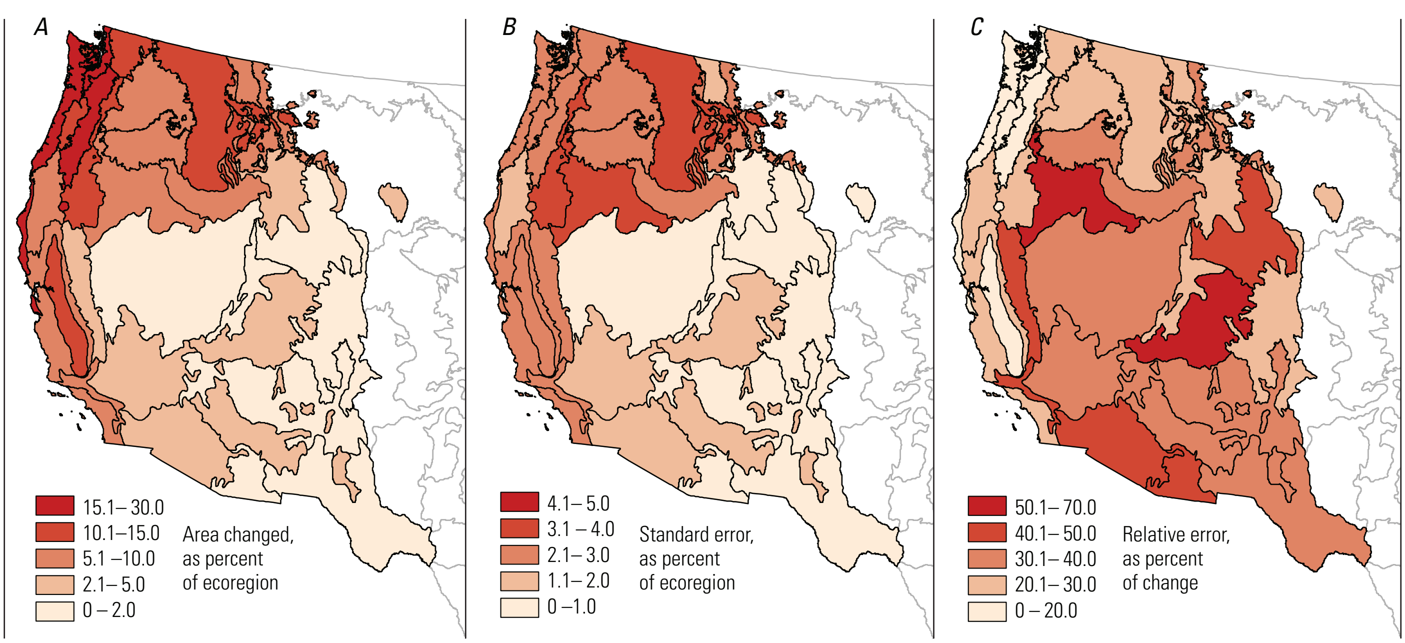


Figure 2. Maps showing (*A*) overall spatial change as percent of ecoregion area, (*B*) standard error as percent of ecoregion area, and (*C*) relative error as percent of change, for all 30 Western United States ecoregions over entire study period (1973–2000).

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)	Overall spatial change [margin of error] (% 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]

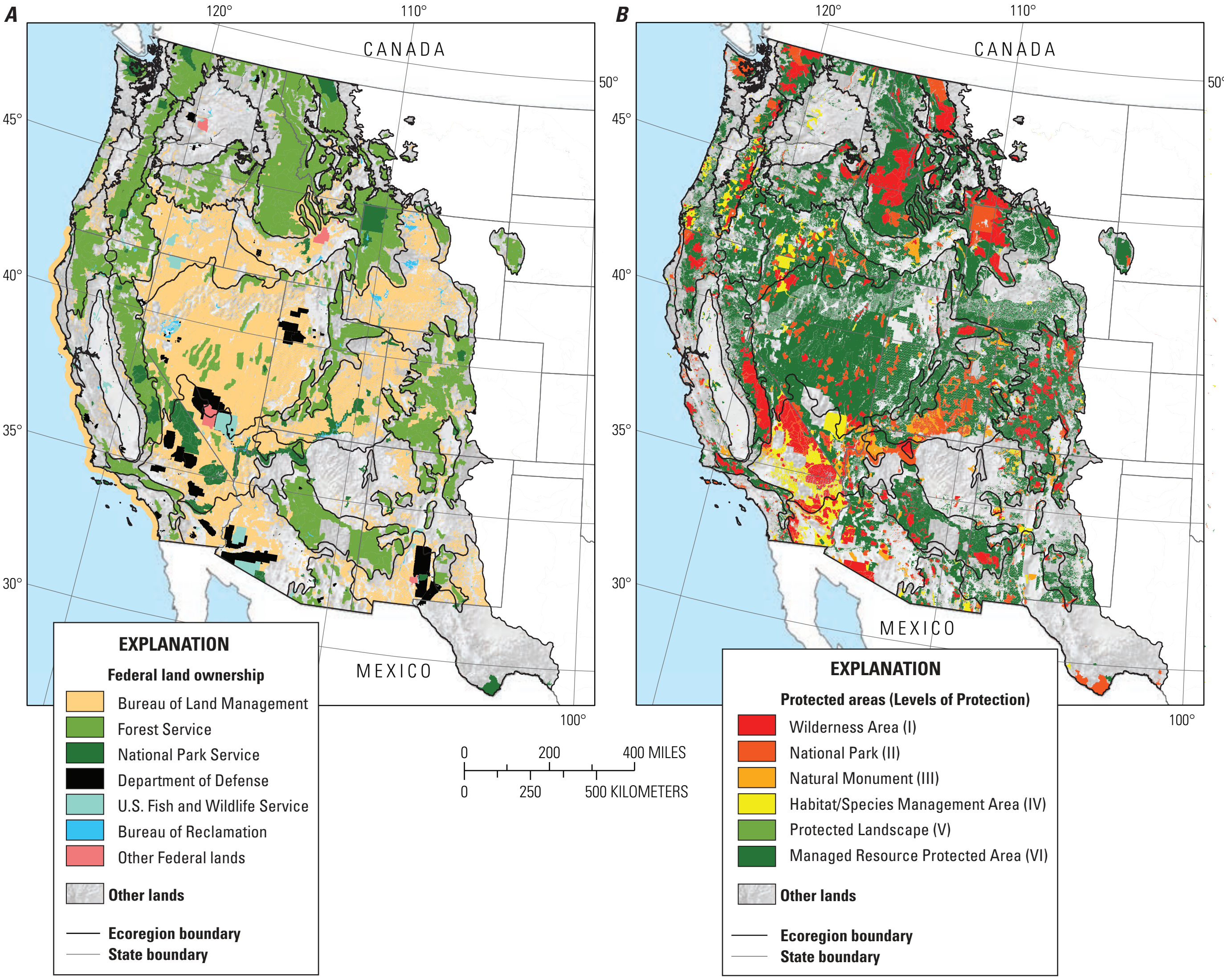


Figure 3. Maps showing (*A*) federal land ownership (National Atlas of the United States, 2006) and (*B*) protected areas (Conservation Biology Institute, 2010), in all 30 Western United States ecoregions. Bureau of Land Management lands offshore of California are part of California Coastal National 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]

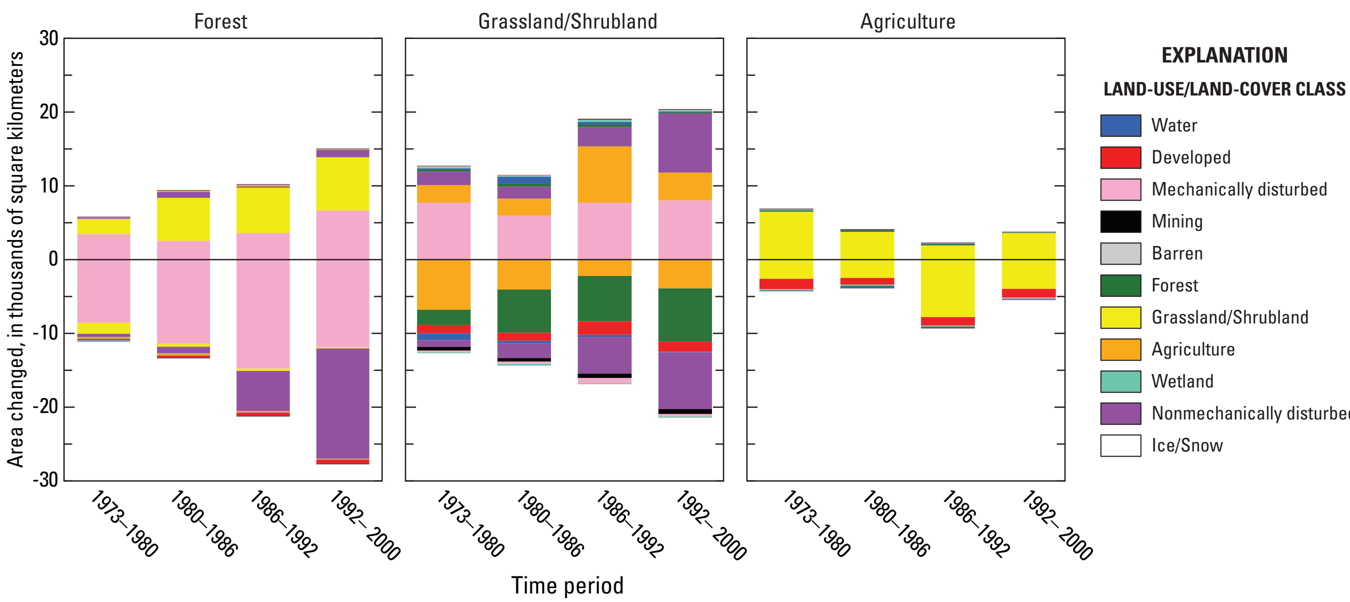


Figure 4. Gross changes (areas gained from, and lost to, other land-cover classes) in forest, grassland/shrubland, and agriculture land-cover classes, in all 30 Western United States ecoregions over entire study period (1973–2000). For each of these three classes, colored bars above zero axis indicate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

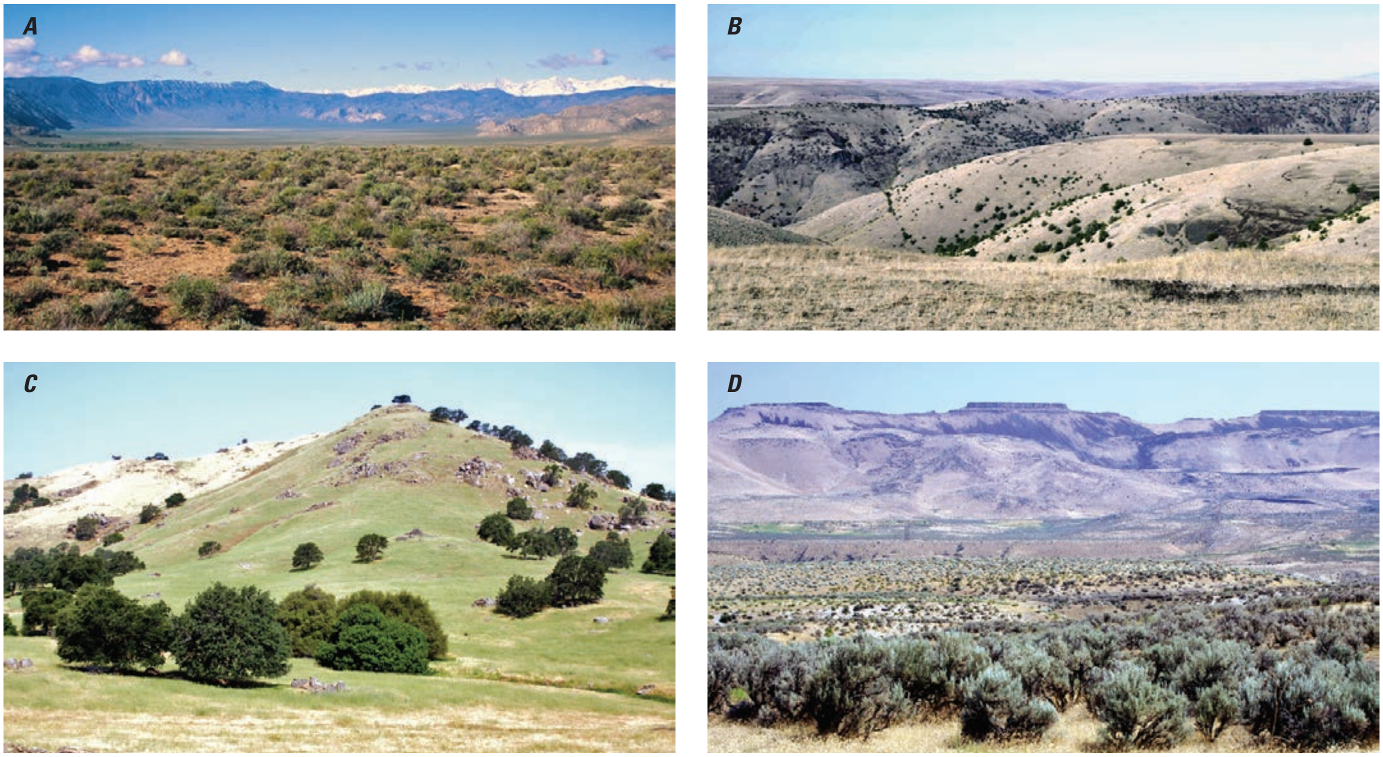


Figure 5. Areas of grassland/shrubland in western United States. *A*, Shrubland in northeastern Inyo County, east-central California, in Central Basin and Range Ecoregion. In distance to east are White Mountains, along California–Nevada border. *B*, Grassland in Gilliam County, northern Oregon, in southern 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)	(km^2)
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

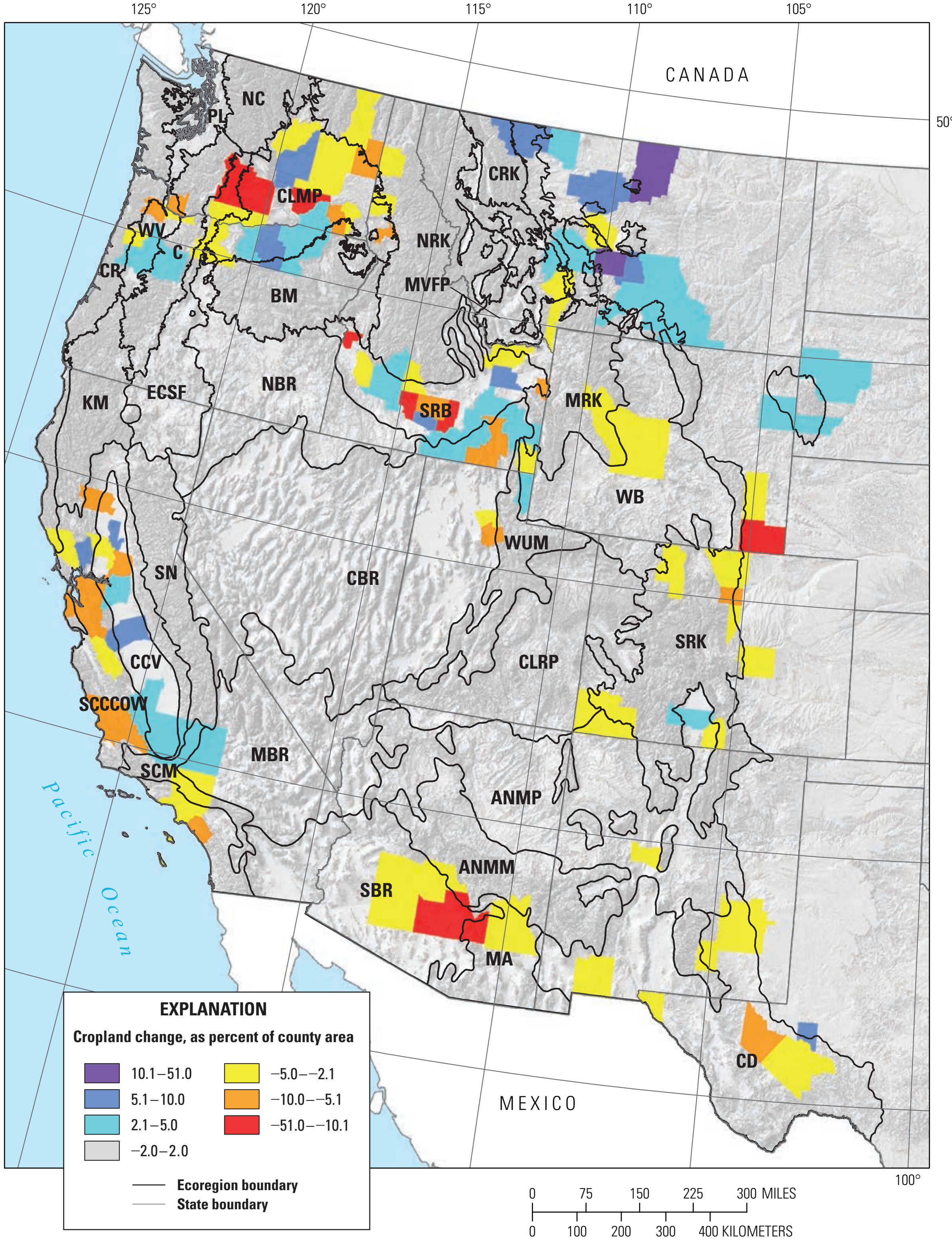


Figure 8. Map of counties that intersect Western United States ecoregions, showing counties whose land changed either into (positive values) or out of (negative values) cropland between 1969 and 1997. County data are based on U.S. Department of Agriculture's (2004) Census of Agriculture estimates.

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] (km²)	Converted from agriculture class [margin of error] (km²)	Converted from forest class [margin of error] (km²)	Net change in developed class [margin of error] (km²)
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 km² (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 km² in 1973 but, by 2000, had expanded to cover 39,393 km². 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 km² 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

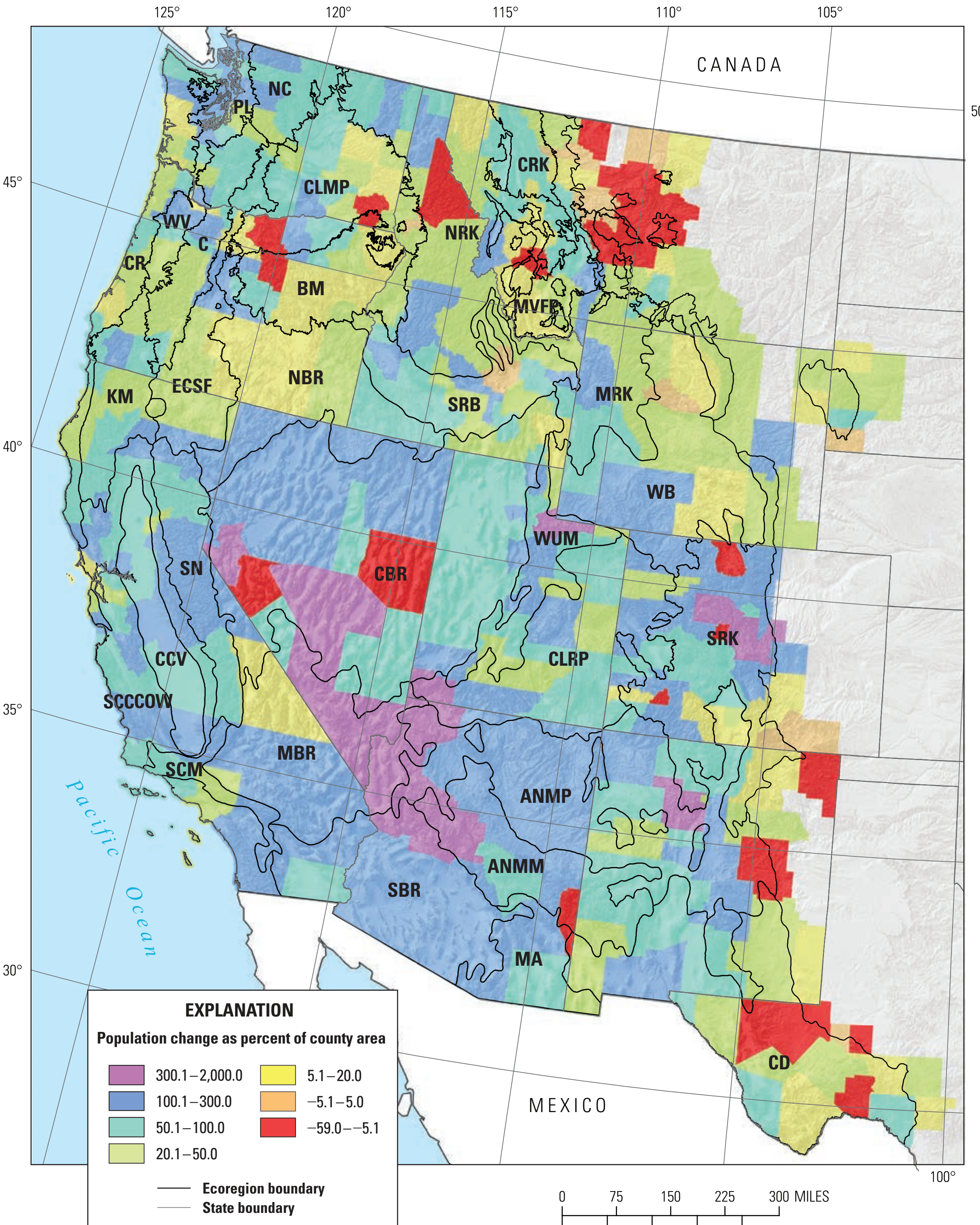


Figure 10. Map of counties that intersect Western United States ecoregions, showing counties that either gained (positive values) or lost (negative values) population between 1970 and 2000. Gains and losses expressed as percentage of change from 1970 population levels (U.S. Census Bureau, 2001).

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).

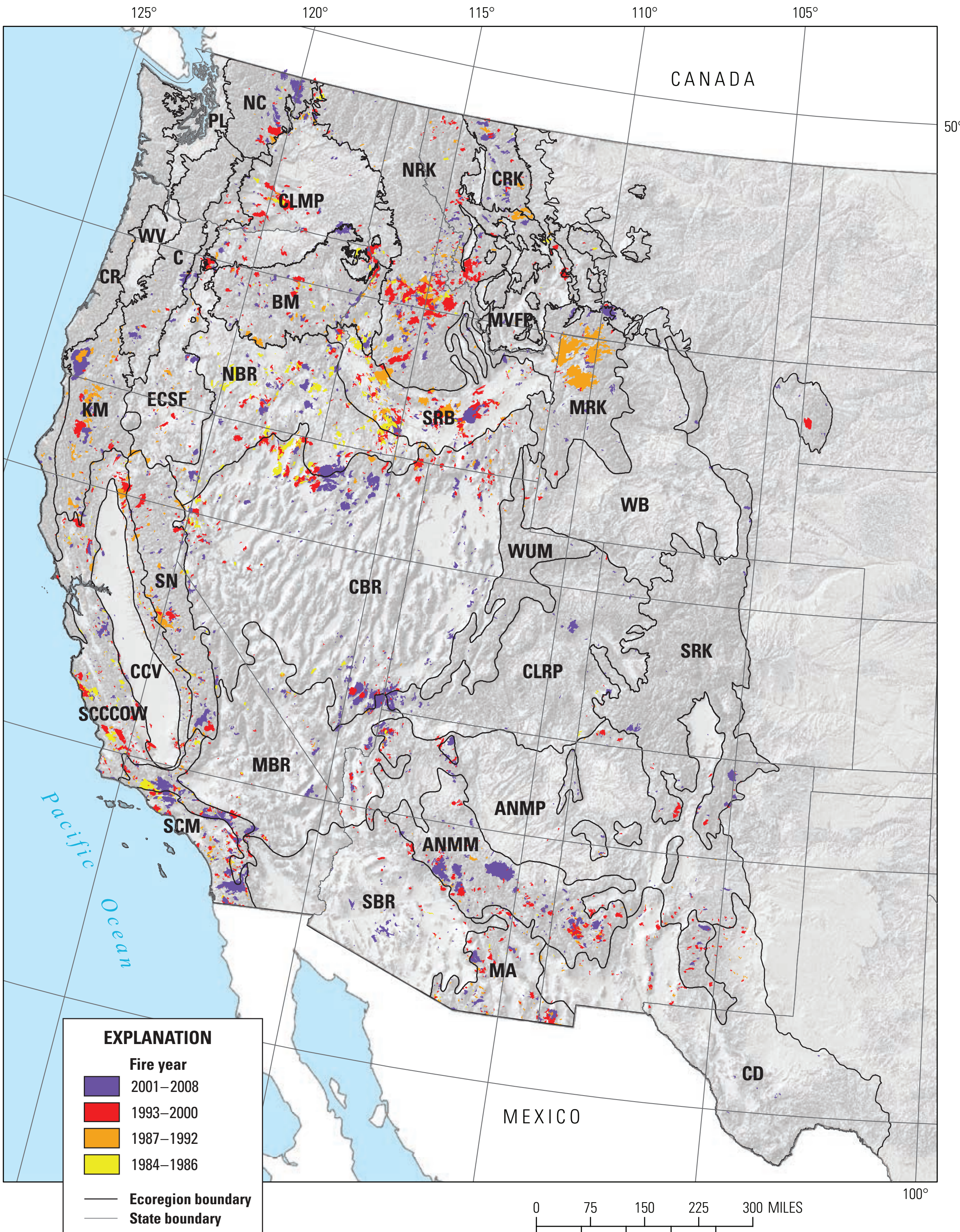


Figure 13. Areas of large fires in western United States between 1984 and 2008. Fire data captured by Monitoring Trends in Burn Severity project (Eidenshink and others, 2007).

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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Marine West Coast Forests Ecoregions

Chapter 1

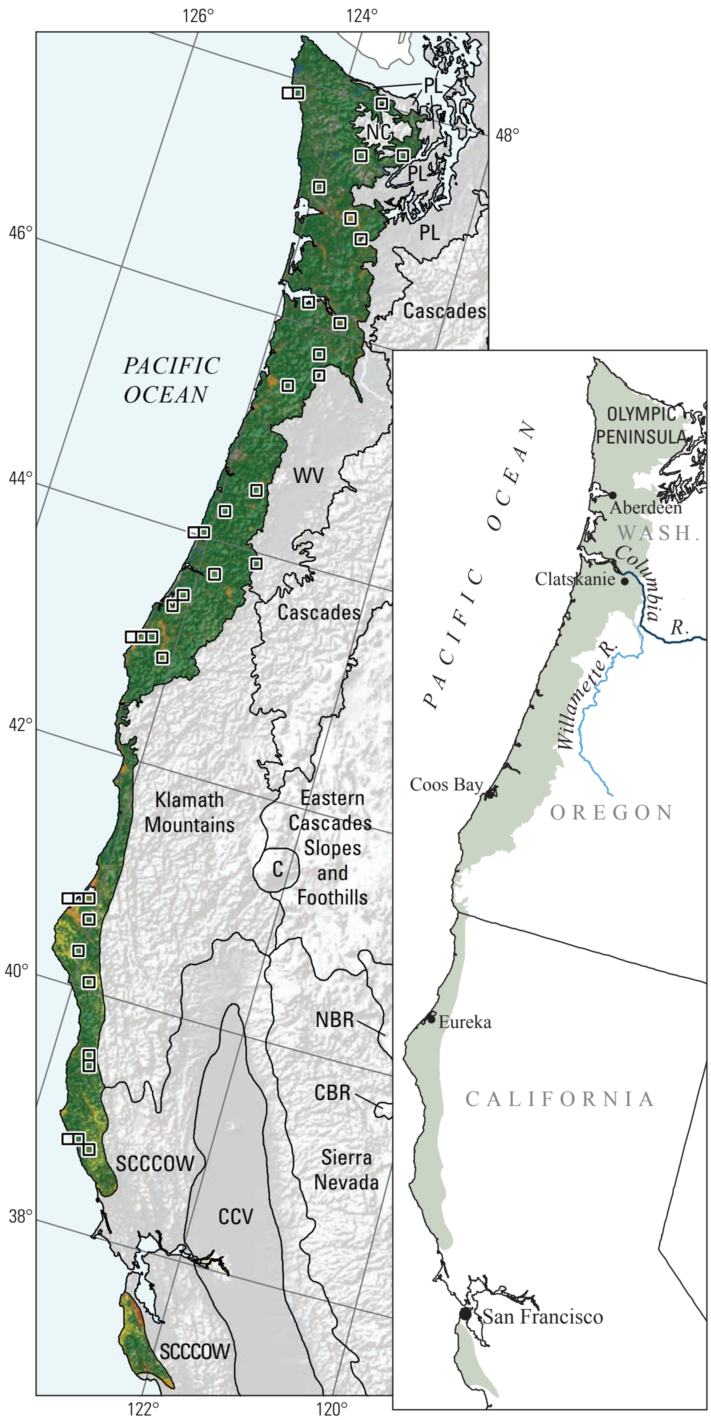
Coast Range Ecoregion

By Terry L. Sohl

Ecoregion Description

The Coast Range Ecoregion, which covers approximately 57,338 km^2 (22,138 mi^2), is a thin, linear ecoregion along the Pacific Coast, stretching roughly 1,300 km from the Olympic Peninsula, in northwest Washington, to an area south of San Francisco, California (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). It is bounded on the east by the Puget Lowland, the Willamette Valley, the Klamath Mountains, and the Southern and Central California Chaparral and Oak Woodlands Ecoregions.

Almost the entire Coast Range Ecoregion lies within 100 km of the coast. Topography is highly variable, with coastal mountain ranges and valleys ranging from sea level to over 1,000 m in elevation (fig. 2). A maritime climate, along with high topographic relief, results in substantial, but regionally variable, amounts of rainfall, ranging from 130 cm to more than 350 cm per year. The favorable climate of the Coast Range Ecoregion has supported forests of Sitka spruce (*Picea sitchensis*) along its northern coast and coast redwoods (*Sequoia sempervirens*) along its southern coast, as well as Douglas-fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) inland (Omernik, 1987). Today, however, much of the forest is heavily managed for logging (fig. 3), although the ecoregion still



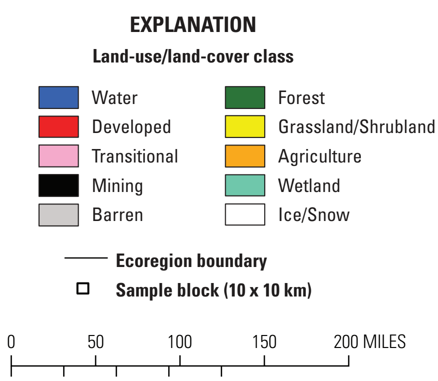


Figure 1. Map of Coast Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. Pacific Coast and forested coastal mountains of Coast Range Ecoregion.

Figure 3. Clearcut area and subsequent regrowth of planted trees in Coast Range Ecoregion.

supports some of the largest remaining areas of old-growth forest in the Pacific Northwest. Agriculture is a minor component of the landscape, present locally in flat lands and valleys near the coast. Urban development is minimal; Eureka, California, is the only urban center in the ecoregion, with a population of over 26,000 (U.S. Census Bureau, 2000).

Contemporary Land-Cover Change (1973 to 2000)

The footprint of change (the percentage of area that changed at least one time between 1973 and 2000) in the ecoregion was 25.5 percent (table 1), indicating that the Coast Range Ecoregion had one of the highest levels of change in the western United States (fig. 4). When normalized to account for varying lengths of study periods, annual rates of change increased through the first three time periods, peaking between 1986 and 1992, and then they declined slightly in the last period, between 1992 and 2000 (table 2; fig. 5).

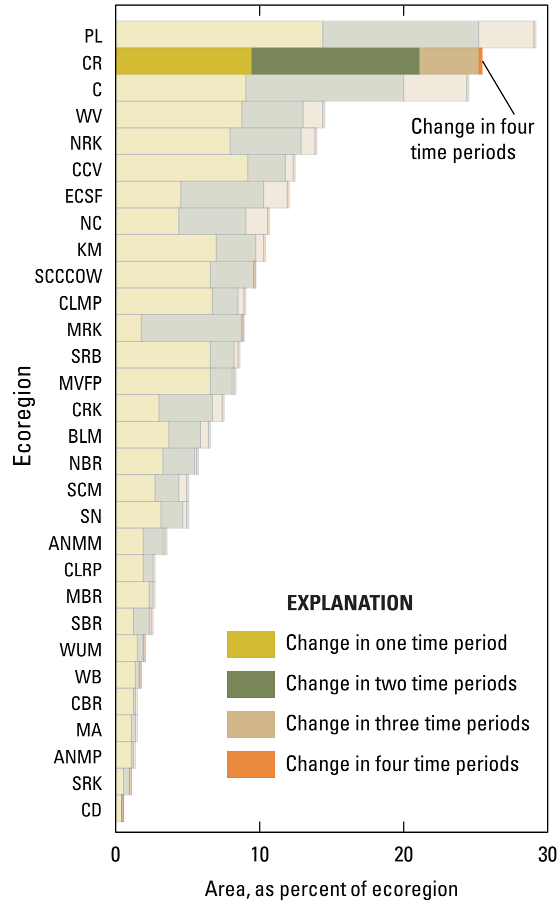


Figure 4. Overall spatial change in Coast Range Ecoregion (CR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during time periods 1, 2, 3, or 4; highest level of spatial change in Coast Range Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

A statistically significant negative trend was determined for forest land, which had a decline of 5.0 percent between 1973 and 2000 (table 3). Balancing the decline in forest land were corresponding statistically significant positive trends in the mechanically disturbed (51.3 percent) and grassland/shrubland (36.9 percent) classes. However, these gains were not constant over the four time periods. Both mechanically disturbed and grassland/shrubland experienced two periods of net gain and two periods of net loss (fig. 6).

In the Coast Range Ecoregion, the vast majority of mechanically disturbed land and grassland/shrubland were associated with the logging and subsequent replanting and regrowth of forest (fig. 7). Clearcut forest patches are initially mapped as mechanically disturbed. Depending upon local site conditions and the length of time between initial cutting and the next mapped time period, these mechanically disturbed patches typically are mapped either as an intermediate grassland/shrubland class in subsequent time periods or as forest once regrowth has

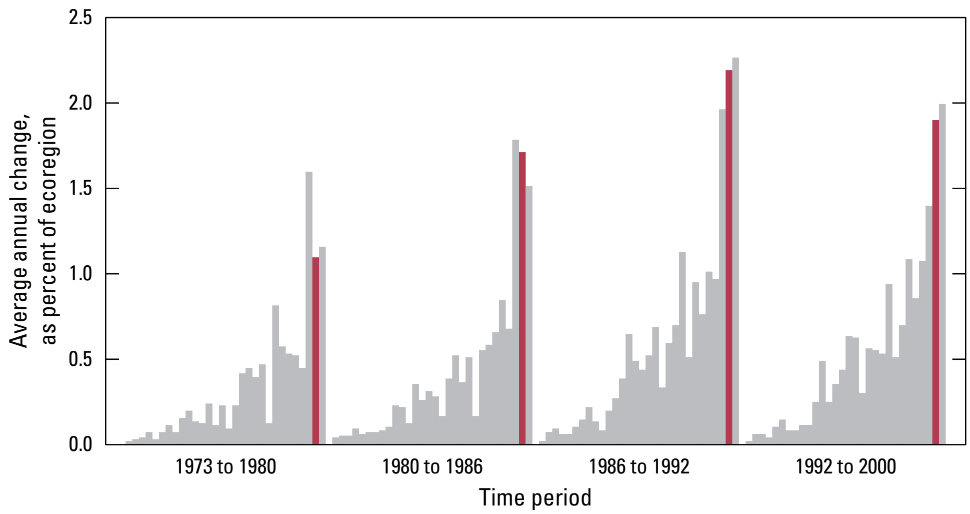


Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Coast Range Ecoregion are represented by red bars in each time period.

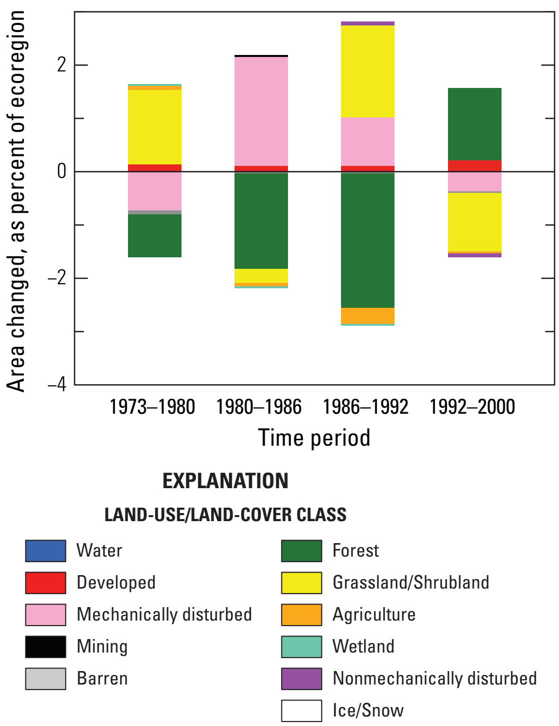


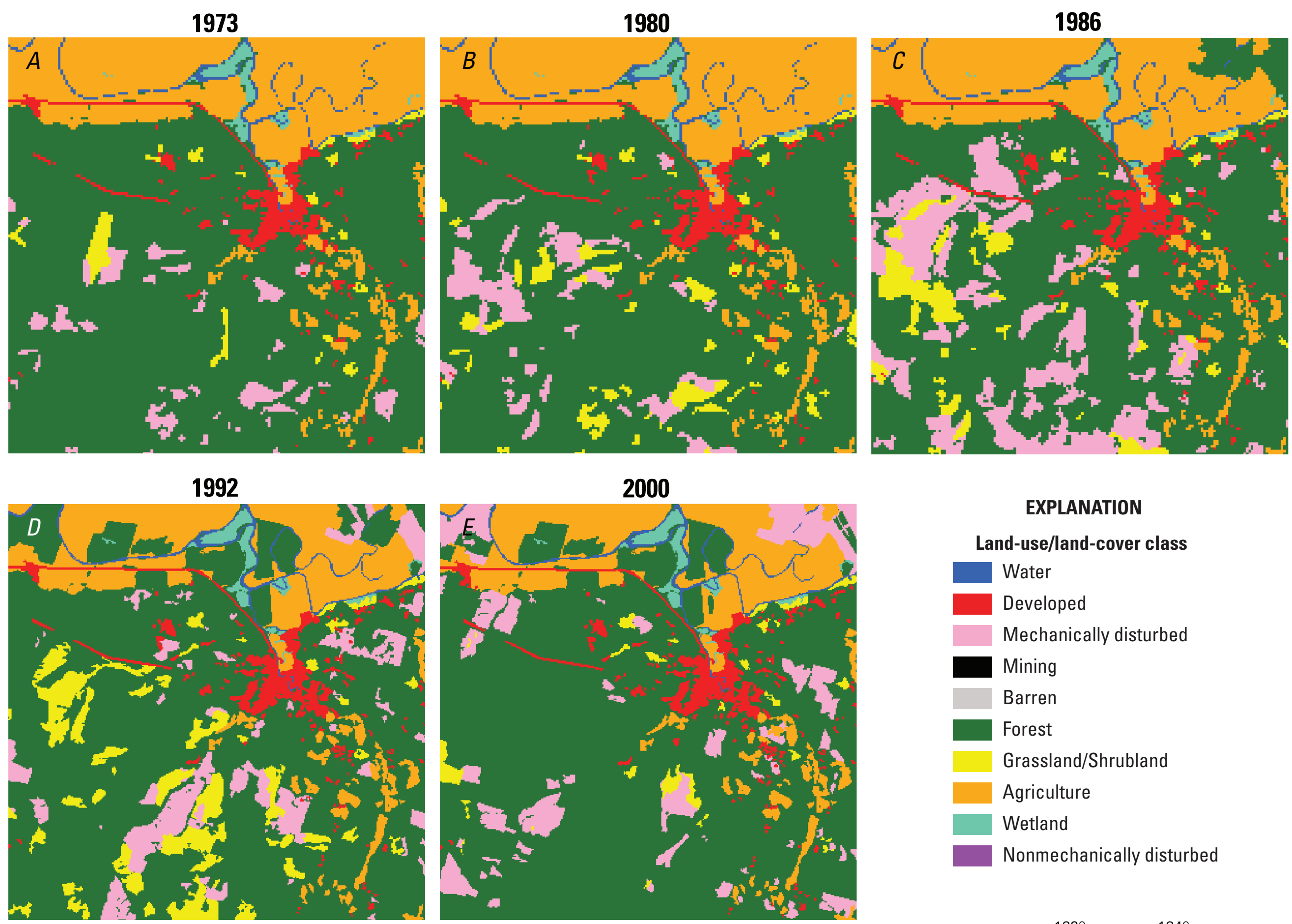
Figure 6. Normalized average net change in Coast Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

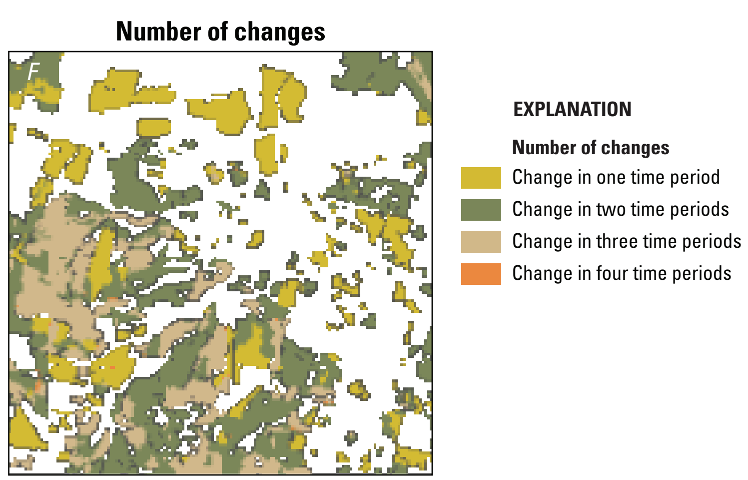
Figure 7. Clearcut (mechanically disturbed) forest in Coast Range Ecoregion and subsequent regrowth.

Figure 8. Lumberyard in Coast Range Ecoregion.

advanced sufficiently. Overall, while per-period trends in forest, mechanically disturbed, and grassland/shrubland land-cover classes fluctuated throughout the study period, total forest use (defined as the sum of forest land, mechanically disturbed land, and grassland/shrubland) remained remarkably constant (table 4).

The timber industry's effect on the landscape dominated the story of change in the ecoregion (fig. 8). For every time period, forest cutting (forest to mechanically disturbed) was the most common type of land-cover change, whereas each of the next three most common changes were related to forest regeneration (mechanically disturbed to grassland/shrubland, mechanically disturbed to forest, or grassland/shrubland to forest) (table 5). For the whole ecoregion, over 95 percent of change was associated with the timber-cutting cycle, with nearly 11,000 km^2 of cutting occurring between 1973 and 2000. Large swaths of forest land in the Coast Range Ecoregion were cut between 1973 and 2000, and they now are in a forest-regeneration stage because of the coalescence of individual patches of cut forest (fig. 9).





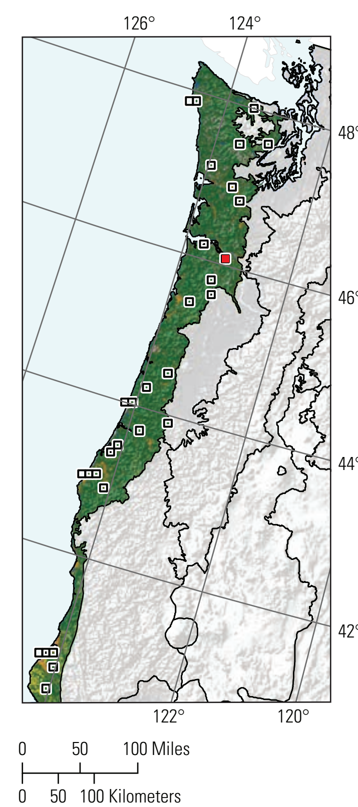


Figure 9. Maps of sample block 1-189 (red square on index map) in Coast Range Ecoregion, showing land-use/land-cover data in 1973 (*A*), 1980 (*B*), 1986 (*C*), 1992 (*D*), and 2000 (*E*). Developed (red) area is town of Clatskanie, Oregon. Over 43 percent of sample block experienced some form of land-cover change between 1973 and 2000, vast majority of which was related to timber industry. *F*, Map of sample block 1-189, showing areas that changed at least once throughout entire 27-year study period.

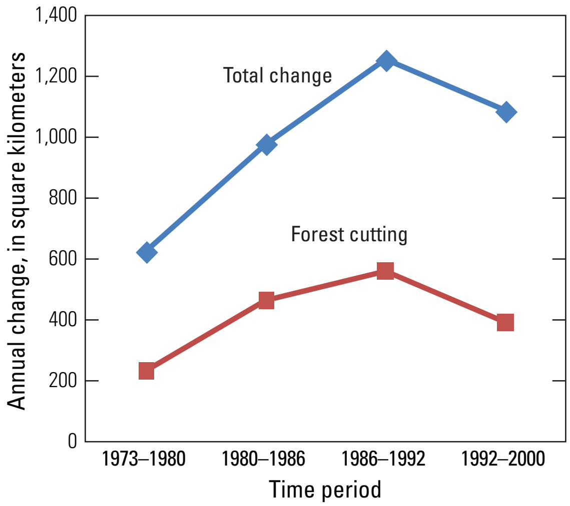


Figure 10. Annual land-cover change related to forest cutting in Coast Range Ecoregion, compared to that of total land-use/land-cover changes, for each of four time periods. Both change related to forest cutting and total change peaked between 1986 and 1992 and then declined between 1992 and 2000.

From the 1940s through the 1980s, forestry activity in the area generally focused on the cutting of natural forests and the establishment of Douglas-fir plantations on these lands (Swanson and Franklin, 1992). The annual rate of forest cutting steadily rose during the first three time periods, peaking between 1986 and 1992, and then declined between 1992 and 2000 (fig. 10). Although multiple drivers are responsible for the declines in forest cutting after 1992, the status and protection of the Northern Spotted Owl (*Strix occidentalis caurina*) likely had the biggest influence. In 1990, the Northern Spotted Owl was listed as "threatened" under the Endangered Species Act. In February 1991, an interagency scientific committee published a report addressing conservation of the Northern Spotted Owl (Thomas and others, 1990), leading U.S. District Court Judge Dwyer to block timber sales in national forest lands in the area to protect the species. In December 1994, Judge Dwyer accepted the Northwest Forest Plan, a comprehensive document directing coordinated management activities for lands administered by the U.S. Forest Service and the Bureau of Land Management. The plan permitted the cutting of 1 billion board feet of timber from public lands per year, only one-fourth the timber-harvest levels of the 1980s (Espy and Babbitt, 1994).

Another contributing factor responsible for the 1990s decline in forest cutting was the very high rate of logging in the 1980s, which may have been unsustainable over the long term given the 40- to 60-year cutting cycle that is typical for Douglas-fir in the ecoregion. In addition, Pacific Northwest forestry as a whole has been increasingly outcompeted by forestry operations in the southeastern United States and the interior of Canada, and the ecoregion has been at a competitive disadvantage for providing wood products to markets in the eastern and southern United States. Siberian larch (*Larix sibirica*) and Norway spruce (*Picea abies*) from Russian plantations, as well as Monterey pine (*Pinus radiata*) from more recently established plantations in New Zealand and Chile, also strongly increased their presence in the softwood lumber market in the 1990s (Gataulina and Waggener, 1998; Center for International Trade in Forest Products, 1993). At the same time, once-strong Pacific Northwest exports of wood products to large Asian markets (primarily Japan, South Korea, and China) declined throughout the 1990s (fig. 11). Changes in the Japanese housing industry, along

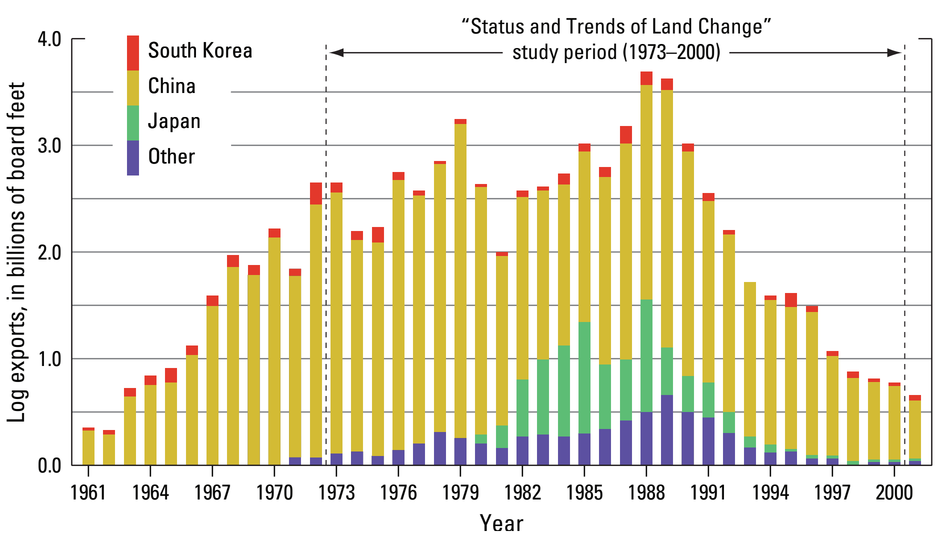


Figure 11. Exports of Pacific Northwest logs between 1961 and 2001 (from Daniels, 2005). Note how exports to all areas fell dramatically during 1990s.

with the Asian economic collapse of the 1990s, were major factors in declining exports (Daniels, 2005).

Land-cover changes in the ecoregion, other than those related to logging, were relatively minor. A statistically significant trend occurred in developed lands, which increased from 2.5 to 3.1 percent of the ecoregion between 1973 and 2000 (table 3). Most of the observed development was associated with the largest cities in the ecoregion: Eureka, California (population over 26,128 in 2000); Aberdeen, Washington (population, 16,461 in 2000); and Coos Bay, Oregon (population, 15,374) (U.S. Census, 2000). In addition, scattered high-value developments were found in areas with recreational amenities.

Table 1. Percentage of Coast Range Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (74.5 percent), whereas 25.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	9.5	1.5	7.9	11.0	1.0	10.9
2	11.6	1.9	9.7	13.5	1.3	11.1
3	4.2	1.1	3.1	5.4	0.8	18.2
4	0.2	0.1	0.1	0.3	0.1	27.5
Overall spatial change	25.5	3.9	21.7	29.4	2.6	10.3

Table 2. Raw estimates of change in Coast Range Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	7.6	1.2	6.4	8.8	0.8	10.6	1.1
1980–1986	10.3	2.0	8.2	12.3	1.4	13.4	1.7
1986–1992	13.1	2.3	10.9	15.4	1.5	11.8	2.2
1992–2000	15.2	2.9	12.3	18.1	2.0	13.0	1.9
Estimate of change, in square kilometers							
1973–1980	4,380	688	3,692	5,068	465	10.6	626
1980–1986	5,880	1,168	4,712	7,047	789	13.4	980
1986–1992	7,535	1,312	6,223	8,848	887	11.8	1,256
1992–2000	8,700	1,668	7,032	10,369	1,128	13.0	1,088

Table 3. Estimated area (and margin of error) of each land-cover class in Coast Range Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	5.1	3.0	2.5	1.3	3.7	0.9	0.0	0.0	1.2	0.6	76.2	4.1	4.6	1.4	5.7	2.1	1.0	0.7	0.0	0.0
1980	5.1	3.0	2.6	1.3	3.0	0.5	0.0	0.0	1.1	0.6	75.4	4.2	6.0	1.0	5.7	2.1	1.0	0.7	0.0	0.0
1986	5.1	3.0	2.8	1.4	5.0	1.2	0.0	0.0	1.1	0.6	73.5	4.1	5.7	1.1	5.7	2.1	1.0	0.7	0.0	0.0
1992	5.1	3.0	2.9	1.4	6.0	1.2	0.0	0.0	1.1	0.6	71.0	3.9	7.4	1.2	5.4	2.0	1.0	0.7	0.1	0.1
2000	5.1	3.0	3.1	1.5	5.6	1.4	0.0	0.0	1.0	0.5	72.4	4.0	6.3	1.2	5.4	2.0	1.0	0.7	0.0	0.0
Net change	0.0	0.0	0.6	0.3	1.9	1.5	0.0	0.0	−0.2	0.1	−3.8	1.9	1.8	1.0	−0.3	0.4	0.0	0.0	0.0	0.0
Gross change	0.1	0.0	0.6	0.3	10.4	2.1	0.0	0.0	0.2	0.1	12.9	2.1	8.2	2.1	0.8	0.5	0.0	0.0	0.1	0.2
Area, in square kilometers																				
1973	2,941	1,696	1,438	744	2,142	493	18	17	673	364	43,676	2,349	2,627	782	3,245	1,215	562	406	0	0
1980	2,937	1,695	1,516	770	1,723	314	21	17	641	348	43,208	2,382	3,422	595	3,288	1,211	565	407	0	0
1986	2,941	1,699	1,579	789	2,890	698	23	19	633	335	42,165	2,368	3,284	610	3,247	1,181	558	406	0	0
1992	2,940	1,699	1,647	823	3,423	688	25	19	614	329	40,720	2,226	4,270	672	3,087	1,136	557	406	39	56
2000	2,947	1,707	1,772	845	3,227	794	25	20	584	307	41,504	2,270	3,636	680	3,073	1,139	553	398	0	0
Net change	7	15	334	162	1,085	850	7	6	−89	79	-2,172	1,074	1,009	594	−172	246	-9	10	0	0
Gross change	38	23	335	162	5,977	1,203	8	6	120	79	7,397	1,177	4,719	1,194	445	287	20	13	77	111

Table 4. Percentages of forest use, defined as sum of forest, mechanically disturbed, and grassland/shrubland land-cover classes, in Coast Range Ecoregion, showing that forest use remained remarkably constant over study period.

Year	Forest use (% of ecoregion)
1973	84.5
1980	84.3
1986	84.3
1992	84.4
2000	84.4

Table 5. Principal land-cover conversions in Coast Range Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	1,638	282	191	2.9	37.4
	Mechanically disturbed	Grassland/Shrubland	1,195	309	209	2.1	27.3
	Mechanically disturbed	Forest	863	288	195	1.5	19.7
	Grassland/Shrubland	Forest	451	228	154	0.8	10.3
	Forest	Agriculture	60	63	42	0.1	1.4
	Other	Other	174	n/a	n/a	0.3	4.0
		Totals	4,380			7.6	100.0
1980–1986	Forest	Mechanically disturbed	2,796	686	464	4.9	47.6
	Grassland/Shrubland	Forest	1,094	304	206	1.9	18.6
	Mechanically disturbed	Grassland/Shrubland	920	215	146	1.6	15.6
	Mechanically disturbed	Forest	734	177	120	1.3	12.5
	Agriculture	Forest	61	59	40	0.1	1.0
	Other	Other	274	n/a	n/a	0.5	4.7
		Totals	5,880			10.3	100.0
1986–1992	Forest	Mechanically disturbed	3,362	675	456	5.9	44.6
	Mechanically disturbed	Grassland/Shrubland	1,801	543	367	3.1	23.9
	Mechanically disturbed	Forest	1,049	344	232	1.8	13.9
	Grassland/Shrubland	Forest	911	203	137	1.6	12.1
	Agriculture	Forest	124	142	96	0.2	1.6
	Other	Other	288	n/a	n/a	0.5	3.8
		Totals	7,535			13.1	100.0
1992–2000	Forest	Mechanically disturbed	3,147	780	527	5.5	36.2
	Mechanically disturbed	Forest	2,173	557	376	3.8	25.0
	Grassland/Shrubland	Forest	1,847	560	378	3.2	21.2
	Mechanically disturbed	Grassland/Shrubland	1,178	327	221	2.1	13.5
	Forest	Developed	92	45	31	0.2	1.1
	Other	Other	263	n/a	n/a	0.5	3.0
		Totals	8,700			15.2	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	10,943	1,973	1,334	19.1	41.3
	Mechanically disturbed	Grassland/Shrubland	5,093	1,116	755	8.9	19.2
	Mechanically disturbed	Forest	4,820	975	659	8.4	18.2
	Grassland/Shrubland	Forest	4,303	926	626	7.5	16.2
	Forest	Developed	236	117	79	0.4	0.9
	Other	Other	1,100	n/a	n/a	1.9	4.2
		Totals	26,495			46.2	100.0

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Chapter 2

Puget Lowland Ecoregion

By Daniel G. Sorenson

Ecoregion Description

The Puget Lowland Ecoregion covers an area of approximately 18,009 km² (6,953 mi²) within northwestern Washington (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion is located between the Coast Range Ecoregion to the west, which includes the Olympic Mountains, and the North Cascades and the Cascades Ecoregions to the east, which include the Cascade Range. From the north, the ecoregion follows the Interstate 5 corridor, from the Canadian border south through Bellingham, Seattle, Olympia, and Longview, Washington, to the northern border of the Willamette Valley Ecoregion. The Puget Lowland Ecoregion borders the shoreline of the greater Puget Sound, a complex bay and saltwater estuary fed by spring freshwater runoff from the Olympic Mountains and Cascade Range watersheds. The ecoregion is situated in a continental glacial trough that has many islands, peninsulas, and bays. Relief is moderate, with elevations ranging from sea level to 460 m but averaging approximately 150 m (DellaSala and others, 2001).

Proximity to the Pacific Ocean gives the Puget Lowland Ecoregion its mild maritime climate (U.S. Environmental Protection Agency, 1999). Mean annual temperature is 10.5°C, with an average of 4.1°C in January and 17.7°C in July (Guttman and Quayle, 1996). Average annual precipitation ranges from 800 to 900 mm, but some areas in the rain shadow of the Olympic Mountains receive as little as 460 mm (DellaSala and

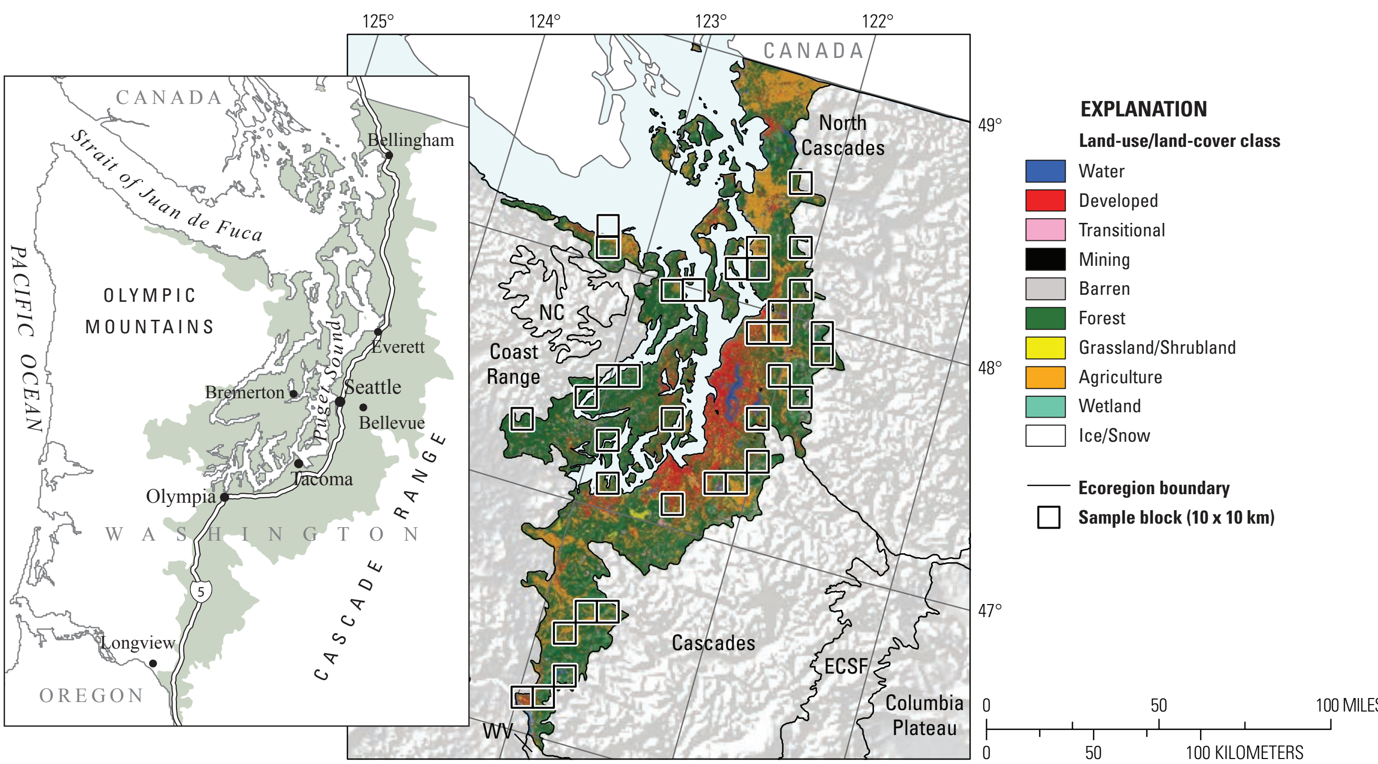

Figure 1. Map of Puget Lowland Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

others, 2001). Varying annual average precipitation greatly influences vegetation and soil type in the ecoregion. In the Puget Lowland Ecoregion, soils are dominated by Inceptisols in the north and Ultisols in the south (Jones, 2003). Before European settlement, most of the ecoregion was covered by coniferous forests, with species composition dependent on local climate (U.S. Environmental Protection Agency, 1999). The World Wildlife Fund places the Puget Lowland Ecoregion in the Western Hemlock Vegetation Zone. Although this vegetation zone is named after the western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*) is the dominant tree species.

Seattle, which had an estimated population of 563,376 in 2000, is the largest city in the Puget Lowland Ecoregion (Puget Sound Regional Council, 2001). The greater Seattle metropolitan area, comprising Seattle, Tacoma, Bellevue, and Bremerton, had an estimated population of 3.5 million people in 2000 (U.S. Census Bureau, 2000). Other sizable cities in the ecoregion include the state capital Olympia, as well as Tacoma, Bellingham, and Everett, Washington. The center of the Puget Lowland Ecoregion is dominated by the Seattle metropolitan area and developed land cover, whereas agriculture occurs mainly on river floodplains in the north and south. The remainder of the ecoregion area is dominated by forest land cover (fig. 1).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change in the Puget Lowland Ecoregion (that is, the percentage of the land cover that changed at least once between 1973 and 2000) was estimated at 28.0 percent (5,041 km²) (table 1). When compared with other ecoregions in the western United States, the Puget Lowland Ecoregion had the highest percentage of change in the last two of the four time periods analyzed (fig. 2). Between 1992 and 2000 alone, 16.0 percent of the ecoregion changed from one land-cover class to another (table 2). However, when the change estimates are normalized to an annual average to account for varying lengths of study periods, the normalized annual average rate of change was highest in the third time period between 1986 and 1992, at 2.3 percent (table 2). Compared to other western ecoregions, Puget Lowland Ecoregion experienced the most overall change of any ecoregion in the West (fig. 3).

Land-cover estimates in 2000 for the Puget Lowland Ecoregion show forest as the most common land-cover class (47.1 percent), followed by developed (18.8 percent), water (12.9 percent), and agriculture (10.4 percent). All other land-cover classes were estimated at less than 5 percent of the ecoregion's land cover (table 3). Land-cover classes with the highest estimates of change were the forest, developed, mechanically disturbed, and grassland/shrubland. Between 1973 and 2000, the largest net change in land cover occurred in the forest class, with an estimated loss of 17.2 percent (1,767 km²). The second largest absolute net change in the ecoregion was the 53.8 percent (1,186 km²) increase in developed lands. Mechanical disturbance played a large role in land-cover change in the Puget Lowland Ecoregion. This transitional land-cover class, attributed primarily to forest cutting in this ecoregion, affected an estimated 3,591 km², with the highest estimates recorded between 1986 and 1992 (6 percent of ecoregion area; 1,084 km²). Agriculture decreased by 5.4 percent (107 km²), with all losses occurring in the last two time periods. Grassland/shrubland more than doubled, increasing by 327 km² during the study period, but still accounted for only 3.1 percent of the ecoregion in 2000. All other classes increased or decreased less than 50 km² (table 3; fig. 4).

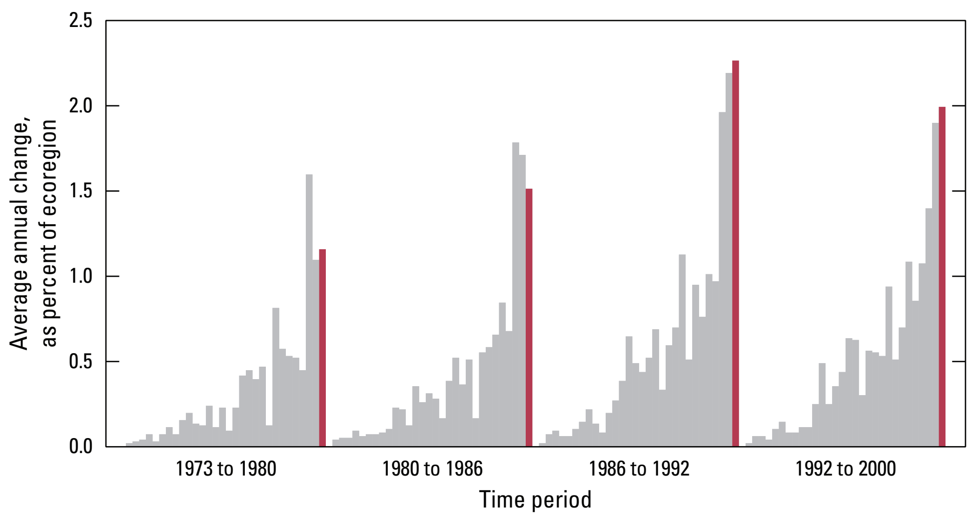

Figure 2. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Puget Lowland Ecoregion are represented by red bars in each time period.

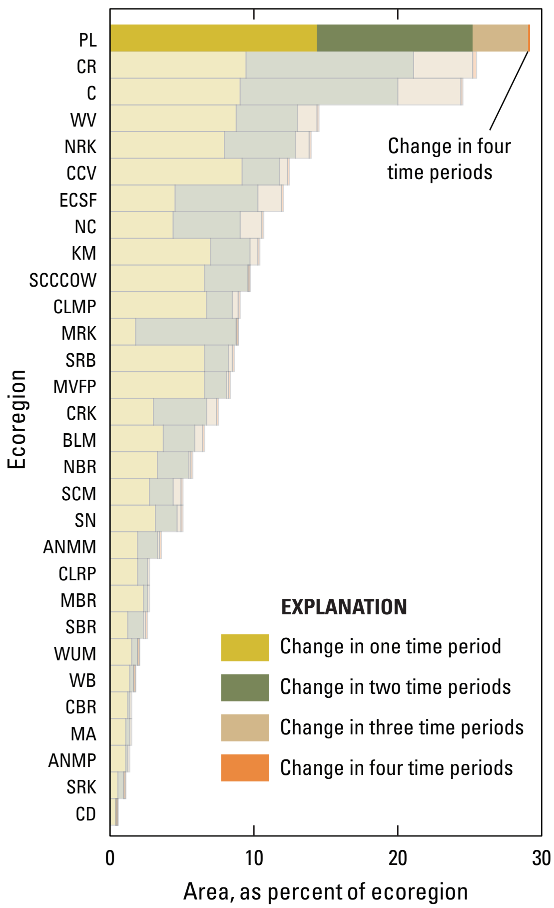

Figure 3. Overall spatial change in Puget Lowland Ecoregion (PL; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Puget Lowland Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

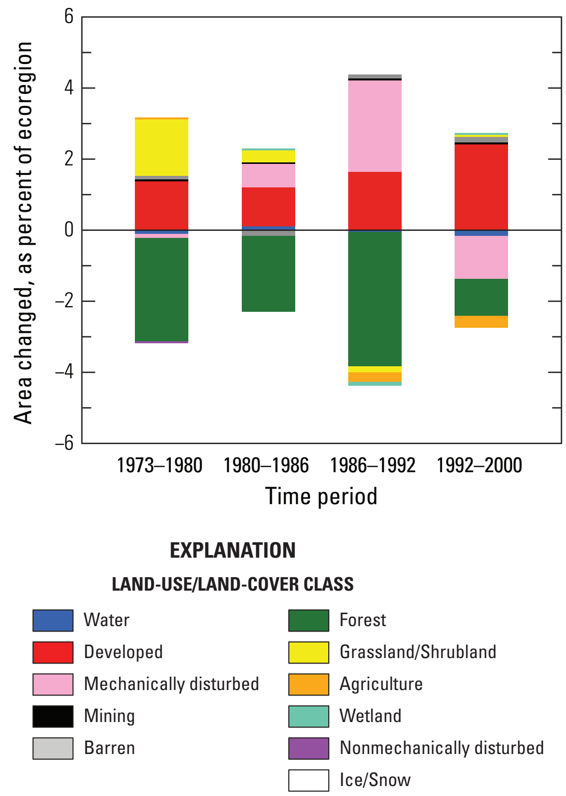

Figure 4. Normalized average net change in Puget Lowland Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Four of the top five largest land-cover conversions in the ecoregion were associated with timber harvest and forest regeneration (table 4; figs. 5,6). Timber harvesting is generally accepted as a change from forest to mechanically disturbed, with forest regrowth occurring either rapidly (mechanically disturbed directly back to forest) or more slowly (mechanically disturbed to grassland/shrubland and then grassland/shrubland to forest). The only leading land-cover conversion not related to timber harvest and forest regeneration was losses of forest to developed land. In each time period except the last, the conversion from forest to other land-cover classes accounted for at least half of all land-cover change.

Regrowth of forest here occurs at a moderate pace, aided by mandated replanting efforts (fig. 6). Since 1975, the Washington State Department of Natural Resources (WADNR) has required land owners to plant seedlings of desirable species within 3 years of forest harvest to prevent the spread of invasive species (Washington State Department of Natural Resources, 2001). This requirement also helps establish steady forest regrowth rates after harvest. Logging declines estimated in the last time period between 1992 and 2000 coincide with notable declines in lumber and wood exports from Washington in the 1990s (fig. 7). The export market suffered as a result of market downturns in Japan and Asia, reducing demand for wood-based products. At the same time, forests in the Pacific Northwest also faced increasing competition from other wood-producing countries, such as Russia, Canada, and New Zealand.

The 1990s also ushered in an era of federal forest protection in the Pacific Northwest. The Northwest Forest Plan was implemented to protect the old-growth forest habitat of the threatened Northern Spotted Owl (*Strix occidentalis caurina*). (Daniels, 2005). The Northern Spotted Owl prefers to roost, forage, and nest in old growth forests that have moderate to high canopy enclosure and many large trees (Tesky, 1992). Under the Northwest Forest Plan, timber harvest was banned on 10 million of the 17 million acres (40,000 of 69,000 km^2) of national forest land in the Pacific Northwest. Before the Northwest Forest Plan, timber sales from these national forests were approximately 4 to 5 billion board feet per year. After

Figure 5. Transportation of logged trees in Puget Lowland Ecoregion.

Figure 6. Logging activity and various stages of forest regrowth in Puget Lowland Ecoregion, including recently replanted seedlings in addition to reestablished forest stand next to older growth trees.

Figure 7. Logging exports at one of many shipping ports along Puget Sound.

1990, sales dropped to less than a billion board feet per year. The WADNR changed its regulatory rules for State forests in the 1990s as well, to ensure sustainable logging practices and protect critical wildlife habitat. In 1999, the Forests and Fish Law was enacted in Washington, protecting critical salmon (*Oncorhynchus* spp.) habitat by requiring tree buffers along stream banks, even on private land (Daniels, 2005).

The second most important driver of land-cover change in the Puget Lowland Ecoregion was the increase in developed land. Most of the developed land (73.4 percent) was in areas that were previously forest land (fig. 8). The largest gain in developed land occurred between 1992 and 2000, and the slowest growth occurred between 1980 and 1986. During the 1980s, the Puget Lowland Ecoregion experienced an economic downturn. By 1982, the unemployment rate was above 10 percent. Net migration of people into the ecoregion dropped to zero in 1983 but remained above 20,000 per year for the rest of the study period (Puget Sound Regional Council, 2007). By the 1990s, the economic situation in Puget Lowland Ecoregion improved, and the population increased, led by employment opportunities and growth in the technology sector, including the biotechnology, computer, electronic equipment, software, and telecommunications industries. The ecoregion experienced a 65.4 percent increase in technology jobs between 1995 and 2001, adding more than 60,000 jobs at a 7.8 percent rate

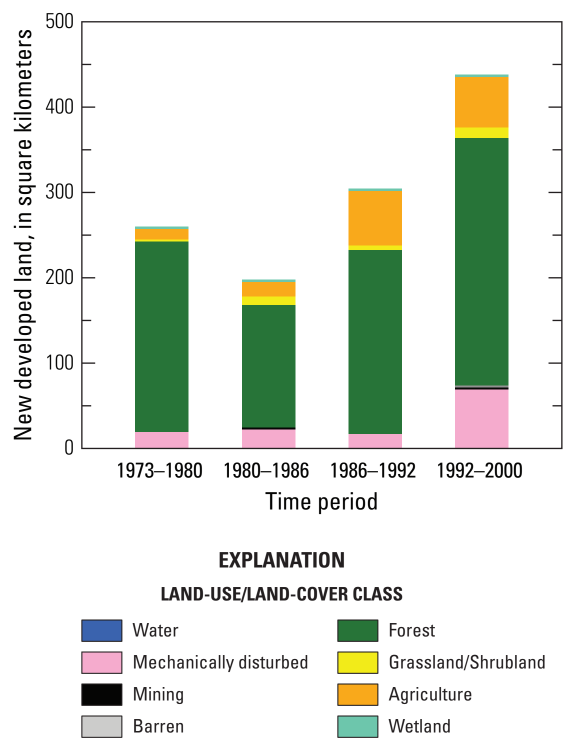

Figure 8. Gains in developed land-cover class in Puget Lowland Ecoregion. Values are areas in square kilometers that converted into developed land. Colors indicate which land-cover class converted to developed land.

Figure 9. New developed land along forest margin in Puget Lowland Ecoregion, with agricultural land preserved.

annually (Puget Sound Regional Council, 2006). By 1999, the technology sector of manufacturing (excluding transportation equipment) and industrial machinery surpassed lumber and wood products as Washington's third leading export commodity (Lin and Schmidt, 2000).

With a substantial growth in developed land in Puget Lowland Ecoregion, one might expect a large decline in agricultural land, but this was not the case (table 3; fig. 9). Only 12.8 percent of new developed land came at the expense of agriculture. Although western Washington makes up only 5 percent of the state's farmland, it contributed 23 percent of the agricultural earnings in 1992. Small farms tend to grow high-value crops such as fruits, vegetables, and greenhouse products. To prevent the loss of large amounts of agriculture land to developed land, the Washington State legislature enacted the Washington State Growth Management Act (GMA) in 1990. The GMA requires the fastest growing and most populated counties to adopt broad land-use plans. One of GMA's provisions is the protection of agricultural lands of long-term commercial significance for the safeguarding of food production (Klein and Reganold, 1997). A principal goal of the GMA was to reduce the conversion of undeveloped and agricultural land into sprawling, low-density developed land. The intention was to direct new development to urban growth areas (UGA) that are usually located adjacent to existing cities and towns. The Puget Sound Regional Council reported that, between 1995 and 2000, 87 percent of the population growth in the region occurred inside the UGAs. Directing growth within UGAs allowed natural resource lands, such as farms and forests, to be conserved and to retain their rural character (Washington State Department of Community Trade and Economic Development, 2003).

The Puget Lowland Ecoregion experienced some of the highest estimates of land-cover change that occurred in the western United States over the entire study period (1973–2000). The largest proportion of change was attributed to land-cover conversions related to forestry and forest regeneration. Clearcut areas tend to be large, and the successional regrowth takes many years, depending on replanting times and local climate. Along with the changes in forests, the Puget Lowland Ecoregion had a notable increase in developed land. The aerospace and computer technology industries fostered an economic boom in the Puget Lowland Ecoregion in the 1990s, with associated population expansion and increased housing demand. Agricultural land cover remained fairly stable, with a slight net decline.

Table 1. Percentage of Puget Lowland Ecoregion that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (72.0 percent), whereas 28.0 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	13.1	1.1	12.2	14.5	0.8	5.7
2	10.7	1.9	8.8	12.6	1.3	12.1
3	3.7	0.9	2.8	4.5	0.6	15.7
4	0.2	0.1	0.2	0.3	0.0	15.2
Overall spatial change	28.0	3.1	24.9	31.1	2.1	7.4

Table 2. Raw estimates of change in Puget Lowland Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	8.1	1.0	7.1	9.1	0.7	8.1	1.2
1980–1986	9.1	1.5	7.6	10.6	1.0	11.3	1.5
1986–1992	13.6	2.2	11.4	15.8	1.5	10.9	2.3
1992–2000	16.0	2.4	13.6	18.4	1.6	10.2	2.0
			Estimate of change, in square kilometers				
1973–1980	1,463	175	1,287	1,638	119	8.1	209
1980–1986	1,639	273	1,366	1,911	185	11.3	273
1986–1992	2,454	395	2,058	2,849	268	10.9	409
1992–2000	2,877	433	2,444	3,310	293	10.2	360

Table 3. Estimated area (and margin of error) of each land-cover class in Puget Lowland Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	13.1	5.3	12.2	2.6	2.9	0.7	0.2	0.1	0.4	0.1	56.9	4.0	1.3	0.4	11.0	2.6	1.9	0.5	0.0	0.1
1980	13.1	5.3	13.6	2.8	2.8	0.7	0.2	0.1	0.5	0.2	54.0	4.0	2.9	0.7	11.0	2.6	1.9	0.5	0.0	0.0
1986	13.2	5.3	14.7	3.0	3.4	0.9	0.3	0.1	0.3	0.1	51.9	3.9	3.2	0.7	11.0	2.6	1.9	0.5	0.0	0.0
1992	13.1	5.3	16.4	3.2	6.0	1.3	0.3	0.1	0.4	0.1	48.1	3.7	3.1	0.7	10.7	2.6	1.8	0.5	0.0	0.0
2000	12.9	5.3	18.8	3.4	4.8	1.0	0.4	0.1	0.6	0.2	47.1	3.9	3.1	0.7	10.4	2.6	1.9	0.5	0.0	0.0
Net change	−0.2	0.1	6.6	1.3	1.9	0.9	0.2	0.1	0.2	0.1	−9.8	1.3	1.8	0.6	−0.6	0.5	0.0	0.1	0.0	0.1
Gross change	0.8	0.4	6.6	1.3	10.6	2.1	0.2	0.1	0.7	0.4	13.1	1.8	7.2	1.4	1.4	0.5	0.3	0.1	0.0	0.1
									Area, in square kilometers											
1973	2,367	958	2,204	461	523	125	31	11	71	25	10,254	721	233	79	1,974	466	345	87	8	11
1980	2,352	958	2,457	499	498	120	41	15	88	32	9,733	721	523	130	1,979	471	339	85	0	0
1986	2,373	960	2,653	532	619	159	48	18	61	21	9,345	705	583	123	1,981	473	347	87	0	0
1992	2,361	958	2,954	579	1,084	243	58	21	76	24	8,667	659	550	127	1,929	477	332	84	0	0
2000	2,329	954	3,390	617	867	183	68	27	104	35	8,487	695	561	121	1,867	469	337	84	0	0
Net change	−38	23	1,186	231	344	154	37	17	33	24	−1,767	239	327	115	−107	95	−8	13	−8	11
Gross change	144	72	1,186	231	1,916	371	43	16	124	69	2,360	328	1,298	255	245	88	58	26	8	11

Table 4. Principal land-cover conversions in Puget Lowland Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	485	120	81	2.7	33.2
	Mechanically disturbed	Grassland/Shrubland	361	100	68	2.0	24.7
	Forest	Developed	222	62	42	1.2	15.2
	Mechanically disturbed	Forest	137	57	38	0.8	9.3
	Grassland/Shrubland	Forest	76	32	22	0.4	5.2
	Other	Other	182	n/a	n/a	1.0	12.5
		Totals	1,463			8.1	100.0
1980–1986	Forest	Mechanically disturbed	611	158	107	3.4	37.3
	Mechanically disturbed	Grassland/Shrubland	315	90	61	1.7	19.2
	Grassland/Shrubland	Forest	244	61	41	1.4	14.9
	Mechanically disturbed	Forest	153	48	32	0.8	9.3
	Forest	Developed	144	56	38	0.8	8.8
	Other	Other	172	n/a	n/a	1.0	10.5
		Totals	1,639			9.1	100.0
1986–1992	Forest	Mechanically disturbed	1,067	243	165	5.9	43.5
	Grassland/Shrubland	Forest	363	97	66	2.0	14.8
	Mechanically disturbed	Grassland/Shrubland	335	93	63	1.9	13.7
	Mechanically disturbed	Forest	260	90	61	1.4	10.6
	Forest	Developed	215	52	35	1.2	8.8
	Other	Other	214	n/a	n/a	1.2	8.7
		Totals	2,454			13.6	100.0
1992–2000	Forest	Mechanically disturbed	851	183	124	4.7	29.6
	Mechanically disturbed	Forest	559	183	124	3.1	19.4
	Mechanically disturbed	Grassland/Shrubland	442	112	76	2.5	15.4
	Grassland/Shrubland	Forest	425	113	76	2.4	14.8
	Forest	Developed	290	43	29	1.6	10.1
	Other	Other	310	n/a	n/a	1.7	10.8
		Totals	2,877			16.0	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	3,013	598	405	16.7	35.7
	Mechanically disturbed	Grassland/Shrubland	1,453	278	189	8.1	17.2
	Grassland/Shrubland	Forest	1,109	226	153	6.2	13.1
	Mechanically disturbed	Forest	1,108	314	213	6.2	13.1
	Forest	Developed	871	186	126	4.8	10.3
	Other	Other	878	n/a	n/a	4.9	10.4
		Totals	8,432			46.8	100.0

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Chapter 3

Willamette Valley Ecoregion

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Ecoregion Description

The Willamette Valley Ecoregion (as defined by Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 14,458 km² (5,582 mi²), making it one of the smallest ecoregions in the conterminous United States. The long, alluvial Willamette Valley, which stretches north to south more than 193 km and ranges from 32 to 64 km wide, is nestled between the sedimentary and metamorphic Coast Ranges (Coast Range Ecoregion) to the west and the basaltic Cascade Range (Cascades Ecoregion) to the east (fig. 1). The Lewis and Columbia Rivers converge at the ecoregion's northern boundary in Washington state; however, the majority of the ecoregion falls within northwestern Oregon. Interstate 5 runs the length of the valley to its southern boundary with the Klamath Mountains Ecoregion. Topography here is relatively flat, with elevations ranging from sea level to 122 m. This even terrain, coupled with mild, wet winters, warm, dry summers, and nutrient-rich soil, makes the Willamette Valley the most important agricultural region in Oregon. Population centers are concentrated along the valley floor. According to estimates from the Oregon Department of Fish and Wildlife (2006), over 2.3 million people lived in Willamette Valley in 2000. Portland, Oregon, is the largest city, with 529,121 residents (U.S. Census Bureau, 2000). Other sizable cities include Eugene, Oregon; Salem (Oregon's state capital); and Vancouver, Washington.

Despite the large urban areas dotting the length of the Willamette Valley Ecoregion, agriculture and forestry products are its economic foundation (figs. 2,3). The valley is a major producer of grass seed, ornamental plants, fruits, nuts, vegetables, and grains, as well as poultry, beef, and dairy

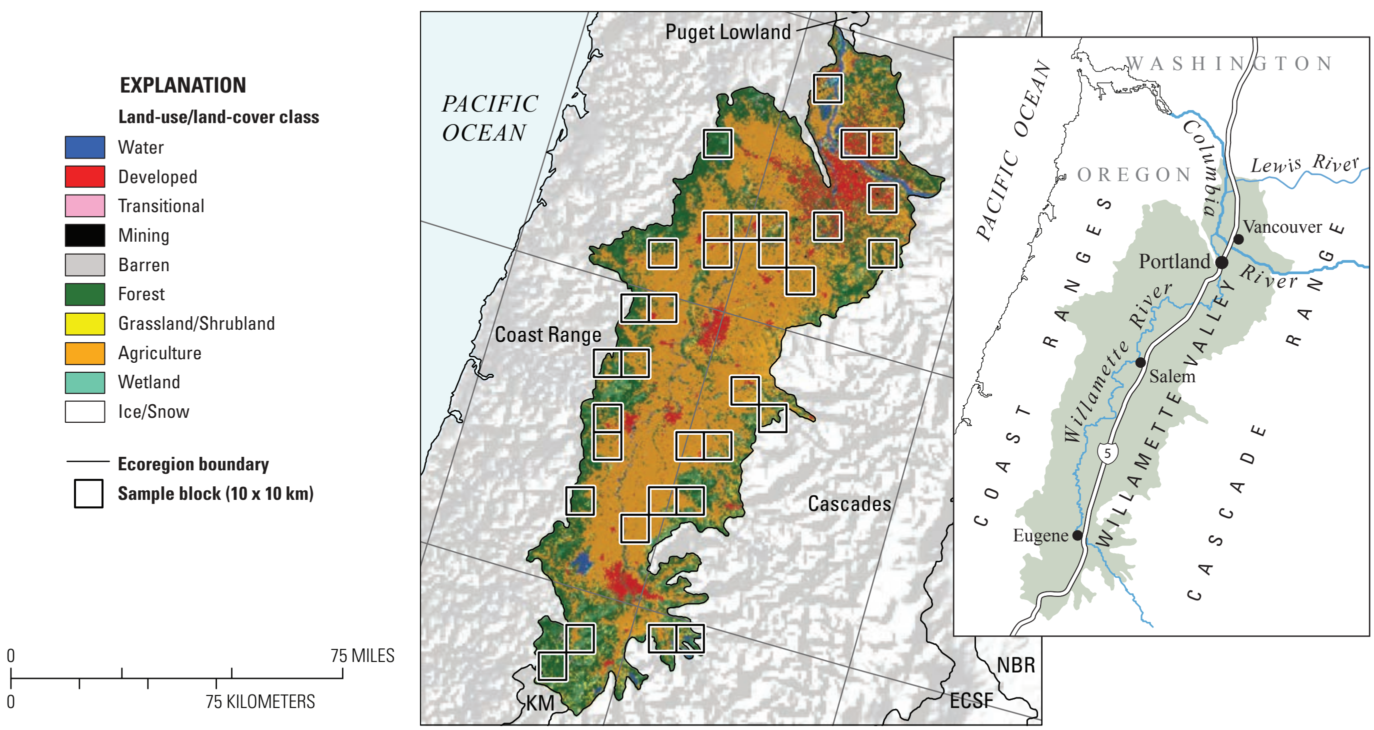

Figure 1. Map of Willamette Valley Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. Vineyard adjacent to forested foothills in Willamette Valley Ecoregion. Note recovering clearcut hillside (upper left).

Figure 3. Livestock grazing in Willamette Valley Ecoregion.

products. The forestry and logging industries also are primary employers of the valley's rural residents (Rooney, 2008). These activities have affected the watershed significantly, with forestry and agricultural runoff contributing to river sedimentation and decreased water quality in the Willamette River and its tributary streams (Oregon Department of Fish and Wildlife, 2006).

Recent years have seen a marked decline in forest health related to the increased frequency of multiyear droughts. Insect damage and other diseases also are present; however, drought-related water stress is the primary factor in coniferous-tree mortality (Oregon Department of Forestry, 2008). Trees most at risk include Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and western red cedar (*Thuja plicata*). Overstocking by timber companies and planting on sites with poor conditions increase susceptibility. Over time, these problems may lead to changes in planting practices and the use of more drought-tolerant species such as ponderosa pine (*Pinus ponderosa*).

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the footprint (overall areal extent) of land-use/land-cover change in the Willamette Valley Ecoregion was 14.5 percent, or approximately 2,090 km² of area changed (table 1). This change is high when compared to land-cover change in other Western United States ecoregions (fig. 4). The footprint of change can be interpreted as the area that changed during at least one of the four multiyear periods in the 27-year study period. Overall, an estimated 1,240 km² in the ecoregion changed in at least one of the time periods, 594 km² changed during two time periods, 195 km² changed during three periods, and less than 7 km² changed in all four time periods (table 1).

The average annual rate of change in the Willamette Valley Ecoregion between 1973 and 2000 was 0.8 percent (table 2). This measurement, which normalizes the results for each period to an annual scale, indicates that the region averaged an estimated 113.6 km² of change each year in the 27-year study period. A closer look at successive time periods reveals a steady increase in annual change during the study period (fig. 5). Between 1973 and 1980, the annual rate of

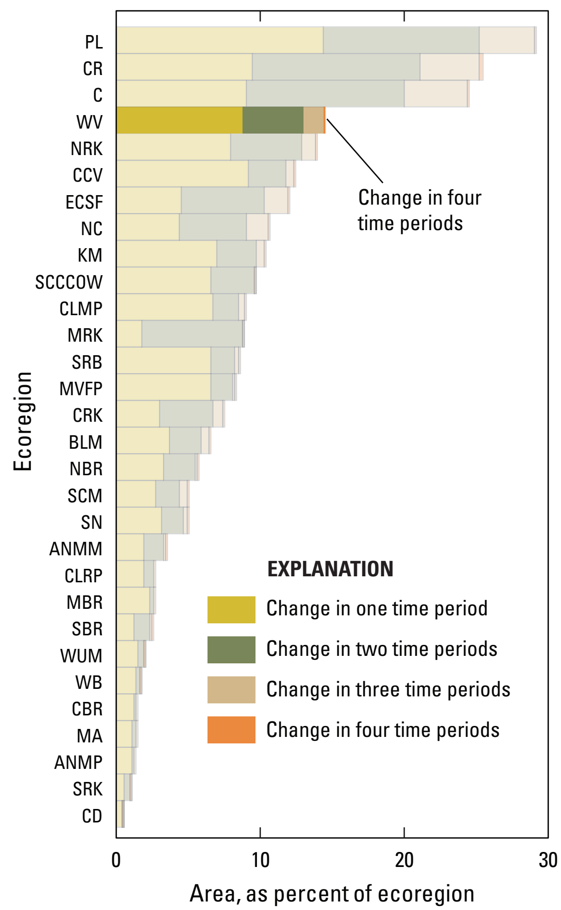

Figure 4. Overall spatial change in Willamette Valley Ecoregion (WV; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Willamette Valley Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

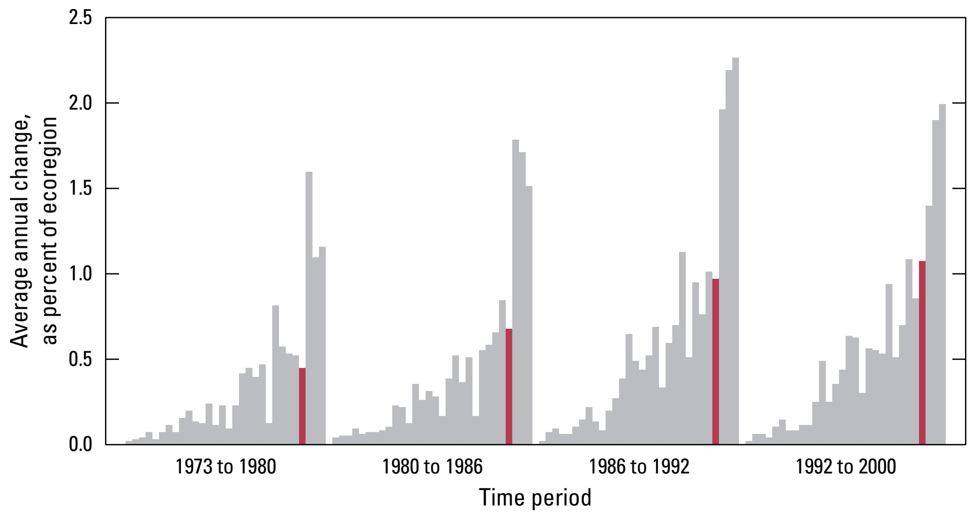

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Willamette Valley Ecoregion are represented by red bars in each time period.

change was 0.4 percent (65 km²), increasing to 0.7 percent (98 km²) from 1980 to 1986. This rate continued to rise to 1.0 percent (140 km²) between 1986 and 1992 and again to 1.1 percent (155 km²) between 1992 and 2000 (table 2).

Results from 2000 illustrate an estimated dominance of four of the ten land-cover classes in the Willamette Valley Ecoregion: agriculture (45.1 percent), forest (33.5 percent), developed (12.5 percent), and mechanically disturbed (4.0 percent) (table 3). These estimates from the sampled area are extraordinarily similar to land-cover percentages reported for the entire ecoregion (Oregon Department of Fish and Wildlife, 2006). The remaining six classes together accounted for the final 4.8 percent of the classified area in 2000, and each of these classes alone represents less than two percent of the sampled area (table 3). Between 1973 and 2000, there were considerable net losses in the areas of forest land (-11.0 percent) and agricultural land (-4.7 percent), along with net gains in developed land (33.4 percent) and mechanically disturbed land (236 percent, from 1.2 to 4.0 percent of the total ecoregion area) (fig. 6).

Net change, however, represents only changes between the first and final time periods, or the difference between land cover in 1973 and that in 2000. Net change is not the best indicator of within-class variability for those classes experiencing spatial and temporal fluctuations. The net-change metric does not reveal dynamics of change within and between time periods. Analysis of gross change (area gained and lost) by individual land-cover classes by time period shows that classes have fluctuated throughout the 27-year study period to a greater degree than net-change values indicate (Raumann and others, 2007). Classes may experience gains and losses in area between time periods. For example, mechanically disturbed land experienced a net increase of 2.8 percent between 1973 and 2000, but variable rates of forest cutting and other disturbances throughout the study period show a gross change of 3.3 percent. This equates to a net change in mechanically disturbed land of 404.7 km² (area in 2000 minus area in 1973) compared with a gross change of 476.3 km² over the entire study period.

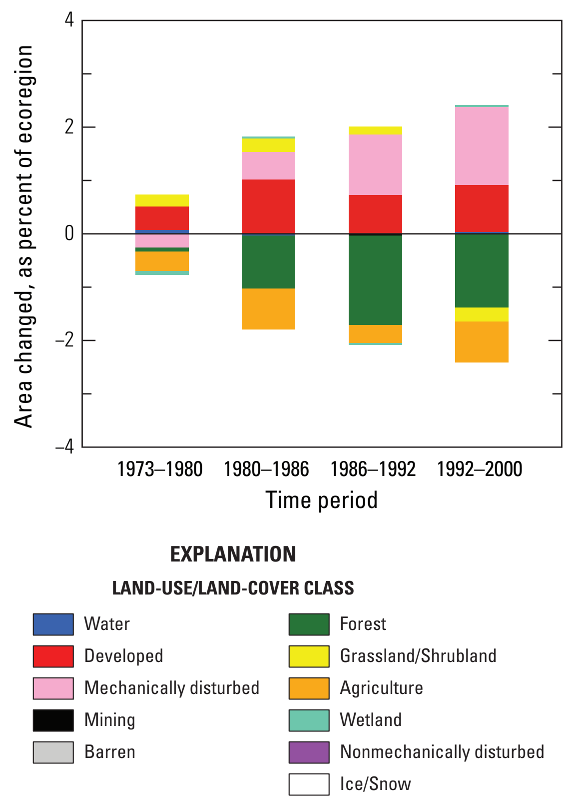

Figure 6. Normalized average net change in Willamette Valley Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

The "from class–to class" information afforded by a postclassification comparison was used to identify land-cover class conversions and rank them according to their magnitude. Table 4 illustrates the most frequent conversions between 1973 and 2000. Nearly 80 percent of land-cover class conversions were related to timber harvest and successional regrowth. The mechanical disturbance of forests accounted for 51.1 percent of the changes related to timber harvesting, with 18.2 percent recovering directly back to forest and 16.3 percent converting to grassland/shrubland. Overall, the cumulative effect of forest clearing represents 1,254 km^2 of disturbed landscape. The majority of changes occurred along the ecoregion periphery within higher elevation forests. Another important conversion somewhat masked by the dominance of forestry is the loss of agricultural land to developed land (table 4). In the first change period (1973–1980), only 10.3 percent of all changes were from agriculture to developed, but between 1980 and 1986, this land-cover conversion more than doubled to 22.3 percent (132 km^2).

Table 1. Percentage of Willamette Valley Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (85.5 percent), whereas 14.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	8.8	1.7	7.1	10.5	1.2	13.4
2	4.2	1.2	3.0	5.5	0.8	20.0
3	1.4	0.5	0.9	1.9	0.3	23.6
4	0.0	0.0	0.0	0.1	0.0	33.5
Overall spatial change	14.5	3.0	11.5	17.4	2.0	13.9

Table 2. Raw estimates of change in Willamette Valley Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	3.1	0.9	2.2	4.1	0.6	20.4	0.4
1980–1986	4.1	1.0	3.1	5.0	0.6	15.9	0.7
1986–1992	5.8	1.4	4.4	7.2	0.9	16.0	1.0
1992–2000	8.6	2.1	6.5	10.6	1.4	16.2	1.1
Estimate of change, in square kilometers							
1973–1980	454	137	317	591	93	20.4	65
1980–1986	590	138	452	728	94	15.9	98
1986–1992	841	198	642	1,039	134	16.0	140
1992–2000	1,238	296	942	1,535	201	16.2	155

Table 3. Estimated area (and margin of error) of each land-cover class in Willamette Valley Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	1.8	0.8	9.4	3.6	1.2	0.5	0.2	0.1	0.0	0.0	37.7	6.0	0.8	0.4	47.3	6.2	1.6	0.9	0.0	0.0
1980	1.8	0.8	9.8	3.8	0.9	0.4	0.2	0.1	0.0	0.0	37.6	6.0	1.1	0.3	47.0	6.3	1.5	0.8	0.0	0.0
1986	1.8	0.8	10.9	4.0	1.4	0.4	0.2	0.1	0.0	0.0	36.6	5.9	1.3	0.4	46.2	6.3	1.5	0.8	0.0	0.0
1992	1.8	0.8	11.6	4.3	2.6	0.8	0.2	0.1	0.0	0.0	34.9	5.6	1.5	0.4	45.9	6.3	1.5	0.8	0.0	0.0
2000	1.8	0.8	12.5	4.5	4.0	1.2	0.2	0.1	0.1	0.0	33.5	5.3	1.2	0.4	45.1	6.3	1.5	0.8	0.0	0.0
Net change	0.1	0.1	3.1	1.4	2.8	1.0	0.0	0.0	0.0	0.0	−4.1	1.4	0.4	0.6	−2.2	1.2	−0.1	0.1	0.0	0.0
Gross change	0.2	0.1	3.1	1.4	4.8	1.3	0.1	0.0	0.0	0.0	6.1	1.4	2.6	0.8	3.1	1.1	0.2	0.1	0.0	0.0
Area, in square kilometers																				
1973	253	116	1,359	524	172	76	29	13	6	4	5,450	870	120	59	6,842	902	226	123	0	0
1980	264	116	1,422	544	136	53	31	15	6	4	5,440	874	153	50	6,790	908	216	118	0	0
1986	260	116	1,574	579	207	60	32	14	6	4	5,298	853	189	55	6,676	904	216	117	0	0
1992	261	115	1,681	615	371	110	30	14	6	4	5,051	813	210	58	6,631	905	216	117	0	0
2000	265	116	1,813	651	578	180	31	14	7	4	4,851	770	174	59	6,521	905	218	117	0	0
Net change	12	13	454	205	407	142	2	5	1	1	−600	196	54	80	−322	175	−8	15	0	0
Gross change	25	18	454	205	694	193	12	5	4	4	876	207	376	115	444	161	28	14	0	0

Table 4. Principal land-cover conversions in Willamette Valley Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	127	53	36	0.9	28.0
	Mechanically disturbed	Grassland/Shrubland	85	42	28	0.6	18.8
	Mechanically disturbed	Forest	85	44	30	0.6	18.6
	Grassland/Shrubland	Forest	52	38	26	0.4	11.4
	Agriculture	Developed	45	26	18	0.3	10.0
	Other	Other	60	n/a	n/a	0.4	13.2
		Totals	454			3.1	100.0
1980–1986	Forest	Mechanically disturbed	201	59	40	1.4	34.1
	Agriculture	Developed	132	81	55	0.9	22.3
	Mechanically disturbed	Grassland/Shrubland	94	35	23	0.6	15.9
	Grassland/Shrubland	Forest	60	30	20	0.4	10.2
	Mechanically disturbed	Forest	34	23	15	0.2	5.7
	Other	Other	70	n/a	n/a	0.5	11.8
		Totals	590			4.1	100.0
1986–1992	Forest	Mechanically disturbed	360	110	74	2.5	42.8
	Mechanically disturbed	Grassland/Shrubland	119	39	27	0.8	14.2
	Grassland/Shrubland	Forest	102	45	30	0.7	12.1
	Agriculture	Developed	77	35	24	0.5	9.2
	Mechanically disturbed	Forest	73	30	20	0.5	8.7
	Other	Other	109	n/a	n/a	0.8	13.0
		Totals	841			5.8	100.0
1992–2000	Forest	Mechanically disturbed	566	182	123	3.9	45.7
	Mechanically disturbed	Forest	256	96	65	1.8	20.7
	Grassland/Shrubland	Forest	138	51	35	1.0	11.1
	Mechanically disturbed	Grassland/Shrubland	101	37	25	0.7	8.2
	Agriculture	Developed	93	39	27	0.6	7.5
	Other	Other	84	n/a	n/a	0.6	6.7
		Totals	1,238			8.6	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	1,255	369	250	8.7	40.2
	Mechanically disturbed	Forest	447	176	120	3.1	14.3
	Mechanically disturbed	Grassland/Shrubland	399	126	86	2.8	12.8
	Grassland/Shrubland	Forest	352	131	89	2.4	11.3
	Agriculture	Developed	347	164	111	2.4	11.1
	Other	Other	322	n/a	n/a	2.2	10.3
		Totals	3,122			21.6	100.0

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Rocky Mountains Ecoregions

Status and Trends of Land Change in the Western United States—1973 to 2000
Edited by Benjamin M. Sleeter, Tamara S. Wilson, and William Acevedo
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Chapter 4

Canadian Rockies Ecoregion

By Janis L. Taylor

Ecoregion Description

The Canadian Rockies Ecoregion covers approximately 18,494 km^2 (7,141 mi^2) in northwestern Montana (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The east side of the ecoregion is bordered by the Montana Valley and Foothill Prairies Ecoregion, which also forms a large part of the western border of the ecoregion. In addition, the Northern Rockies Ecoregion wraps around the ecoregion to the northwest and south (fig. 1). As the name implies, the Canadian Rocky Mountains are located mostly in Canada, straddling the border between Alberta and British Columbia. However, this ecoregion only includes the part of the northern Rocky Mountains that is in the United States. This ecoregion is characterized by steep, high-elevation mountain ranges similar to most of the rest of the Rocky Mountains. Compared to the Northern Rockies Ecoregion, however, the Canadian Rockies Ecoregion reaches higher elevations and contains a greater proportion of perennial snow and ice (Omernik, 1987) (fig. 2). Over the years, this section of the Rocky Mountains has garnered many different names, including “Crown of the Continent” by George Bird Grinnell (Waldt, 2008) and “Backbone of the World” by the Blackfeet (Pikuni) Nation.

Throughout the ecoregion, montane, subalpine, and alpine ecosystems have distinct flora and fauna elevation zones. Glaciers, permanent snowfields, and seasonal snowpack are found at the highest elevations. Spring and summer runoff fills lakes and tarns that form the headwaters of numerous streams and rivers, including the Columbia and Missouri Rivers that flow west and east, respectively, from the Continental Divide.

Many of the vast coniferous forests (fig. 3) throughout the Canadian Rockies Ecoregion lie within four national forests (Flathead, Lolo, Lewis and Clark, and Helena), and Glacier National Park is located entirely within the ecoregion. In 1932, Glacier National Park was combined with Waterton Lakes National Park, just across the Canadian border, to form

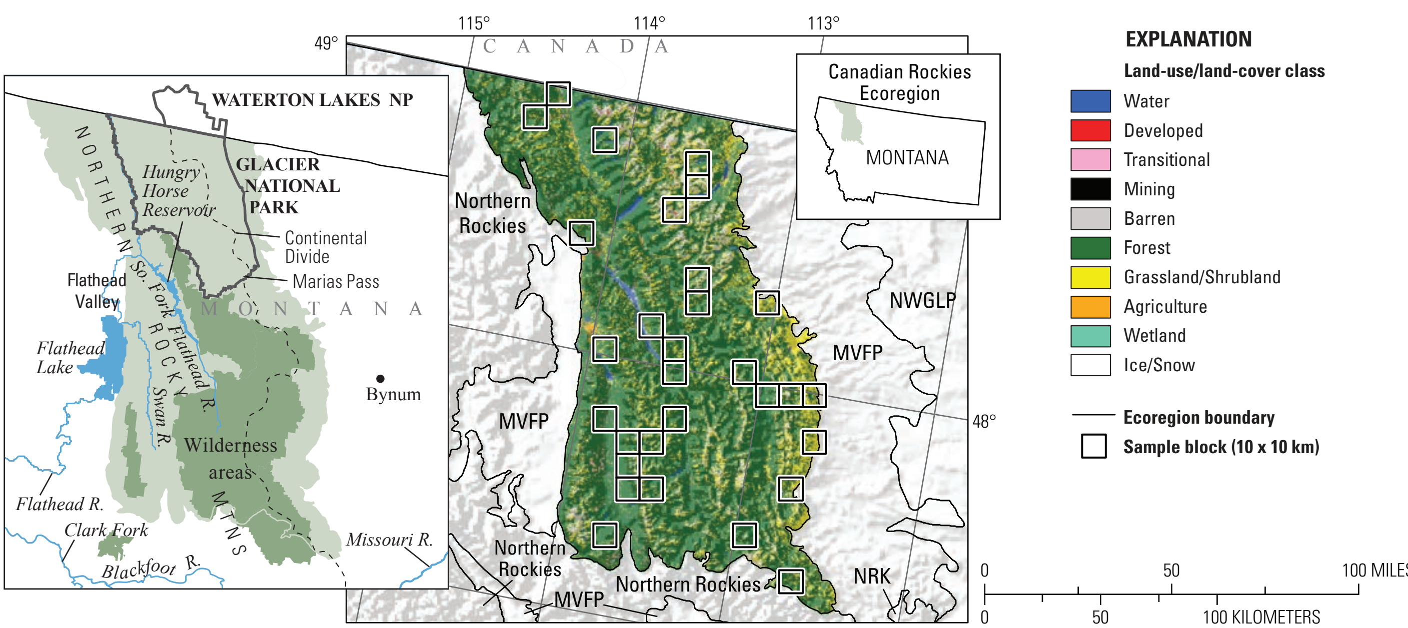

Figure 1. Map of Canadian Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown is part of one Great Plains Ecoregion, Northwestern Glaciated Plains (NWGLP). See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. High peaks along east slope of northern Rocky Mountains, near Bynum, Montana. State-owned Blackleaf Wildlife Management Area lies at lower elevations in this area. Photograph taken in June 2009.

Figure 3. South Fork Flathead River, with dense forest throughout river valley and hillsides.

Figure 4. Forest logging activity in Swan River valley, Montana.

the world's first International Peace Park, Waterton-Glacier International Peace Park. This area is also designated as a World Heritage Site, and it is rich in flora and fauna.

Throughout the Canadian Rockies Ecoregion, more than 70 species of mammals, including lynx (*Lynx canadensis*), mountain lions (*Puma concolor*), wolves (*Canis lupus irremotus*), black bears (*Ursus americanus*), moose (*Alces alces*), bighorn sheep (*Ovis canadensis*), mountain goats (*Oreamnos americanus*), elk (*Cervus elaphus*), and wolverines (*Gulo gulo*), roam and mate in large tracts of undeveloped land. Designated wilderness areas within the national forests and on tribal lands, combined with Glacier National Park, make up 68 percent of the ecoregion (table 1; fig. 3). Surrounding this large, protected landscape are open lands across the Blackfeet Nation and Flathead Reservations and roadless lands in national forests, as well as wild and scenic rivers, all of which provide habitat vast enough to support large grizzly bear (*Ursus arctos horribilis*) populations (Waldt, 2008; Mace and Chilton, unpub. data, 2009).

Native Americans have hunted in and harvested this ecoregion for over 5,000 years (Malone and others, 1991). Though still sparsely populated, communities are linked together by highway corridors that bisect vast areas of undeveloped, roadless landscape. Economies in the small communities are closely tied to the natural landscape. Approximately 2 million people visit Glacier National Park annually. Lakes, rivers, and winter snow further support a tourism economy through recreation, including skiing, hiking, biking, all-terrain-vehicle use, snowmobiling, camping, hunting, and fishing. Government agencies, the private timber industry, and tourist destinations and services provide the bulk of employment in the ecoregion. Harvesting of timber and other forest products has continued for more than a century (fig. 4). However, harvesting levels have varied over time and under different tract ownership.

Climate within the Canadian Rockies Ecoregion varies significantly from west to east. The climate on the west side of the Rocky Mountains is moderated by a maritime influence, whereas the climate on the east side has a harsher, more continental regime. Throughout the ecoregion, the higher elevations force moisture out of the atmosphere to precipitate primarily as snow, leaving a drier climate in the surrounding valleys. Because of the mountainous terrain, there are many local climatic effects, including aspect, exposure to prevailing wind, thermal inversions, and dry pockets (Ricketts and others, 1999).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change—the percentage of land area within the Canadian Rockies Ecoregion where land cover changed at least once between 1973 and 2000—was 7.6 percent (1,397 km^2). Estimates show that 3.0 percent (555 km^2) of the ecoregion changed at least one time, and 4.6 percent (851 km^2) changed two or more times (table 2). Comparing the amount of overall change in each of the 30 western United

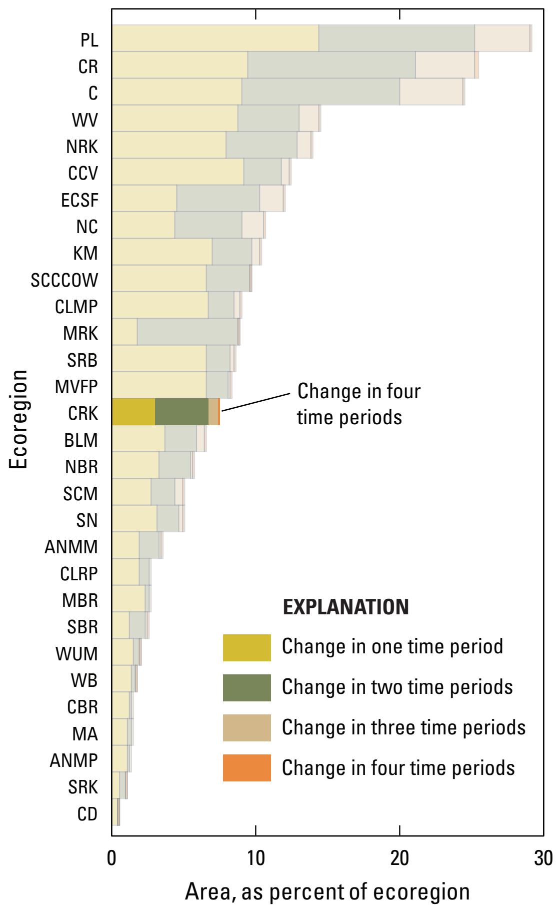

Figure 5. Overall spatial change in Canadian Rockies Ecoregion (CRK; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that change during one, two, three, or four time periods; highest level of spatial change in Canadian Rockies Ecoregion (four time periods) labeled for clarity. See table 3 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

States ecoregions, the Canadian Rockies Ecoregion's overall change is moderate (fig. 5).

Total percent change in each of the four time periods in this study ranges from a low of 2.2 percent (400 km^2) between 1980 and 1986 to a high of 4.4 percent (809 km^2) between 1992 and 2000. After normalizing the land-cover change in each time period to an annual rate of change, the rates range from a low of 0.4 percent (67 km^2) per year between 1980 and 1986 to a high of 0.6 percent (110 km^2) per year between 1986 and 1992 (table 3) (fig. 6).

Forest, the major land-cover class, covered 70.1 percent (12,964 km^2) of the ecoregion in 1973, and it experienced a 2.3 percent (293 km^2) decrease during the entire study period. Grassland/shrubland, which covered 18.5 percent (3,418 km^2) of the ecoregion in 1973, increased 8.2 percent (277 km^2) over the study period. The mechanically disturbed class accounted for 1.5 percent (281 km^2) of the land cover in 1973 and 1.1 percent (196 km^2) in 2000 (table 4). Net change in all land-use/land-cover categories is presented in figure 7.

The top four land-cover conversions were all components of man-made and naturally occurring forest change and regeneration: (1) forest to mechanically disturbed, (2) mechanically disturbed to grassland/shrubland, (3) grassland/shrubland to forest, and (4) forest to nonmechanically disturbed (table 5). Forest cuts, which were documented as mechanically disturbed, were the most common land-cover conversions between 1980 and 1986 and between 1986 and 1992 (table 4). Between 1986 and 1992, the second most common conversion was forest to nonmechanically disturbed, a result of natural-disturbance events such as fire and (or) beetle kill.

Forest products and their rate of harvest have changed in the decades between 1970 and 2000, affecting the rates of change of forest land cover. As early as 1976, the U.S. Forest Service stopped approving the clearcutting of areas larger than 40 acres (U.S. Department of Agriculture, 1998). In 1989, the U.S. Forest Service established and implemented an annual forest-management plan that defined a more comprehensive

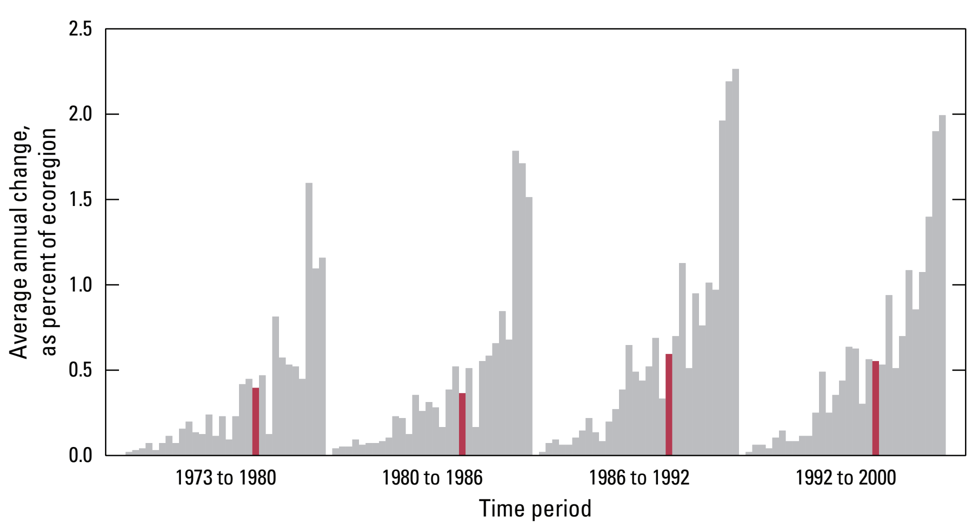

Figure 6. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Canadian Rockies Ecoregion are represented by red bars in each time period.

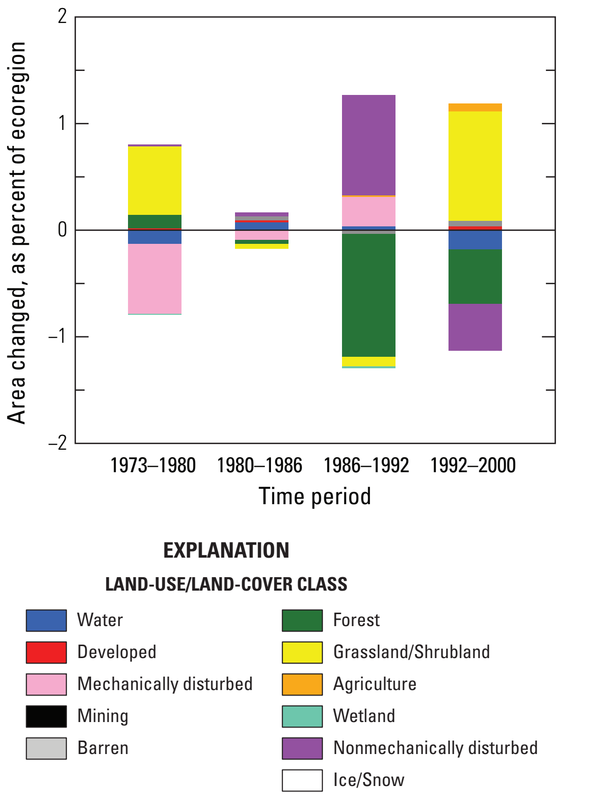

Figure 7. Normalized average net change in Canadian Rockies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 8. Glaciers and snowpack in Glacier National Park.

Figure 9. Tourists in Glacier National Park.

Figure 10. Highway 2 over Rocky Mountains at Marias Pass, Montana. Highway affects movement of large mammals in region.

list of forest uses. After 1992, stringent restrictions were applied to clearcutting, and its use continues to decline. The most common timber harvested in the 1980s was the large-girth tree for lumber and sheet products, but this is being replaced by the harvest of dead or small-diameter trees by stewardship projects, which aim to improve wildlife habitat and (or) enhance cultural features. Today, overall timber-harvest rates are near 1950 levels (U.S. Department of Agriculture, 1998).

The vast wild and protected landscapes in the Canadian Rockies Ecoregion provide a crucial link for the Yellowstone to Yukon ("Y2Y") Initiative. Furthermore, the "Crown of the Continent" is a priority area where various conservation efforts are underway to protect movement of animals as they travel between parks and other forested lands. A goal of the Y2Y Initiative is to protect both the wild and human inhabitants so that they remain connected and healthy into the future. The grizzly bear is one of the many animals that require large amounts of land. The Northern Continental Divide Grizzly Bear Project has determined that this area has the largest grizzly bear populations found in the lower 48 states (Kendall and others, 2008; Mace and Chilton, unpub. data, 2009). Projects like the Y2Y Initiative may limit future land-use/land-cover change if implementation successfully continues.

Mountain glaciers, along with annual snowpack and rainfall, support the headwaters of large rivers (fig. 8). Because of the quality and quantity of the water, the rivers and streams, along with the riparian corridors that they flow through, provide habitat for a wide variety of species, as well as critical habitat for several fish species. A particularly important factor is the input of glacial meltwater that enters the streams during

Figure 11. Remnants of forest fire above Hungry Horse Reservoir, Montana.

the hottest and driest days of late summer, sustaining temperature-sensitive species (Hall and Fagre, 2003).

The landscape is rich in the ecosystem services that it provides, which include forest products, habitat for wildlife, fresh water, and recreational opportunities. In the future, these services may change along with the forest as the result of both human and natural processes.

Natural amenities, such as forests, lakes, and rivers, provide outdoor recreation opportunities for numerous visitors, making them an economic asset to local communities (fig. 9). Towns directly adjacent to the Canadian Rockies Ecoregion, such as those in the Flathead Valley, observed an increase in population and housing starts throughout the 1980s and 1990s (Baron and others, 2000), and the ecoregion's developed area doubled in size (from 17 to 33 km^2) over the course of the study.

Future change in this forested ecoregion is inevitable. Increased human use of the landscape may affect water quality (and quantity) and, thus, wildlife habitat, and transportation corridors may fragment the landscape (fig. 10). Clean water may be especially at risk owing to human activities such as mining, as well as human-caused impacts from erosion and runoff from landscaping and septic systems (Baron and others, 2000). Because humans have actively controlled and suppressed fire in this region for decades, forests have grown dense with vegetation, and infestations have killed off large swaths of trees. Future wildfires may be large and devastating in some areas (Arno and Allison-Bunnell, 2002).

Climate change may also play a strong role in future changes. Glaciers are melting in Glacier National Park (Fagre, 2005); as of 2000, only 37 of the estimated original 150 mountain glaciers remained. Summer and winter temperatures are expected to rise; models predict that by 2030 all of the glaciers within Glacier National Park will have melted (Fagre, 2005; Hall and Fagre, 2003; Fagre and others, 2003). Increasing temperatures, increasing numbers of frost-free days, and decreasing numbers of extended periods of very cold temperatures during winter may further influence disturbance regimes in the forests from both wildfires (fig. 11) and insect infestations (Carter, 2003).

Table 1. Sizes of natural areas in Montana, which together represent one of the most completely preserved mountain ecosystems in the world.

Natural area	Acres	Square kilometers	Square miles
Bob Marshall Wilderness	1,009,356	4,085	1,577
Scapegoat Wilderness	239,936	971	375
Great Bear Wilderness	286,700	1,160	448
Mission Mountains Wilderness	73,877	299	115
Mission Mountains Tribal Wilderness	89,500	362	140
Jewel Basin	15,349	62	24
Hungry Horse Reservoir	23,813	96	37
Glacier National Park	1,400,000	5,665	2,187
Total	3,138,531	12,701	4,904

Table 2. Percentage of Canadian Rockies Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (92.4 percent), whereas 7.6 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	3.0	1.3	1.8	4.3	0.9	28.2
2	3.8	1.3	2.5	5.1	0.9	23.8
3	0.7	0.4	0.3	1.0	0.2	36.8
4	0.1	0.0	0.0	0.1	0.0	47.6
Overall spatial change	7.6	2.4	5.1	10.0	1.6	21.7

Table 3. Raw estimates of change in Canadian Rockies Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	2.7	1.1	1.6	3.9	0.8	27.7	0.4
1980–1986	2.2	0.8	1.4	3.0	0.5	25.0	0.4
1986–1992	3.6	1.3	2.3	4.8	0.8	23.8	0.6
1992–2000	4.4	1.4	2.9	5.8	1.0	22.1	0.5
			Estimate of change, in square kilometers				
1973–1980	505	207	299	712	140	27.7	72
1980–1986	400	148	252	548	100	25.0	67
1986–1992	659	232	427	891	157	23.8	110
1992–2000	809	264	545	1074	179	22.1	101

Table 4. Estimated area (and margin of error) of each land-cover class in Canadian Rockies Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	1.7	0.8	0.1	0.1	1.5	0.7	0.0	0.0	6.9	2.6	70.1	4.7	18.5	3.8	0.3	0.3	0.4	0.2	0.0	0.0
1980	1.6	0.8	0.1	0.1	0.9	0.4	0.0	0.0	6.9	2.6	70.2	4.7	19.1	3.7	0.4	0.3	0.4	0.2	0.0	0.0
1986	1.6	0.8	0.1	0.1	0.8	0.4	0.0	0.0	7.0	2.6	70.2	4.7	19.1	3.7	0.4	0.3	0.4	0.2	0.0	0.0
1992	1.7	0.8	0.1	0.1	1.1	0.4	0.0	0.0	6.9	2.6	69.0	4.7	19.0	3.8	0.4	0.3	0.4	0.2	1.0	0.9
2000	1.5	0.7	0.2	0.1	1.1	0.5	0.0	0.0	7.0	2.6	68.5	4.6	20.0	3.7	0.4	0.3	0.4	0.2	0.5	0.5
Net change	−0.2	0.2	0.1	0.1	−0.5	0.5	0.0	0.0	0.1	0.1	−1.6	1.2	1.5	1.1	0.1	0.1	0.0	0.0	0.5	0.5
Gross change	0.4	0.5	0.1	0.1	3.4	1.2	0.0	0.0	0.1	0.1	4.1	1.2	3.4	1.2	0.1	0.1	0.0	0.0	2.6	1.9
									Area, in square kilometers											
1973	312	152	17	10	281	124	1	1	1,284	474	12,964	878	3,418	700	64	54	80	29	0	0
1980	288	147	21	13	159	73	1	1	1,284	474	12,988	874	3,536	691	65	55	80	29	0	1
1986	303	149	24	15	144	70	1	1	1,291	477	12,980	873	3,527	691	66	55	80	29	6	8
1992	309	151	27	18	194	82	1	1	1,285	474	12,765	862	3,510	696	67	55	79	28	182	174
2000	277	137	33	23	196	89	2	1	1,294	479	12,671	847	3,699	691	80	60	79	28	98	91
Net change	−35	35	16	13	−85	99	1	1	10	12	−293	213	281	196	16	19	−1	1	98	91
Gross change	78	88	16	13	622	226	1	1	21	20	751	231	621	216	18	19	2	1	473	353

Table 5. Principal land-cover conversions in Canadian Rockies Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Mechanically disturbed	Grassland/Shrubland	174	87	59	0.9	34.3
	Forest	Mechanically disturbed	137	70	47	0.7	27.1
	Mechanically disturbed	Forest	107	91	62	0.6	21.2
	Grassland/Shrubland	Forest	58	66	45	0.3	11.6
	Water	Mechanically disturbed	21	28	19	0.1	4.1
	Other	Other	9	n/a	n/a	0.0	1.7
		Totals	505			2.7	100.0
1980–1986	Forest	Mechanically disturbed	141	70	47	0.8	35.3
	Grassland/Shrubland	Forest	84	44	30	0.5	21.0
	Mechanically disturbed	Grassland/Shrubland	76	56	38	0.4	19.0
	Mechanically disturbed	Forest	62	45	30	0.3	15.4
	Mechanically disturbed	Water	15	20	13	0.1	3.7
	Other	Other	23	n/a	n/a	0.1	5.7
		Totals	400			2.2	100.0
1986–1992	Forest	Mechanically disturbed	194	81	55	1.1	29.5
	Forest	Nonmechanically disturbed	182	174	118	1.0	27.6
	Grassland/Shrubland	Forest	120	69	47	0.6	18.2
	Mechanically disturbed	Grassland/Shrubland	102	59	40	0.5	15.4
	Mechanically disturbed	Forest	41	24	16	0.2	6.2
	Other	Other	21	n/a	n/a	0.1	3.1
		Totals	659			3.6	100.0
1992–2000	Nonmechanically disturbed	Grassland/Shrubland	182	174	118	1.0	22.5
	Forest	Mechanically disturbed	165	88	59	0.9	20.3
	Mechanically disturbed	Grassland/Shrubland	123	60	41	0.7	15.2
	Grassland/Shrubland	Forest	110	75	51	0.6	13.6
	Forest	Nonmechanically disturbed	86	78	53	0.5	10.6
	Other	Other	144	n/a	n/a	0.8	17.8
		Totals	809			4.4	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	637	258	174	3.4	26.8
	Mechanically disturbed	Grassland/Shrubland	474	218	147	2.6	20.0
	Grassland/Shrubland	Forest	372	213	144	2.0	15.7
	Forest	Nonmechanically disturbed	275	185	125	1.5	11.6
	Mechanically disturbed	Forest	272	174	117	1.5	11.4
	Other	Other	345	n/a	n/a	1.9	14.5
		Totals	2,374			12.8	100.0

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Chapter 5

Middle Rockies Ecoregion

By Janis L. Taylor

Ecoregion Description

The Middle Rockies Ecoregion—characterized by steep, high-elevation mountain ranges and intermountain valleys—is a disjunct ecoregion composed of three distinct geographic areas: the Greater Yellowstone area in northwest Wyoming, southwest Montana, and eastern Idaho; the Bighorn Mountains in north-central Wyoming and south-central Montana; and the Black Hills in western South Dakota and eastern Wyoming (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion covers approximately 90,160 km^2 (34,881 mi^2), and its three distinct geographic sections are bordered by several other ecoregions (fig. 1). The Yellowstone section abuts the Montana Valley and Foothill Prairies and the Northern Rockies Ecoregions to the north, the Snake River Basin and the Central Basin and Range Ecoregions to the west, and the Wyoming Basin Ecoregion to the south and east. The Bighorn Mountains section lies between the Wyoming Basin Ecoregion to the west and the Northwestern Great Plains Ecoregion to the east, and it abuts the Montana Valleys and Foothill Prairies Ecoregion to the north. The Black Hills section is entirely surrounded by the Northwestern Great Plains Ecoregion. The Continental Divide crosses the ecoregion from the southeast along the Wind River Range, through Yellowstone National Park, and west along the Montana-Idaho border. On both sides of the divide, topographic relief causes local climate variability, particularly the effects of aspect, exposure to prevailing wind, thermal

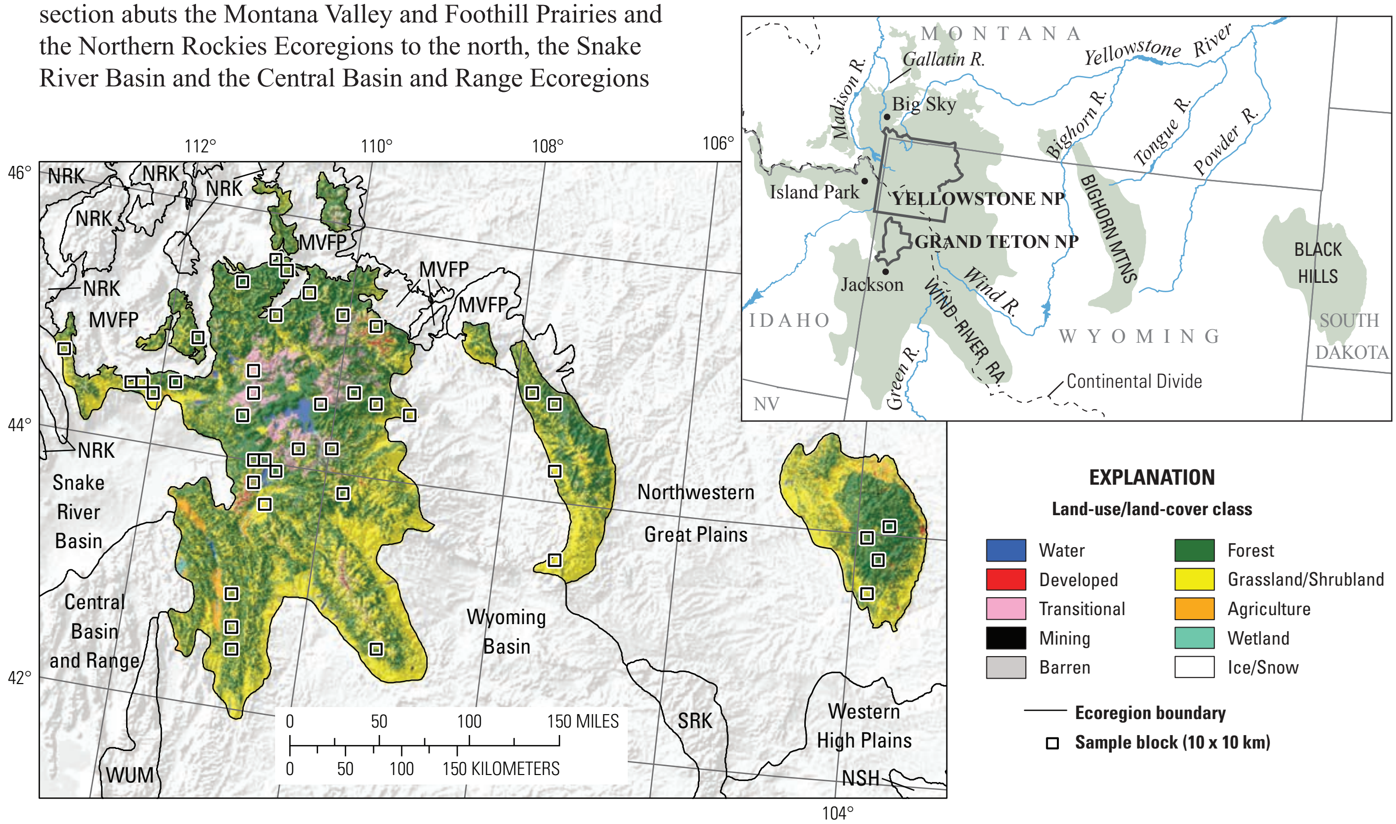

Figure 1. Map of Middle Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map are parts of three Great Plains ecoregions: Northwestern Great Plains, Western High Plains, and Nebraska Sand Hills (NSH). See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. Small alfalfa field and flat to rolling agricultural land at base of forested hills in Middle Rockies Ecoregion. Photograph by Terry Sohl, 2008.

Figure 3. Sagebrush (grassland/shrubland) dominates flatter, lower elevation areas west of Interstate 15 in Middle Rockies Ecoregion. Photograph by Terry Sohl, 2008.

inversions, and rain-shadow effects, that are reflected in the wide variety of flora and fauna within the ecoregion (Ricketts and others, 1999).

The three main land uses common to the Middle Rockies Ecoregion are logging, recreation, and agriculture. Agricultural land use within the intermountain valleys includes managed hay fields and pasture lands, irrigated alfalfa, and other scattered crops (fig. 2). Grazing of cattle and sheep occurs in the valleys year-round and on higher elevation open areas in summer. There are ski resorts and destination communities such as the towns of Big Sky, Montana; Jackson, Wyoming; and Island Park, Idaho. Yellowstone National Park and Grand Teton National Park, both in the ecoregion, draw millions of visitors each year. There are nine national forests within the ecoregion that are managed for multiple uses including logging, grazing, and recreation.

Land cover in the valleys is dominated by grassland/shrubland (fig.3). Common grass species include grama grass (*Bouteloua* spp.), wheatgrass (*Eremopyrum* spp.), and needlegrass (*Nassella* spp.). Common shrubs include sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus viscidiflorus*), and serviceberry (*Amelanchier arborea*). Hillsides are mostly forested. Lodgepole pine (*Pinus contorta*) is the most common conifer throughout the Yellowstone area and the Bighorn Mountains, but ponderosa pine (*Pinus ponderosa*) is more common in the Black Hills, which are lower in elevation (Mohlenbrock, 2002). Perennial streams and rivers run through many of the valleys, and riparian vegetation such as cottonwoods (*Populus* spp.) and aspens (*Populus tremuloides*) line the banks. The headwaters for the Yellowstone, Wind, Snake, Powder, Tongue, Green, Madison, and Gallatin Rivers are all within the ecoregion, making it a major source of water for the central United States.

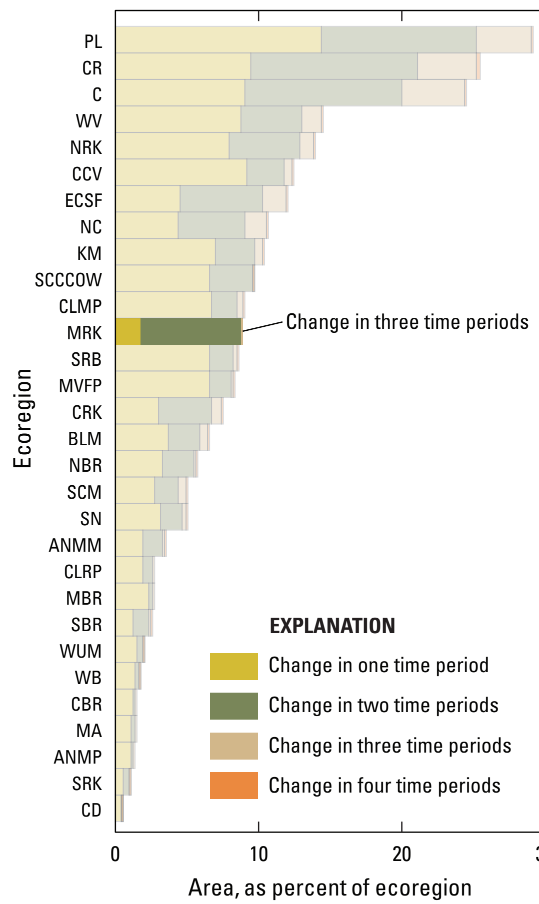

Figure 4. Overall spatial change in Middle Rockies Ecoregion (MRK; darker bars) compared with that of all 30 Western United States ecoregions. Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Middle Rockies Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change—the percentage of land area within the ecoregion where land cover changed at least once between 1973 and 2000—was 8.8 percent (7,974 km^2) (table 1). Of that total, 1.7 percent (1,533 km^2) changed one time, and 7.1 percent (6,401 km^2) changed two times. The amount of change in this ecoregion is moderate when compared with all 30 Western United States ecoregions (fig. 4).

Total change in each of the four time periods selected for this study ranged from a low of 0.9 percent (795 km^2) between 1973 and 1980 to a high of 7.5 percent (6,740 km^2) between 1992 and 2000 (table 2). After normalizing to an annual rate of change, the rates ranged from a low of 0.1 percent (114 km^2) per year between 1973 and 1980 to a high of 1.1 percent (1,012 km^2) per year between 1986 and 1992 (fig. 5).

In 1973, forest made up 50.4 percent (45,463 km^2) of the ecoregion, grassland/shrubland made up 44.4 percent (40,061 km^2), wetland and agriculture each covered roughly 1.0 percent of the ecoregion, and barren (for example, mountain peaks) covered 2.0 percent (table 3). Forest decreased 11.3 percent by 2000, and grassland/shrubland increased 10.3 percent. In the first two time periods, nonmechanically disturbed land (areas subject to wildfire or insect-caused mortality) never accounted for more than 0.1 percent of the ecoregion, but in the period between 1986 and 1992, that value jumped to 5.7 percent of the ecoregion (5,159 km^2), largely as a result of the 1988 Yellowstone fires (fig. 6).

Forest to nonmechanically disturbed, nonmechanically disturbed to grassland/shrubland, and grassland/shrubland to nonmechanically disturbed were three of the four largest land-cover conversions (table 4), and all are related to wildfires. Of the 30 sample blocks that were interpreted, 6 showed greater than 20 percent change, and 5 of these were located within the perimeter of the 1988 wildfires (fig. 7). The sixth block with greater than 20 percent change was located in the Black Hills,

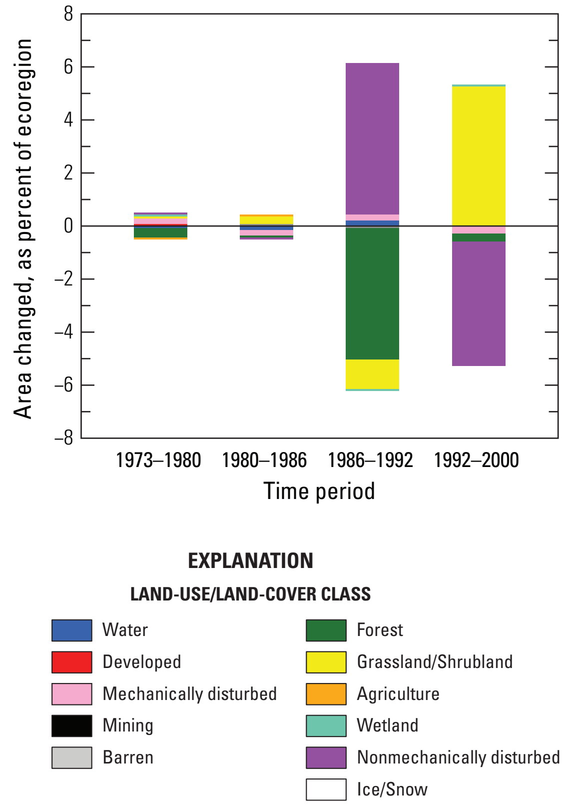

Figure 6. Normalized average net change in Middle Rockies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

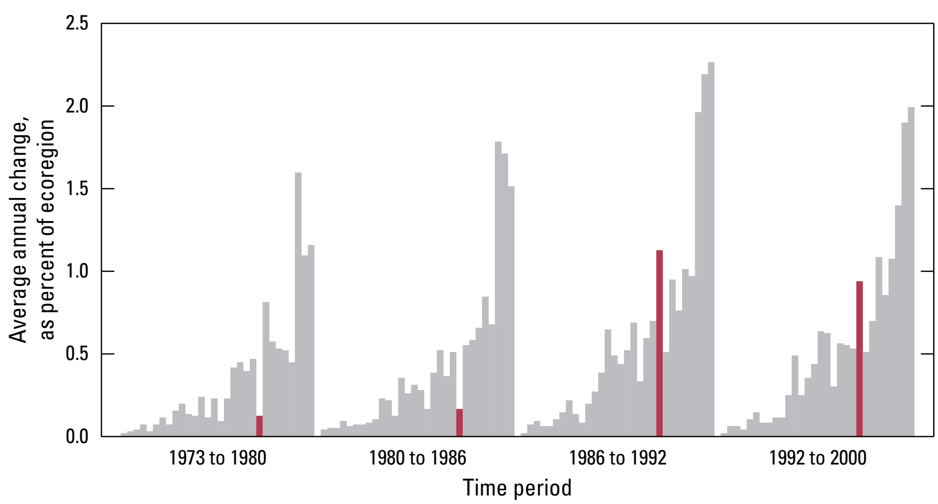

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Middle Rockies Ecoregion are represented by red bars in each time period.

Figure 7. In 1988, Yellowstone area fires caused marked increase in area of nonmechanically disturbed land. Photographs by Terry Sohl, 2008. *A*, Interpretive sign about "Huck Fire," one of three largest fires to strike Yellowstone area in 1988. In northern part of this sample block, forest along road ends abruptly at edge of burn. *B*, Near "Huck Fire" interpretive sign, forest was completely burned; now, 20-year-old regenerating trees cover much of area. Small marsh area lines stream in foreground.

where the Jasper fire burned in 2000. The fourth most common land-cover change was forest to mechanically disturbed, a result of timber harvest.

The 1988 Yellowstone fires represented by far the largest changes in this ecoregion. The fires followed a prolonged drought and burned more than 3,200 km^2 in and around Yellowstone National Park (Christensen and others, 1989). Dry-lightning storms sparked numerous blazes that converged to become a single major fire. In the decades following the fire, vegetation changes continued, with vigorous herbaceous growth and young forests replacing burned stands of forest (Knight and Wallace, 1989). Lodgepole pines are adapted to fire and produce serotinous cones that respond to fire by opening up to release seed, facilitating forest regrowth.

Additional ecoregion change came from timber harvest in national forests and private forests. One example of such activity is 20 years of salvage logging in Targhee National Forest near Island Park, Idaho, between 1970 and 1990 (Wilkinson, 1999). Large areas were clearcut, right up to the border of Yellowstone National Park, in order to remove beetle-killed lodgepole pine trees. In 1990, the U.S. Forest Service changed their management practices and harvest rates in the Targhee National Forest and in eight other national forests within the ecoregion (Hansen and others, 2002).

Table 1. Percentage of Middle Rockies Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (91.2 percent), whereas 8.8 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.7	1.0	0.6	2.7	0.7	42.1
2	7.1	3.4	3.7	10.5	2.3	32.2
3	0.0	0.0	0.0	0.1	0.0	50.4
4	0.0	0.0	0.0	0.0	0.0	92.3
Overall spatial change	8.8	3.4	5.4	12.3	2.3	26.5

Table 2. Raw estimates of change in Middle Rockies Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	0.9	0.4	0.5	1.2	0.2	27.2	0.1
1980–1986	0.9	0.4	0.5	1.4	0.3	31.2	0.2
1986–1992	6.7	3.3	3.4	10.1	2.3	33.9	1.1
1992–2000	7.5	3.3	4.1	10.8	2.3	30.5	0.9
			Estimate of change, in square kilometers				
1973–1980	795	318	477	1,113	216	27.2	114
1980–1986	856	392	464	1,248	267	31.2	143
1986–1992	6,075	3,019	3,055	9,094	2,057	33.9	1,012
1992–2000	6,740	3,019	3,722	9,759	2,056	30.5	843

Table 3. Estimated area (and margin of error) of each land-cover class in Middle Rockies Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	0.7	0.5	0.1	0.1	0.2	0.1	0.0	0.0	1.9	0.8	50.4	5.7	44.4	5.7	1.1	0.8	1.0	0.3	0.0	0.0
1980	0.7	0.4	0.2	0.1	0.4	0.3	0.0	0.0	1.9	0.8	50.0	5.7	44.5	5.7	1.0	0.8	1.0	0.3	0.1	0.1
1986	0.5	0.3	0.2	0.1	0.2	0.1	0.0	0.0	2.0	0.8	50.0	5.7	44.9	5.7	1.1	0.8	1.0	0.3	0.0	0.0
1992	0.7	0.5	0.2	0.2	0.4	0.3	0.0	0.0	1.9	0.8	45.0	5.4	43.8	5.7	1.1	0.7	1.0	0.3	5.7	3.3
2000	0.7	0.5	0.2	0.2	0.2	0.2	0.0	0.0	1.9	0.8	44.7	5.2	49.0	5.4	1.0	0.7	1.0	0.3	1.0	1.0
Net change	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	−5.7	2.7	4.6	2.6	0.0	0.1	0.0	0.0	1.0	1.0
Gross change	0.4	0.6	0.1	0.1	1.5	0.7	0.0	0.0	0.2	0.2	7.6	3.1	7.6	3.9	0.2	0.1	0.1	0.1	12.5	6.7
									Area, in square kilometers											
1973	648	419	96	74	182	135	17	15	1,721	746	45,463	5,170	40,061	5,168	966	725	897	298	0	0
1980	610	378	158	127	380	252	18	15	1,726	749	45,113	5,142	40,161	5,150	932	679	910	307	46	66
1986	473	255	161	130	193	128	18	16	1,788	751	45,081	5,180	40,462	5,126	955	680	909	306	22	32
1992	671	446	173	147	396	233	20	16	1,728	750	40,606	4,890	39,467	5,152	948	664	899	297	5,159	2,993
2000	674	449	174	147	169	139	21	17	1,739	752	40,327	4,674	44,207	4,854	938	663	901	296	937	930
Net change	27	33	78	82	−13	144	4	3	17	16	−5,135	2,425	4,146	2,348	−27	80	4	40	937	930
Gross change	385	505	79	82	1,387	671	4	3	143	162	6,810	2,770	6,865	3,522	165	113	79	73	11,294	6,008

Table 4. Principal land-cover conversions in Middle Rockies Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	378	252	172	0.4	47.5
	Mechanically disturbed	Grassland/Shrubland	113	114	77	0.1	14.2
	Mechanically disturbed	Forest	69	74	51	0.1	8.7
	Forest	Nonmechanically disturbed	46	66	45	0.1	5.8
	Agriculture	Developed	36	52	35	0.0	4.5
	Other	Other	153	n/a	n/a	0.2	19.3
		Totals	795			0.9	100.0
1980–1986	Mechanically disturbed	Grassland/Shrubland	233	210	143	0.3	27.2
	Forest	Mechanically disturbed	193	128	87	0.2	22.5
	Mechanically disturbed	Forest	147	149	101	0.2	17.2
	Water	Grassland/Shrubland	79	110	75	0.1	9.3
	Water	Barren	60	81	55	0.1	7.0
	Other	Other	144	n/a	n/a	0.2	16.8
		Totals	856			0.9	100.0
1986–1992	Forest	Nonmechanically disturbed	4,089	2,358	1,606	4.5	67.3
	Grassland/Shrubland	Nonmechanically disturbed	1,068	1,513	1,030	1.2	17.6
	Forest	Mechanically disturbed	394	233	159	0.4	6.5
	Mechanically disturbed	Grassland/Shrubland	174	127	87	0.2	2.9
	Grassland/Shrubland	Water	106	143	98	0.1	1.7
	Other	Other	244	n/a	n/a	0.3	4.0
		Totals	6,075			6.7	100.0
1992–2000	Nonmechanically disturbed	Grassland/Shrubland	4,488	2,538	1,729	5.0	66.6
	Forest	Nonmechanically disturbed	866	861	586	1.0	12.8
	Mechanically disturbed	Grassland/Shrubland	313	223	152	0.3	4.6
	Forest	Mechanically disturbed	169	139	95	0.2	2.5
	Mechanically disturbed	Forest	71	61	41	0.1	1.1
	Other	Other	834	n/a	n/a	0.9	12.4
		Totals	6,740			7.5	100.0
1973–2000 (overall)	Forest	Nonmechanically disturbed	5,024	2,502	1,705	5.6	34.7
	Nonmechanically disturbed	Grassland/Shrubland	4,557	2,602	1,772	5.1	31.5
	Forest	Mechanically disturbed	1,133	610	416	1.3	7.8
	Grassland/Shrubland	Nonmechanically disturbed	1,116	1,512	1,030	1.2	7.7
	Mechanically disturbed	Grassland/Shrubland	833	532	362	0.9	5.8
	Other	Other	1,804	n/a	n/a	2.0	12.5
		Totals	14,466			16.0	100.0

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Chapter 6

Montana Valley and Foothill Prairies Ecoregion

By Janis L. Taylor

Ecoregion Description

The Montana Valley and Foothill Prairies Ecoregion comprises numerous intermountain valleys and low-elevation foothill prairies spread across the western half of Montana, on both sides of the Continental Divide (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion, which covers approximately 64,658 km^2 (24,965 mi^2), includes the Flathead Valley and the valleys surrounding Helena, Missoula, Bozeman, Billings, Anaconda, Dillon, and Lewistown (fig. 1). These valleys are generally characterized by shortgrass prairie vegetation and are flanked by forested mountains (Woods and others, 1999); thus, the valleys' biotas with regards to fish and insects are comparable. In many cases, the valleys are conduits for some of the largest rivers in the state, including Clark Fork and the Missouri, Jefferson, Madison, Flathead, Yellowstone, Gallatin, Smith, Big Hole, Bitterroot, and Blackfoot Rivers (fig. 2). The Montana Valley and Foothill Prairies Ecoregion also includes the "Rocky Mountain front," an area of prairies along the eastern slope of the northern Rocky Mountains. Principal land uses within the ecoregion include farming, grazing, and mining. The valleys serve as major transportation and utility corridors and also contain the majority of Montana's human population.

The Montana Valley and Foothill Prairies Ecoregion extends into 17 mostly rural counties throughout western Montana. Only three of the counties—Carbon, Yellowstone, and Missoula—are part of a metropolitan statistical area with

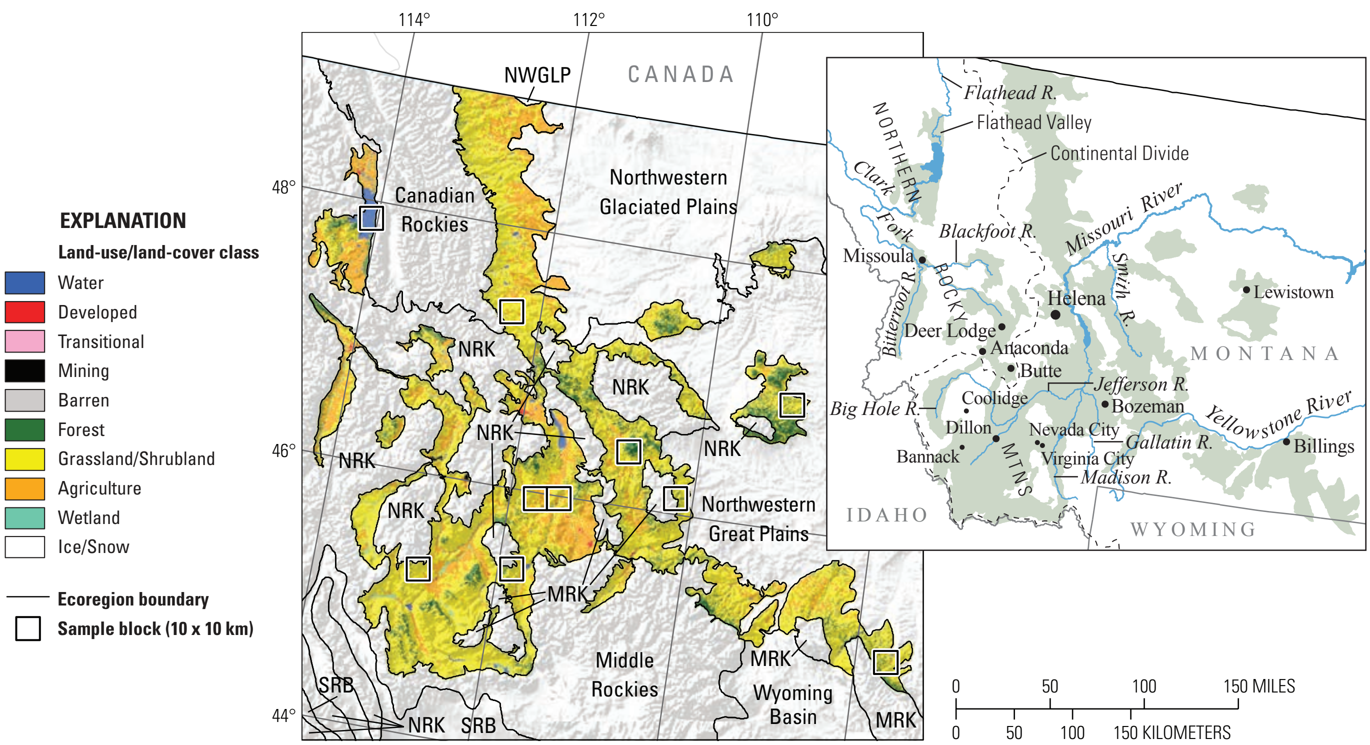

Figure 1. Map of Montana Valley and Foothill Prairies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 20 x 20 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map are parts of two Great Plains ecoregions: Northwestern Glaciated Plains (NWGLP) and Northwestern Great Plains. See appendix 3 for definitions of land-use/land-cover classifications.

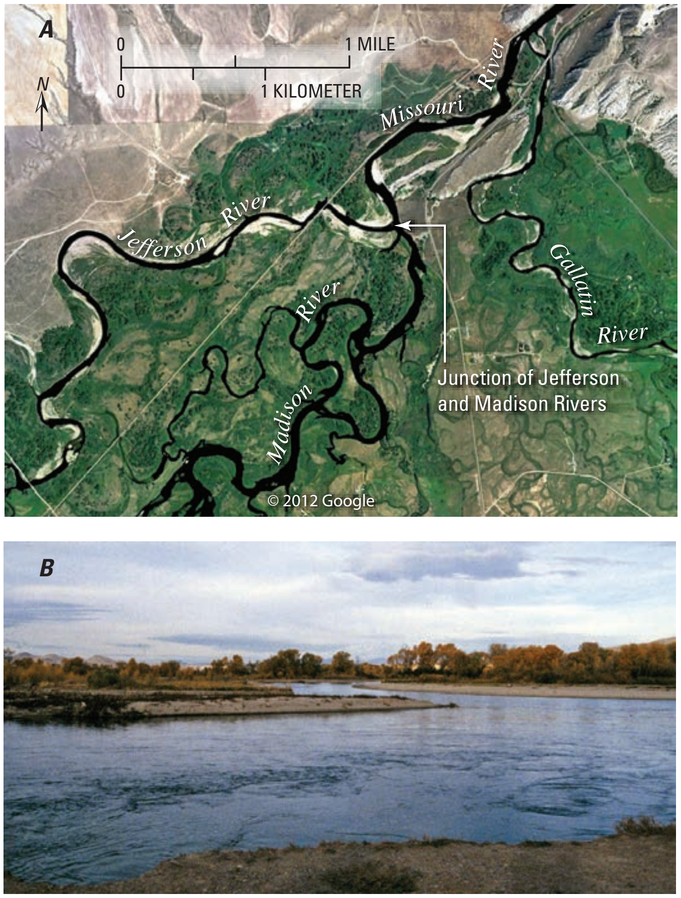

Figure 2. Headwaters of Missouri River in Montana Valley and Foothill Prairies Ecoregion. *A*, Satellite image showing Jefferson and Madison Rivers coming together to form Missouri River. Downstream from junction, note Gallatin River also joining Missouri River. *B*, View to west of junction of Jefferson and Madison Rivers. Photograph by Terry Sohl, 1999.

Figure 3. View of Trident Mine, Montana. Photograph by Terry Sohl, 1999.

contiguous built-up areas tied to an employment center. Nearly two-thirds of Montana residents live in nonmetropolitan counties (Albrecht, 2008). Ten of the counties within the ecoregion had population growth rates greater than national averages (9–13 percent) between 1970 and 2000 (table 1). Ravalli and Gallatin Counties had the highest growth rates. Population growth was largely due to amenity-related in-migration and an economy dependent on tourism, health care, and services. Counties that had population declines, such as Deer Lodge, Silver Bow, and Meagher Counties, also had declines in agriculture and mining activity, and they had railroad closures as well.

Climate varies from north to south and from the east side of the Continental Divide to the west side. However, all areas are semiarid with long cold winters and short growing seasons. In the western part of the ecoregion, Beaverhead, Bitterroot, Flathead, and Lolo National Forests provide the natural resources, particularly timber, that form the economic base for towns within nearby valleys. Mineral resources from mines in and around Anaconda, Deer Lodge, and Butte have long provided an economic base for these towns (fig. 3).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change—the percentage of land area within the Montana Valley and Foothill Prairies Ecoregion where land cover changed at least once between 1973 and 2000—was 8.1 percent (5,252 km^2). Of that total, 6.5 percent (4,203 km^2) changed one time, and 1.5 percent (970 km^2) changed two or more times (table 2). Compared to the amount of overall change in each of the 30 western United States ecoregions, this ecoregion falls in the middle (fig. 4).

Total percent change in each of the four time periods ranged from a low of 1.6 percent (1,039 km^2) between 1973 and 1980 to a high of 3.4 percent (2,229 km^2) between 1992 and 2000. When annualized, the rates of change ranged from a low of 0.2 percent (148 km^2) per year between 1973 and 1980 to a high of 0.5 percent (317 km^2) per year between 1986 and 1992 (table 3; fig. 5).

Net change by time period for all land-use/land-cover classes are presented in figure 6. Grassland/shrubland accounted for 63.5 percent (41,030 km^2) of the ecoregion in 1973. By 2000, an additional 1.7 percent (1,104 km^2) of the ecoregion had converted into grassland/shrubland. Forest covered 18.3 percent (11,861 km^2) of the ecoregion in 1973 and had a net decrease during the study period of 3.5 percent (421 km^2). Agriculture covered 11.0 percent (7,115 km^2) of the land cover in 1973 and had a net decrease of 12.9 percent (920 km^2) during the study period (table 4). Net change doesn't always tell the whole story of change. Gross change, the area gained and lost by individual land-cover classes during each period, shows that,

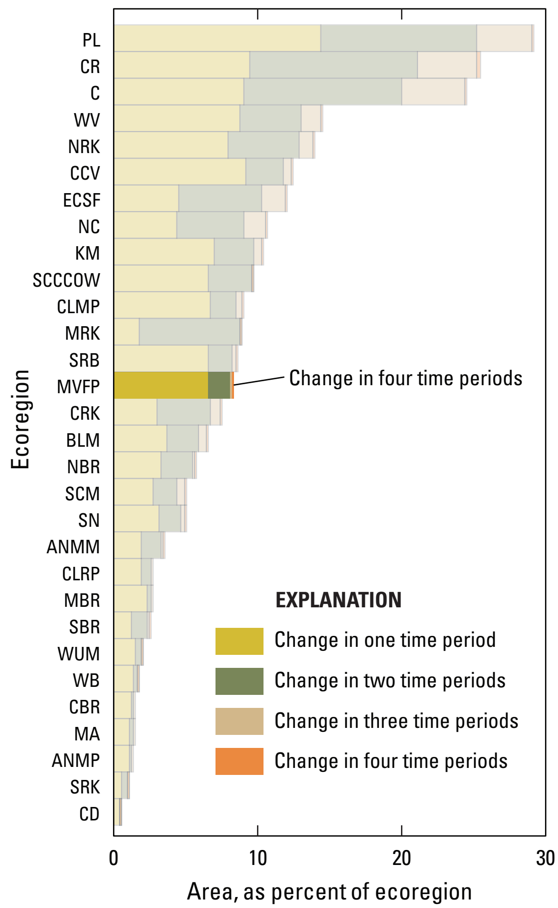

Figure 4. Overall spatial change in Montana Valley and Foothill Prairies Ecoregion (MVFP; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportion of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Montana Valley and Foothill Prairies Ecoregion (four time periods) labeled for clarity. See table 3 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

during the entire study period, individual classes fluctuated to a greater degree than net-change values reflect.

This increased amount of gross change can be further explained by the top two land-cover conversions. Overall, the top two conversions between 1973 and 2000 were agriculture to grassland/shrubland (2,918 km^2) and grassland/shrubland to agriculture (1,972 km^2) (table 5). The mechanical disturbance of forest by logging was the third most common conversion during the study period (371 km^2). The fourth and fifth most common conversions were forest to grassland/shrubland (344 km^2) and grassland/shrubland to forest (301 km^2), respectively. Grassland/shrubland to agriculture was the most common conversion in the first two time periods (1973–1980, 1980–1986), but this reversed in the last two time periods (1986–1992, 1992–2000) when agriculture to grassland/shrubland was the top conversion. This ecoregion has little developed land, and land-cover conversion to developed was very minor in all time periods.

When many of the valleys and prairies throughout the Montana Valley and Foothill Prairies Ecoregion were first homesteaded, farms and ranches sprang up, and some of them are still in existence (Malone, 1996). In the areas around Butte, Anaconda, and Deer Lodge, mining once brought great wealth to southwestern Montana. Towns like Virginia City, Nevada City, Bannack, and Coolidge formed around the search for gold, silver, and other minerals mined from the area (Malone, 1996). In its heyday, the Anaconda Mine was the richest mine on Earth. Many of the mining towns disappeared almost as quickly as they sprang up, whereas others stood the test of time and are still small towns today. Today (2012), the area around Anaconda, Butte, and the whole Upper Clark Fork River District are part of an Environmental Protection Agency Superfund site (Diamond, 2005). The ranching industry began about the same time as the mining industry. Cattle and sheep were raised to feed the miners and homesteaders, often replacing herds of buffalo and elk. Today (2012), ranching remains an important industry (fig. 7).

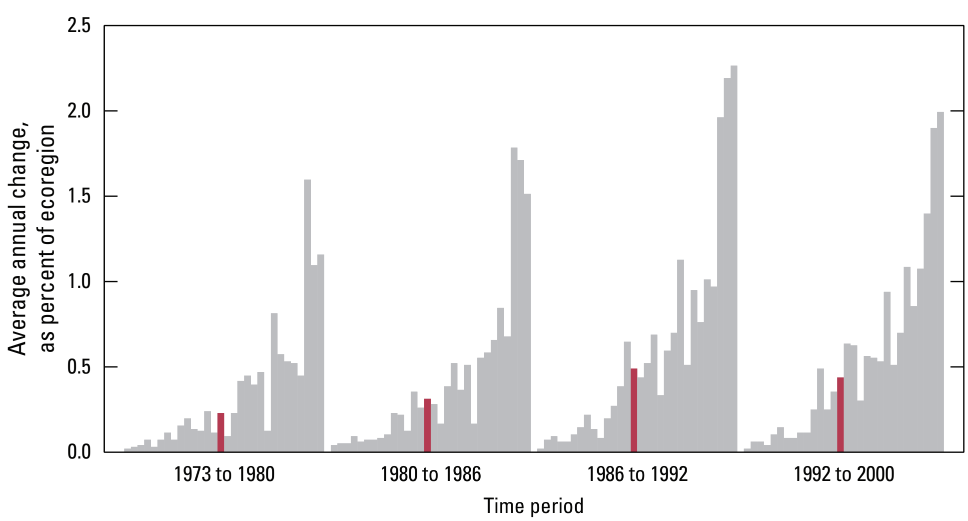

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Montana Valley and Foothill Prairies Ecoregion are represented by red bars in each time period.

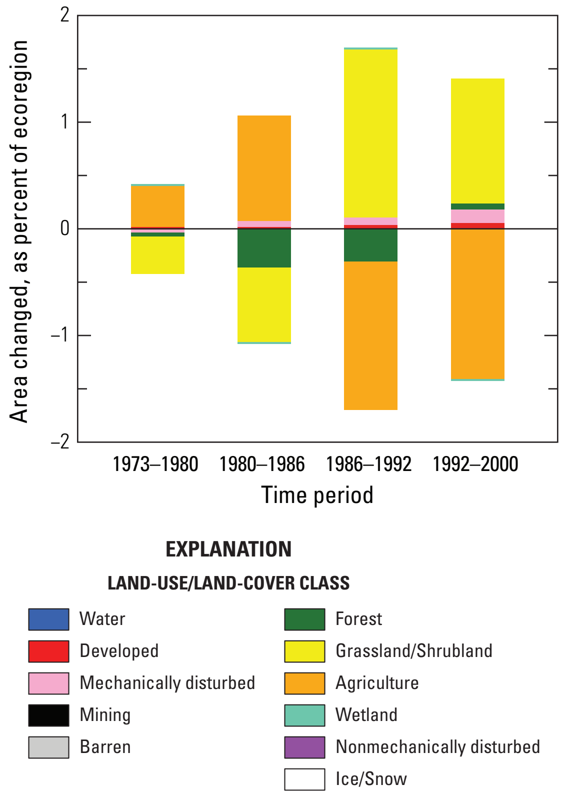

Figure 6. Normalized average net change in Montana Valley and Foothill Prairies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 7. Sheep grazing in Montana Valley and Foothill Prairies Ecoregion. Photograph by Terry Sohl, 1999.

Figure 8. Large farm operation with granaries and numerous outbuildings in Montana Valley and Foothill Prairies Ecoregion. Photograph by Terry Sohl, 1999.

In the 1970s, global demand for wheat increased greatly, and rangeland and other grassland that had not previously been broken was planted with wheat. This trend continued into the 1980s as low-interest bank loans and tax credits for breaking new ground—also known as "sodbusting"—provoked speculators and investors to enter into farming (fig. 8). The trend of purchase, plow, and resell was also bolstered by National Farm Program incentives, such as diversion payments and deficiency payments (Watts and others, 1983). In the mid-1980s, the price of wheat plummeted as the world supplies became saturated, and farmers, both old and new, wanted out of farming. In 1986, the Conservation Reserve Program was started, in which farmers were paid to retire many of the fields broken in the 1970s (Leistritz and others, 2002). These national trends were seen to some degree in the Montana Valley and Foothill Prairies Ecoregion, with increases in agricultural land until 1986 and then declines in agricultural land as it converted back to grassland/shrubland between 1986 and 2000.

Table 1. Population change in 17 Montana counties between 1970 and 2000 (from Forstall, 1995).

County	1970	1980	1990	2000	Total change, # of persons	Change (Percent)
Metropolitan counties						
Carbon County	7,080	8,099	8,080	9,552	2,472	34.9
Yellowstone County	87,367	108,035	113,419	129,352	41,985	48.1
Missoula County	58,263	76,016	78,687	95,802	37,539	64.4
Rural counties						
Beaverhead County	8,187	8,186	8,424	9,202	1,015	12.4
Deer Lodge County	15,652	12,518	10,278	9,417	−6,235	−39.8
Fergus County	12,611	13,076	12,083	11,893	−718	−5.7
Flathead County	39,460	51,966	59,218	74,471	35,011	88.7
Gallatin County	32,505	42,865	50,463	67,831	35,326	108.7
Jefferson County	5,238	7,029	7,939	10,049	4,811	91.8
Lake County	14,445	19,056	21,041	26,507	12,062	83.5
Lewis and Clark County	33,281	43,039	47,495	55,716	22,435	67.4
Meagher County	2,122	2,154	1,819	1,932	−190	−9.0
Park County	11,197	12,660	14,562	15,694	4,497	40.2
Powell County	6,660	6,958	6,620	7,180	520	7.8
Ravalli County	14,409	22,493	25,010	36,070	21,661	150.3
Silver Bow County	41,981	38,092	33,941	34,606	−7,375	−17.6
Teton County	6,116	6,491	6,271	6,445	329	5.4

Table 2. Percentage of Montana Valley and Foothill Prairies Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (91.9 percent), whereas 8.1 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	6.5	3.6	2.9	10.1	2.3	34.9
2	1.5	0.6	0.9	2.1	0.4	26.1
3	0.1	0.1	0.0	0.1	0.0	37.4
4	0.0	0.0	0.0	0.0	0.0	56.2
Overall spatial change	8.1	4.1	4.1	12.2	2.6	31.7

Table 3. Raw estimates of change in Montana Valley and Foothill Prairies Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	1.6	0.5	1.1	2.1	0.3	21.3	0.2
1980–1986	1.8	0.7	1.1	2.6	0.5	24.4	0.3
1986–1992	2.9	1.7	1.2	4.6	1.1	36.6	0.5
1992–2000	3.4	2.6	0.8	6.0	1.7	47.9	0.4
Estimate of change, in square kilometers							
1973–1980	1,039	348	691	1,387	221	21.3	148
1980–1986	1,193	459	734	1,652	291	24.4	199
1986–1992	1,903	1,095	808	2,998	696	36.6	317
1992–2000	2,229	1,680	549	3,909	1,067	47.9	279

Table 4. Estimated area (and margin of error) of each land-cover class in Montana Valley and Foothill Prairies Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	6.1	8.7	0.3	0.2	0.1	0.1	0.0	0.0	0.5	0.4	18.3	6.5	63.5	11.3	11.0	6.3	0.3	0.3	0.0	0.0
1980	6.1	8.7	0.3	0.2	0.0	0.0	0.0	0.0	0.5	0.4	18.3	6.5	63.1	11.2	11.4	6.6	0.3	0.3	0.0	0.0
1986	6.1	8.7	0.4	0.2	0.1	0.1	0.0	0.0	0.5	0.4	17.9	6.3	62.4	11.1	12.4	6.8	0.3	0.3	0.0	0.0
1992	6.1	8.7	0.4	0.2	0.2	0.2	0.0	0.0	0.5	0.4	17.6	6.2	64.0	11.0	11.0	5.3	0.3	0.3	0.0	0.0
2000	6.1	8.7	0.5	0.3	0.3	0.3	0.0	0.0	0.5	0.4	17.7	6.3	65.2	11.4	9.6	3.8	0.3	0.3	0.0	0.0
Net change	0.0	0.0	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0.0	−0.7	0.4	1.7	3.3	−1.4	3.4	0.0	0.0	0.0	0.0
Gross change	0.0	0.0	0.1	0.1	0.4	0.4	0.0	0.0	0.0	0.0	1.0	0.5	5.4	3.8	5.1	3.8	0.0	0.0	0.0	0.0
Area, in square kilometers																				
1973	3,915	5,611	204	142	41	49	21	32	306	287	11,861	4,197	41,030	7,288	7,115	4,094	165	168	0	0
1980	3,915	5,611	221	150	22	26	21	32	306	287	11,834	4,172	40,811	7,261	7,356	4,262	172	178	0	0
1986	3,915	5,611	232	157	59	59	21	32	306	287	11,600	4,062	40,357	7,187	8,001	4,390	167	170	0	0
1992	3,916	5,611	259	159	107	149	21	32	306	287	11,403	4,023	41,379	7,132	7,098	3,426	169	174	0	0
2000	3,917	5,610	298	196	186	222	21	32	303	287	11,441	4,060	42,134	7,345	6,194	2,431	164	167	0	0
Net change	2	3	93	78	145	175	0	0	−3	5	−421	286	1,104	2,152	−920	2,195	0	0	0	0
Gross change	4	4	93	78	273	227	0	0	3	5	630	355	3,509	2,446	3,297	2,461	20	30	0	0

Table 5. Principal land-cover conversions in Montana Valley and Foothill Prairies Ecoregion, showing amount of area changed (and margin of error, calculated a 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	529	290	184	0.8	50.9
	Agriculture	Grassland/Shrubland	291	112	71	0.5	28.0
	Grassland/Shrubland	Forest	46	50	32	0.1	4.5
	Mechanically disturbed	Grassland/Shrubland	41	48	31	0.1	3.9
	Forest	Grassland/Shrubland	39	40	26	0.1	3.8
	Other	Other	93	n/a	n/a	0.1	8.9
		Totals	1,039			1.6	100.0
1980–1986	Grassland/Shrubland	Agriculture	729	359	228	1.1	61.1
	Forest	Grassland/Shrubland	193	185	118	0.3	16.1
	Agriculture	Grassland/Shrubland	104	54	34	0.2	8.7
	Forest	Mechanically disturbed	59	59	37	0.1	5.0
	Grassland/Shrubland	Forest	31	31	20	0.0	2.6
	Other	Other	78	n/a	n/a	0.1	6.5
		Totals	1,193			1.8	100.0
1986–1992	Agriculture	Grassland/Shrubland	1,236	1,056	671	1.9	64.9
	Grassland/Shrubland	Agriculture	334	295	188	0.5	17.6
	Forest	Mechanically disturbed	106	148	94	0.2	5.6
	Forest	Grassland/Shrubland	101	115	73	0.2	5.3
	Mechanically disturbed	Grassland/Shrubland	58	58	37	0.1	3.1
	Other	Other	68	n/a	n/a	0.1	3.6
		Totals	1,903			2.9	100.0
1992–2000	Agriculture	Grassland/Shrubland	1,288	1,552	986	2.0	57.8
	Grassland/Shrubland	Agriculture	380	235	149	0.6	17.1
	Grassland/Shrubland	Forest	198	293	186	0.3	8.9
	Forest	Mechanically disturbed	184	219	139	0.3	8.3
	Mechanically disturbed	Grassland/Shrubland	68	91	58	0.1	3.0
	Other	Other	111	n/a	n/a	0.2	5.0
		Totals	2,229			3.4	100.0
1973–2000 (overall)	Agriculture	Grassland/Shrubland	2,918	2,525	1,604	4.5	45.8
	Grassland/Shrubland	Agriculture	1,972	817	519	3.1	31.0
	Forest	Mechanically disturbed	371	417	265	0.6	5.8
	Forest	Grassland/Shrubland	344	255	162	0.5	5.4
	Grassland/Shrubland	Forest	301	393	249	0.5	4.7
	Other	Other	457	n/a	n/a	0.7	7.2
		Totals	6,364			9.8	100.0

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Chapter 7

Northern Rockies Ecoregion

By Janis L. Taylor

Ecoregion Description

The Northern Rockies Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 162,746 km^2 (63,200 mi^2), primarily in Idaho but also including areas in western Montana and northeastern Washington (fig. 1). Canada forms the northern border of the ecoregion. To the west it is bordered by the Columbia Plateau and Blue Mountains Ecoregions, to the south by the Snake River Basin Ecoregion, and to the east by the Canadian Rockies, Middle Rockies, Northwestern Great Plains, and Northwestern Glaciated Plains Ecoregions; also to the east, the Northern Rockies Ecoregion interfingers with the Montana Valley and Foothill Prairies Ecoregion, each enclosing some isolated areas of the other (fig. 1).

The ecoregion is composed of a series of high, rugged mountain ranges, mostly oriented northwest-southeast, with intermontane valleys between them (fig. 2). The entire ecoregion was glaciated during the Pleistocene (1,800,000 to 11,400 years ago), and today numerous large lakes occupy basins

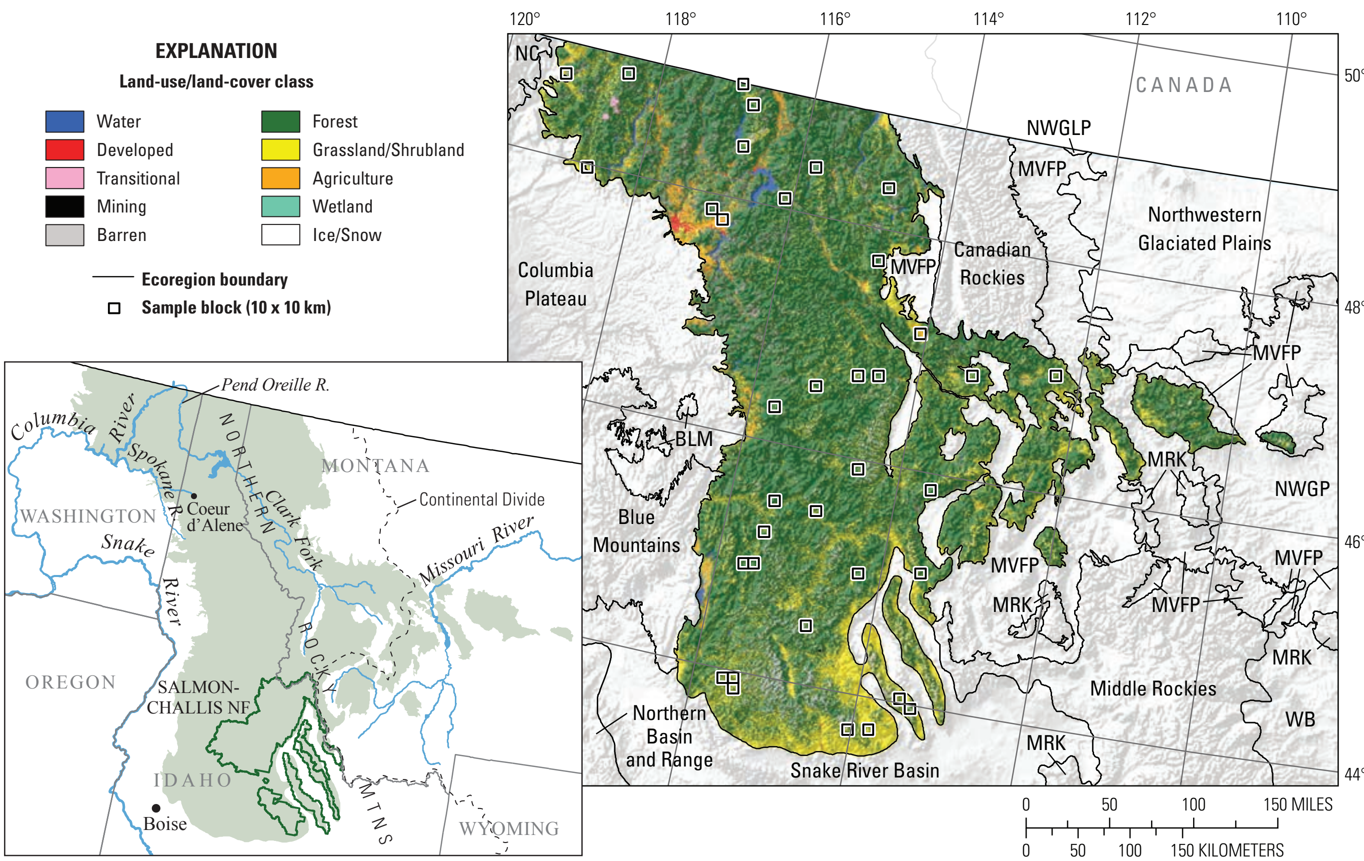

Figure 1. Map of Northern Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Note that all small areas entirely surrounded by Northern Rockies Ecoregion are parts of Montana Valley and Foothill Prairies Ecoregion. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown are parts of two Great Plains ecoregions: Northwestern Glaciated Plains (NWGLP) and Northwestern Great Plains (NWGP). See appendix 3 for definitions of land-use/land-cover classifications.

formed by glacial action (Omernik, 1987; Habeck and Mutch, 1973). Streams draining these mountain ranges provide a water source for many western cities and towns (fig. 3). The Continental Divide, located at the highest elevations along the northern Rocky Mountains, separates rivers that flow westward into the Columbia River watershed from those that flow eastward into the Missouri River watershed.

The ecoregion consists of montane, subalpine, and alpine ecosystems that have distinct floral and faunal elevation zones, with the highest elevations in the southern part of the ecoregion. The lower elevation montane forest provides habitat for mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), mountain lions (*Puma concolor*), bears (*Ursus* spp.), and raptors (for example, bald eagles (*Haliaeetus leucocephalus*), Swainson's hawks (*Buteo swainsoni*), and American kestrels (*Falco sparverius*)) (fig. 4). The winter snowfall supports a lucrative skiing and tourism economy, and ski resorts have been built throughout the midelevation subalpine forest. Alpine ecosystems occupy the highest elevations, where harsh climates support trees and shrubs with smaller, dwarfed structures and more dense ground cover (Barrera, 2009). In addition to the vast conifer forests throughout the Northern Rockies Ecoregion, there are also many mountain meadows, foothill grasslands, and riparian woodlands (fig. 5).

Climate within the Northern Rockies Ecoregion varies extensively from west to east, as well as north to south. The climate on the west side of the Rocky Mountains is moderated by a maritime influence, whereas the climate on the east side is harsher and more continental. Climate likewise varies from north to south across latitude. In general, the higher elevations receive more precipitation and have lower average temperatures. Orographic lifting of air masses over the mountains forces much of the moisture content to precipitate (primarily as snow). Because of the mountainous terrain, local microclimates are highly variable as a result of differences in slope aspect, exposure to prevailing wind, thermal inversions, and dry pockets (Ricketts and others, 1999).

This ecoregion is sparsely populated, but it has been occupied for more than 5,000 years by indigenous peoples who hunted throughout the foothills and valleys of the mountains. In the last two centuries, trappers, traders, and explorers led the tide of European settlers into the ecoregion. The Lewis and Clark expedition crossed through the northern Rocky Mountains twice on their journey to the Pacific Ocean and back. Miners and trappers explored every mountain and established the first industries in the ecoregion. After railroads made the ecoregion more accessible, hard-rock mines for gold, silver, lead, molybdenum, zinc, and even garnets were established. Along with mining, logging of the ecoregion's vast conifer forests still provides its economic backbone (fig. 6).

Most land within the Northern Rockies Ecoregion is publicly owned, the largest part being under the control of the U.S. Forest Service. The first forest reserves in the ecoregion were established in the late 1800s. Today there are 15 different national forests and a number of state-owned forests in the ecoregion (fig. 7). Within the national forests are 10 designated wilderness areas, including the 9,300-km^2 Frank Church–River of No Return Wilderness, the largest contiguous area of protected wilderness in the conterminous United States. There are also four U.S. Fish and Wildlife Service National Wildlife Refuges and several major hydroelectric dams along the ecoregion's large rivers, the Clark Fork, the Pend Oreille River, and the Spokane River.

The Coeur d'Alene metropolitan area in northern Idaho is the largest concentration of population in the ecoregion; in 2000 it had a population of around 100,000. Overall, this large ecoregion includes little developed land. The five Indian reservations within the ecoregion are the Flathead Reservation in Montana (fig. 8), the Colville and the Spokane Reservations in Washington, and the Coeur d'Alene and the Kootenai Reservations in Idaho.

Figure 2. Intermontane valley located between parallel mountain ranges in Northern Rockies Ecoregion. Photograph by Janis Taylor, 2008.

Figure 3. Water, in form of runoff and snowmelt from peaks, feeds rivers and has helped shape mountains in Northern Rockies Ecoregion. These mountain ranges can be considered water towers because they provide water source for many western cities and towns. Photograph by Janis Taylor, 2008.

Figure 4. Lower elevation montane forest in Northern Rockies Ecoregion, which provides habitat for mule deer, elk, moose, mountain lions, raptors, and bears. Photograph by Janis Taylor, 2008.

Figure 5. Wet meadow occupying valley flat in Northern Rockies Ecoregion, with forested hillsides in distance. Photograph by Janis Taylor, 2008.

Figure 6. Effect of logging of vast conifer forests in Northern Rockies Ecoregion is seen in large cut area on near slope of this hillside. Photograph by Janis Taylor, 2008.

Figure 7. Salmon-Challis National Forest is just one of 15 national forests within Northern Rockies Ecoregion. Photograph by Janis Taylor, 2008.

Figure 8. Flathead Reservation is just one of five reservations within Northern Rockies Ecoregion. Photograph by Janis Taylor, 2008.

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change—the percentage of land area within the ecoregion where land cover changed at least once between 1973 and 2000—was 13.8 percent (22,539 km^2). Of that total, 7.8 percent (12,769 km^2) changed one time, and 5.0 percent (8,192 km^2) changed two or more times (table 1). This ecoregion had the fifth highest overall change among all western United States ecoregions (fig. 9). The four ecoregions that had higher overall change were the Puget Lowland, the Coast Range, the Cascades, and the Willamette Valley Ecoregions.

Total change in each of the four time periods selected for this study ranged from a low of 3.7 percent (6,057 km^2) between 1973 and 1980 to a high of 8.7 percent (14,242 km^2) between 1992 and 2000. After normalizing to an annual rate of change, these two time periods still provided the extreme

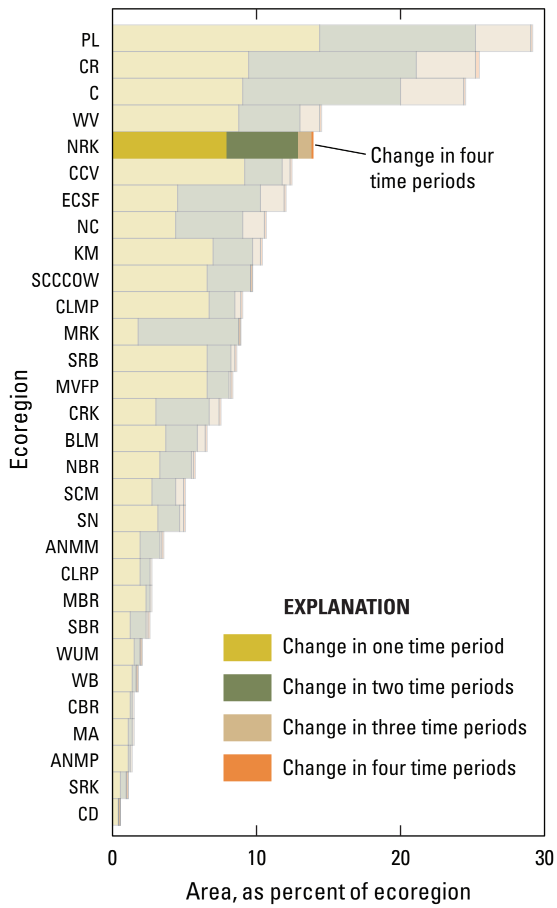

Figure 9. Overall spatial change in Northern Rockies Ecoregion (NRK; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that experienced change during one, two, three, or four time periods; highest level of spatial change in Northern Rockies Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

values: 0.5 percent (818 km^2) per year and 1.1 percent (1,801 km^2) per year, respectively (table 2; fig. 10).

Between 1973 and 1980, forest and grassland/shrubland combined to account for 90 percent (146,557 km^2) of the land cover in the ecoregion (fig. 11). The amount of forest decreased from 72.2 percent (117,534 km^2) of the ecoregion in 1973 to 66.5 percent (108,290 km^2) in 2000 (table 3). The amount of grassland/shrubland increased from 17.8 percent (29,023 km^2) of the ecoregion in 1973 to 20.3 percent (32,962 km^2) in 2000. Net changes in land-use/land-cover classes by period are found in figure 12.

The top four land-cover conversions are forest to mechanically disturbed, forest to nonmechanically disturbed, mechanically disturbed to grassland/shrubland, and grassland/shrubland to forest. These changes are all components of forest change resulting from logging, wildfires, and insect-caused mortality, all common occurrences in the Rocky Mountains. In the first three time periods (1973–1980, 1980–1986, and 1986–1992), the most common land-cover conversion was the result of timber harvest, in which forest is converted to mechanically disturbed land, which regrows to grassland/shrubland and eventually back to forest, representing a cyclic pattern of land-cover change (table 4). Large wildfires (fig. 13) and (or) increased insect mortality (fig. 14) in the last time period (1992–2000) made forest to nonmechanically disturbed the most common land-cover conversion for that time period.

The continuing pattern of timber harvest is supported by the fact that there were areas of mechanically disturbed land in all time periods between 1973 and 2000; 1.9 percent (3,057 km^2) of land was classified as mechanically disturbed in 1973 and 1.1 percent (1,749 km^2) in 2000 (table 3). New forest areas were logged in each of the time periods, and these return to grassland/shrubland and eventually to forest land cover in subsequent time periods.

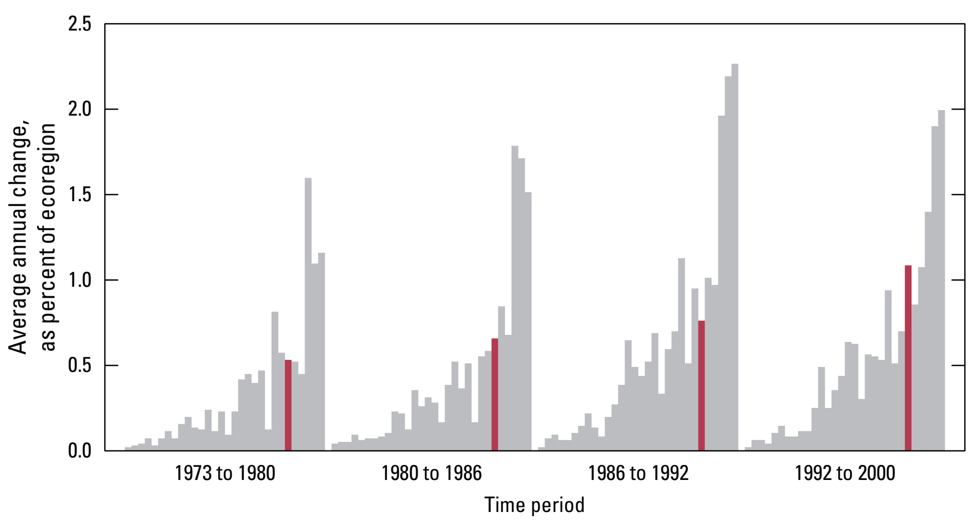

Figure 10. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Northern Rockies Ecoregion are represented by red bars in each time period.

Figure 11. Grassland/shrubland land cover in Northern Rockies Ecoregion. Photograph by Janis Taylor, 2008.

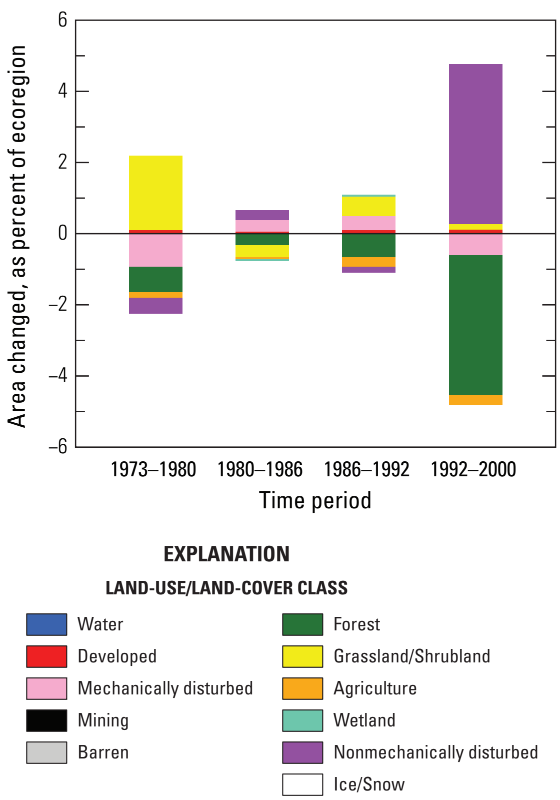

Figure 12. Normalized average net change in Northern Rockies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

The conversion of forest to nonmechanically disturbed land—resulting from wildfires and insect-caused mortality—was not as common in earlier time periods, and the cyclic pattern of land-cover change in forest land was not as prominent. The amount of nonmechanically disturbed land cover was only 0.4 percent (712 km^2) in 1973, increasing dramatically in the last time period to 4.7 percent (7,624 km^2) in 2000, a pattern common throughout the western United States.

This ecoregion provides numerous ecosystem services. Probably the most important is the large amounts of fresh water demanded by rapidly growing urban populations in neighboring ecoregions, as well as for agricultural irrigation, industry, and power generation. Other ecosystem services include wildlife habitat, timber, and snow-based recreation such as ski resorts. Local economies promote tourism through outdoor recreation opportunities, including hiking, backpacking, hunting, fishing, whitewater rafting, mountain biking, skiing, and snowmobiling.

Even though mining was only a minor land cover identified during the study period, there is a long history of mining activity throughout the northern Rocky Mountains. Today, there are numerous abandoned mines, as well as associated

Figure 13. Trees killed during wildfire that burned through previously logged areas in Northern Rockies Ecoregion. Photograph by Janis Taylor, 2008.

Figure 14. Trees killed by insects can be seen on hillside in Northern Rockies Ecoregion. Photograph by Janis Taylor, 2008.

mine tailings, contaminated soils and waterways, and erosion. Many of these mines have had documented impacts on fisheries and vegetation throughout the northern Rocky Mountains (U.S. Environmental Protection Agency, 2001; Montana Department of Environmental Quality, 2009) (fig. 15). Some abandoned open-pit mines have become small mountain lakes. Other mines have reopened with the resurgence in the price of metals. The Coeur d'Alene mining district in Shoshone County in northern Idaho is still considered one of the richest metal mining areas in the world.

Aside from timber harvesting, wildfires and insect-caused mortality are the major disturbance regimes in the Northern Rockies Ecoregion. Human control of wildfires, notably the fire-suppression efforts between 1930 and 1950, have altered the size, incidence, and location of wildfires (Gruell, 1983). As a result, by 1950 the size and intensity of wildfires had grown significantly (Arno, 1980). In the 1980s, these suppression tactics ceased; wildfires were again allowed to burn, and there were notable fires in the Selway-Bitterroot Wilderness and Kootenai National Forest (Arno and Allison-Bunnell, 2002). Scientists continue to study the role of fire as a natural process and its effects on people, wildlife, soil, and water.

Forest recovery has also been studied thoroughly since the 1980s; the following are a couple of findings that are reflected in the state of land cover through time. Some areas that have burned more than one time have the potential to stay in a grassland/shrubland state for a longer period of time than those burned just once. Disturbances that occur near timberline can also expect a slow recovery (Arno and Allison-Bunnell, 2002). On the basis of their study, the overall increase in the amount of grassland/shrubland may, in part, be a result of multiple wildfires at high elevations.

Figure 15. Example of impact from numerous abandoned mines throughout Northern Rockies Ecoregion, showing mine tailings, contaminated soils and waterways, and erosion. Photograph by Janis Taylor.

Current research indicates that climate change will result in a higher likelihood of wildfires and insect-caused mortality (Carter, 2003). In this ecoregion, the number of frost-free days per year has already increased, and there have been fewer extended periods of very cold temperatures during winter. Because of these changes, in combination with recurring drought, scientists predict an increase in insect infestations (Shore and others, 2003), killing more trees and thus adding to a higher potential for regional fire events.

Table 1. Percentage of Northern Rockies Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (86.2 percent), whereas 13.8 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	7.8	2.9	4.9	10.8	2.0	25.5
2	5.0	1.7	3.3	6.8	1.2	23.5
3	0.9	0.6	0.3	1.5	0.4	45.0
4	0.0	0.1	0.0	0.1	0.0	75.4
Overall spatial change	13.8	3.9	9.9	17.8	2.7	19.2

Table 2. Raw estimates of change in Northern Rockies Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	3.7	1.7	2.0	5.4	1.2	31.5	0.5
1980–1986	3.9	1.8	2.1	5.7	1.2	30.9	0.7
1986–1992	4.5	1.5	3.0	6.1	1.0	22.8	0.8
1992–2000	8.7	2.9	5.8	11.6	2.0	22.6	1.1
			Estimate of change, in square kilometers				
1973–1980	5,990	2,774	3,217	8,764	1,884	31.5	856
1980–1986	6,408	2,912	3,496	9,320	1,978	30.9	1,068
1986–1992	7,394	2,485	4,909	9,879	1,688	22.8	1,232
1992–2000	1,4169	4,710	9,459	18,879	3,200	22.6	1,771

Table 3. Estimated area (and margin of error) of each land-cover class in Northern Rockies Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	0.8	0.8	0.3	0.3	1.9	1.0	0.0	0.0	3.0	1.6	72.2	5.3	17.8	3.7	3.2	2.7	0.4	0.2	0.4	0.6
1980	0.8	0.8	0.4	0.5	1.0	0.5	0.0	0.0	3.0	1.6	71.5	5.3	19.9	3.5	3.0	2.5	0.4	0.2	0.0	0.0
1986	0.8	0.8	0.5	0.6	1.3	0.6	0.0	0.0	3.0	1.6	71.2	5.4	19.6	3.5	3.0	2.5	0.4	0.2	0.3	0.3
1992	0.8	0.8	0.6	0.8	1.6	0.6	0.0	0.0	3.0	1.6	70.5	5.4	20.1	3.8	2.8	2.2	0.4	0.2	0.2	0.1
2000	0.8	0.8	0.7	0.9	1.1	0.4	0.0	0.0	3.0	1.6	66.5	5.6	20.3	3.7	2.5	2.0	0.4	0.2	4.7	2.9
Net change	0.0	0.0	0.4	0.6	−0.8	0.9	0.0	0.0	0.0	0.0	−5.7	3.2	2.4	1.3	−0.6	1.0	0.0	0.0	4.2	3.0
Gross change	0.0	0.0	0.4	0.6	4.2	1.4	0.0	0.0	0.0	0.0	9.3	3.2	5.8	2.3	0.8	1.0	0.0	0.0	6.0	2.9
									Area, in square kilometers											
1973	1,290	1,280	495	529	3,057	1,584	21	17	4,833	2,540	117,534	8,592	29,023	6,012	5,131	4,348	646	274	712	1,036
1980	1,275	1,277	694	804	1,555	885	37	26	4,842	2,540	116,362	8,611	32,412	5,752	4,920	4,089	629	264	20	20
1986	1,266	1,260	813	947	2,059	964	27	23	4,844	2,542	115,864	8,786	31,834	5,765	4,899	4,026	624	262	515	547
1992	1,274	1,277	1,031	1,246	2,673	976	38	34	4,840	2,540	114,770	8,821	32,725	6,147	4,515	3,610	628	264	248	206
2000	1,274	1,277	1,212	1,466	1,749	678	61	56	4,842	2,541	108,290	9,114	32,962	6,097	4,102	3,231	628	265	7,624	4,666
Net change	−16	24	717	938	−1,308	1,500	40	57	9	9	−9,244	5,237	3,939	2,183	−1,030	1,559	−18	21	6,913	4,847
Gross change	63	52	717	938	6,865	2,272	61	56	18	16	15,086	5,219	9,364	3,794	1,244	1,555	36	35	9,753	4,707

Table 4. Principal land-cover conversions in Northern Rockies Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Mechanically disturbed	Grassland/Shrubland	2,697	1,535	1,043	1.7	45.0
	Forest	Mechanically disturbed	1,543	881	599	0.9	25.8
	Nonmechanically disturbed	Grassland/Shrubland	707	1,029	699	0.4	11.8
	Mechanically disturbed	Forest	336	261	177	0.2	5.6
	Grassland/Shrubland	Forest	162	116	79	0.1	2.7
	Other	Other	545	n/a	n/a	0.3	9.1
		Totals	5,990			3.7	100.0
1980–1986	Forest	Mechanically disturbed	2,018	949	644	1.2	31.5
	Grassland/Shrubland	Forest	1,879	1,596	1,084	1.2	29.3
	Mechanically disturbed	Grassland/Shrubland	1,363	860	584	0.8	21.3
	Forest	Nonmechanically disturbed	433	495	336	0.3	6.8
	Mechanically disturbed	Forest	169	138	94	0.1	2.6
	Other	Other	545	n/a	n/a	0.3	8.5
		Totals	6,408			3.9	100.0
1986–1992	Forest	Mechanically disturbed	2,597	949	644	1.6	35.1
	Mechanically disturbed	Grassland/Shrubland	1,672	925	628	1.0	22.6
	Grassland/Shrubland	Forest	1,286	921	625	0.8	17.4
	Nonmechanically disturbed	Grassland/Shrubland	427	457	310	0.3	5.8
	Mechanically disturbed	Forest	346	227	154	0.2	4.7
	Other	Other	1,066	n/a	n/a	0.7	14.4
		Totals	7,394			4.5	100.0
1992–2000	Forest	Nonmechanically disturbed	6,906	4,510	3,064	4.2	48.7
	Forest	Mechanically disturbed	1,729	673	457	1.1	12.2
	Mechanically disturbed	Grassland/Shrubland	1,727	713	484	1.1	12.2
	Grassland/Shrubland	Forest	1,476	700	475	0.9	10.4
	Mechanically disturbed	Forest	722	500	340	0.4	5.1
	Other	Other	1,609	n/a	n/a	1.0	11.4
		Totals	14,169			8.7	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	7,888	2,834	1,926	4.8	23.2
	Forest	Nonmechanically disturbed	7,459	4,494	3,053	4.6	22.0
	Mechanically disturbed	Grassland/Shrubland	7,458	3,575	2,429	4.6	22.0
	Grassland/Shrubland	Forest	4,803	2,986	2,028	3.0	14.1
	Mechanically disturbed	Forest	1,573	867	589	1.0	4.6
	Other	Other	4,780	n/a	n/a	2.9	14.1
		Totals	33,962			20.9	100.0

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Chapter 8

Southern Rockies Ecoregion

By Mark A. Drummond

Ecoregion Description

The Southern Rockies Ecoregion is a high-elevation mountainous ecoregion that covers approximately 138,854 km² (53,612 mi²), including much of central Colorado and parts of southern Wyoming and northern New Mexico (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). It abuts six other ecoregions: the Wyoming Basin and Colorado Plateaus Ecoregions on the north and west, the Arizona/New Mexico Plateau Ecoregion on the south, and the Northwestern Great Plains, Western High Plains, and Southwestern Tablelands Ecoregions on the east (fig. 1). The ecoregion receives most of its annual precipitation (25–100 cm) as snowfall, which provides a significant amount of high-elevation snowpack that is an important water source for surrounding ecoregions. The Southern Rockies Ecoregion has a steep elevation gradient from low foothills to high peaks, with several hundred summits higher than 3,660 m (12,000 ft). As a southern extension of the larger Rocky Mountain system, it is composed primarily of seven main north-south trending mountain ranges that are separated by four large intermontane basins. A fifth basin, the San Luis Valley, is outside the ecoregion, forming a northern finger of the Arizona/New Mexico Plateau Ecoregion that lies mostly to the south. To the east, late Tertiary sand and gravel deposits that were eroded from the relatively young Rocky Mountains were carried eastward by streams, forming the nearby Western High Plains Ecoregion and its underlying Ogallala aquifer.

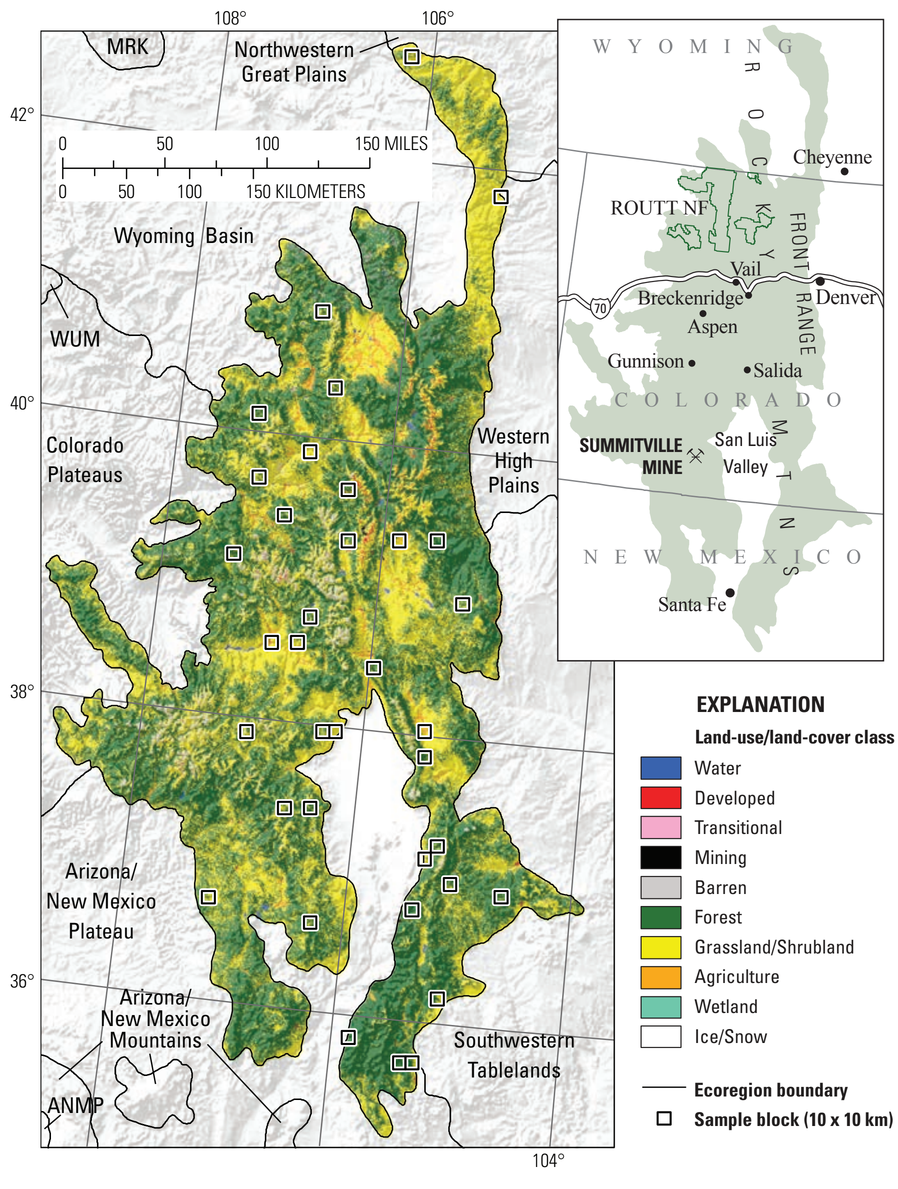

Figure 1. Map of Southern Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map are three Great Plains ecoregions: Northwestern Great Plains, Western High Plains, and Southwestern Tablelands. See appendix 3 for definitions of land-use/land-cover classifications.

Approximately 56 percent of the ecoregion is forested in a heterogeneous pattern, whereas grassland/shrubland cover makes up nearly 38 percent of the total area (table 1). There are many forest types, including the more prevalent spruce-fir (*Picea* spp. and *Abies* spp.), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), aspen (*Populus tremuloides*), and pinyon-juniper (*Pinus edulis* and *Juniperus scopulorum*, *monosperma*, and *osteosperma*) types. Vegetation patterns correspond with the steep elevation gradient. In general, grassland and shrubland covers the lower elevation valleys and intermontane basins. Sagebrush (*Artemisia tridentata*), oak (*Quercus* spp.), pinyon-juniper woodland, and blue grama grass (*Bouteloua gracilis*) are common at lower elevations, which range from 1,828 to 2,438 m (Chapman and others, 2006). Ponderosa pine, aspen, juniper, and oak are common at middle elevations. The higher elevation subalpine forests are often dense, consisting of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). High-elevation alpine zones are above the tree line and support a variety of low shrubs, wildflowers, krummholz (stunted trees), and other vegetation interspersed with exposed rocks, peaks, and permanent snowfields.

Many of the forest systems are heavily influenced by disturbances, particularly those caused by fire and insects, but high winds, avalanches, and disease are also factors. Forests of lodgepole pine, ponderosa pine, and aspen have all been affected by frequent low-intensity fires (Buskirk and others 2000). The low-intensity fire regimes have been altered by historical land-management practices of fire exclusion and suppression, contributing to higher density, even-aged forest stands as well as high-intensity, stand-replacing fires from the resulting heavy fuel loads. Substantial areas of western North American coniferous forest have been affected since 2000 by bark beetle (*Dendroctonus* spp., *Ips* spp., and *Dryocoetes confusus*) outbreaks related to climate variability and change (fig. 2). Drought and warming amplify the effects of insect outbreaks and also cause additional tree mortality and forest dieback (Breshears and others, 2005; van Mantgem and others, 2009). Atmospheric warming and precipitation changes may have a significant effect on the future elevations of upper and lower tree lines. Blowdown events can be substantial—high winds downed an 80-km^2 area of spruce trees in the Routt National Forest in 1997 (Neely and others, 2001).

The human population of the Rocky Mountains is growing three times faster than the national rate (Baron and others, 2000). Despite the high rate of population growth, the Southern Rockies Ecoregion had no towns of more than 15,000 people during the study period. The permanent populations of many of the larger towns range from 3,000 to 6,000 people, including the more agriculturally inclined cities of Gunnison and Salida in central Colorado, as well as the ski towns of Breckenridge, Vail, and Aspen, Colorado. Besides the permanent population, many amenity-rich areas have a significantly higher seasonal population. Breckenridge had 2,366 permanent residents in 2000, but of the 4,229 total housing units, 3,166 were vacant, primarily because of seasonal use patterns

Figure 2. Example of beetle-killed trees (with brown needles) in central Colorado.

Figure 3. Valley development along Interstate 70 corridor near Vail, Colorado.

(U.S. Census Bureau, 2000). Several large cities, including Denver, Colorado, and other Front Range communities lie just outside this ecoregion, and their suburbs and other exurban development has spread into the Southern Rockies Ecoregion. The Interstate 70 corridor that cuts across Colorado is also a central locus of new residential, commercial, and economic development, although growth and tourism reach many rural communities as well.

The steep elevation gradient is important to land-use and land-ownership patterns. Large tracts of high-elevation forest and wilderness are publically owned, whereas many of the small towns characteristic of the ecoregion are located in the valleys and near riparian zones (fig. 3). Approximately 40 percent of the region is privately owned, and 60 percent is managed as public land. More than 80 percent of the public land is managed by the U.S. Forest Service. The numerous amenity-rich rural areas and recreation opportunities, including national parks and monuments, other public lands, and ski resorts, play a role in attracting new development, tourism, and regional population growth. Land-use changes in the valley bottoms, which are often disproportionately rich in habitat diversity, can affect wildlife and habitat connectivity when grasslands, shrublands, and riparian areas are lost or fragmented by development (Theobald and others, 1996). Similarly, the subdivision of valley ranches into smaller "ranchette" developments is a concern for biodiversity (Mitchell and others, 2002; Theobald and others, 1996). Land-cover changes also occur as residential development spreads into nearby forest edges (fig. 4).

Timber harvesting in the Rocky Mountain region accounts for approximately 5 percent of the national total (Darr, 1995). In the Southern Rockies Ecoregion, forest regeneration after clearcutting is slow compared to many other United States ecoregions because of the shorter growing season and relatively dry climate. This makes the ecoregion less attractive for large-scale industrial silviculture, although the recent forest die-off may cause an increase in timber clearance. Reservoir construction also affects the ecoregion, particularly as agricultural land uses and cities along the drier Front Range require an increasing reliable supply of water. Agriculture in the Southern Rockies Ecoregion is primarily related to livestock grazing (fig. 5), which occurs on both private and public lands, and hay production (fig. 6). Abandoned or reclaimed precious metal mines are a relatively common feature (fig. 7).

Contemporary Land-Cover Change (1973 to 2000)

Land-cover changes between 1973 and 2000 were very low (fig. 8), with no net or gross changes greater than 1.0 percent of ecoregion area for any time period or land-cover class (table 1). Net forest land declined by an estimated 0.6 percent (452 km^2), which is the highest amount of net change in absolute terms (fig. 9). Forest land also had a relatively

Figure 4. Exurban development near Colorado's western slope.

Figure 5. Cattle and maintained pasture in south-central Colorado.

Figure 6. Hay field with aspen and coniferous forest in background in Southern Rockies Ecoregion.

Figure 7. Summitville Mine Superfund Site in southern part of Colorado.

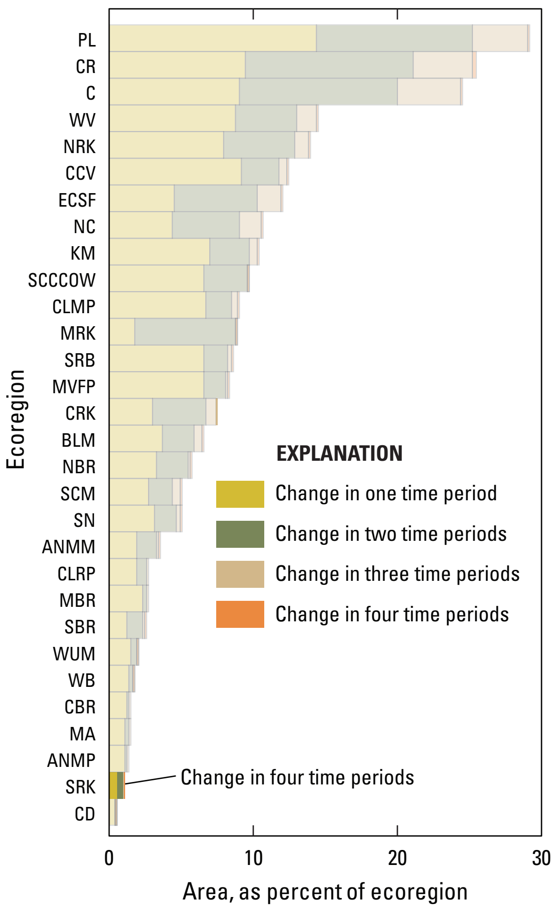

Figure 8. Overall spatial change in Southern Rockies Ecoregion (SRK; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Southern Rockies Ecoregion (four time periods) labeled for clarity. See table 4 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

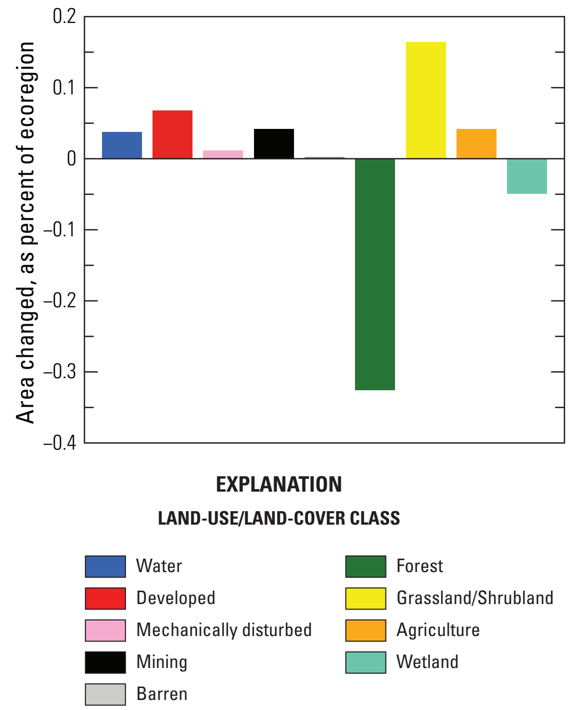

Figure 9. Estimates of net land-cover change in Southern Rockies Ecoregion for each land-cover class between 1973 and 2000. Bars above zero axis represent net gain, whereas bars below zero represent net loss. See appendix 3 for definitions of land-use/land-cover classifications.

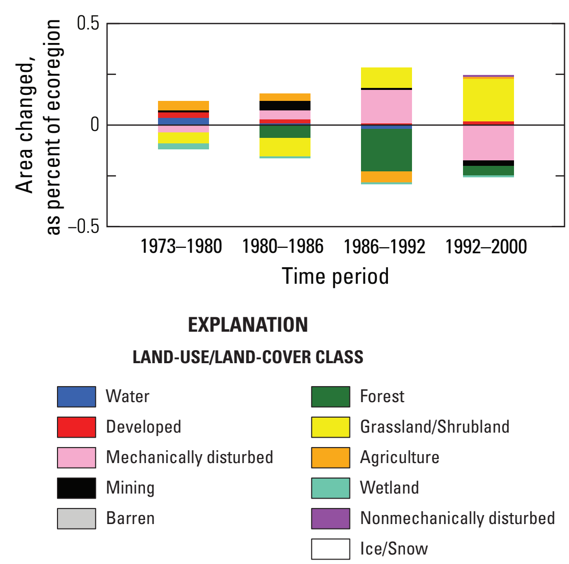

Figure 10. Normalized average net change in Southern Rockies Ecoregion by time period for each land cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

high level of gross change (684 km^2), in comparison to the other land-cover types. Grassland/shrubland and mechanically disturbed land had the highest gross changes, at 1,021 km^2 and 848 km^2, respectively.

The declines in forest resulted from mechanical disturbance (table 2), which is caused primarily by clearcutting and other timber harvest practices. A smaller amount of forest recovered from mechanical disturbance during the study period, indicating the slow recovery of those forests. Most of the reforestation occurred from an intermediate cover of grassland/shrubland that followed mechanical disturbance. Additional forest land was lost to mining and developed land. The largest extent of forest loss, 299 km^2, occurred between 1986 and 1992 (fig. 10).

The gross changes in grassland/shrubland were related to mechanical disturbance of forest that caused an intermediate stage of vegetated land cover. Switches between

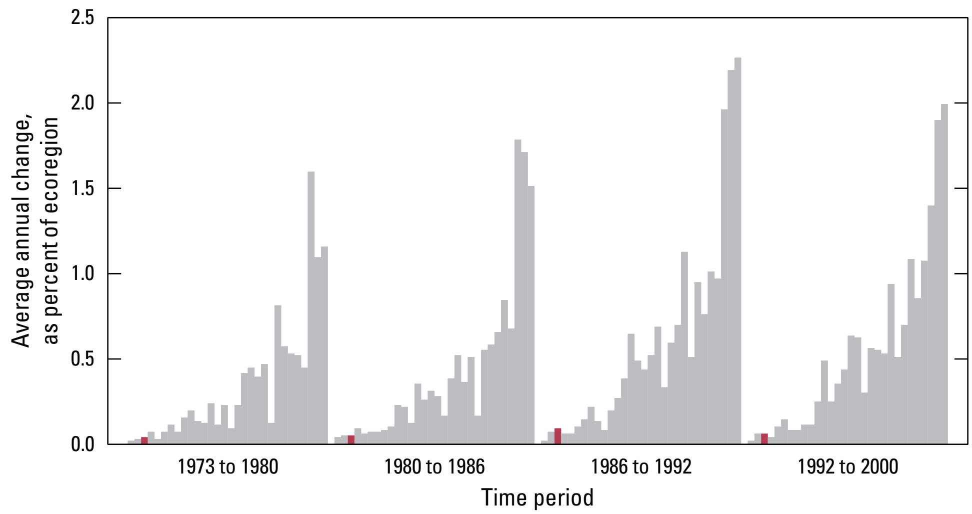

Figure 11. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Southern Rockies Ecoregion are represented by red bars in each time period.

grassland/shrubland and agriculture also caused gross change, but these resulted in only a small amount of agricultural expansion (59 km^2). Gains in agriculture between 1973 and 1980 and between 1980 and 1986 were offset somewhat by conversion to grassland/shrubland between 1986 and 1992, when the Conservation Reserve Program (CRP) may have had an impact. The CRP, enacted by Congress in 1985, pays farmers to take marginal cropland out of production and return it to a seminatural grassland condition. Switches between grassland/shrubland and mining, which occur as mining areas expand and are eventually able to recover to vegetated land cover, resulted in minor losses to mining. Development expanded into some grassland/shrubland areas.

The two most common types of land conversion involved mechanical disturbance. Forest to mechanically disturbed, discussed above, was the most common conversion (518 km^2), followed by mechanically disturbed to grassland/shrubland (462 km^2). Because this a transitional land cover, it experienced little net change and a high rate of gross change, which affected 0.6 percent of ecoregion area.

Developed land increased by only 13 percent during the study period but still occupied only 0.6 percent of the ecoregion. The remaining land-cover types had negligible amounts of net change.

Overall, only 1.0 percent of the ecoregion's land cover changed between 1973 and 2000 (table 3). The rates of change during each time period were consistently low (table 4; fig. 11). Compared to other western United States ecoregions, change in the Southern Rockies Ecoregion was very low (fig. 8). Relatively small amounts of change, combined with some variability in the rates of change between the 36 sample sites, resulted in high margins of error. More than one-third of the sample blocks had no change or negligible change during all time periods, which is reflective of a large amount of relatively stable land use. This contrasts with the much smaller area undergoing intense land conversion, such as development in valleys and the suburban and exurban growth associated with the Front Range urban corridor and Interstate 70.

Land use in the West is often cited as undergoing a conversion from a resource-extraction economy to one that is increasingly based on service and technical industries. This is accompanied by population expansion, as technology allows telecommuting and a move towards amenity-rich mountain areas. The change analysis does not target the specific locations where the much-discussed amenity-driven land conversion occurs. However, it does provide a regional overview of land-cover change that reflects the large expanses of land in public ownership, whereas other case studies provide an in-depth understanding of the intensive local-scale changes.

Since 2000, the Southern Rockies Ecoregion has also undergone a substantial amount of forest change. Significant areas of forest are affected by insect outbreaks and the amplifying effects of drought and climate warming. This will likely have a host of consequences affecting fire regimes, logging, carbon sequestration, hydrology, ecosystem function, and tourism.

Table 1. Estimated area (and margin of error) of each land-cover class in Southern Rockies Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.1	0.1	0.5	0.4	0.1	0.0	0.1	0.0	1.1	0.6	56.3	6.4	37.5	5.4	2.8	1.7	1.4	1.0	0.0	0.0
1980	0.2	0.1	0.6	0.5	0.0	0.0	0.1	0.0	1.1	0.6	56.3	6.4	37.5	5.4	2.8	1.8	1.4	1.0	0.0	0.0
1986	0.2	0.1	0.6	0.5	0.1	0.0	0.1	0.1	1.1	0.6	56.3	6.4	37.4	5.4	2.9	1.8	1.4	1.0	0.0	0.0
1992	0.2	0.1	0.6	0.5	0.2	0.2	0.1	0.1	1.1	0.6	56.1	6.3	37.5	5.4	2.8	1.7	1.4	1.0	0.0	0.0
2000	0.2	0.1	0.6	0.5	0.1	0.0	0.1	0.1	1.1	0.6	56.0	6.3	37.7	5.3	2.8	1.7	1.4	1.0	0.0	0.0
Net change	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	−0.3	0.2	0.2	0.2	0.0	0.1	0.0	0.0	0.0	0.0
Gross change	0.1	0.1	0.1	0.1	0.6	0.4	0.1	0.1	0.0	0.0	0.5	0.2	0.7	0.3	0.3	0.2	0.1	0.0	0.0	0.0
Area, in square kilometers																				
1973	197	137	731	599	71	55	77	56	1,528	826	78,228	8,857	52,120	7,490	3,887	2,410	1,983	1,349	0	0
1980	244	161	771	627	28	18	88	66	1,529	826	78,221	8,857	52,046	7,481	3,955	2,487	1,940	1,347	0	0
1986	260	166	791	640	95	60	157	138	1,528	826	78,138	8,840	51,919	7,467	4,005	2,491	1,929	1,347	0	0
1992	241	159	805	642	331	248	169	160	1,529	826	77,839	8,763	52,055	7,464	3,936	2,394	1,917	1,347	0	0
2000	249	162	826	646	89	64	137	121	1,529	826	77,776	8,753	52,350	7,388	3,946	2,375	1,915	1,347	4	5
Net change	52	50	94	70	18	87	61	69	1	1	−452	286	230	308	59	102	−68	58	4	5
Gross change	102	80	94	70	848	491	132	149	2	2	684	313	1,021	374	367	249	94	64	4	5

Table 2. Principal land-cover conversions in Southern Rockies Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	81	90	61	0.1	24.1
	Mechanically disturbed	Water	42	45	31	0.0	12.4
	Grassland/Shrubland	Forest	33	18	12	0.0	9.9
	Mechanically disturbed	Grassland/Shrubland	29	33	23	0.0	8.6
	Forest	Mechanically disturbed	28	18	12	0.0	8.2
	Other	Other	124	n/a	n/a	0.1	36.8
		Totals	336			0.2	100.0
1980–1986	Forest	Mechanically disturbed	90	61	41	0.1	23.5
	Grassland/Shrubland	Agriculture	77	69	47	0.1	20.3
	Grassland/Shrubland	Mining	41	42	29	0.0	10.9
	Grassland/Shrubland	Forest	38	26	18	0.0	10.0
	Mechanically disturbed	Grassland/Shrubland	28	18	12	0.0	7.2
	Other	Other	107	n/a	n/a	0.1	28.1
		Totals	381			0.3	100.0
1986–1992	Forest	Mechanically disturbed	319	248	169	0.2	44.9
	Mechanically disturbed	Grassland/Shrubland	94	60	41	0.1	13.3
	Agriculture	Grassland/Shrubland	93	116	79	0.1	13.1
	Grassland/Shrubland	Forest	58	44	30	0.0	8.1
	Forest	Mining	21	31	21	0.0	3.0
	Other	Other	125	n/a	n/a	0.1	17.7
		Totals	711			0.5	100.0
1992–2000	Mechanically disturbed	Grassland/Shrubland	311	246	167	0.2	50.0
	Forest	Mechanically disturbed	82	64	43	0.1	13.1
	Grassland/Shrubland	Agriculture	46	29	19	0.0	7.5
	Agriculture	Grassland/Shrubland	39	31	21	0.0	6.3
	Mining	Grassland/Shrubland	37	40	27	0.0	5.9
	Other	Other	107	n/a	n/a	0.1	17.3
		Totals	622			0.4	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	518	295	201	0.4	25.3
	Mechanically disturbed	Grassland/Shrubland	462	285	194	0.3	22.5
	Grassland/Shrubland	Agriculture	223	133	90	0.2	10.9
	Agriculture	Grassland/Shrubland	162	148	100	0.1	7.9
	Grassland/Shrubland	Forest	150	74	50	0.1	7.3
	Other	Other	536	n/a	n/a	0.4	26.1
		Totals	2,051			1.5	100.0

Table 3. Percentage of Southern Rockies Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (99.0 percent), whereas 1.0 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	0.6	0.2	0.4	0.8	0.1	22.4
2	0.4	0.2	0.2	0.6	0.1	35.2
3	0.0	0.0	0.0	0.0	0.0	62.5
4	0.0	0.0	0.0	0.0	0.0	98.7
Overall spatial change	1.0	0.3	0.7	1.4	0.2	20.3

Table 4. Raw estimates of change in Southern Rockies Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.2	0.1	0.1	0.3	0.1	26.2	0.0
1980–1986	0.3	0.1	0.2	0.4	0.1	25.3	0.0
1986–1992	0.5	0.2	0.3	0.7	0.2	29.5	0.1
1992–2000	0.4	0.2	0.3	0.6	0.1	29.1	0.1
Estimate of change, in square kilometers							
1973–1980	336	129	207	466	88	26.2	48
1980–1986	381	142	239	523	96	25.3	64
1986–1992	711	309	402	1,019	210	29.5	118
1992–2000	622	267	356	889	181	29.1	78

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Chapter 9

Wasatch and Uinta Mountains Ecoregion

By Mark S. Brooks

Ecoregion Description

The Wasatch and Uinta Mountains Ecoregion covers approximately 44,176 km^2 (17, 057 mi^2) (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). With the exception of a small part of the ecoregion extending into southern Wyoming and southern Idaho, the vast majority of the ecoregion is located along the eastern mountain ranges of Utah. The ecoregion is situated between the Wyoming Basin and Colorado Plateaus Ecoregions to the east and south and the Central Basin and Range Ecoregion to the west; in addition, the Middle Rockies, Snake River Basin, and Northern Basin and Range Ecoregions are nearby to the north. Considered the western front of the Rocky Mountains, the two major mountain ranges that define the Wasatch and Uinta Mountains Ecoregion include the north-south-trending Wasatch Range and east-west-trending Uinta Mountains. Both mountain ranges have been altered by multiple mountain building and burial cycles since the Precambrian era 2.6 billion years ago, and they have been shaped by glacial processes as early as 1.6 million years ago. The terrain is defined by sharp ridgelines, glacial lakes, and narrow canyons, with elevations ranging from 1,829 m in the lower

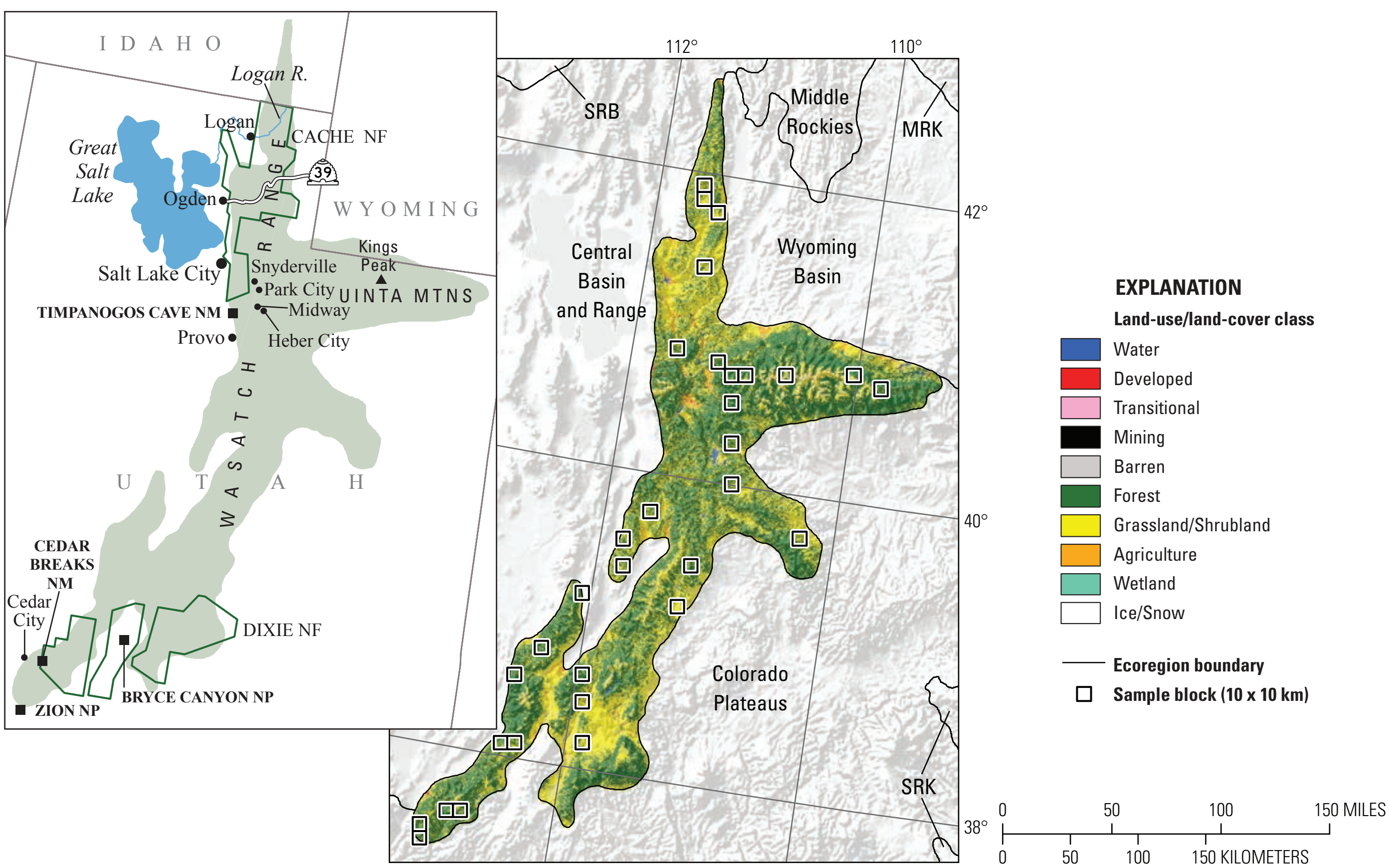

Figure 1. Map of Wasatch and Uinta Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

canyons to 4,123 m at Kings Peak, the highest point in Utah (Milligan, 2010).

The climate is a midlatitude highland climate influenced by Pacific storms moving in from the west. Average temperature and precipitation vary with elevation and latitude. The southern part of the ecoregion is generally 6° to 8°C warmer than northern parts at similar elevations. The average annual precipitation varies between 457 and 1,016 mm (Utah Center for Climate and Weather, 2009).

The ecoregion is largely made up of federally managed lands. Approximately 67 percent (30,000 km^2) of the ecoregion falls within six National Forests (Wasatch-Cache, Ashley, Uinta, Manti–La Sal, Fishlake, and Dixie), seven Wilderness Areas (Mount Naomi, High Uintas, Twin Peaks, Lone Peak, Mount Timpanogos, Box–Death Hollow, and Ashdown Gorge), two National Monuments (Timpanogos Cave and Cedar Breaks), one National Park (Zion), and a number of Bureau of Land Management Public Domain lands. The Uintah and Ouray Reservation is also located within the ecoregion.

The ecoregion's forest lands, which cover approximately 61 percent of its area, vary according to elevation, soils, precipitation, and temperature. Gambel's oak (*Quercus gambelii*) and canyon maple (*Acer grandidentatum*) live on lower mountain slopes and foothills, giving way to pinyon-juniper forests along the drier foothills. The pinyon-juniper forests include the singleleaf pinyon pine (*Pinus monophylla*), Colorado pinyon (*Pinus edulis*), and two types of juniper, the Utah juniper (*Juniperus osteosperma*) and Rocky Mountain juniper (*Juniperus scopulorum*). The middle elevations support Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), and lodgepole pine (*Pinus contorta*). The higher elevations support quaking aspen (*Populus tremuloides*), Engelmann spruce (*Picea engelmannii*), and balsam fir (*Abies lasiocarpa*) (Utah Department of Natural Resources, Division of Forestry, Fire and State Lands, 2003).

Grassland/shrubland land cover accounts for approximately 34 percent of the ecoregion. Similar to forest land cover, grassland/shrubland in the ecoregion also varies according to elevation, soils, precipitation, and temperature. Big sagebrush (*Artemesia tridentata*) is commonly found along the drier foothills, whereas perennial bunchgrasses and mixed forbs can be found at the middle elevations. Herbaceous plants, grasses, sedges, and rushes are found in upland meadows (Grahame and Sisk, 2002).

Owing to the steep terrain and rugged landscape of the ecoregion, most developed land is located in the fertile valleys and the unincorporated area surrounding Snyderville, known informally as "Snyderville Basin," situated between the Wasatch Range and Uinta Mountains just east of Salt Lake City, Utah. The Wasatch and Uinta Mountains Ecoregion is sparsely populated with only one town of over 20,000 people recorded in the 2000 Census (Cedar City, Utah, population 20,527); the next three largest towns were Park City, Utah (population 7,371), Heber City, Utah (population 7,291), and Midway, Utah (population 2,121) (U.S. Census Bureau, 2010). However, an estimated 1.7 million people live just west of the ecoregion boundary along the Wasatch Front (extending roughly 129 km from Ogden, Utah, to Provo, Utah) (Economic Development Corporation of Utah, 2008). Agriculture, which is not a significant land cover within the ecoregion, is limited to irrigated pasture and hay in fertile lowland stream valleys.

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the ecoregion's overall spatial change (the percentage of area undergoing at least one land-cover change during the study period) is estimated at approximately 2.0 percent, and an estimated 0.5 percent of the ecoregion area changed in two or more time periods (fig. 2). The vast majority of land, approximately 98 percent, did not change

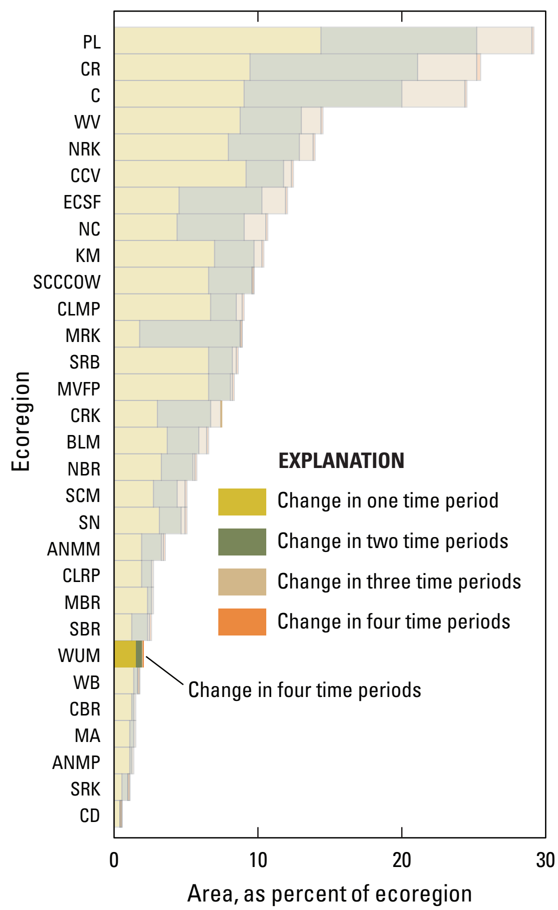

Figure 2. Overall spatial change in Wasatch and Uinta Mountains Ecoregion (WUM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Wasatch and Uinta Mountains Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

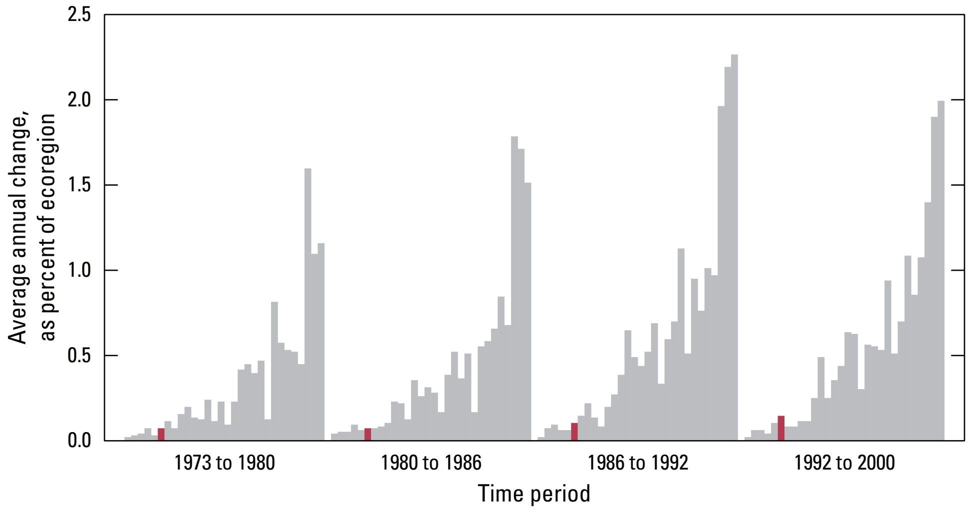

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Wasatch and Uinta Mountains Ecoregion are represented by red bars in each time period.

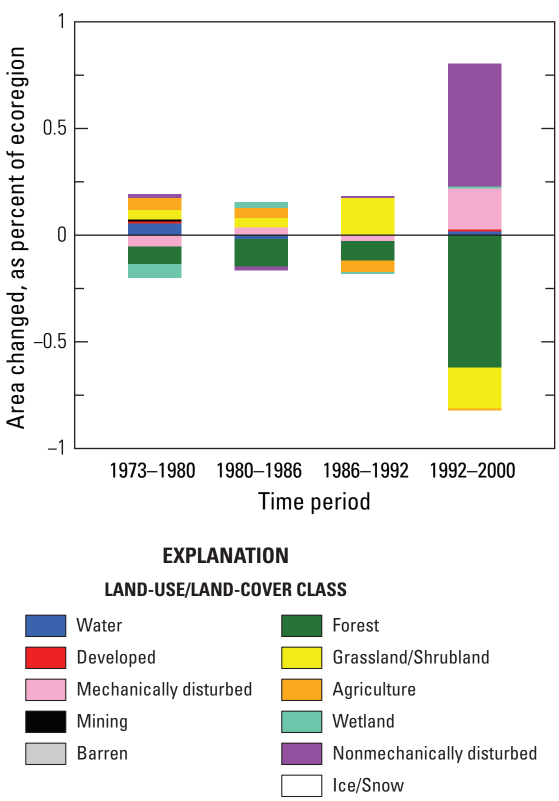

Figure 4. Normalized average net change in Wasatch and Uinta Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

during the study period (table 1). This level of change is among the lowest of the western United States ecoregions (fig. 2).

The total land-cover change estimated within the four time periods varied only slightly between 1973 and 2000. The first three time periods showed similar amounts of change, but the last time period, between 1992 and 2000, had the greatest amount of change at 1.1 percent of the ecoregion (table 2). When time periods are normalized to an average annual rate of change to adjust for uneven time periods, all four time periods had a minimal change rate of approximately 0.1 percent per year (table 2; fig. 3).

The land-use/land-cover composition of the ecoregion experienced little change during the study period. In 2000, forest was the dominant land cover at approximately 60.8 percent of the ecoregion, followed by grassland/shrubland (33.7 percent), barren (2.9 percent), and agriculture (0.9 percent); the remaining land-cover classes combined for approximately 1 percent of the ecoregion (table 3).

The most significant net gain and net loss identified between 1973 and 2000 was the net loss of approximately 1.4 percent (408 km^2) of forest and a net gain of approximately 261 km^2 of nonmechanically disturbed lands, which did not occupy any area in 1973 (table 3; fig. 4). The association between the loss of forest and the increase in nonmechanical disturbance is likely the result of beetle infestation and wildfire (fig. 5). Increased beetle infestation, which is a natural process, is believed to be caused by warmer winters, extended drought, and the practice of fire suppression over several decades. Forest-management activities that include prescribed burns and mechanical thinning have been implemented in recent years to improve forest health and reduce the likelihood of large-scale natural fires (Utah Department of Natural Resources, Division of Forestry and State Lands, 2003) (fig. 6).

Figure 5. Stand of Engelmann spruce showing impact of spruce beetle infestation in Dixie National Forest, Utah (elevation, 2,970 m).

Figure 6. Mechanical thinning of stand of Engelmann spruce devastated by spruce beetle infestation near Cedar Breaks National Monument in Dixie National Forest, Utah.

The three leading conversions during the 1973 to 2000 study period involved the disturbance of forest either by mechanical means (timber harvesting or mechanical thinning) or by nonmechanical means (beetle infestation or fire) and the subsequent recovery of disturbed land to grassland/shrubland. An estimated 58 percent of all change is explained by this cyclical pattern of land-cover conversion. The fourth and fifth leading conversions identified are fluctuations between agriculture and grassland/shrubland, with an estimated 92 km^2 of grassland/shrubland converting to agriculture, and an estimated 70 km^2 of agriculture converting back to grassland/shrubland during the study period (table 4).

The Wasatch and Uinta Mountains Ecoregion experienced little change during the study period. The low level of change can be largely explained by the remote and rugged terrain characterized by its sharp ridgelines and narrow canyons (fig. 7). In addition, the presence of federal lands may also inhibit change within the ecoregion (fig. 8). The change that did occur resulted from either natural processes (beetle infestation and natural fire) or anthropogenic disturbance (prescribed burns, timber harvesting, and mechanical thinning). Combined, these processes accounted for an estimated net loss of 408 km^2 of forest. Given probable increases in temperature and prolonged periods of drought, future changes are likely to involve a higher incidence of nonmechanical disturbance including natural fires and insect infestations (Utah Department of Natural Resources, Division of Forestry and State Lands, 2003).

Figure 7. Logan River rushing through steep, narrow canyon in Cache National Forest, Utah.

Figure 8. Aspen, pine, spruce, and fir along State Route 39 in Cache National Forest, Utah, with towering Wasatch Range in distance (elevation, 2,650 m).

Table 1. Percentage of Wasatch and Uinta Mountains Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (98.0 percent), whereas 2.0 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.5	0.6	0.8	2.1	0.4	29.2
2	0.5	0.3	0.2	0.7	0.2	38.4
3	0.0	0.0	0.0	0.1	0.0	35.6
4	0.0	0.0	0.0	0.0	0.0	96.3
Overall spatial change	2.0	0.8	1.2	2.8	0.5	26.3

Table 2. Raw estimates of change in Wasatch and Uinta Mountains Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.5	0.4	0.1	0.8	0.2	49.9	0.1
1980–1986	0.4	0.2	0.2	0.6	0.1	34.4	0.1
1986–1992	0.6	0.3	0.3	0.9	0.2	32.4	0.1
1992–2000	1.1	0.5	0.6	1.6	0.4	32.8	0.1
Estimate of change, in square kilometers							
1973–1980	216	159	57	375	108	49.9	31
1980–1986	184	93	91	277	63	34.4	31
1986–1992	255	122	133	377	83	32.4	42
1992–2000	485	234	250	719	159	32.8	61

Table 3. Estimated area (and margin of error) of each land-cover class in Wasatch and Uinta Mountains Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.2	0.1	0.1	0.1	0.2	0.2	0.0	0.0	2.9	1.9	61.7	5.2	33.7	5.0	0.9	0.6	0.3	0.2	0.0	0.0
1980	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	2.9	1.9	61.7	5.2	33.7	5.0	0.9	0.6	0.3	0.1	0.0	0.0
1986	0.2	0.1	0.1	0.1	0.2	0.1	0.0	0.0	2.9	1.9	61.5	5.1	33.8	4.9	1.0	0.7	0.3	0.2	0.0	0.0
1992	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	2.9	1.9	61.4	5.1	33.9	4.9	0.9	0.7	0.3	0.2	0.0	0.0
2000	0.2	0.1	0.1	0.1	0.3	0.2	0.0	0.0	2.9	1.9	60.8	5.0	33.7	4.8	0.9	0.7	0.3	0.2	0.6	0.5
Net change	0.1	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	−0.9	0.5	0.1	0.6	0.0	0.3	0.0	0.0	0.6	0.5
Gross change	0.2	0.1	0.0	0.0	0.8	0.4	0.0	0.0	0.0	0.0	1.1	0.5	1.1	0.5	0.3	0.3	0.1	0.1	0.7	0.5
Area, in square kilometers																				
1973	71	42	47	35	76	86	2	1	1,298	836	27,276	2,286	14,878	2,222	376	257	150	77	0	0
1980	98	50	52	37	53	59	6	5	1,299	836	27,241	2,277	14,895	2,200	401	275	122	62	10	14
1986	92	46	53	38	69	64	6	5	1,299	836	27,182	2,264	14,913	2,184	423	294	136	67	4	5
1992	92	48	54	38	60	43	7	5	1,300	835	27,141	2,256	14,988	2,153	399	302	131	67	6	6
2000	101	52	57	38	144	92	8	6	1,299	836	26,868	2,212	14,903	2,107	398	302	136	71	261	209
Net change	30	19	10	8	68	121	6	6	1	1	−408	234	25	262	22	114	−14	13	261	209
Gross change	86	64	10	8	373	188	6	6	3	3	483	234	474	240	120	114	61	59	292	218

Table 4. Principal land-cover conversions in Wasatch and Uinta Mountains Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Mechanically disturbed	Grassland/Shrubland	65	82	55	0.1	30.1
	Forest	Mechanically disturbed	47	59	40	0.1	21.8
	Grassland/Shrubland	Agriculture	24	30	20	0.1	11.2
	Wetland	Water	24	32	21	0.1	10.9
	Grassland/Shrubland	Forest	21	27	18	0.0	9.8
	Other	Other	35	n/a	n/a	0.1	16.2
		Totals	216			0.5	100.0
1980–1986	Forest	Mechanically disturbed	66	64	43	0.2	36.1
	Mechanically disturbed	Grassland/Shrubland	47	59	40	0.1	25.6
	Grassland/Shrubland	Agriculture	22	30	21	0.0	11.8
	Water	Wetland	12	17	11	0.0	6.5
	Nonmechanically disturbed	Forest	8	11	7	0.0	4.1
	Other	Other	29	n/a	n/a	0.1	15.8
		Totals	184			0.4	100.0
1986–1992	Mechanically disturbed	Grassland/Shrubland	60	62	42	0.1	23.6
	Agriculture	Grassland/Shrubland	57	67	45	0.1	22.3
	Forest	Mechanically disturbed	50	43	29	0.1	19.7
	Grassland/Shrubland	Agriculture	34	48	32	0.1	13.4
	Grassland/Shrubland	Forest	9	9	6	0.0	3.5
	Other	Other	45	n/a	n/a	0.1	17.5
		Totals	255			0.6	100.0
1992–2000	Forest	Nonmechanically disturbed	193	189	128	0.4	39.9
	Forest	Mechanically disturbed	91	58	39	0.2	18.7
	Grassland/Shrubland	Nonmechanically disturbed	67	91	62	0.2	13.8
	Grassland/Shrubland	Mechanically disturbed	36	50	34	0.1	7.4
	Mechanically disturbed	Grassland/Shrubland	31	32	21	0.1	6.5
	Other	Other	67	n/a	n/a	0.2	13.8
		Totals	485			1.1	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	254	148	101	0.6	22.3
	Forest	Nonmechanically disturbed	211	194	132	0.5	18.5
	Mechanically disturbed	Grassland/Shrubland	203	185	125	0.5	17.9
	Grassland/Shrubland	Agriculture	92	123	83	0.2	8.1
	Agriculture	Grassland/Shrubland	70	74	50	0.2	6.2
	Other	Other	308	n/a	n/a	0.7	27.0
		Totals	1,139			2.6	100.0

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Status and Trends of Land Change in the Western United States—1973 to 2000
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Chapter 10

Arizona/New Mexico Mountains Ecoregion

By Jana Ruhlman, Leila Gass, and Barry Middleton

Ecoregion Description

As the name suggests, the Arizona/New Mexico Mountains Ecoregion includes much of the mountainous regions of these two states, plus a very small part in the Guadalupe Mountains of northwestern Texas. Several isolated areas of higher terrain in Arizona and New Mexico are also included in the ecoregion, which occupies approximately 108,432 km^2 (41,866 mi^2) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion is bounded on the south by the Sonoran Basin and Range, Madrean Archipelago, and Chihuahuan Deserts Ecoregions; to the north, the ecoregion is both bounded and surrounded by the Arizona/New Mexico Plateau Ecoregion (fig. 1). The ecoregion encompasses the largest contiguous ponderosa pine (*Pinus ponderosa*) forest in the United States (Strom and Fulé, 2007), which stretches from Williams, Arizona, along the Mogollon Rim, Arizona, into southwestern New Mexico, north and west of Silver City, New Mexico.

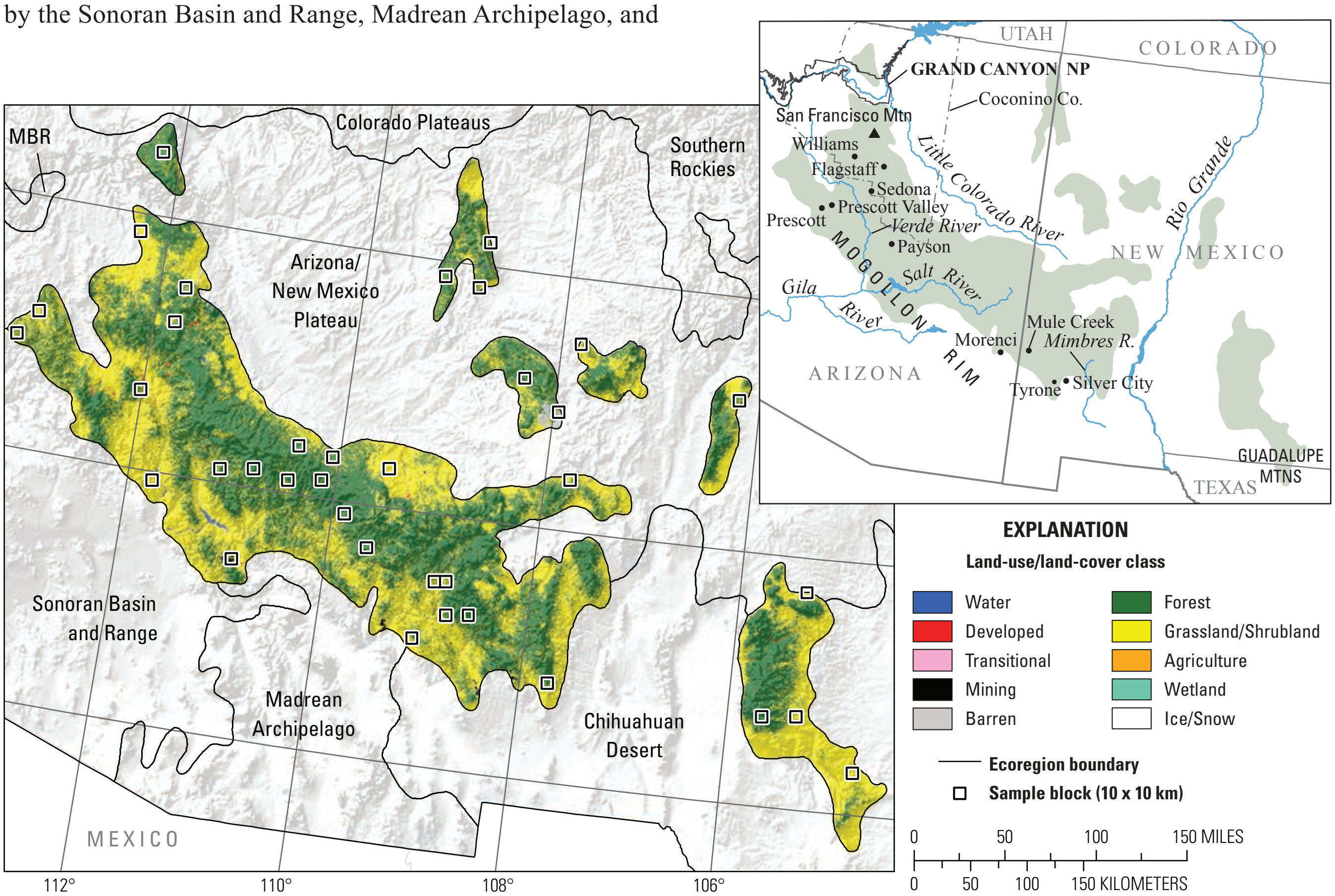

Figure 1. Map of Arizona/New Mexico Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map is part of one Great Plains Ecoregion, Southwestern Tablelands (SWT). See appendix 3 for definitions of land-use/land-cover classifications.

The mountains of the Arizona/New Mexico Mountains Ecoregion are lower in elevation than neighboring mountainous ecoregions and have vegetation indicative of drier, warmer climates (U.S. Environmental Protection Agency, 2002). Semiarid grassland, chaparral, and pinyon-juniper (*Pinus* spp. and *Juniperus* spp.) and oak woodlands (*Quercus* spp.) grow in the lower elevations. Ponderosa pines dominate the higher elevations, along with Douglas-fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), and even alpine tundra atop the highest mountain peaks (fig. 2). San Francisco Mountain (known locally as the "San Francisco Peaks"), Arizona, is the most prominent (and highest) point of the ecoregion, at 3,851 m (12,633 ft). The wide variety of topography results in annual precipitation averages that range from 182 mm (7 in) to 1,293 mm (51 in), in the form of both rain and snow (Daly and others, 2002). Melting snow and summer monsoonal rains feed the headwaters of several river systems within the ecoregion, including the Verde, Salt, Gila, and Little Colorado Rivers in Arizona and the Mimbres River in New Mexico. Average temperatures vary greatly by season and along elevation gradients but range from −18°C during the winter months in the highest elevations to more than 38°C during the summer months in the lowest elevations.

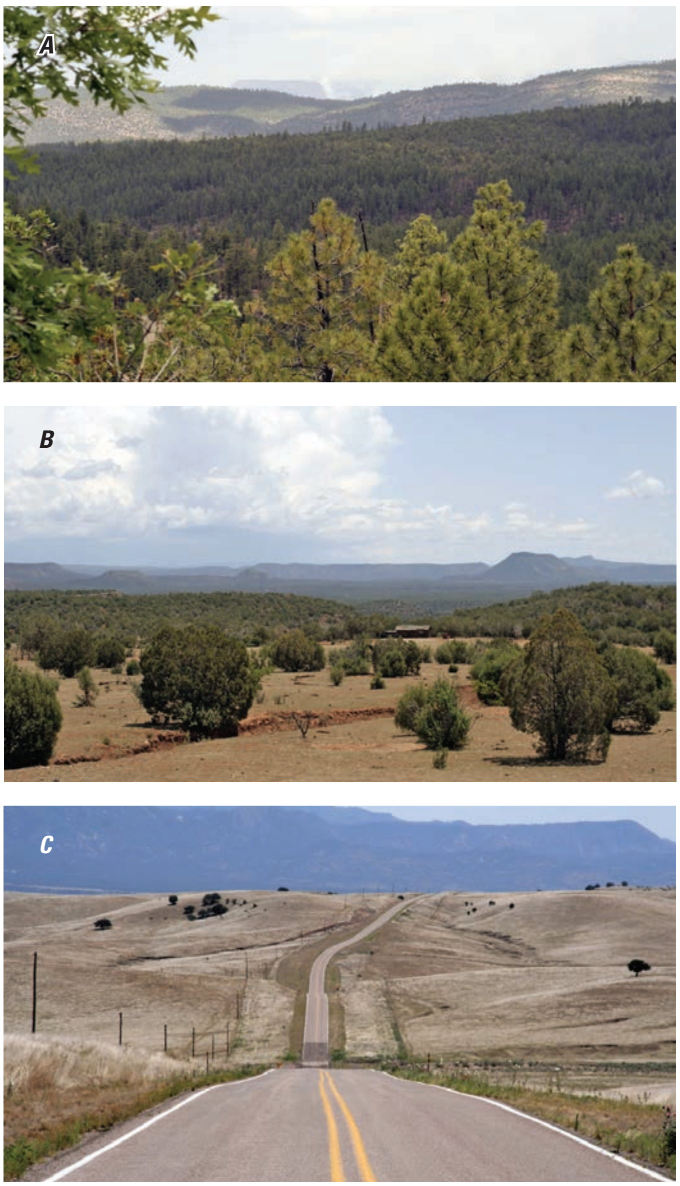

Figure 2. Various vegetation zones of Arizona/New Mexico Mountains Ecoregion. *A*, Ponderosa pine forest in Tonto National Forest, central Arizona. *B*, Pinyon-juniper woodland on Fort Apache Reservation, eastern Arizona. *C*, Grassland near Mule Creek, New Mexico.

Flagstaff, Arizona, is the largest urban area, with a 2000 population of 52,894. Numerous smaller communities exist throughout the ecoregion: Prescott, Prescott Valley, Payson, and Sedona, Arizona, are the only communities that have greater than 10,000 residents (U.S. Census Bureau, 2000). A large part of the conifer forests are on federal (mainly U.S. Forest Service) or tribal lands, and they provide a valuable resource for timber harvesting and livestock grazing, as well as tourism and outdoor recreation. Almost all public land in the ecoregion other than forest is leased for grazing (Arizona Game and Fish Department, 2006), and all eight national forests in the ecoregion sell saw timber and other tree products. Mining is an important contributor to the economy of towns along the southern border of the ecoregion, with major operating copper mines in Morenci, Arizona, and Tyrone, New Mexico. Two sizeable copper mines are also located just outside the ecoregion boundary (Freeport-McMoRan Copper and Gold, 2009). The popularity of the cool mountain country with easy access to the hotter deserts brings millions of visitors to the region to enjoy hiking, camping, skiing, fishing, and hunting, and many towns in the ecoregion rely on tourism for their local economy. Grand Canyon National Park, located in Coconino County, Arizona, in the northwestern part of the ecoregion, receives approximately 3.3 million visitors each year (U.S. Forest Service, 2008).

Contemporary Land-Cover Change (1973 to 2000)

As measured by the project methodology, the Arizona/New Mexico Mountains Ecoregion experienced little land-cover change during the study period (fig. 3). An estimated 3.5 percent of the ecoregion (3,806 km^2) changed land cover during the study period: 2.0 percent of the ecoregion changed only once, 1.3 percent changed twice, and 0.2 percent changed three times (table 1). Compared to other western United States ecoregions, change in the Arizona/New Mexico Mountains Ecoregion was low but not as low as the more arid ecoregions of the Southwest (figs. 3,4).

Estimated change in land cover per time period varied from 0.9 percent (1973–1980) to 2.0 percent (1992–2000). When the change estimates were normalized to account for the varying lengths of time between satellite imagery dates, the average rate

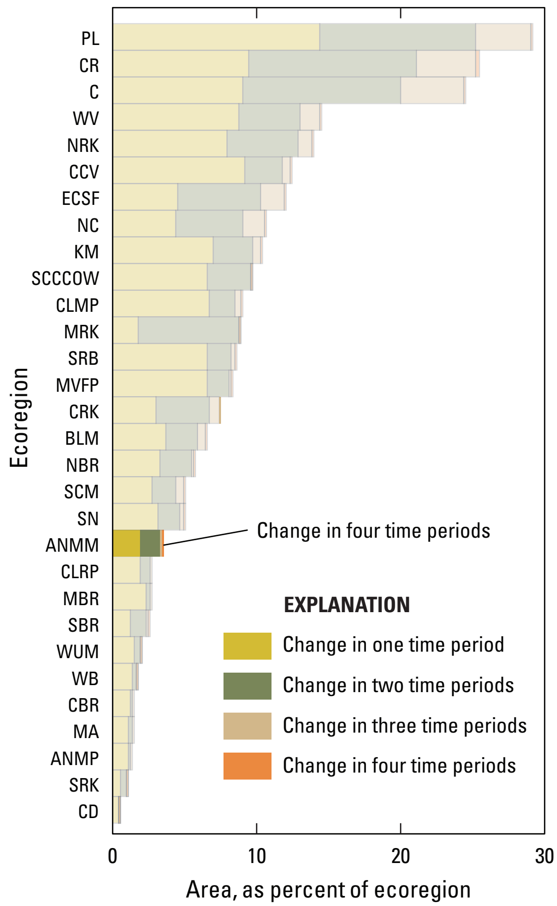

Figure 3. Overall spatial change in Arizona/New Mexico Mountains Ecoregion (ANMM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Arizona/New Mexico Mountains Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

of change per year was 0.1 percent between 1973 and 1980, 0.2 percent between 1980 and 1986 and between 1986 and 1992, and 0.3 percent between 1992 and 2000 (table 2; fig. 4).

The study results showed that forest and grassland/shrubland were the primary land-cover classes in the ecoregion. Grassland/shrubland encompassed approximately 40 percent of the land cover in each time period, whereas the forest class decreased from 58.2 percent in 1973 to 56.6 percent by 2000 (table 3). The nonmechanically disturbed class accounted for 1.2 percent of the land cover in 2000; mining accounted for 1.0 percent; and the developed, barren, and agriculture classes made up the remaining land cover.

The forest and nonmechanically disturbed classes experienced the greatest net change over the study period. Between 1973 and 2000, the forest class declined by 2.7 percent, but the nonmechanically disturbed class increased from 0.1 percent to 1.1 percent. These changes resulted in a net decrease of 1,735 km^2 of forest and a net increase of 1,228 km^2 in nonmechanically disturbed land cover over the study period, primarily owing to fire. The remaining classes experienced very little net change (table 3).

Overall net-change values can, however, mask land-cover dynamics that occur within the study period. Figure 5 illustrates the fluctuations that occurred in land-cover classes in each time period. The decrease in forest occurred at variable rates over the study period; the least amount of decrease occurred between 1986 and 1992, and the greatest decrease occurred between 1992 and 2000. Likewise, despite an overall increasing trend, figure 5 shows that the nonmechanically disturbed class had roughly equal gains and losses in the first two time periods, a small gain in the third, and a large increase in the last time period, a trend seen in many other forested ecoregions in the western United States. The overall changes in the mechanically disturbed class resulted in little net change (fig. 5); however, the gains and losses in this class did affect 1.2 percent of the ecoregion during the 27-year study period. These changes were due mainly to logging and mining activities.

The most common conversions in the Arizona/New Mexico Mountains Ecoregion revolved around changes to

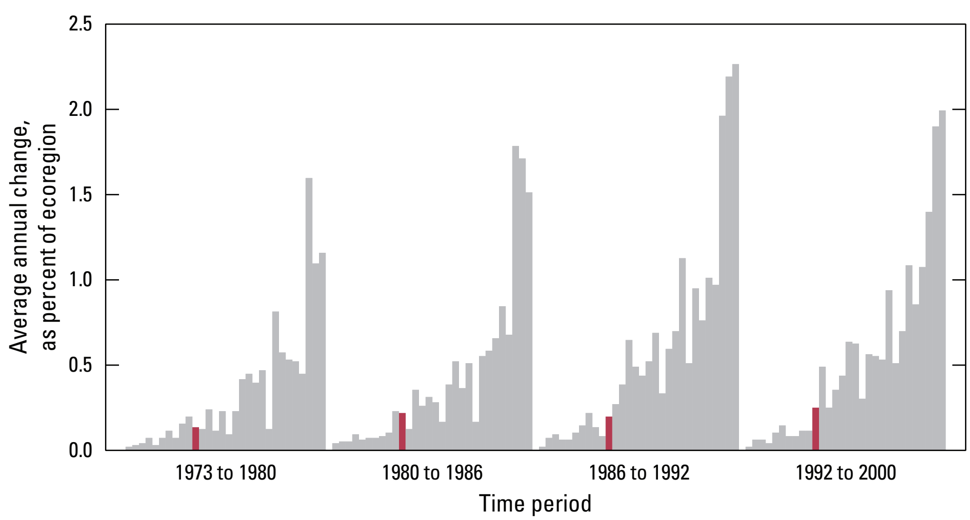

Figure 4. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Arizona/New Mexico Mountains Ecoregion are represented by red bars in each time period.

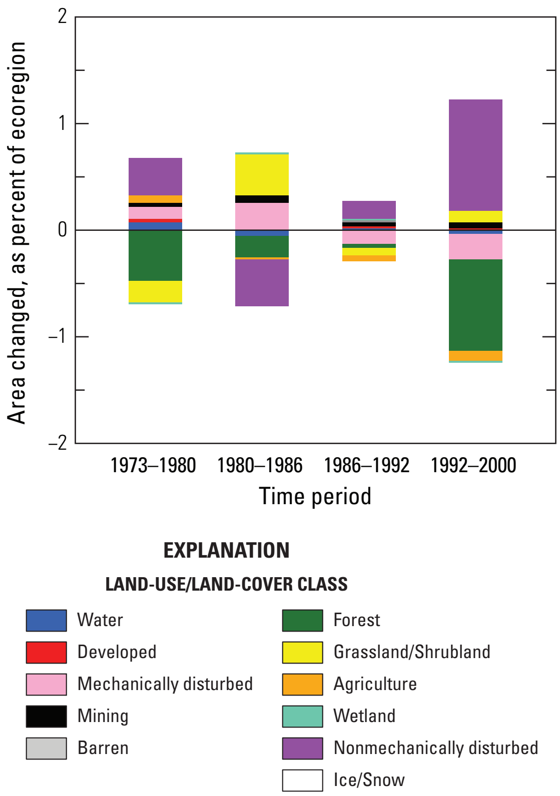

Figure 5. Normalized average net change in Arizona/New Mexico Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

the forest resulting from both mechanical and nonmechanical disturbances (table 4). These conversions, which were the result of both timber harvesting and wildland fires, occasionally involved grassland/shrubland as an intermediary land cover between the disturbance and the reforestation. Regeneration after disturbance was captured in one of two ways. If the disturbance was due to thinning, or to a moderate fire that did not destroy the majority of trees, then, in the next classification year, the land might revert directly to forest. However, if clearcutting or severe fire had eliminated the forest, then the next mapped class would usually be grassland/shrubland. More time would be needed for the grassland/shrubland to eventually revert to forest.

The main story of land-cover change in the Arizona/New Mexico Mountains Ecoregion involves its forests and the changes that occurred from both natural and human-caused disturbances. Changes in the nonmechanically disturbed land-cover class were the result of frequent fire (both lightning- and human-caused), which historically has been a major driver of change in this ecoregion (fig. 6). As of 2005, Coconino National Forest had averaged 501 wildfires per year (U.S. Forest Service, 2005). Dry summer thunderstorms in the forests of Arizona and New Mexico result in a high incidence of lightning strikes, causing the highest average annual number of lightning-caused fires in the nation (Stephens, 2005).

Frequent, low-intensity fires that moved along the ground were part of the evolutionary history of ponderosa pine forests until the early 1900s, but the effects of heavy grazing in the forests, coupled with aggressive fire suppression, have resulted in the unnaturally high tree densities and heavy loads of accumulated fuels that have led to the high-risk fire conditions that exist today (Great Flagstaff Forests Partnership, 2009). These factors may have contributed to the increasing trend in the nonmechanically disturbed class observed in this study. Currently, concerns over insect infestation and catastrophic wildfire events have resulted in ongoing hazardous-fuel–reduction projects (thinning and prescribed burning) throughout the national forests in the ecoregion, which will reduce fuel loads and promote forest health. Success of these methods may eventually reduce the growing number of acres lost to catastrophic wildland fires each year within the ecoregion.

Timber harvesting, either through clearcutting or thinning, accounted for the majority of change in the mechanically disturbed land-cover class. Since 1908, the U.S. Forest Service has been tracking the sale of timber from forests in Arizona and New Mexico. The U.S. Forest Service data correlate with the results of this study, which show that harvests increased between 1973 and 1980 and between 1980 and 1986, and they decreased between 1982 and 1992 and between 1992 and 2000 (Paul Fink, U.S. Forest Service, written commun., 2009; see also, fig. 5). Harvests began to decline in 1990 owing to changes in timber-management practices, environmental concerns, and the lack of large, profitable trees to cut (Kelley, 1998). In 1986, the U.S. Forest Service sold the rights to nearly 447 million board feet of timber in Arizona and New Mexico forests, which corresponded to the logging peak within the study period. In 2000, this number dropped to below 69 million board feet of timber (Paul Fink, U.S. Forest Service, written commun., 2009). The small towns within the

Figure 6. Aftermath of fire in Coconino National Forest, north of Flagstaff, Arizona, which occurred between 1992 and 2000. Photograph taken in June 2007.

ecoregion that relied on timber were severely impacted by these decreases, increasing the importance of tourism to their economies (Kelley, 1998).

Historically, logging and frequent forest fires have been major drivers of land-cover change within this ecoregion, and they will both likely continue to impact the cycle of change within the forests. Although the populations of the main cities and towns in the ecoregion continue to increase, many of these population centers are bounded by public lands unavailable to urbanization. Coupled with the fact that nearly 80 percent of the ecoregion is managed public and tribal lands, land-cover change in the Arizona/New Mexico Mountain Ecoregion is likely to remain low.

Table 1. Percentage of Arizona/New Mexico Mountains Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (96.5 percent), whereas 3.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	2.0	0.9	1.1	2.8	0.6	29.8
2	1.3	0.7	0.6	2.0	0.5	34.9
3	0.2	0.2	0.0	0.4	0.1	72.6
4	0.0	0.0	0.0	0.1	0.0	73.0
Overall spatial change	3.5	1.5	2.0	5.0	1.0	28.3

Table 2. Raw estimates of change in Arizona/New Mexico Mountains Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.9	0.6	0.3	1.5	0.4	46.1	0.1
1980–1986	1.3	0.7	0.5	2.0	0.5	39.2	0.2
1986–1992	1.1	0.6	0.6	1.7	0.4	34.1	0.2
1992–2000	2.0	0.9	1.1	2.9	0.6	31.1	0.3
Estimate of change, in square kilometers							
1973–1980	995	676	319	1,671	459	46.1	142
1980–1986	1,373	793	581	2,166	538	39.2	229
1986–1992	1,237	622	616	1,859	422	34.1	206
1992–2000	2,171	995	1,177	3,166	676	31.1	271

Table 3. Estimated area (and margin of error) of each land-cover class in Arizona/New Mexico Mountains Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.0	0.0	0.4	0.3	0.0	0.0	0.8	1.1	0.1	0.1	58.2	8.5	39.9	8.3	0.4	0.3	0.0	0.0	0.1	0.1
1980	0.1	0.1	0.4	0.3	0.1	0.1	0.8	1.2	0.1	0.1	57.7	8.5	39.7	8.3	0.5	0.4	0.0	0.0	0.5	0.6
1986	0.0	0.0	0.4	0.3	0.4	0.4	0.9	1.3	0.1	0.1	57.5	8.4	40.1	8.3	0.5	0.3	0.0	0.0	0.0	0.0
1992	0.1	0.1	0.4	0.3	0.2	0.3	0.9	1.3	0.1	0.1	57.5	8.4	40.0	8.3	0.4	0.3	0.0	0.0	0.2	0.2
2000	0.0	0.0	0.4	0.3	0.0	0.0	1.0	1.4	0.1	0.1	56.6	8.3	40.1	8.2	0.4	0.2	0.0	0.0	1.2	0.8
Net change	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.3	0.0	0.0	−1.6	1.0	0.2	0.6	−0.1	0.1	0.0	0.0	1.1	0.8
Gross change	0.2	0.3	0.1	0.0	1.2	1.0	0.2	0.3	0.0	0.0	3.0	1.5	1.8	0.9	0.3	0.3	0.0	0.0	2.6	1.7
Area, in square kilometers																				
1973	25	16	391	313	2	3	855	1,227	146	152	63,129	9,265	43,260	9,033	476	315	39	47	109	148
1980	112	107	418	314	123	124	898	1,287	149	152	62,609	9,170	43,042	9,033	557	392	34	46	490	620
1986	52	41	426	314	398	396	978	1,402	149	152	62,386	9,151	43,450	8,949	545	377	35	45	13	14
1992	79	62	448	317	268	309	1,022	1,463	156	152	62,334	9,119	43,383	8,957	482	306	49	49	211	204
2000	36	29	475	323	25	36	1,078	1,532	152	152	61,395	8,972	43,502	8,932	384	250	48	52	1,337	879
Net change	11	17	84	50	23	36	223	306	6	7	−1,735	1,092	242	634	−92	135	9	7	1,228	896
Gross change	231	280	84	50	1,346	1,076	223	306	33	25	3,208	1,651	1,981	1,012	277	354	29	31	2,801	1,879

Table 4. Principal land-cover conversions in Arizona/New Mexico Mountains Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Nonmechanically disturbed	445	563	382	0.4	44.7
	Forest	Mechanically disturbed	121	122	83	0.1	12.1
	Grassland/Shrubland	Water	83	101	68	0.1	8.4
	Grassland/Shrubland	Agriculture	83	110	75	0.1	8.3
	Nonmechanically disturbed	Grassland/Shrubland	55	71	48	0.1	5.5
	Other	Other	209	n/a	n/a	0.2	21.0
		Totals	995			0.9	100.0
1980–1986	Nonmechanically disturbed	Grassland/Shrubland	485	620	421	0.4	35.3
	Forest	Mechanically disturbed	398	396	269	0.4	29.0
	Grassland/Shrubland	Forest	162	203	138	0.1	11.8
	Mechanically disturbed	Grassland/Shrubland	91	93	63	0.1	6.6
	Grassland/Shrubland	Mining	69	100	68	0.1	5.0
	Other	Other	169	n/a	n/a	0.2	12.3
		Totals	1,373			1.3	100.0
1986–1992	Mechanically disturbed	Forest	306	368	250	0.3	24.7
	Forest	Mechanically disturbed	265	306	208	0.2	21.4
	Forest	Nonmechanically disturbed	207	204	138	0.2	16.7
	Grassland/Shrubland	Forest	120	125	85	0.1	9.7
	Mechanically disturbed	Grassland/Shrubland	91	117	79	0.1	7.3
	Other	Other	249	n/a	n/a	0.2	20.1
		Totals	1,237			1.1	100.0
1992–2000	Forest	Nonmechanically disturbed	1,295	844	573	1.2	59.7
	Mechanically disturbed	Forest	262	305	207	0.2	12.1
	Nonmechanically disturbed	Grassland/Shrubland	168	190	129	0.2	7.7
	Agriculture	Grassland/Shrubland	97	123	84	0.1	4.5
	Grassland/Shrubland	Forest	82	105	71	0.1	3.8
	Other	Other	268	n/a	n/a	0.2	12.3
		Totals	2,171			2.0	100.0
1973–2000 (overall)	Forest	Nonmechanically disturbed	1,955	1,262	857	1.8	33.8
	Forest	Mechanically disturbed	808	624	424	0.7	14.0
	Nonmechanically disturbed	Grassland/Shrubland	714	662	450	0.7	12.4
	Mechanically disturbed	Forest	600	548	372	0.6	10.4
	Grassland/Shrubland	Forest	382	336	228	0.4	6.6
	Other	Other	1,317	n/a	n/a	1.2	22.8
		Totals	5,777			5.3	100.0

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Western Mountain Ranges Ecoregions

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Chapter 11

Cascades Ecoregion

By Daniel G. Sorenson

Ecoregion Description

The Cascades Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 46,787 km² (18,064 mi²) in Washington, Oregon, and California (fig. 1). The main body of the ecoregion extends from Snoqualmie Pass, Washington, in the north, to Hayden Mountain, near State Highway 66 in southern Oregon. Also included in the ecoregion is a small isolated section south of Bend, Oregon, as well as a larger one around Mount Shasta, California. The ecoregion is bounded on the west by the Klamath Mountains, Willamette Valley, and Puget Lowland Ecoregions; on the north by the North Cascades Ecoregion; and on the east by the Eastern Cascades Slopes and Foothills Ecoregion.

The Cascades Ecoregion is a forested, mountainous ecoregion, and it contains a large amount of Cenozoic volcanic rock and many active and inactive volcanoes, especially in the east (McNab and Avers, 1994). Elevations range from near sea level at the Columbia River to 4,390 m at Mount Rainier in Washington, with most of the ecoregion between 645 and 2,258 m. The

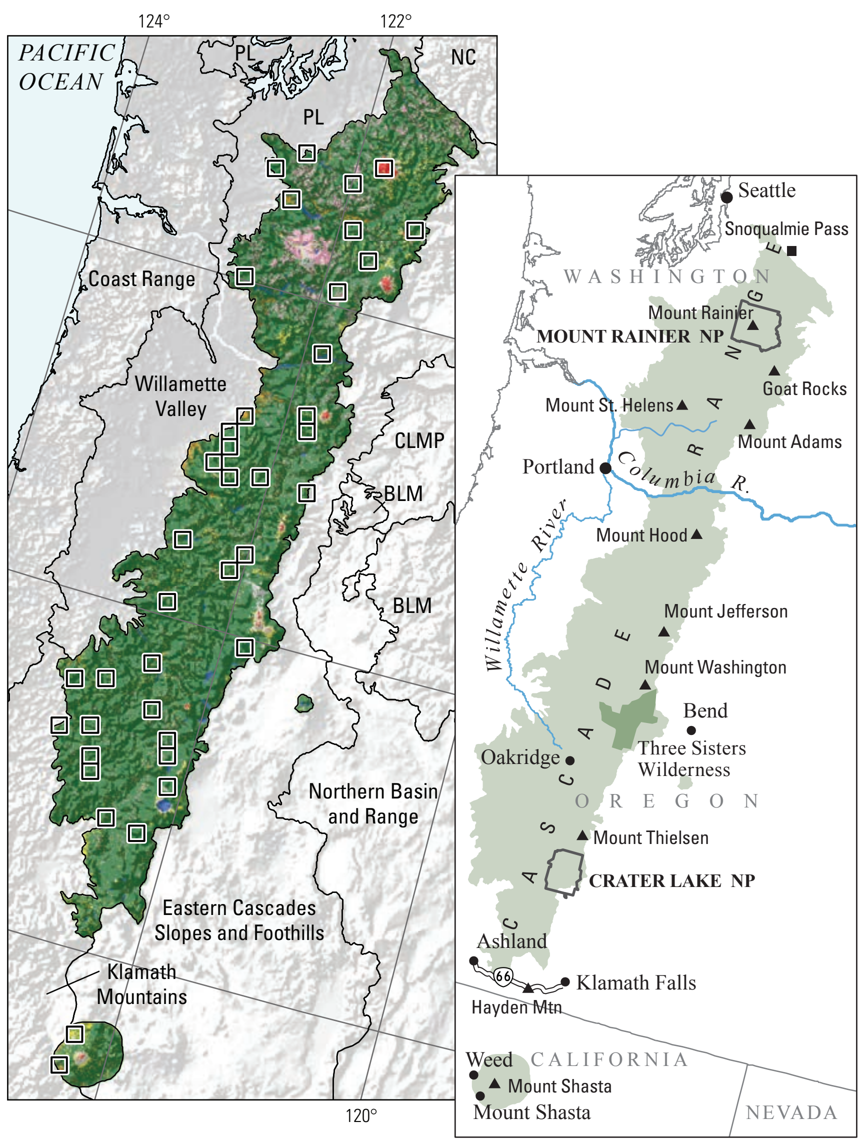
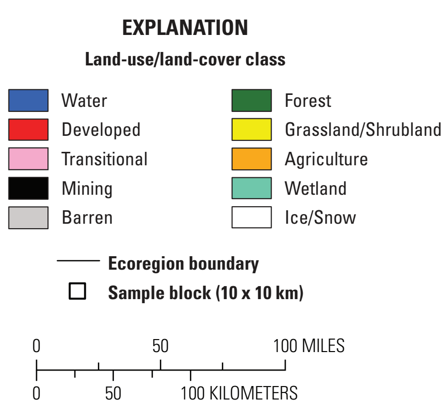


Figure 1. Map of Cascades Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.



west side of the ecoregion is characterized by long, steep ridges and wide river valleys. Subalpine meadows are present at higher elevations, and alpine glaciers have left till and outwash deposits (McNab and Avers, 1994). Precipitation in the Cascades Ecoregion ranges from 1,300 to 3,800 mm, falling mostly as rain and snow from October to June. Average annual temperatures range from –1ºC to 11ºC. The length of the growing season varies from less than 30 days to 240 days (McNab and Avers, 1994).

The dominant vegetation on the lower slopes (below 1,000 m) is Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). At middle elevations (from about 800 to 1,280 m), Pacific silver fir (*Abies amabilis*) and noble fir (*Abies procera*) become prevalent. Lush wildflower meadows can be found in these areas. At higher elevations, mountain hemlock (*Tsuga mertensiana*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*) are common. At elevations as high as 3,350 m are alpine meadows that consist of huckleberry (*Vaccinium L.* spp.) and heath (*Erica L.* spp.) fields, as well as barren areas.

The Cascades Ecoregion contains numerous state and national forests, including the Mount Baker–Snoqualmie, Mount Hood, Deschutes, Willamette, Umpqua, Rogue River–Siskiyou, and Shasta–Trinity National Forests. Wilderness areas include the Goat Rocks, Mount Adams, Mount Hood, Mount Jefferson, Mount Thielsen, Mount Washington, Three Sisters, and Mount Shasta Wildernesses. The ecoregion also contains Mount Rainier and Crater Lake National Parks. Much of the land at middle and higher elevations is held publically in national forests, whereas private ownership (especially by the forest industry) is more common at lower elevations where Douglas-fir and hemlock forests dominate (Risser and others, 2000). Land management on public lands varies from intensive forestry, especially on the lower slopes, to protected wilderness areas (McNab and Avers, 1994).

Before European settlement, natural disturbances, especially fire, were the dominant forces driving land-cover change in the Cascades Ecoregion. The southern part of the ecoregion is prone to frequent lightning-caused fires, having fire return intervals of around 55 years (Sugihara and others, 2006). In the north, fires are less frequent but can be more severe (Risser and others, 2000), with fire return intervals as long as 500 years around Mount Rainier (Agee, 1993). After European settlement in the mid-1800s, forest landscapes were increasingly influenced by anthropogenic disturbance in the form of timber harvesting, as well as fire suppression in the early 20th century. Replanting practices resulted in a more uniform, even-aged forest structure and greater landscape fragmentation (Wallin and others, 1996). Reforestation practices resulted in a simplification of species composition, with Douglas-fir replacing a variety of hardwoods and other softwoods (Alig and others, 2000). These homogenous forests often lack the large trees, snags, downed wood, and tree-species diversity that are needed to promote wildlife diversity (Risser and others. 2000).

The ecoregion is sparsely populated. The largest cities are Mount Shasta, California (population 3,624), Oakridge, Oregon (3,148), and Weed, California (2,978) (U.S. Census Bureau, 2000). With the decline of the timber industry in the Cascades Ecoregion, most small towns that have historically relied on a timber-based economy are now relying more on recreation and other industries to sustain their economy (Jacklet, 2009).

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the areal extent of land-use/land-cover change (area that experienced land-cover change at least once in the 27-year study period) in the Cascades Ecoregion was 24.6 percent, or approximately 11,520 km² (table 1). Compared with other western United States ecoregions, the amount of change was high (fig. 2). Overall, an estimated 4,164 km² (8.9 percent of the total ecoregion area) changed in one of the time periods; 5,240 km² (11.2 percent) changed

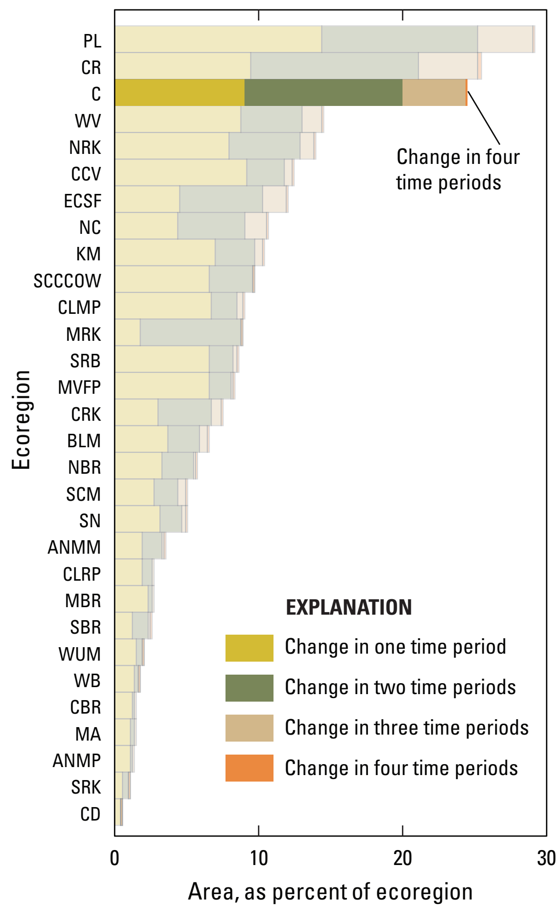


Figure 2. Overall spatial change in Cascades Ecoregion (C; darker bars) compared with that of all 30 all Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Cascades Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

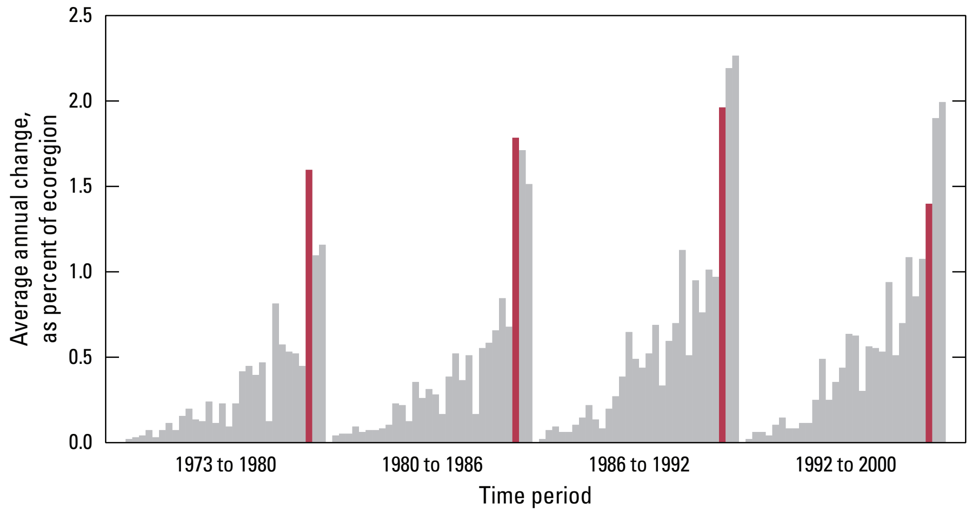


Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Cascades Ecoregion are represented by red bars in each time period.

during two time periods; and 2,012 km² (4.3 percent) changed during three periods. Only 468 km² (0.1 percent) changed in all four time periods (table 1).

The average annual rate of land-cover change in the Cascades Ecoregion was 1.7 percent (795 km²) (table 2). Average annual change for successive time periods reveals a steady increase in rates of land-cover change over the study period for the first three time periods and a slight decline for the last time period. Between 1973 and 1980, the average rate of change was 1.6 percent (749 km²), increasing to 1.8 percent (833 km²) between 1980 and 1986. This rate continued to rise to 2.0 percent (919 km²) between 1986 and 1992, then it declined to 1.4 percent (652 km²) between 1992 and 2000 (fig. 3; table 2).

Forest is the dominant land-cover class in the Cascades Ecoregion (figs. 4,5), accounting for 82.8 percent of the ecoregion in 2000, followed by grassland/shrubland (5.6 percent), mechanically disturbed (3.5 percent), and agriculture (2.1 percent) (table 3). The seven remaining land-cover classes accounted for 6.0 percent of the ecoregion (table 3).

The leading conversion in all time periods was from forest to mechanically disturbed, the result of clearcut logging (fig. 5). Changes associated with timber harvest and forest regeneration account for over 98 percent of all land-cover conversions, and they represent the top four land-cover conversions in the ecoregion throughout the study period (table 4). The timber-harvest-to-forest-regeneration process starts after the removal of trees (that is, forest to mechanically disturbed), after which the area is replanted with seedlings or regenerates naturally (mechanically disturbed to grassland/shrubland) (fig. 6). The successional process continues as the seedlings grow tall enough (at least 2 m) to be classified as forest (grassland/shrubland to forest). In some areas, forest regeneration is rapid, and so the study's six- to eight-year sampling interval did not capture the grassland/shrubland successional stage, the lack of which resulted in conversions from mechanically disturbed directly back to forest.

Between 1973 and 1992, a net loss of forest occurred in every time period, resulting in a net decline in forest land of approximately 10,800 km². This trend reversed between 1992

Figure 4. Forested hillsides in Cascades Ecoregion, showing logging roads and clearcut scars. Dominant land-cover class in Cascades Ecoregion is forest, which in 2000 made up almost 83 percent of all land cover in ecoregion.

Figure 5. Freshly clearcut hillside in Cascades Ecoregion. Logging, usually clearcutting, was leading driver of land-cover change in Cascades Ecoregion for all time periods.

Figure 6. Aftermath of timber harvest in Cascades Ecoregion, showing that most of slash is removed, burnt, or buried and then seedlings (wrapped in protective mesh) are planted. Some states, such as Washington, have laws that prescribe how soon to replant after tree harvesting to guard against invasive species (Washington State Department of Natural Resources, 2001).

and 2000 with an 11,050 km² gain in forest land, suggesting that the losses in the early years were generally replaced by gains in the last time period (table 3; figs. 7,8). Types of land ownership and land management influenced the changes that occurred. Sample blocks in the Cascades Ecoregion that fell in protected areas experienced the least amount of change, whereas sample blocks in privately held land experienced the greatest amount of change (fig. 9).

Several factors were involved in the decline of forest products from the Pacific Northwest between 1992 and 2000 (fig. 7; table 4). Lumber and wood-product exports from the Pacific Northwest declined in the 1990s because their main markets (Japan and other Asian countries) suffered economic downturns that reduced demand for wood-based commodities. This caused an oversupply of wood products that led to a collapse in prices and the amount of exports (Perez-Garcia and Barr, 2005). The Pacific Northwest also faced increased competition during this time from other wood-producing countries such as Russia, Finland, Canada, and New Zealand (Daniels, 2005). A significant reason for the increase in Canadian exports was the increased harvest rate implemented to avert fires resulting from trees killed by mountain pine beetle and other pests (Perez-Garcia and Barr, 2005).

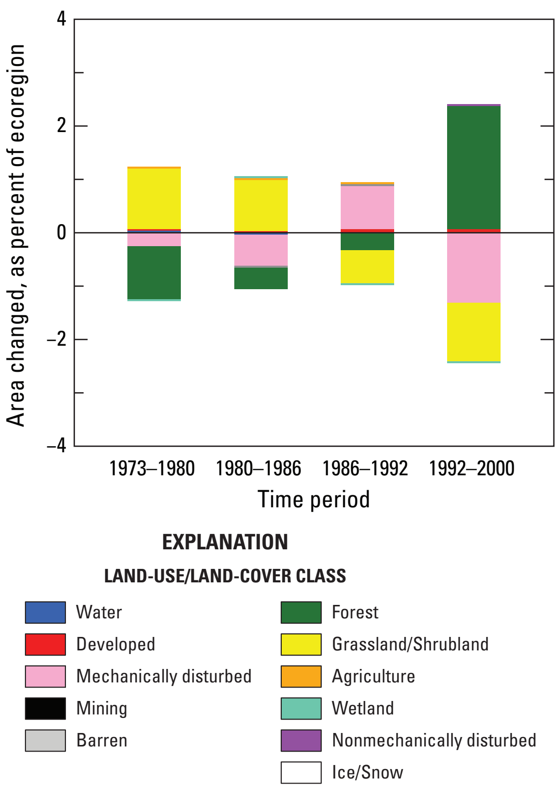


Figure 7. Normalized average net change in Cascades Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

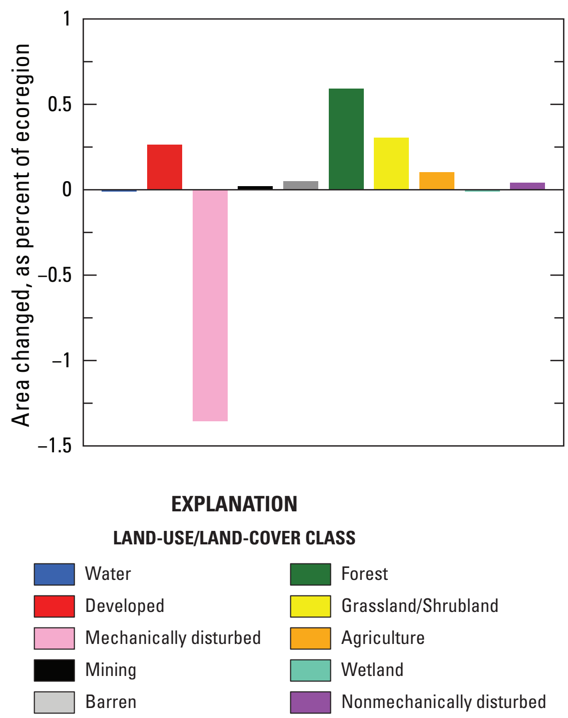


Figure 8. Estimated cumulative change in Cascades Ecoregion for each land-cover class between 1973 and 2000. Bars above zero axis represent overall gain, whereas bars below zero represent overall loss. Mechanically disturbed class experienced largest decrease, while grassland/shrubland and forest classes had highest gains. No change was detected for ice/snow class.

In the 1990s, the Northwest Forest Plan (Espy and Babbitt, 1994) was developed to protect the habitat of the threatened Northern Spotted Owl (*Strix occidentalis caurina*) (Daniels, 2005). Under this plan, timber harvest was banned or reduced on 10 million of the 17 million acres (40,469 of 68,797 km²) of national forests in the Pacific Northwest. Before the Northwest Forest Plan, timber sales from these national forests were about 4 to 5 billion board feet per year. After 1990, sales dropped to less than a billion board feet per year (Daniels, 2005). A consequence of the reduced harvest in national forests in the Pacific Northwest was an increase in harvesting from privately owned land. On public land, stand replacement after timber harvest was 2 to 10 times more likely to occur than stand replacement (full or partial) as a result of wildfire (Alig and others, 2000).

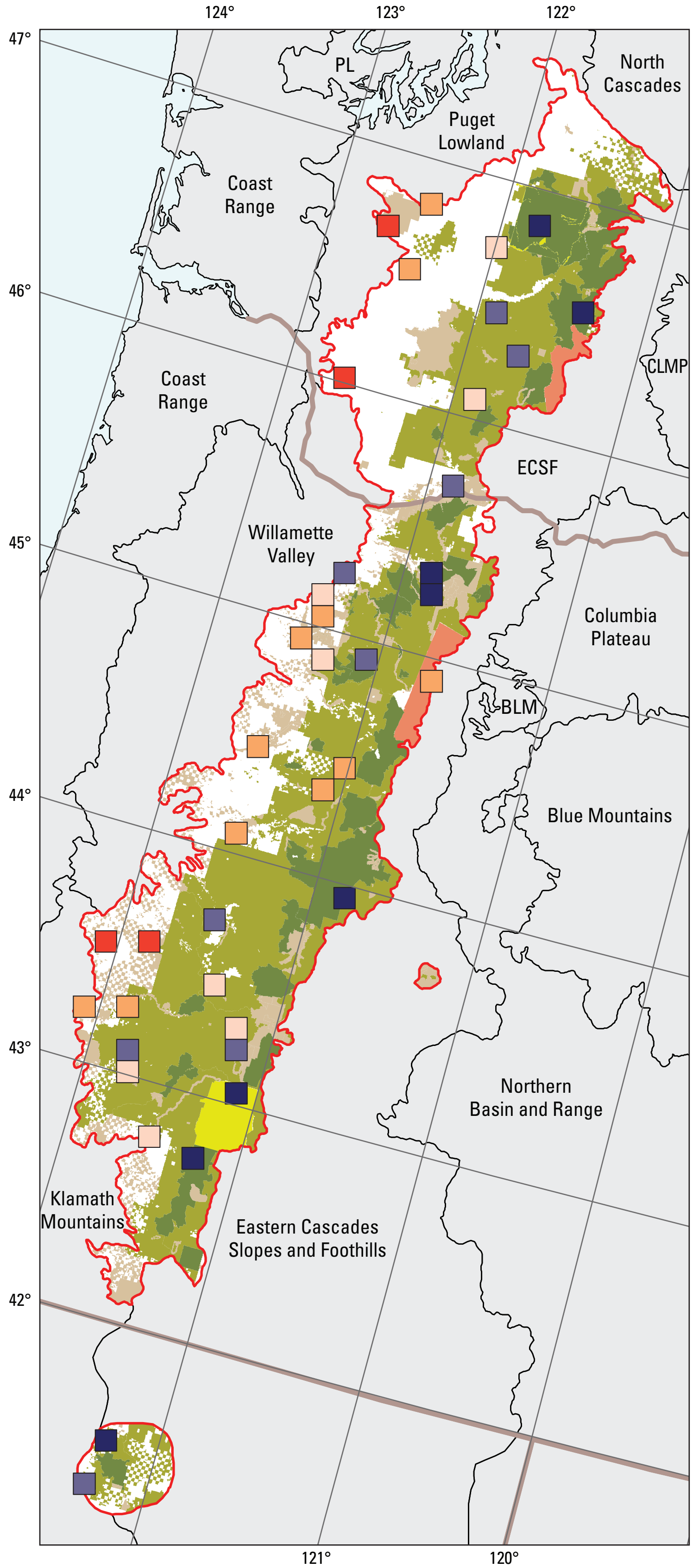


Figure 9. Federal land ownership and cumulative land-use/land-cover change (as percent of sample-block area) from 1973 to 2000 in Cascades Ecoregion. Sample blocks that fell on wilderness areas witnessed least amount of change. Most sample blocks that saw highest amount of change fell on privately held land at lower elevations. Land-ownership data from National Atlas of the United States (2006). See appendix 2 for abbreviations for Western United States ecoregions.

EXPLANATION

Federal land-ownership class

- Wilderness Area
- National Forest
- National Monument or Park
- Tribal lands
- Other Federal lands
- Other lands

Overall spatial change
(per 10 x 10 km sample block)

- 0.0–10.0
- 10.1–20.0
- 20.1–30.0
- 30.1–50.0
- 50.1–70.4

Boundaries

- Cascades Ecoregion
- Other ecoregion
- State boundary

0 50 100 MILES
0 50 100 KILOMETERS

Table 1. Percentage of Cascades Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (75.4 percent), whereas 24.6 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	9.0	1.7	7.4	10.7	1.1	12.6
2	11.2	1.6	9.5	12.8	1.1	10.0
3	4.3	0.9	3.4	5.2	0.6	13.9
4	0.1	0.0	0.1	0.2	0.0	18.3
Overall spatial change	24.6	3.7	20.9	28.3	2.5	10.2

Table 2. Raw estimates of change in Cascades Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	11.2	2.1	9.2	13.3	1.4	12.5	1.6
1980–1986	10.7	1.9	8.8	12.6	1.3	12.1	1.8
1986–1992	11.8	1.7	10.0	13.5	1.2	10.1	2.0
1992–2000	11.1	2.1	9.1	13.2	1.4	12.5	1.4
			Estimate of change, in square kilometers				
1973–1980	5,242	960	4,283	6,202	654	12.5	749
1980–1986	4,998	889	4,108	5,887	606	12.1	833
1986–1992	5,515	817	4,698	6,333	557	10.1	919
1992–2000	5,214	959	4,254	6,173	653	12.5	652

Table 3. Estimated area (and margin of error) of each land-cover class in Cascades Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	1.1	0.7	1.1	0.5	4.8	1.1	0.0	0.0	1.4	1.2	82.2	3.5	5.3	1.3	2.0	1.3	0.5	0.2	0.0	0.0
1980	1.2	0.7	1.2	0.5	4.6	1.0	0.1	0.0	1.4	1.2	81.3	3.5	6.4	1.3	2.0	1.3	0.5	0.2	0.0	0.0
1986	1.1	0.7	1.2	0.6	4.0	0.7	0.1	0.0	1.4	1.2	80.9	3.6	7.4	1.4	2.0	1.3	0.5	0.2	0.0	0.0
1992	1.1	0.7	1.3	0.6	4.8	0.8	0.1	0.0	1.4	1.2	80.5	3.6	6.8	1.3	2.0	1.3	0.5	0.2	0.0	0.0
2000	1.1	0.7	1.4	0.6	3.5	1.3	0.1	0.1	1.4	1.2	82.8	3.6	5.6	1.2	2.1	1.3	0.5	0.2	0.0	0.0
Net change	0.0	0.0	0.3	0.1	−1.4	1.5	0.0	0.0	0.1	0.0	0.6	1.2	0.3	1.0	0.1	0.1	0.0	0.0	0.0	0.0
Gross change	0.1	0.1	0.3	0.1	10.6	2.0	0.0	0.0	0.1	0.1	10.7	1.9	8.0	1.6	0.1	0.1	0.0	0.0	0.0	0.0
Area, in square kilometers																				
1973	529	338	529	240	2,254	497	21	14	641	560	38,479	1,621	2,490	603	916	601	221	94	0	0
1980	544	346	547	249	2,130	482	24	18	646	559	38,019	1,646	3,017	599	933	602	219	94	0	0
1986	527	337	570	259	1,854	341	25	18	643	560	37,828	1,667	3,465	662	949	602	220	95	0	0
1992	524	339	616	277	2,226	384	29	21	659	559	37,686	1,663	3,162	615	958	610	219	94	0	0
2000	523	340	650	287	1,620	591	31	24	666	559	38,755	1,677	2,634	577	964	616	219	95	16	17
Net change	−6	12	121	54	−634	695	11	11	25	23	276	557	144	472	48	37	−2	6	16	17
Gross change	63	49	121	54	4,956	928	11	11	40	25	4,994	869	3,734	750	58	40	6	6	16	17

Table 4. Principal land-cover conversions in Cascades Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	2,134	486	331	4.6	40.7
	Mechanically disturbed	Grassland/Shrubland	1,412	389	265	3.0	26.9
	Mechanically disturbed	Forest	975	263	179	2.1	18.6
	Grassland/Shrubland	Forest	710	196	134	1.5	13.5
	Forest	Agriculture	20	11	8	0.0	0.4
	Other	Other	−9	n/a	n/a	0.0	−0.2
		Totals	5,242			11.2	100.0
1980–1986	Forest	Mechanically disturbed	1,830	337	230	3.9	36.6
	Mechanically disturbed	Grassland/Shrubland	1,418	363	247	3.0	28.4
	Grassland/Shrubland	Forest	954	217	148	2.0	19.1
	Mechanically disturbed	Forest	716	205	139	1.5	14.3
	Water	Mechanically disturbed	19	24	16	0.0	0.4
	Other	Other	60	n/a	n/a	0.1	1.2
		Totals	4,998			10.7	100.0
1986–1992	Forest	Mechanically disturbed	2,209	380	259	4.7	40.1
	Grassland/Shrubland	Forest	1,379	332	226	2.9	25.0
	Mechanically disturbed	Grassland/Shrubland	1,078	214	146	2.3	19.6
	Mechanically disturbed	Forest	745	189	129	1.6	13.5
	Forest	Developed	36	17	12	0.1	0.7
	Other	Other	68	n/a	n/a	0.1	1.2
		Totals	5,515			11.8	100.0
1992–2000	Forest	Mechanically disturbed	1,613	592	403	3.4	30.9
	Mechanically disturbed	Forest	1,434	348	237	3.1	27.5
	Grassland/Shrubland	Forest	1,315	263	179	2.8	25.2
	Mechanically disturbed	Grassland/Shrubland	777	135	92	1.7	14.9
	Forest	Developed	29	14	10	0.1	0.6
	Other	Other	46	n/a	n/a	0.1	0.9
		Totals	5,214			11.1	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	7,786	1,344	915	16.6	37.1
	Mechanically disturbed	Grassland/Shrubland	4,686	869	592	10.0	22.3
	Grassland/Shrubland	Forest	4,358	775	528	9.3	20.8
	Mechanically disturbed	Forest	3,870	820	559	8.3	18.5
	Forest	Developed	98	45	30	0.2	0.5
	Other	Other	172	n/a	n/a	0.4	0.8
		Totals	20,969			44.8	100.0

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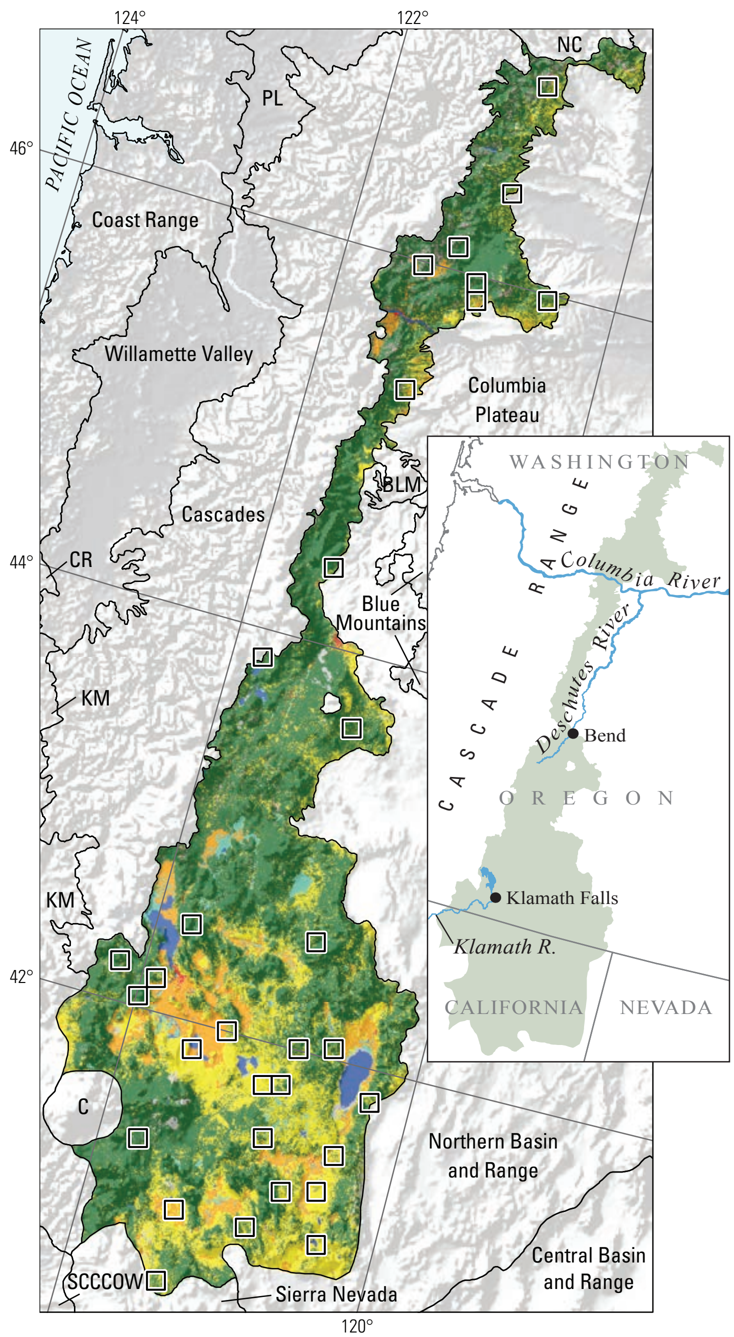
Chapter 12

Eastern Cascades Slopes and Foothills Ecoregion

By Daniel G. Sorenson

Ecoregion Description

The Eastern Cascades Slopes and Foothills Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 57,329 km² (22,135 mi²) in the states of Washington, Oregon, and California (fig. 1). The ecoregion is bounded on the east by the Columbia Plateau, Blue Mountains, and Northern Basin and Range Ecoregions; on the south by the Sierra Nevada Ecoregion; on the west by the Klamath Mountains and Cascades Ecoregions; and on the north by the North Cascades Ecoregion (fig. 1). Because the Eastern Cascades Slopes and Foothills Ecoregion lies within the rain shadow of the Cascade Range, the annual amount of precipitation varies greatly, from 500 mm in the eastern and southern sections of the ecoregion to 3,000 mm in the area bordering the higher Cascade Range to the west. Precipitation (either rain or snow) falls mostly in the fall, through winter into spring. Elevations range from near sea level at the Columbia River to more than 3,300 m; most of the region is between 900 and 2,000 m high.



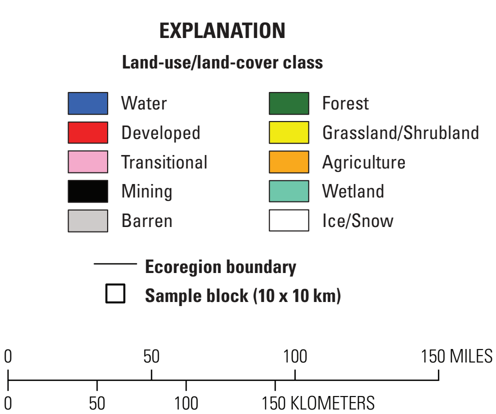


Figure 1. Map of Eastern Cascades Slopes and Foothills Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Map shows that land cover is more diverse in southern part of ecoregion. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. Grassy meadow and forested hillsides in Eastern Cascades Slopes and Foothills Ecoregion. Dominant land-cover class in Eastern Cascades Slopes and Foothills Ecoregion is forest, although grassland/shrubland makes up about one-third of ecoregion. Forests tend to be at higher elevations, in areas with more precipitation, whereas grassland/shrubland areas are found mostly in valley bottoms and drier locations. Photograph by Terry Sohl.

In the plateaus, elevation generally varies from 60 to 600 m (McNab and Avers, 1994).

The Eastern Cascades Slopes and Foothills Ecoregion formed from tectonic uplift with mountain ranges and valleys oriented north-to-south; it is a relatively young ecoregion with numerous lava flows, volcanic cones, and buttes (U.S. Environmental Protection Agency, 2010). Population is sparse: the two largest cities are Bend, Oregon, with a population of 52,029, and Klamath Falls, Oregon, with 19,462 residents (U.S. Census Bureau, 2000).

Forest is the primary land cover in the Eastern Cascades Slopes and Foothills Ecoregion (figs. 1,2), and fire plays an important role in forest composition. Ponderosa pine (*Pinus ponderosa*) is the dominant tree species, and lodgepole pine (*Pinus contorta*) is common in the drier parts of the ecoregion (Risser, 2000). The bark on older, larger ponderosa pines is thick, providing protection from fires. Ponderosa pines are usually little affected if 50 percent or less of the crown is destroyed by fire, giving them an advantage over less fire-tolerant tree species (Oliver and Ryker, 1990). Lodgepole pines have serotinous or closed cones that only open and release seeds when exposed to extreme heat during a fire. As a result, postfire colonization of burned areas by lodgepole pines is rapid, outpacing most other species (Lotan and Chritchfield, 1990).

The northern part of the Eastern Cascades Slopes and Foothills Ecoregion drains into the Deschutes and Columbia Rivers. Spring-fed tributaries and snow melt provide most of the rivers' water. The southern section is drained by the Klamath River, which is fed by a vast interior wetland. Approximately 75 percent of the historic wetlands of the Klamath Basin have been drained for crops. The most common crops grown in the Eastern Cascades Slopes and Foothills Ecoregion are hay, alfalfa, cereal grains, potatoes, onions, and sugar beets (Risser, 2000).

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the areal extent of land-use/land-cover change (the footprint of change, or the area that experienced change at least once during the 27-year study period) in the Eastern Cascades Slopes and Foothills Ecoregion was 12.1 percent, or 6,943 km² (table 1). Compared with other western United States ecoregions, change in the Eastern Cascades Slopes and Foothills Ecoregion was above average (fig. 3). Overall, an estimated 2,637 km² (4.6 percent) of the ecoregion changed in one time period; 3,268 km²

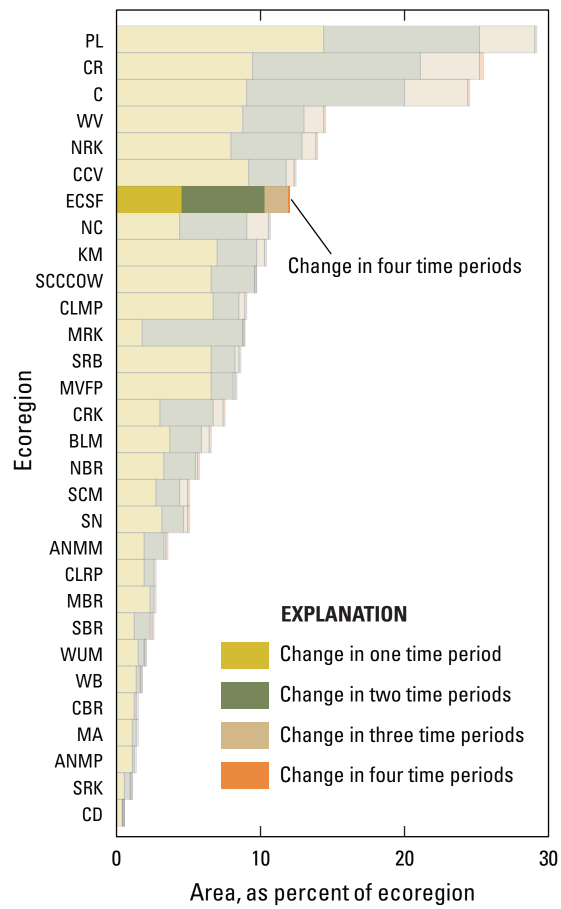


Figure 3. Overall spatial change in Eastern Cascades Slopes and Foothills Ecoregion (ECSF; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Eastern Cascades Slopes and Foothills Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

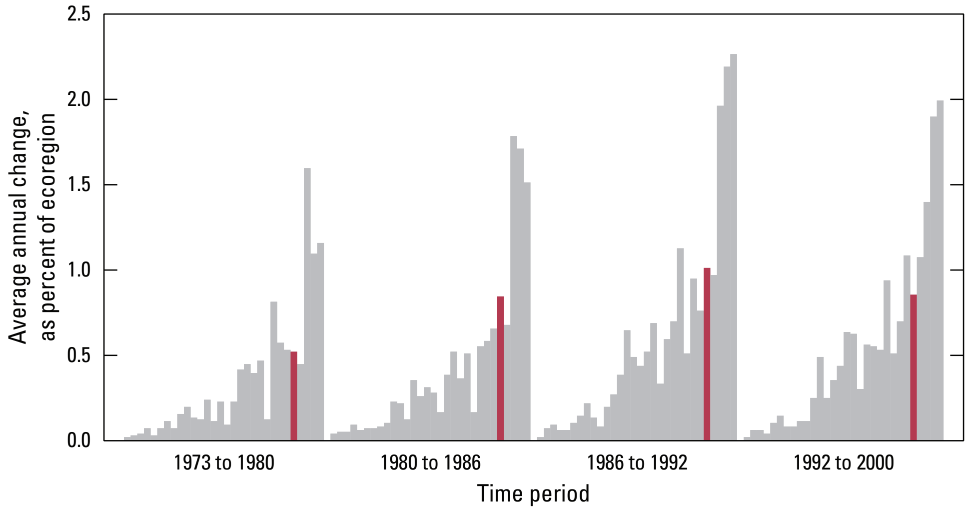


Figure 4. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Eastern Cascades Slopes and Foothills Ecoregion are represented by red bars in each time period.

(5.7 percent) changed in two time periods; 1,032 km² (1.8 percent) changed in three periods; and less than 57 km² (0.1 percent) area changed in all four time periods (table 1). The average annual rate of change in the Eastern Cascades Slopes and Foothills Ecoregion between 1973 and 2000 was 0.8 percent (table 2). Average annual change for successive time periods reveals a steady increase during the study period for the first three time periods and a slight decline for the last time period. Between 1973 and 1980, the annual rate of change was 0.5 percent (295 km²), increasing to 0.8 percent (486 km²) between 1980 and 1986. This rate continued to rise to 1.0 percent (580 km²) between 1986 and 1992 and then dropped slightly to 0.9 percent (489 km²) between 1992 and 2000 (fig. 4; table 2).

In 2000, three of the ten land-cover classes in the Eastern Cascades Slopes and Foothills Ecoregion dominate total land cover: forest (53.2 percent), grassland/shrubland (33.3 percent), and agriculture (7.1 percent) (table 3; fig. 1). The remaining seven classes contained the remaining 6.5 percent of the classified landscape in 2000. Each of these classes alone represented less than 2.5 percent of the sampled area. Between 1973 and 2000, the land-cover classes that experienced a measurable net change in relation to the total ecoregion area include net losses of forest (6.8 percent), in addition to net gains in grassland/shrubland (8.7 percent) and mechanically disturbed (7.2 percent) (table 3; fig. 5).

The top four land-cover conversions in the ecoregion for all time periods (except the fourth) were associated with timber harvest and forest regeneration (fig. 6). The principal type of change in all time periods was from forest to mechanically disturbed, caused by forest logging through clearcutting. The timber harvest-to-regeneration process starts after the removal of trees (forest to mechanically disturbed), after

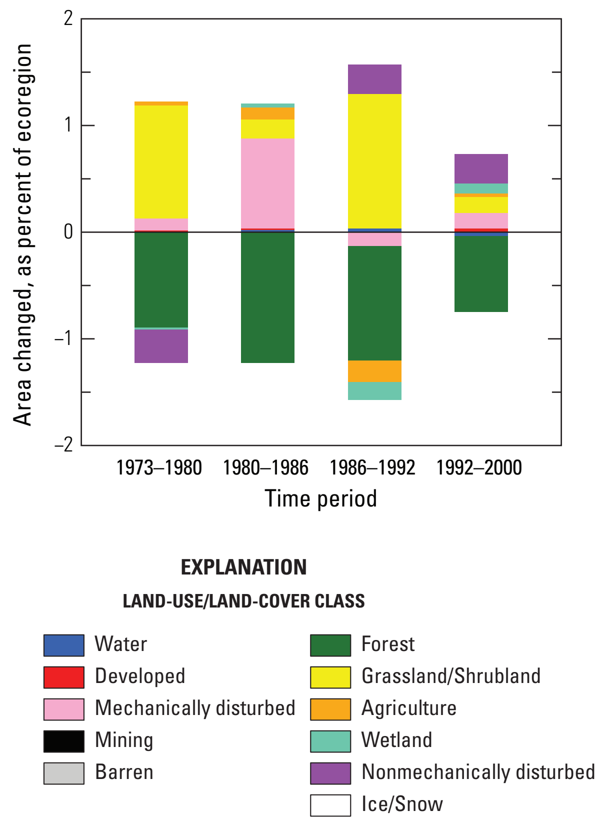


Figure 5. Normalized average net change in Eastern Cascades Slopes and Foothills Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 6. Clearcutting of forested area. Principal cause of land-cover change in Eastern Cascades Slopes and Foothills Ecoregion was logging and forest regenerations. Photograph by Terry Sohl.

which the area is replanted with tree seedlings or regenerates naturally (mechanically disturbed to grassland/shrubland). The process continues as the seedlings grow tall enough (at least 2 m high) to be classified as trees (grassland/shrubland to forest). In some areas, forest regeneration was rapid, and so the six-to-eight year sampling interval missed the grassland/shrubland stage, which resulted in the apparent conversion from mechanically disturbed directly to forest. Forest cutting and regeneration accounted for almost all the change in the Eastern Cascades Slopes and Foothills Ecoregion, which was between 83 and 88 percent of all periods (table 4).

Several factors were involved in the decline of forest cutting. Lumber and wood exports declined in the 1990s because the primary market for Pacific Northwest wood products (Japan and other Asian counties) experienced an economic downturn that reduced demand. The 1990s saw more wood-producing countries such as Russia, Canada, and New Zealand increase their exports. In addition, the Northwest Forest Plan was implemented in 1996 to protect the threatened Northern Spotted Owl (*Strix occidentalis caurina*), which prefers to roost in old-growth forest that has moderate to high canopy enclosure. Timber sales in protected areas declined from 4 to 5 billion board feet per year to less than a billion board feet per year, and almost 60 percent of Pacific Northwest national forest was taken out of timber production (Daniels, 2005).

The rate of change and dominant land cover for the sample blocks in California (4.5 percent) was lower than that for the rest of the ecoregion (12.1 percent). In 2000, the top three land-cover classes in the California section of the ecoregion were grassland/shrubland (48.0 percent), forest (35.3 percent), and agriculture (10.3 percent), whereas, for the Eastern Cascades Slopes and Foothills Ecoregion as a whole, the percentages for forest, grassland/shrubland, and agriculture were 53.2 percent, 33.3 percent, and,7.0 percent, respectively. Although 50.6 percent of all land-cover change in the California section was the result of logging and forest regeneration, not all of the top land-cover conversions were related to logging. Fire disturbance and recovery (nonmechanically disturbed) was one of the top conversions, as was water-to-wetland conversion (table 4). Further research is needed to explore the cause of land-cover differences in this ecoregion. Possible factors might include elevation, annual precipitation, and varying land-use practices and policies in California, Oregon, and Washington.

Table 1. Percentage of Eastern Cascades Slopes and Foothills Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (87.9 percent), whereas 12.1 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	4.6	1.4	3.2	5.9	0.9	20.5
2	5.7	2.0	3.8	7.7	1.3	23.1
3	1.8	0.9	0.8	2.7	0.6	36.4
4	0.1	0.1	0.0	0.1	0.0	57.6
Overall spatial change	12.1	3.5	8.6	15.6	2.4	19.6

Table 2. Raw estimates of change in Eastern Cascades Slopes and Foothills Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	3.6	1.3	2.3	4.9	0.9	25.3	0.5
1980–1986	5.1	1.9	3.2	7.0	1.3	24.9	0.8
1986–1992	6.1	2.2	3.9	8.2	1.5	24.2	1.0
1992–2000	6.8	2.1	4.7	8.9	1.4	21.0	0.9
			Estimate of change, in square kilometers				
1973–1980	2,065	771	1,294	2,836	522	25.3	295
1980–1986	2,917	1,074	1,843	3,990	727	24.9	486
1986–1992	3,478	1,243	2,235	4,721	842	24.2	580
1992–2000	3,915	1,212	2,702	5,127	821	21.0	489

Table 3. Estimated area (and margin of error) of each land-cover class in Eastern Cascades Slopes and Foothills Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	1.5	1.1	0.1	0.1	1.4	0.7	0.0	0.0	0.2	0.2	57.1	7.6	30.6	6.7	7.1	3.7	1.6	0.7	0.3	0.4
1980	1.5	1.2	0.1	0.1	1.5	0.7	0.0	0.0	0.2	0.2	56.2	7.4	31.7	6.5	7.2	3.7	1.6	0.7	0.0	0.0
1986	1.5	1.2	0.1	0.1	2.3	1.0	0.0	0.0	0.2	0.2	55.0	7.3	31.9	6.4	7.3	3.7	1.6	0.7	0.0	0.0
1992	1.6	1.2	0.2	0.1	2.2	0.9	0.0	0.0	0.2	0.2	54.0	7.1	33.1	6.3	7.1	3.7	1.5	0.7	0.3	0.3
2000	1.5	1.1	0.2	0.1	2.3	1.0	0.0	0.0	0.2	0.2	53.2	6.9	33.3	6.2	7.1	3.7	1.5	0.7	0.6	0.8
Net change	0.0	0.1	0.1	0.1	1.0	1.0	0.0	0.0	0.0	0.0	−3.9	1.7	2.7	1.7	0.0	0.2	−0.1	0.1	0.2	0.9
Gross change	0.7	0.4	0.1	0.1	6.0	1.9	0.0	0.0	0.0	0.0	6.4	2.2	6.3	2.1	0.6	0.6	0.7	0.4	1.4	1.2
									Area, in square kilometers											
1973	850	652	73	40	781	421	4	4	115	129	32,761	4,385	17,555	3,857	4,093	2,105	917	412	179	257
1980	856	679	78	42	843	414	4	4	115	129	32,247	4,265	18,171	3,723	4,110	2,101	904	412	0	0
1986	870	673	83	45	1,327	586	5	5	115	129	31,550	4,158	18,276	3,692	4,177	2,103	925	419	0	0
1992	889	660	90	49	1,262	541	5	5	114	128	30,930	4,042	18,990	3,583	4,057	2,122	832	383	160	161
2000	867	630	108	65	1,344	589	5	5	114	128	30,525	3,942	19,085	3,531	4,076	2,120	886	392	317	455
Net change	17	53	35	29	563	557	1	1	−1	1	−2,236	955	1,531	986	−17	131	−31	59	138	529
Gross change	377	218	35	29	3,442	1,076	1	1	1	1	3,643	1,281	3,587	1,191	334	336	377	231	816	696

Table 4. Principal land-cover conversions in Eastern Cascades Slopes and Foothills Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	835	409	277	1.5	40.4
	Mechanically disturbed	Grassland/Shrubland	558	343	232	1.0	27.0
	Mechanically disturbed	Forest	206	163	111	0.4	10.0
	Nonmechanically disturbed	Grassland/Shrubland	165	236	160	0.3	8.0
	Grassland/Shrubland	Forest	85	63	42	0.1	4.1
	Other	Other	216	n/a	n/a	0.4	10.5
		Totals	2,065			3.6	100.0
1980–1986	Forest	Mechanically disturbed	1,310	582	394	2.3	44.9
	Mechanically disturbed	Grassland/Shrubland	594	341	231	1.0	20.4
	Grassland/Shrubland	Forest	378	302	204	0.7	13.0
	Mechanically disturbed	Forest	238	155	105	0.4	8.1
	Grassland/Shrubland	Agriculture	164	222	150	0.3	5.6
	Other	Other	233	n/a	n/a	0.4	8.0
		Totals	2,917			5.1	100.0
1986–1992	Forest	Mechanically disturbed	1,190	538	364	2.1	34.2
	Mechanically disturbed	Grassland/Shrubland	1,011	500	339	1.8	29.1
	Grassland/Shrubland	Forest	384	219	148	0.7	11.0
	Mechanically disturbed	Forest	296	182	123	0.5	8.5
	Agriculture	Grassland/Shrubland	164	232	157	0.3	4.7
	Other	Other	433	n/a	n/a	0.8	12.4
		Totals	3,478			6.1	100.0
1992–2000	Forest	Mechanically disturbed	1,309	587	398	2.3	33.4
	Mechanically disturbed	Grassland/Shrubland	983	484	328	1.7	25.1
	Grassland/Shrubland	Forest	686	432	293	1.2	17.5
	Grassland/Shrubland	Nonmechanically disturbed	268	384	260	0.5	6.8
	Mechanically disturbed	Forest	236	165	112	0.4	6.0
	Other	Other	432	n/a	n/a	0.8	11.0
		Totals	3,915			6.8	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	4,645	1,751	1,186	8.1	37.5
	Mechanically disturbed	Grassland/Shrubland	3,146	1,434	971	5.5	25.4
	Grassland/Shrubland	Forest	1,533	766	519	2.7	12.4
	Mechanically disturbed	Forest	977	591	400	1.7	7.9
	Grassland/Shrubland	Nonmechanically disturbed	316	387	262	0.6	2.6
	Other	Other	1,758	n/a	n/a	3.1	14.2
		Totals	12,375			21.6	100.0

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Chapter 13

Klamath Mountains Ecoregion

By Benjamin M. Sleeter and James P. Calzia

Ecoregion Description

The Klamath Mountains Ecoregion covers approximately 47,791 km^2 (18,452 mi^2) of the Klamath and Siskiyou Mountains of northern California and southern Oregon (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion is flanked by the Coast Range Ecoregion to the west, the Southern and Central California Chaparral and Oak Woodlands Ecoregion to the south, the Cascades and the Eastern Cascades Slopes and Foothills Ecoregions to the east, and the Willamette Valley Ecoregion to the north. The mild Mediterranean climate of the ecoregion is characterized by hot, dry summers and wet winters; the amount of winter moisture varies within the ecoregion, decreasing from west to east. The Klamath–Siskiyou Mountains region is widely recognized as an important biodiversity hotspot (Whittaker, 1960; Kruckeberg, 1984; Wagner, 1997; DellaSala and others, 1999), containing more than 3,500 plant species, more than 200 of which are endemic (Sawyer, 2007). A biological assessment by DellaSala and others (1999) ranked the Klamath–Siskiyou Mountains region as the fifth richest coniferous forest in terms of species diversity. In addition, the International Union for the Conservation of Nature considers the region an area of notable botanical importance (Wagner, 1997). Twenty-nine different species of conifers can be found in the Klamath Mountains Ecoregion (Sawyer, 1996).

This ecoregion is underlain by belts of Paleozoic to Mesozoic metasedimentary and metavolcanic rocks separated by linear belts of serpentinite. Most of these serpentinite

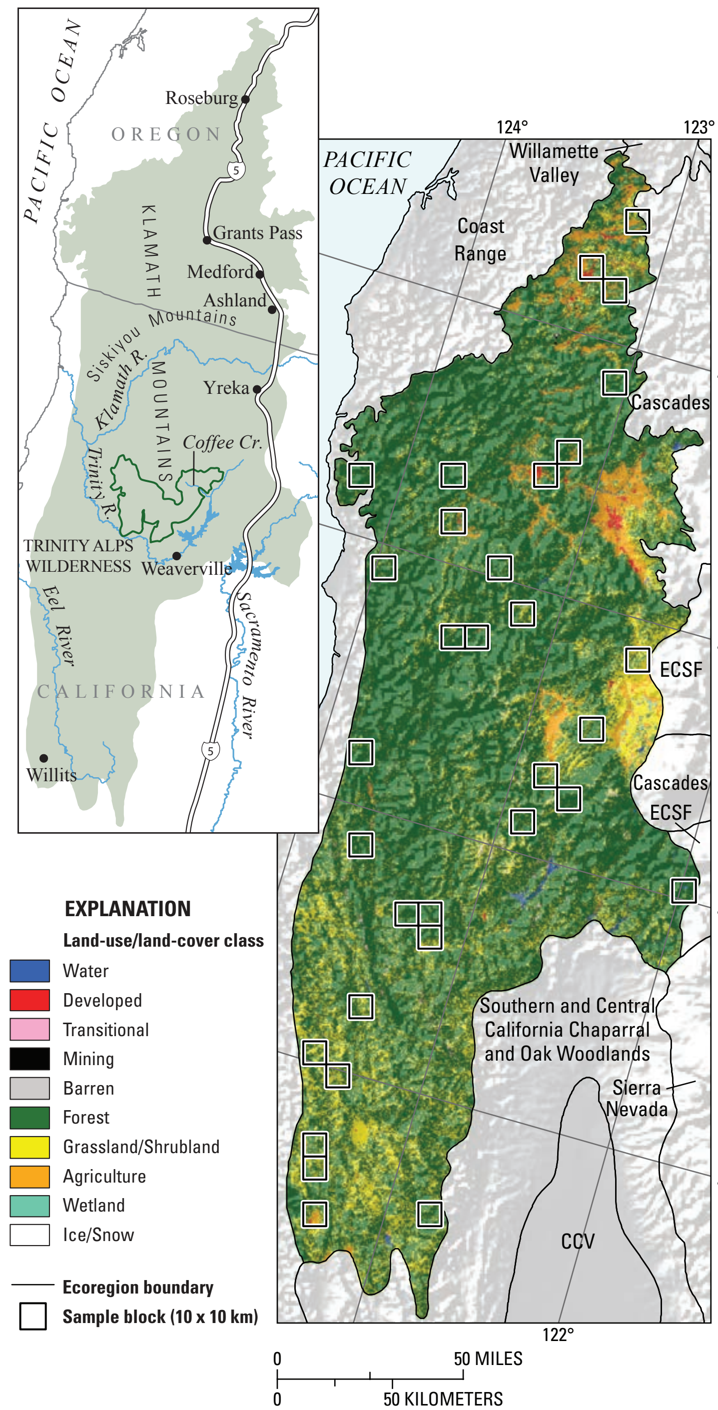

Figure 1. Map of Klamath Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

belts are intruded by Mesozoic granitic rocks and (or) overlain by late Mesozoic sedimentary rocks. All of these rocks are overlain by gravel and alluvial deposits of Cenozoic age (Irwin, 1966; Snoke and Barnes, 2006). Soils developed on serpentinite, which are toxic and nutrient poor, are characterized by high levels of magnesium, nickel, and chromium and low levels of calcium. Seventy endemic species of plants are associated only with serpentinite extrusions in the Siskiyou Mountains, outnumbering those associated with any other serpentinite outcrop in North America (Coleman and Kruckeberg, 1999; Sawyer, 2007).

Forests, which cover approximately three-quarters of the Klamath Mountains Ecoregion, are generally organized along elevation and longitudinal gradients, whereas grasslands and shrubs account for approximately 15 percent of the ecoregion (Homer and others, 2007). Redwood (*Sequoia sempervirens*) forests that dominate the coastal parts of the ecoregion give way to Douglas-fir (*Pseudotsuga menziesii*), tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*), and canyon live oak (*Quercus chrysolepis*) further inland, as well as Douglas-fir and ponderosa pine (*Pinus ponderosa*) in the eastern parts of the ecoregion (Sawyer, 1996). White fir (*Abies concolor*) and Shasta fir (*Abies magnifica*) can be found at higher elevations, and Mountain hemlock (*Tsuga mertensiana*) is common at subalpine elevations (Sawyer, 1996). Oak

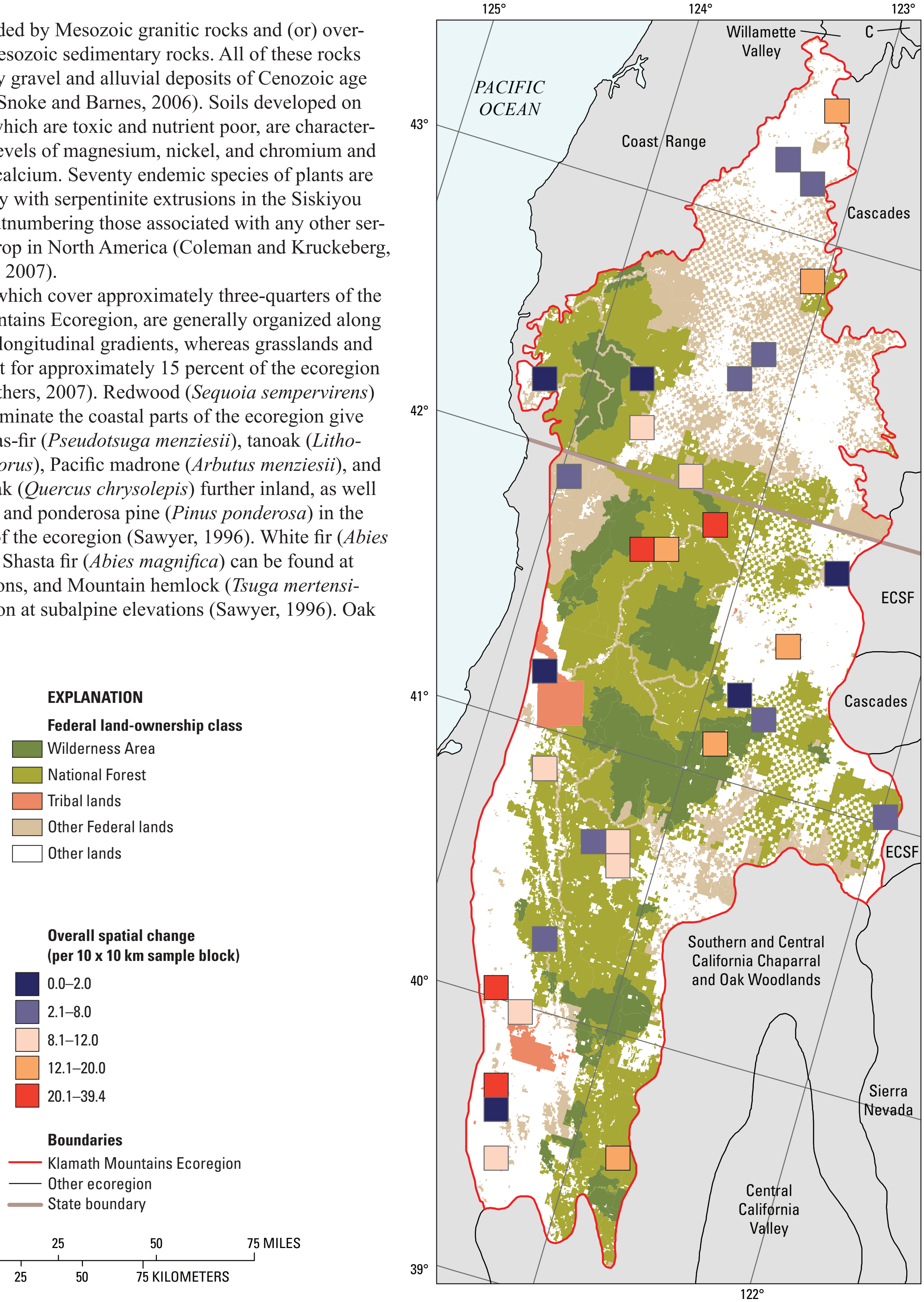

Figure 2. Federal land ownership and cumulative land-use/land-cover change (as percent of sample-block area) from 1973 to 2000 in Klamath Mountains Ecoregion. Land-ownership data from National Atlas of the United States (2006). See appendix 2 for abbreviations for Western United States ecoregions.

Figure 3. White-water rafting along Klamath River in Klamath Mountains Ecoregion.

(*Quercus* spp.) woodlands are common in foothills of the Eel, Trinity, and Sacramento Rivers' watersheds.

Agriculture and developed landscapes make up much of the remainder of the Klamath Mountains Ecoregion. The major land uses within the ecoregion include forestry, farming, grazing, tourism, and mining. Approximately 83 percent of the ecoregion is managed by the Federal Government, mostly for public use and recreation (figs. 2,3). The U.S. Forest Service manages 12 wilderness areas and 8 national forests, accounting for the majority of public lands in the ecoregion. Other federal landholders include the Bureau of Land Management, National Park Service, and Bureau of Reclamation. In addition, several tribal lands are located across the ecoregion. Protected lands (Conservation Biology Institute, 2003), which limit permanent anthropogenic conversion and are managed for natural ecosystem values,[1] make up 17.3 percent of the ecoregion.

Farming is limited and is generally confined to the larger alluvial valleys. One of the more productive agricultural locations in the ecoregion exists in a corridor between Ashland, Medford, and Grants Pass, Oregon. Developed land uses are sparse. Medford and Grants Pass in Oregon are the two largest urban areas, with 2000 population estimates of 63,154 and 23,003, respectively (U.S. Census Bureau, 2008). Other urban areas include Roseburg and Ashland in Oregon and Willits and Yreka in California.

[1] Protected lands, which are classified as having either GAP protection status code 1 or 2, are lands managed for different levels of biodiversity protection (Scott and others, 1993; DellaSala and others, 2001). GAP protection status codes are defined as follows: status code 1 is an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management; status code 2 is an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but it may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change in the Klamath Mountains Ecoregion (that is, the amount of area that changed at least one time between 1973 and 2000) was 8.5 percent (4,929 km^2) (table 1). Compared to other western United States ecoregions, the Klamath Mountains Ecoregion experienced a modest amount of change, although the rate was substantially lower than other forested ecoregions in the Pacific Northwest (fig. 4). An estimated 5.2 percent of the ecoregion experienced change in more than one time period, indicating a cyclic pattern that is consistent with the changes associated with forestry. Change within the four individual time periods ranged from a low of 3.0 percent between 1980 and 1986 to a high of 4.2 percent between 1986 and 1992 and between 1992 and 2000 (table 2). When the change estimates are normalized to an average

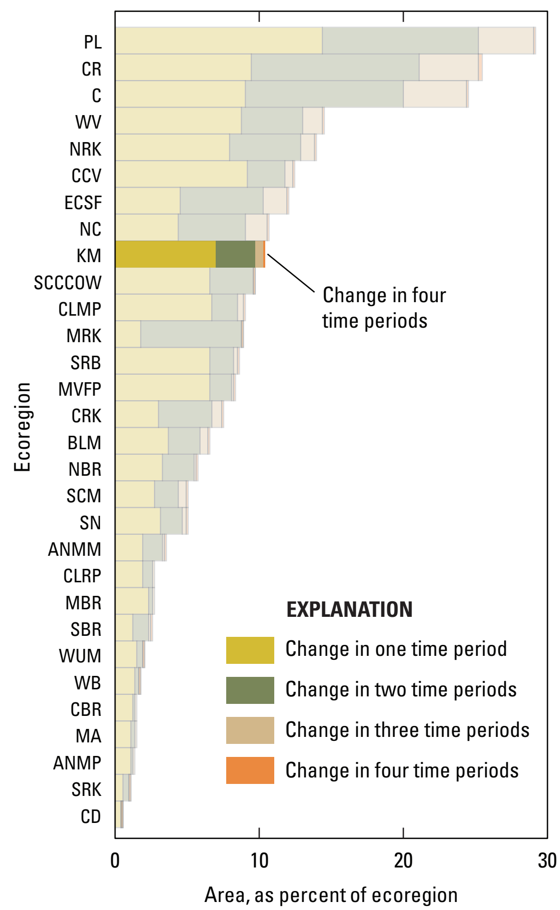

Figure 4. Overall spatial change in Klamath Mountains Ecoregion (KM; darker bars) compared with that of all Western United States Ecoregions (lighter bars). Each horizontal set of bars shows proportion of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Klamath Mountains Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

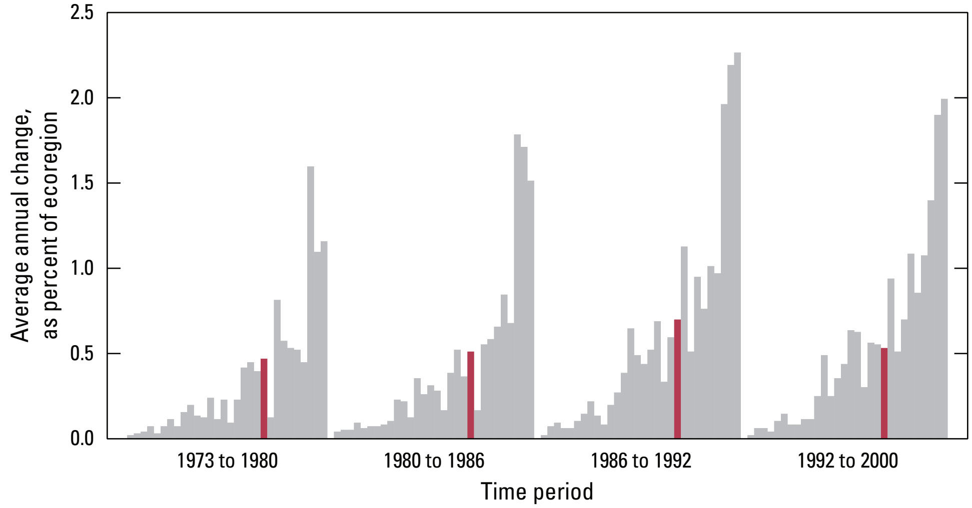

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Klamath Mountains Ecoregion are represented by red bars in each time period.

annual rate to compensate for the varying lengths of time periods, the time period between 1986 and 1992 experienced the highest rate of change, at 0.7 percent per year (fig. 5). The other three time periods were fairly stable, at approximately 0.5 percent per year (table 2). Staus and others (2002) found similar rates of forest disturbance between 1972 and 1992 in the Klamath–Siskiyou Mountains region. The fact that land-cover change in the Klamath Mountains Ecoregion was substantially lower than that of the adjacent Coast Range Ecoregion is explained, in part, by the Klamath Mountains Ecoregion's larger percentage of public lands, particularly areas of high protection (for example, wilderness areas; fig. 6), that either minimize, or severely restrict, timber harvest. Table 3 provides estimates of net forest change, public land ownership, and protected lands for forest-dominated ecoregions in the western United States. The Klamath Mountains Ecoregion had the lowest net loss of forest land cover in the Pacific Northwest over the 27-year study period (594 km^2), with the exception of the Cascades Ecoregion (tables 3,4; fig. 7), and it ranked behind only the Sierra Nevada Ecoregion in terms of the proportion of public lands found within the ecoregion.

Figure 6. Wilderness area along Coffee Creek in Trinity Alps Wilderness, Klamath Mountains, California.

Forest covered an estimated 76.6 percent of the ecoregion in 1973 and declined to 75.3 percent by 2000, a loss of 1.6 percent (fig. 8). The only time period to experience a net increase in forest was between 1980 and 1986, with an increase of 73 km^2. Grassland/shrubland, which accounted for an estimated 14.3 percent of the ecoregion in 1973, increased

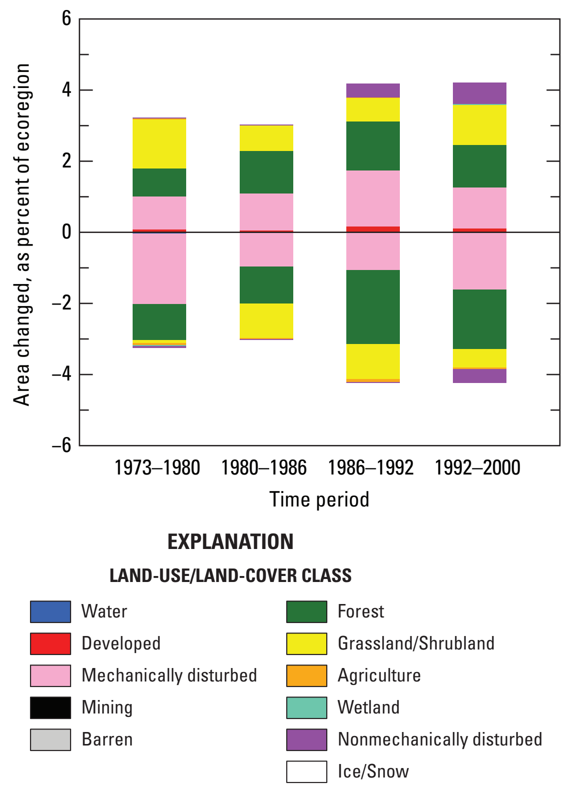

Figure 7. Gross change (area gained and lost) in Klamath Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

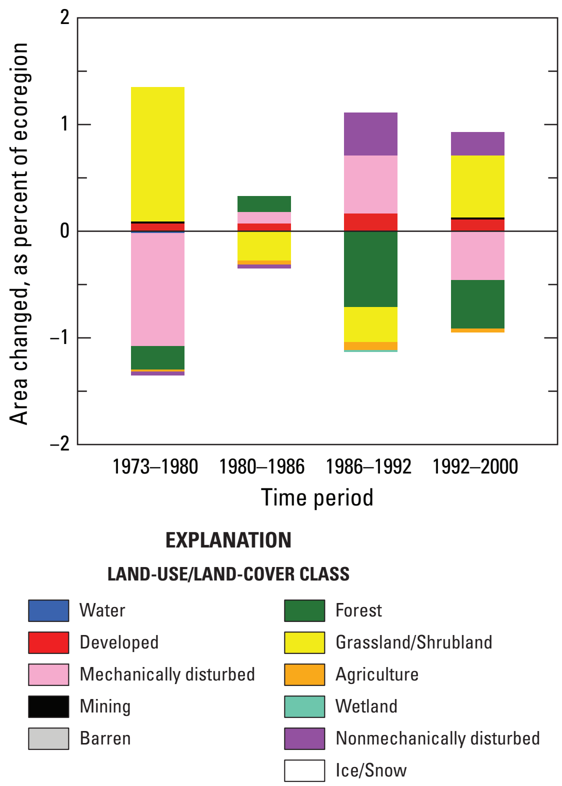

Figure 8. Normalized average net change in Klamath Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 9. Forested hillside regenerating after clearcut in Klamath Mountains Ecoregion.

Figure 10. New home construction and development in Grants Pass, Oregon.

to 15.5 percent in 2000, a net increase of 598 km^2 over 27 years. Furthermore, it is estimated that, between 1973 and 1980, regrowth of forest, often captured as grassland/shrubland in the earliest stages of regeneration (fig. 9), outpaced logging by approximately 74 km^2 per year. Logging accelerated in the 1980s and early 1990s (Daniels, 2005), resulting in a deficit of 43 km^2 per year between 1986 and 1992. The 1990s saw a shift back to trends witnessed during the 1970s when regrowth outpaced cutting at a rate of approximately 26 km^2 per year. These trends are consistent with findings from Cohen and others (2002), who investigated forest disturbance in western Oregon. Changes in land-cover classes over the four time periods can be found in table 4.

Agriculture, which was the third most common land cover in the Klamath Mountains Ecoregion, was generally confined to the eastern and northern parts of the ecoregion. Farmland remained stable throughout the study period, at approximately 4.5 percent of the ecoregion.

Changes associated with new development were relatively minor in the Klamath Mountains Ecoregion. It is estimated that developed land increased by 24 percent over the entire 27-year study, an increase of approximately 205 km^2. Developed land was estimated at 1.8 percent of the ecoregion in 1973, increasing to 2.2 percent by 2000. New development focused around existing cities in Oregon such as Roseburg, as well as along the Interstate 5 corridor between Grants Pass and Medford (fig. 10). The ecoregion's only urban areas in California are Yreka, Weaverville, and Willits.

As expected, the leading land-cover conversions were associated with timber harvesting (table 5; fig. 11). Changes associated with logging accounted for most of the change in each time period, ranging from a high of nearly 95 percent between 1973 and 1980 to 72 percent between 1992 and 2000. Changes between forest, mechanically disturbed, and grassland/shrubland are closely linked and, when combined, represent the cyclical nature of logging. During the last two time periods, fire (classified as nonmechanical disturbance) took on a larger role as an agent for land change; nonmechanically disturbed land accounted for an estimated 189 km^2 between 1986 and 1992 and 206 km^2 between 1992 and 2000 (table 5).

Drivers of land-cover change in the Klamath Mountains Ecoregion were numerous and diverse. Private-forest-management policies controlled much of the change associated with logging; however, in later years, state and federal environmental policies have taken on increasing importance. The collapse of the Asian log-export market in the 1990s, the listing of the Northern Spotted Owl (*Strix occidentalis caurina*) on the endangered species list in 1990, and the

Figure 11. Lumber mill in Roseburg, Oregon.

Northwest Forest Plan of 1994 (Espy and Babbitt, 1994) all are likely drivers of land-cover change in the ecoregion, the most direct result being a decrease of timber production to approximately 25 percent of 1980s levels (Daniels, 2005). Decades of fire suppression and climate change have likely contributed to the more recent emergence of fire as a major land-cover conversion. Fires over this period are typified by more frequent, high-intensity, stand-replacing burns in northern California (Westerling and others, 2006).

Table 1. Percentage of Klamath Mountains Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (91.5 percent), whereas 8.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	3.3	1.0	2.3	4.3	0.7	20.5
2	4.3	1.3	3.0	5.6	0.9	20.2
3	0.8	0.4	0.4	1.3	0.3	36.9
4	0.1	0.1	0.0	0.1	0.0	53.3
Overall spatial change	8.5	2.3	6.3	10.8	1.5	17.9

Table 2. Raw estimates of change in Klamath Mountains Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	3.3	1.1	2.1	4.4	0.8	23.2	0.5
1980–1986	3.0	1.0	2.1	4.0	0.6	21.4	0.5
1986–1992	4.2	1.2	3.0	5.4	0.8	19.9	0.7
1992–2000	4.2	1.3	2.9	5.5	0.9	21.1	0.5
Estimate of change, in square kilometers							
1973–1980	1,554	533	1,022	2,087	361	23.2	222
1980–1986	1,449	457	992	1,906	310	21.4	242
1986–1992	2,011	592	1,419	2,603	401	19.9	335
1992–2000	2,017	627	1,390	2,644	425	21.1	252

Table 3. Comparison of areas of forest change, protected lands, and publicly held lands in Klamath Mountains Ecoregion with that of other forested ecoregions in western United States.

Ecoregion	Ecoregion area	Forest area in 2000	Change in forest area in 2000		Protected lands (GAP codes 1,2)[1]		Publicly held lands	
	(km²)	(% of ecoregion)	(km²)	(% of ecoregion)	(km²)	(% of ecoregion)	(km²)	(% of ecoregion)
Coast Range	53,986	72.4	−2,051	−5.2	6,531	12.1	13,359	24.7
Puget Lowland	16,454	48.4	−1,662	−20.8	83	0.5	567	3.4
Willamette Valley	14,883	33.5	−625	−12.5	156	1	561	3.8
Cascades	46,416	82.3	232	0.6	13,500	29.1	30,952	66.7
Sierra Nevada	52,872	70.1	−1,851	−4.9	15,143	28.6	42,166	79.8
Klamath Mountains	48,537	75.3	−594	−1.6	8,393	17.3	34,678	71.4

[1] Protected lands, classified as having either GAP protection status code 1 or 2, are lands managed for different levels of biodiversity protection (Scott and others, 1993; DellaSala and others, 2001). GAP protection status codes are defined as follows: status code 1 is area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management; status code 2 is area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain primarily natural state, but it may receive uses or management practices that degrade quality of existing natural communities, including suppression of natural disturbance.

Table 4. Estimated area (and margin of error) of each land-cover class in Klamath Mountains Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/−	%	+/−	%	+/−	%	+/−	%	+/−	%	+/−	%	+/−	%	+/−	%	+/−	%	+/−
										Area, in percent stratum										
1973	0.3	0.1	1.8	1.3	2.0	0.9	0.1	0.1	0.2	0.1	76.6	4.2	14.3	3.7	4.5	1.9	0.1	0.1	0.1	0.1
1980	0.3	0.1	1.9	1.3	0.9	0.3	0.1	0.1	0.2	0.1	76.4	4.2	15.5	3.5	4.5	2.0	0.1	0.1	0.0	0.1
1986	0.3	0.1	1.9	1.4	1.1	0.4	0.1	0.1	0.2	0.1	76.5	4.3	15.2	3.6	4.5	2.0	0.1	0.1	0.0	0.0
1992	0.3	0.1	2.1	1.6	1.6	0.6	0.1	0.1	0.2	0.1	75.8	4.3	14.9	3.6	4.4	2.0	0.1	0.1	0.4	0.4
2000	0.3	0.1	2.2	1.6	1.2	0.4	0.1	0.1	0.2	0.1	75.3	4.3	15.5	3.5	4.4	2.0	0.1	0.1	0.6	0.5
Net change	0.0	0.0	0.4	0.4	−0.9	0.6	0.0	0.0	0.0	0.0	−1.2	1.0	1.3	0.9	−0.1	0.2	0.0	0.0	0.6	0.5
Gross change	0.0	0.0	0.4	0.4	4.3	1.3	0.0	0.0	0.0	0.0	4.4	1.1	4.3	1.3	0.3	0.2	0.0	0.0	1.1	0.8
										Area, in square kilometers										
1973	132	61	851	608	962	413	39	35	112	38	36,600	2,030	6,814	1,786	2,171	931	72	41	38	46
1980	128	57	892	639	449	164	42	37	112	38	36,499	2,009	7,417	1,691	2,162	935	70	39	19	27
1986	127	57	926	670	504	187	43	37	112	38	36,572	2,032	7,285	1,710	2,153	935	70	39	1	1
1992	133	61	1,001	741	764	277	43	37	113	38	36,229	2,039	7,131	1,724	2,115	933	69	38	193	211
2000	133	60	1,056	786	551	211	47	38	113	38	36,006	2,065	7,412	1,685	2,100	932	70	40	302	232
Net change	2	4	205	193	−412	305	7	6	0	1	−594	489	598	410	−70	106	−1	2	264	238
Gross change	17	16	205	193	2,071	633	10	8	0	1	2,111	543	2,045	638	134	103	4	5	510	386

Table 5. Principal land-cover conversions in Klamath Mountains Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Mechanically disturbed	Grassland/Shrubland	631	267	181	1.3	40.6
	Forest	Mechanically disturbed	434	164	111	0.9	27.9
	Mechanically disturbed	Forest	323	240	162	0.7	20.8
	Grassland/Shrubland	Forest	30	25	17	0.1	1.9
	Agriculture	Developed	24	24	16	0.1	1.6
	Other	Other	113	n/a	n/a	0.2	7.3
		Totals	1,554			3.3	100.0
1980–1986	Forest	Mechanically disturbed	487	184	125	1.0	33.6
	Grassland/Shrubland	Forest	446	207	140	0.9	30.8
	Mechanically disturbed	Grassland/Shrubland	325	159	108	0.7	22.4
	Mechanically disturbed	Forest	115	49	33	0.2	7.9
	Agriculture	Developed	16	20	13	0.0	1.1
	Other	Other	61	n/a	n/a	0.1	4.2
		Totals	1,449			3.0	100.0
1986–1992	Forest	Mechanically disturbed	753	276	187	1.6	37.4
	Grassland/Shrubland	Forest	449	220	149	0.9	22.3
	Mechanically disturbed	Grassland/Shrubland	306	156	105	0.6	15.2
	Mechanically disturbed	Forest	190	102	69	0.4	9.5
	Forest	Nonmechanically disturbed	189	208	141	0.4	9.4
	Other	Other	124	n/a	n/a	0.3	6.2
		Totals	2,011			4.2	100.0
1992–2000	Forest	Mechanically disturbed	549	211	143	1.1	27.2
	Mechanically disturbed	Grassland/Shrubland	442	235	159	0.9	21.9
	Mechanically disturbed	Forest	313	157	107	0.7	15.5
	Forest	Nonmechanically disturbed	206	164	111	0.4	10.2
	Grassland/Shrubland	Forest	166	75	51	0.3	8.2
	Other	Other	341	n/a	n/a	0.7	16.9
		Totals	2,017			4.2	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	2,222	687	466	4.6	31.6
	Mechanically disturbed	Grassland/Shrubland	1,704	656	444	3.6	24.2
	Grassland/Shrubland	Forest	1,091	430	291	2.3	15.5
	Mechanically disturbed	Forest	941	452	306	2.0	13.4
	Forest	Nonmechanically disturbed	415	373	253	0.9	5.9
	Other	Other	659	n/a	n/a	1.4	9.4
		Totals	7,032			14.7	100.0

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Chapter 14

North Cascades Ecoregion

By Tamara S. Wilson

Ecoregion Description

The North Cascades Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 30,421 km^2 (11,746 mi^2) of predominantly steep, mountainous terrain, home to peaks rising more than 3,000 m, which are carved by valleys that drop below 150 m elevation (fig. 1). The unique topography in this geographically isolated ecoregion has been shaped by glacial processes, and its deep drainage canyons have been further incised by subsequent runoff. Beautiful alpine scenery is a major feature of the ecoregion, which includes several national forests, parks, and wilderness areas such as the North Cascades National Park, the Mount Baker–Snoqualmie National Forest, the Okanogan National Forest, and the Wenatchee National Forest, as well as the Pasayten Wilderness, the Glacier Peak Wilderness, the Alpine Lakes Wilderness, and the Henry M. Jackson Wilderness.

The North Cascades Ecoregion extends north of the Canadian border into British Columbia; however, this study covers only the part that is in the United States, in north-central Washington (fig. 1). The ecoregion is bounded on the

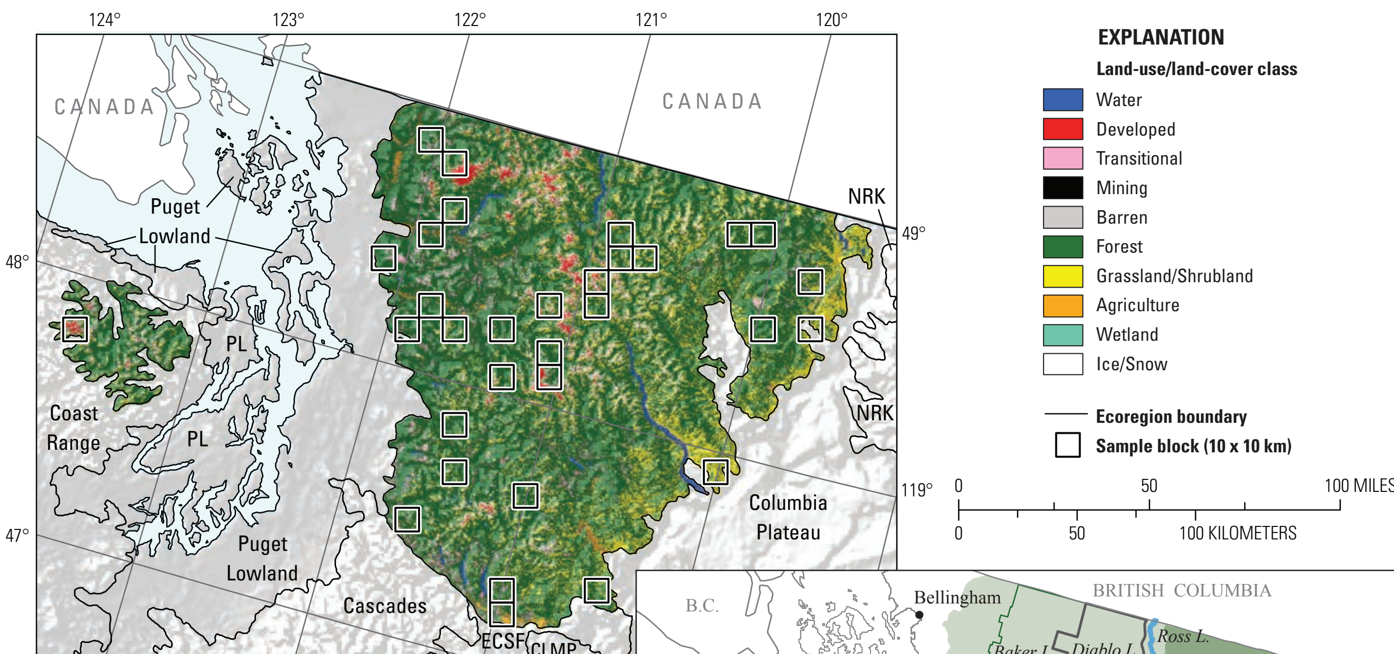

Figure 1. Map of North Cascades Ecoregion and surrounding ecoregions, showing land-use/land cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in this study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land cover classifications.

east by the Columbia Plateau Ecoregion; on the south by the Cascades Ecoregion and the Eastern Cascades Slopes and Foothills Ecoregion; and on the west by the Puget Lowland Ecoregion. Farther west, an isolated section of the ecoregion on the Olympic Peninsula is entirely surrounded by the Coast Range Ecoregion.

Climate in the North Cascades Ecoregion is remarkably varied. From fall to spring, most upper elevation areas are blanketed in snow. Strong weather systems from the Pacific Ocean pass over the mountain peaks, making this region one of the snowiest on earth (National Park Service, 2009). The western part of the North Cascades Ecoregion receives, on average, 193 cm of rain and 1,034 cm of snow annually, creating the lush, evergreen forests in this area. These precipitation totals are higher than in the far eastern part of the ecoregion (National Park Service, 2009), where conditions are markedly drier and where dense forests give way to more grasses and shrubland (fig. 1). Harnessing the annual snowmelt are the large-scale dam operations, reservoirs, and hydroelectric power plants at Diablo Lake (4 km^2; fig. 2), Ross Lake (48 km^2), and Baker Lake (15 km^2), as well as Lake Chelan (247 km^2), the third deepest lake in the entire United States at 457 m deep.

This ecoregion is sparsely populated: its largest towns are Darrington (population 1,354 in 2009) and Leavenworth (population 2,347 in 2009), Washington (U.S. Census Bureau, 2009). However, several cities are located not far outside the ecoregion boundary (for example, Seattle, Tacoma, Everett, Bellingham, and Wenatchee, Washington). Agriculture, which is a major land use along low-lying valley bottoms, consists of irrigated pastureland and crops such as alfalfa, wheat, corn, and other feed crops in the western part of the ecoregion. Apple and pear orchards predominate in the ecoregion's eastern part.

The North Cascades Ecoregion supports a diverse range of forests, including some of the oldest and richest tracts remaining in the conterminous United States. At lower elevations and along the west flank of the Cascade Range, these forests are composed of western red cedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllum*) (fig. 3). Upslope, lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), Pacific silver fir (*Abies amabilis*), Engelmann spruce (*Picea engelmannii*), western larch (*Larix occidentalis*), and whitebark pine (*Pinus albicaulis*) are more common (Uhler, 2007; Washington Department of Fish and Wildlife, 2005).

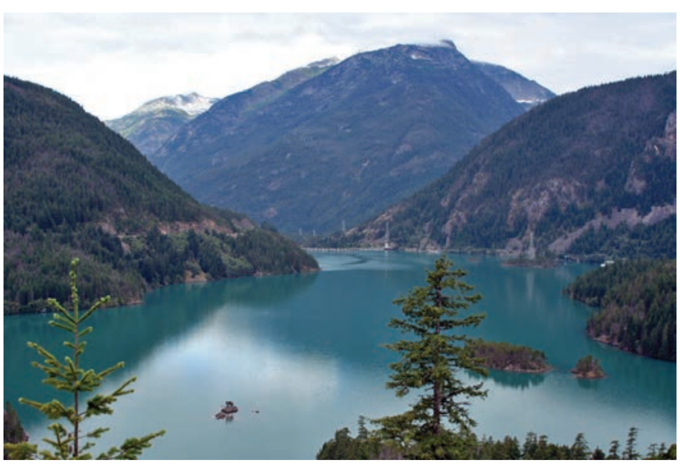

Figure 2. Diablo Lake, man-made reservoir along North Cascades Highway in North Cascades National Park, Washington.

Figure 3. Lush riparian forest and undergrowth within Mount Baker–Snoqualmie National Forest, Washington.

Late 20th century land-cover change in the North Cascades Ecoregion was associated predominantly with timber harvesting by means of clearcut logging (fig. 4). Large-scale forestry operations were established in areas of easiest access, where harvest-delivery options were most efficient. Timber harvesting, which is more common on private rather than public lands, is especially important along the ecoregion periphery at lower elevations. According to the National Park Service (1999), widespread logging in this area was not logistically possible in the 19th century given the rugged terrain and lack of reliable transportation. In addition, the availability of more accessible stands elsewhere in the area further slowed its expansion (National Park Service, 1999). In the late 1800s to early 1900s, mills operated along the Stehekin River valley (upstream of Lake Chelan), processing logs for use as apple shipping boxes (National Park Service, 2009). Selective harvest of western red cedar also was allowed along the Skagit River in the early 20th

Figure 4. Clearcut logging and regrowth in North Cascades Ecoregion, Washington.

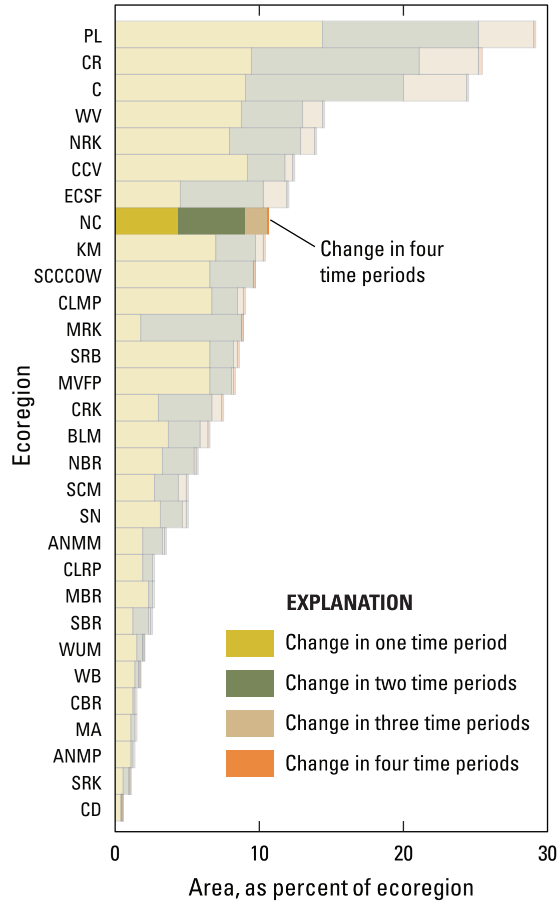

Figure 5. Overall spatial change in North Cascades Ecoregion (NC; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during time periods 1, 2, 3, or 4; highest level of spatial change in North Cascades Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

century in what today is the Mount Baker–Snoqualmie National Forest, but the harvest was halted by the early 1920s (National Park Service, 1999).

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the areal extent of land-use/land-cover change (that is, the area that experienced change during at least one of the four multiyear periods within the 27-year study period) in the North Cascades Ecoregion was 10.5 percent (approximately 3,200 km^2) (table 1). The North Cascades Ecoregion experienced a modest amount of change compared to other western United States ecoregions, although the rate was substantially lower than that experienced by other forested ecoregions in the Pacific Northwest (fig. 5). Overall, an estimated 3.9 percent (1,186 km^2) of land experienced change in at least one time period, 5.1 percent (1,551 km^2) changed in two time periods, 1.4 percent (426 km^2) changed in three periods, and 0.1 percent (30 km^2) of sampled land area changed in all four time periods (table 1).

The average annual rate of land-cover change in the North Cascades Ecoregion between 1973 and 2000 was 0.7 percent (212.7 km^2) in the 27-year study period (table 2). This measurement is a cumulative average of the annual average change values for each time period studied. A steady rate of annual change is observed in the first two time periods (0.6 percent), peaking at 0.9 percent between 1986 and 1992 and dropping again to 0.7 percent between 1992 and 2000 (table 2). Figure 6 shows the percent change by time period, normalized to annual rates for all western United States ecoregions.

In 2000, an estimated 70.3 percent of the North Cascades Ecoregion was covered by forest, followed by grassland/shrubland (17.6 percent), barren (5.2 percent, mostly rock outcrops and mountaintops), and mechanically disturbed (2.0 percent) (table 3). An additional 2.6 percent was covered by ice/snow. Only 0.6 percent of the ecoregion was developed, and 1.1 percent was devoted to agriculture (table 3). The remaining four land-cover classes made up less than 1 percent of the remaining area in the ecoregion (table 3). Between 1973 and 2000, there were net losses overall of forest (1.8 percent; 385 km^2) and mechanically disturbed (16.5 percent; 121 km^2) land, as well as net gains in grassland/shrubland (10.4 percent; 507 km^2) (fig. 7).

Postclassification analysis of these results allowed for the identification of "from class–to class" land-cover conversions and the ranking of these conversions according to their magnitude. In the North Cascades Ecoregion, more than 97 percent of all land-cover conversions between 1973 and 2000 were related to timber harvesting (forest to mechanically disturbed) and successional regrowth (mechanically disturbed to grassland/shrubland or forest, as well as grassland/shrubland to forest) (table 4). Overall, an estimated 2,320 km^2 of forest land was mechanically disturbed (table 4), equating to approximately 7.6 percent of the total ecoregion area. Of particular note is the

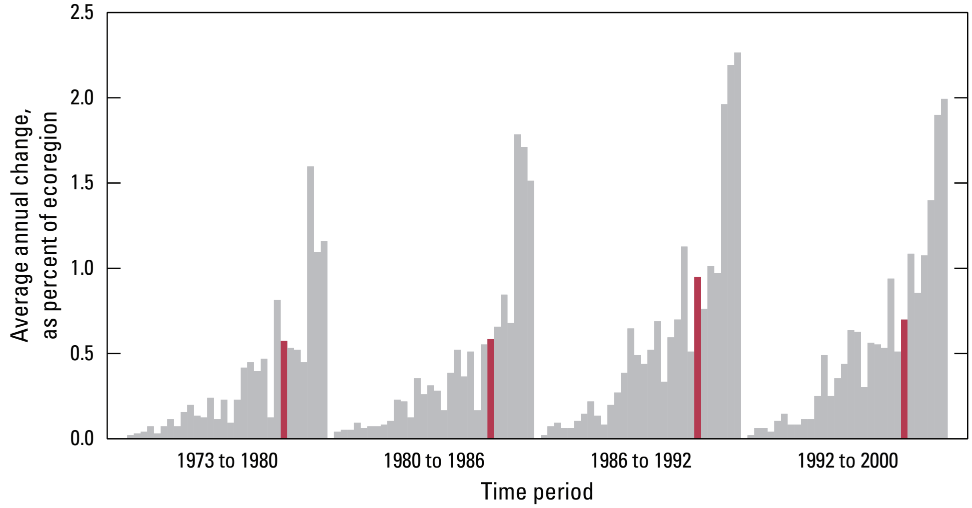

Figure 6. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for North Cascades Ecoregion are represented by red bars in each time period.

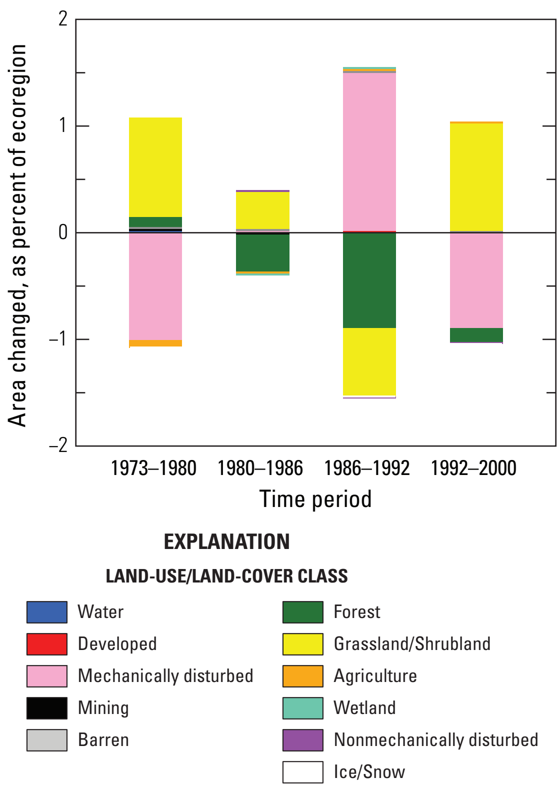

Figure 7. Normalized average net change in North Cascades Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

doubling of timber-harvest rates between 1986 and 1992 and the subsequent sharp decline after 1992, although the rate remained above pre-1986 levels (table 4). This pattern is mirrored in other forest-dominated ecoregions of the western United States (for example, the Klamath Mountains, Coast Range, and Sierra Nevada Ecoregions).

The timber industry has had a dominant influence on land-cover change in the North Cascades Ecoregion; however, external drivers of change, such as federal endangered-species protection and international timber markets, have helped dictate the amount and type of forest harvesting during the study period. Public lands occupy most of the North Cascades Ecoregion and are subject to state and federal regulation. The Washington State Wilderness Act of 1984 set aside more than a million acres of new wilderness area in the state, the majority within the North Cascades Ecoregion, including the Mount Baker Wilderness, Henry M. Jackson Wilderness, Lake Chelan–Sawtooth Wilderness, Pasayten Wilderness (additions), Boulder River Wilderness, Buckhorn Wilderness, Clearwater Wilderness, Glacier Peak Wilderness, and others (Arthur and others, 2009; U.S. Congress, 1984).

In 1990, the Northern Spotted Owl (*Strix occidentalis caurina*) was listed as “threatened” under the Endangered Species Act. In addition, new habitat-protection measures outlined by the Northwest Forest Plan in 1994 set harvesting limits on lands administered by the Forest Service and the Bureau of Land Management. Timber yields were set at 25 percent of the 1980s baseline, which dropped the allowable harvest to 1 billion board feet (Espy and Babbitt, 1994). Additional timber-harvesting restrictions imposed by endangered-species protection led to a 30 percent decline in overall timber volume from 1980s levels (Daniels, 2005). These reductions, coupled with reductions in global timber demand, also have influenced the decline in logging activity since 1992 (Warren, 1999; Daniels, 2005). In the 1990s, changes in the Japanese housing industry and Asia’s economic collapse significantly reduced the demand for lumber, along with greater competition from forest products from the southern United States and Canada (Daniels, 2005).

Table 1. Percentage of North Cascades Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (89.5 percent), whereas 10.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	3.9	1.5	2.4	5.4	1.0	25.4
2	5.1	1.9	3.2	7.0	1.3	25.6
3	1.4	0.7	0.8	2.1	0.4	31.4
4	0.1	0.1	0.0	0.2	0.0	47.9
Overall spatial change	10.5	3.9	6.6	14.4	2.6	25.2

Table 2. Raw estimates of change in North Cascades Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	4.0	1.9	2.1	5.9	1.3	32.1	0.6
1980–1986	3.5	1.5	2.0	5.0	1.0	28.3	0.6
1986–1992	5.7	2.2	3.5	7.8	1.5	25.8	0.9
1992–2000	5.6	2.0	3.5	7.6	1.4	24.6	0.7
Estimate of change, in square kilometers							
1973–1980	1,225	581	644	1,805	393	32.1	175
1980–1986	1,065	444	621	1,510	301	28.3	178
1986–1992	1,724	656	1,069	2,380	444	25.8	287
1992–2000	1,689	614	1,076	2,303	416	24.6	211

Table 3. Estimated area (and margin of error) of each land-cover class in North Cascades Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Snow/Ice	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.3	0.1	0.5	0.5	2.4	1.3	0.0	0.0	5.1	1.7	71.6	5.2	16.0	4.5	1.2	0.9	0.2	0.1	2.6	1.5
1980	0.3	0.1	0.5	0.5	1.4	0.7	0.0	0.0	5.2	1.7	71.7	5.2	16.9	4.4	1.1	0.9	0.2	0.1	2.6	1.5
1986	0.3	0.1	0.5	0.5	1.4	0.6	0.0	0.0	5.2	1.7	71.3	5.2	17.2	4.3	1.1	0.9	0.2	0.1	2.6	1.5
1992	0.3	0.1	0.6	0.5	2.9	1.1	0.0	0.0	5.2	1.8	70.5	5.1	16.6	4.4	1.1	0.9	0.2	0.1	2.6	1.5
2000	0.3	0.1	0.6	0.5	2.0	0.9	0.0	0.0	5.2	1.8	70.3	5.1	17.6	4.3	1.1	0.9	0.2	0.1	2.6	1.5
Net change	0.0	0.0	0.0	0.0	−0.4	1.2	0.0	0.0	0.1	0.1	−1.3	1.6	1.7	0.7	0.0	0.1	0.0	0.0	−0.1	0.1
Gross change	0.0	0.0	0.0	0.0	6.0	2.1	0.0	0.0	0.1	0.1	6.6	2.6	4.6	2.0	0.1	0.2	0.0	0.0	0.1	0.1
Area, in square kilometers																				
1973	85	36	165	139	733	399	7	8	1,566	529	21,781	1,571	4,856	1,356	361	266	66	31	801	464
1980	92	43	166	139	425	211	9	9	1,572	532	21,813	1,568	5,139	1,324	343	263	66	31	795	459
1986	92	42	166	139	434	176	6	4	1,573	531	21,705	1,569	5,248	1,323	338	261	65	30	795	459
1992	94	43	169	139	886	332	4	3	1,582	533	21,432	1,553	5,057	1,343	339	261	66	31	792	456
2000	95	45	169	139	612	265	4	3	1,588	537	21,396	1,564	5,362	1,305	347	264	64	29	783	450
Net change	10	12	4	4	−121	368	−3	8	22	17	−385	493	507	216	−14	28	−2	3	−18	17
Gross change	13	13	4	4	1,836	625	7	8	30	20	1,999	777	1,407	618	39	47	5	6	18	17

Table 4. Principal land-cover conversions in North Cascades Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	420	211	143	1.4	34.3
	Mechanically disturbed	Forest	412	322	218	1.4	33.7
	Mechanically disturbed	Grassland/Shrubland	309	192	130	1.0	25.2
	Grassland/Shrubland	Forest	46	36	24	0.1	3.7
	Agriculture	Grassland/Shrubland	18	25	17	0.1	1.4
	Other	Other	20	n/a	n/a	0.1	1.6
		Totals	1,225			4.0	100.0
1980–1986	Forest	Mechanically disturbed	415	176	119	1.4	39.0
	Mechanically disturbed	Grassland/Shrubland	314	186	126	1.0	29.5
	Grassland/Shrubland	Forest	217	124	84	0.7	20.4
	Mechanically disturbed	Forest	93	74	50	0.3	8.7
	Agriculture	Grassland/Shrubland	9	12	8	0.0	0.8
	Other	Other	17	n/a	n/a	0.1	1.6
		Totals	1,065			3.5	100.0
1986–1992	Forest	Mechanically disturbed	876	328	222	2.9	50.8
	Grassland/Shrubland	Forest	388	237	161	1.3	22.5
	Mechanically disturbed	Forest	225	124	84	0.7	13.1
	Mechanically disturbed	Grassland/Shrubland	203	86	58	0.7	11.7
	Forest	Barren	7	7	5	0.0	0.4
	Other	Other	26	n/a	n/a	0.1	1.5
		Totals	1,724			5.7	100.0
1992–2000	Forest	Mechanically disturbed	609	264	179	2.0	36.0
	Mechanically disturbed	Grassland/Shrubland	475	220	149	1.6	28.1
	Mechanically disturbed	Forest	408	260	176	1.3	24.2
	Grassland/Shrubland	Forest	166	79	54	0.5	9.8
	Snow/Ice	Barren	8	8	6	0.0	0.5
	Other	Other	22	n/a	n/a	0.1	1.3
		Totals	1,689			5.6	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	2,320	882	598	7.6	40.7
	Mechanically disturbed	Grassland/Shrubland	1,301	537	364	4.3	22.8
	Mechanically disturbed	Forest	1,139	703	477	3.7	20.0
	Grassland/Shrubland	Forest	816	391	265	2.7	14.3
	Agriculture	Grassland/Shrubland	26	37	25	0.1	0.5
	Other	Other	100	n/a	n/a	0.3	1.8
		Totals	5,703			18.7	100.0

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Status and Trends of Land Change in the Western United States—1973 to 2000
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Chapter 15

Sierra Nevada Ecoregion

By Christian G. Raumann and Christopher E. Soulard

This chapter has been modified from original material published in Raumann and Soulard (2007), entitled “Land-cover trends of the Sierra Nevada Ecoregion, 1973–2000” (U.S. Geological Survey Scientific Investigations Report 2007–5011).

Ecoregion Description

The Sierra Nevada Ecoregion covers approximately 53,413 km² (20,623 mi²) with the majority of the area (98 percent) in California and the remainder in Nevada (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The Sierra Nevada Ecoregion is generally oriented north-south and is essentially defined by the Sierra Nevada physiographic province, which separates California’s Central Valley to the west from the Great Basin to the east. It is bounded by seven other ecoregions: Southern and Central California Chaparral and Oak Woodlands Ecoregion on the west; Klamath Mountains and Eastern Cascades Slopes and Foothills Ecoregions on the north; Southern California Mountains Ecoregion on the south; and Northern Basin and Range, Central Basin and Range, and Mojave Basin and Range Ecoregions on the east (fig. 1). The Sierra Nevada range is a granitic batholith, much of which is exposed at higher elevations, with a gradual western slope and a generally steep eastern escarpment.

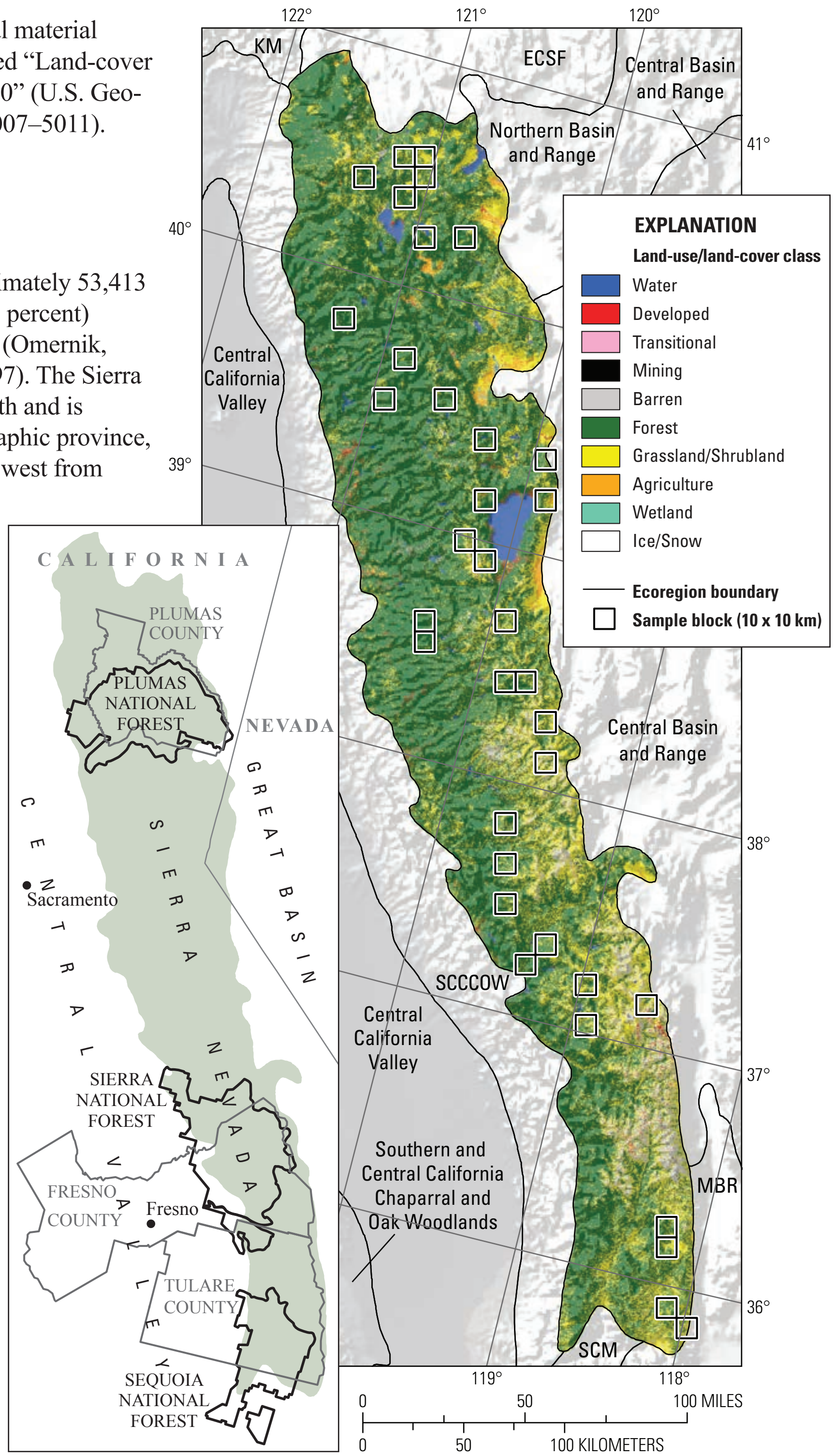


Figure 1. Map of Sierra Nevada Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

The climate of the Sierra Nevada Ecoregion is primarily Mediterranean, characterized by cool, wet winters and long, dry summers. Most areas of elevation above 2,100 m have a Boreal climate, and the highest elevations, typically above 3,600 m, have an Alpine climate. Precipitation increases with elevation from west to east as storm systems moving from the west are subject to orographic uplift, causing rain and snowfall. Because most precipitation from storm systems falls on the western slope of the Sierra Nevada range, a strong rainshadow limits precipitation on the steep eastern slope. This climatic gradient plays a significant role in determining the type and distribution of ecological communities. In order to provide water resources for the growing populations in low-elevation areas of California and Nevada, numerous reservoirs on the western and eastern slopes of the Sierra Nevada range collect runoff from the winter snow pack.

Before the 20th century, resource use within the Sierra Nevada Ecoregion was largely unregulated. However, laws and administrative policies such as the Wilderness Act of 1964, National Environmental Policy Act of 1969, and National Forest Management Act of 1976 provided a mechanism for managing national forests. Furthermore, other environmental laws, annual appropriations legislation, and administrative policies relating to fire and fuels management have guided resource use and likely have had significant environmental effects in the Sierra Nevada Ecoregion (Ruth, 1996). Today, public lands make up 74.6 percent (39,433 km²) of the ecoregion, with the majority (57.8 percent of the ecoregion) managed by the U.S. Forest Service as National Forests and Wilderness Areas.

Despite resource regulation, California's growing urban population has greatly increased the demand for wood, water, hydroelectricity, and recreational opportunities from the Sierra Nevada Ecoregion. Timber harvesting surged in the 1950s to 1970s but decreased substantially after the economic recession in the early 1980s. Water is considered the region's most valuable resource, and it is controlled in nearly every major river basin in the region and also managed to provide municipal water supplies and hydroelectric power (Sierra Nevada Ecosystem Project Science Team and Special Consultants, 1996). Major highways and ski resorts were constructed in the 1950s and 1960s to meet the demand for year-round recreation (Sierra Nevada Ecosystem Project Science Team and Special Consultants, 1996). Over the past several decades, the demand for natural resources within the Sierra Nevada Ecoregion has altered ecological communities in the region by changing land-use/land-cover patterns.

In terms of nonmechanical land-cover change components, frequent fires of low to moderate intensity are an integral driver of change within the region's ecological communities. Fires create a cycle of disturbance and succession that floral and faunal communities have adapted to and often require to propagate and thrive (Skinner and Chang, 1996). By the late 20th century the regional fire regime had greatly changed, primarily as a result of logging during the settlement period of the 1950s and 1960s and effective fire suppression activities mandated by State and Federal policies since the 1920s. Consequently, fires were less frequent and more severe than before (Skinner and Chang, 1996). Forest density increased and contributed to higher tree mortality because of greater intertree competition, insect attack, disease, and storm damage (Oliver and others, 1996). These conditions led to an increased supply of fuel which, in turn, resulted in an increased fire hazard, including the likelihood of high-severity fire (Manley and others, 2000). A shift to a warmer and moister climate may also have contributed to this altered fire regime by reducing winter severity and providing a longer growing season (McKelvey and others, 1996; Stine, 1996).

Contemporary Land-Cover Change (1973 to 2000)

The overall areal extent, or "footprint," of land-cover change between 1973 and 2000 was 5.0 percent (2,645 km²), which means that 5.0 percent of the Sierra Nevada Ecoregion underwent change over at least one of the four time periods that make up the entire 27-year study period. Areas totaling 3.1 percent of the ecoregion changed during only one period, 1.6 percent changed during two periods, and 0.3 percent changed during three periods (table 1). This footprint of change in the Sierra Nevada Ecoregion was low to moderate when compared to other ecoregions in the western United States (fig. 2).

The estimated average annual rate of land-cover change is calculated by normalizing each period's gross change by the number of years in that period. Normalizing gross change by year allows comparison of the amount of change in each period when periods are of varying length. It is important to note that the resulting rates of change, although presented as per-year rates, are only an estimate and should be viewed as a description of the period and not of the individual years within the period. The estimated average annual rate of change for the entire 27-year study period between 1973 and 2000 was 0.3 percent/year, which means that on average 0.3 percent (or roughly 144 km²) of the Sierra Nevada Ecoregion changed each year. However, the annual rate of change has not been constant during the 27-year study period, as shown by the estimated average annual rates for the four periods. Between 1973 and1980 and between 1980 and 1986, change occurred at 0.1 percent/year. The annual rate of change increased to 0.3 percent/year between 1986 and 1992 and continued to increase to 0.5 percent/year between 1992 and 2000 (table 2; fig. 3).

Results show that in 2000 the Sierra Nevada Ecoregion was dominated by forest (70.1 percent), with grassland/shrubland (20.4 percent), barren (2.7 percent), nonmechanically disturbed (2.4 percent), wetland (2.2 percent), and water (1.1 percent) making up almost all the remainder of land cover (table 3). Developed, mining, agriculture, ice/snow, and mechanically disturbed classes each made up less than one percent of the region (table 3). Land-use/land-cover classes

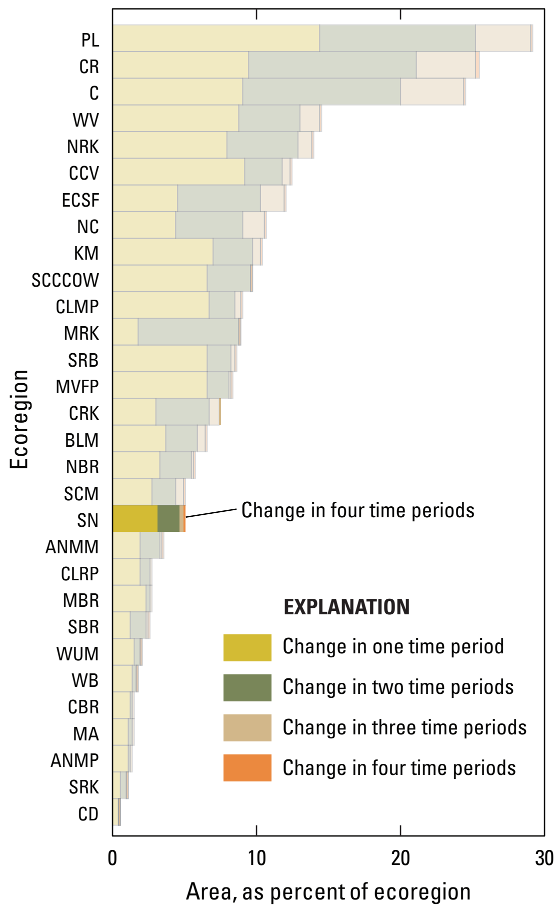


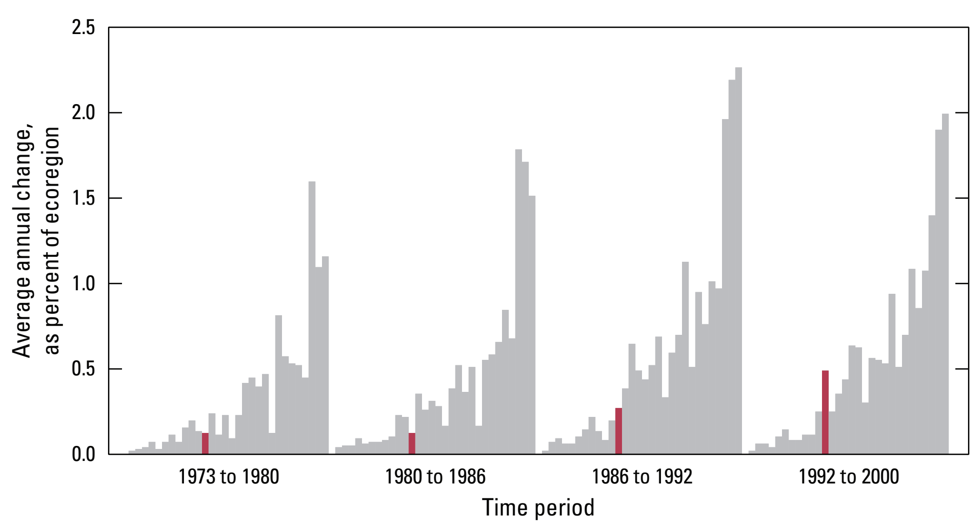
Figure 2. Overall spatial change in Sierra Nevada Ecoregion (SN; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Sierra Nevada Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

that underwent the greatest net change (that is, total area gained minus total area lost) in relation to their area in 1973 were forest (4.7 percent decrease), grassland/shrubland (6.0 percent increase), and nonmechanically disturbed (which accounted for 0.2 percent or less of the ecoregion's area in each year between 1973 and 1992 but increased to 2.4 percent of the classified area in 2000). Although the developed and agriculture classes each made up less than 1 percent of the Sierra Nevada Ecoregion, the developed class underwent the greatest relative increase in area (16.6 percent), and agriculture underwent the greatest relative decrease in area (5.2 percent). However, it is important to note that considerable uncertainty is associated with estimates for very rare land-cover classes.

The net change values as a percentage of ecoregion area at the beginning (1973) and end (2000) dates of the study period in table 3 show little variability and may seem to indicate stability (fig. 4). Net change values, however, often mask land-use/land-cover dynamics. For example, a class may gain 100 km² and at the same time lose 100 km², which would yield a net change of 0 km². Reporting the net change value of 0 km² misses much of the story of landscape change. However, analysis of gross change (that is, area gained and area lost) by individual land-cover classes by period shows that classes have fluctuated throughout the 27-year study period to a greater degree than net change values may indicate. Figure 5 shows that the forest, grassland/shrubland, mechanically disturbed, and nonmechanically disturbed classes were the most dynamic between 1973 and 2000. The transitional characteristic of the mechanically disturbed class is also illustrated by the fact that area gained (809 km²) nearly equals area lost (753 km²) between 1973 and 2000. Land-cover change was clearly at its peak during the period between 1992 and 2000 when gains and losses were generally greatest for the four most dynamic classes.

All individual land-cover conversions between classes were ranked by summing the total area changed during each of the four periods. Each conversion documents land changing from one class to another (for example, forest to

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Sierra Nevada Ecoregion are represented by red bars in each time period.



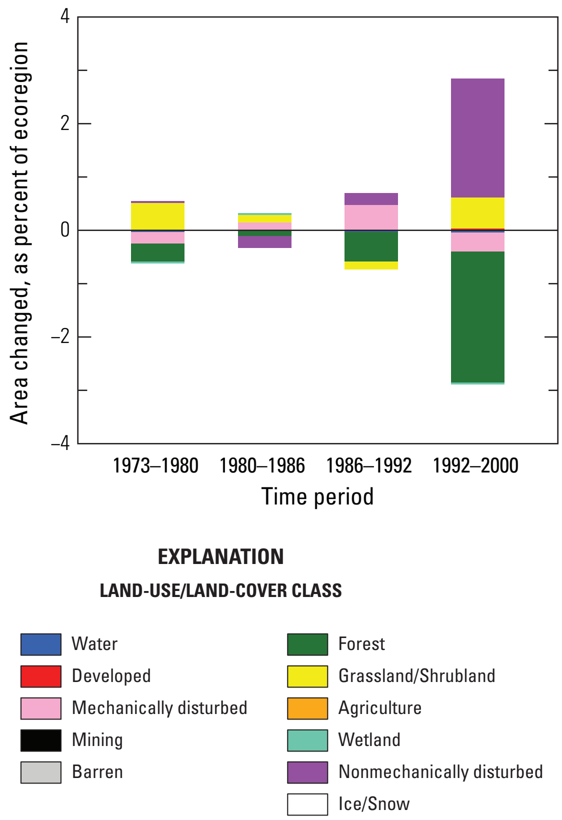


Figure 4. Normalized average net change in Sierra Nevada Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

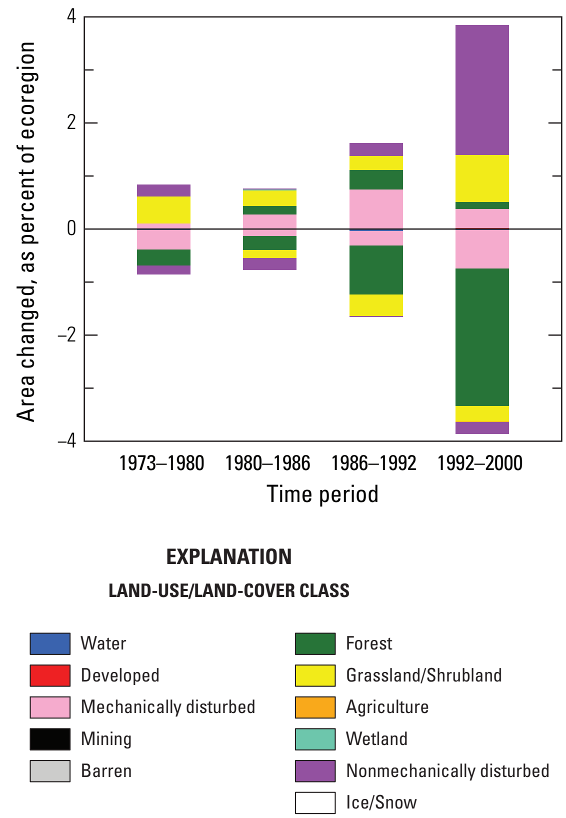


Figure 5. Gross change (area gained and lost) in Sierra Nevada Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

developed) and shows the direction of change. Table 4 shows the individual conversions ranked from greatest to least area converted. The most common individual conversions describe the disturbance of forest land by mechanical (that is, clearcuts) and nonmechanical (that is, fire) means. Overall, the most common conversion was that of 1,404 km^2 of forest to the nonmechanically disturbed class, which accounted for 37.1 percent of all conversions (fig. 6). The second most common conversion was that of 784 km^2 of forest to the mechanically disturbed class, accounting for 20.7 percent of all changes (fig. 7). Conversion of mechanically and nonmechanically disturbed land to the grassland/shrubland class (753 km^2 and 307 km^2, respectively) were the two next most common conversions and represented the process of vegetation regeneration after clearcutting or fire (fig. 8). Similarly, conversion of grassland/shrubland to forest (303 km^2) represented the final stage of the regeneration cycle. A much less common but noteworthy conversion was that of water to mechanically disturbed (26 km^2), which accounted for 0.7 percent of all individual conversions (fig. 9). This conversion indicates surface-level fluctuations of reservoirs in the ecoregion.

More insight can be provided by aggregating the conversions listed in table 4 to identify how a single land-use class was affected. Between 1973 and 2000, 1,540 km^2 of vegetation (forest, grassland/shrubland, and wetland) area was converted to the nonmechanically disturbed class. Fire caused all of these conversions, and almost all of this change (1,302 km^2) took place between 1992 and 2000. Regeneration after disturbance was captured as the conversion of nonmechanically disturbed land to vegetation classes (forest and grassland/shrubland) and conversion of mechanically disturbed land to vegetation classes (forest and grassland/shrubland) for aggregated totals of 307 km^2 and 753 km^2, respectively.

The land-use/land-cover change patterns measured in the Sierra Nevada Ecoregion between 1973 and 2000 are consistent with information in the literature. Much of the clearcutting and reservoir water-level change in the region has been driven by the demand for wood, water, hydroelectricity, and recreational opportunities associated with California's growing urban population. As for fires, many of the severe contemporary fires in the Sierra Nevada Ecoregion are likely the result of a fuel buildup caused by fire suppression activities mandated by State and Federal policies since the 1920s.

Figure 6. September 2004 appearance of area (intermediate background slopes) undergoing regeneration following Manter Fire at southern end of Sierra Nevada Ecoregion in Sequoia National Forest, Tulare County, California. Manter Fire ignited on July 22, 2000, and burned about 300 km². Land-cover types shown are forest, grassland/shrubland, and wetland.

Figure 7. Recently clearcut area near northern end of Sierra Nevada Ecoregion in Plumas National Forest, Plumas County, California. Land-cover types shown are forest and mechanically disturbed.

Figure 8. Forest regeneration after seeding, Plumas National Forest, near northern end of Sierra Nevada Ecoregion. Land-cover types shown are forest and grassland/shrubland.

Figure 9. Courtright Reservoir in Sierra National Forest, Fresno County, California, in southern part of Sierra Nevada Ecoregion, showing lowered surface levels in late summer (September 2004). Land-cover types shown are forest, barren, and mechanically disturbed (latter is due to reservoir drawdown).

Table 1. Percentage of Sierra Nevada Ecoregion land cover that changed at least one time during study period (1973-2000) and associated statistical error.

[Most sample pixels remained unchanged (95.0 percent), whereas 5.0 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	3.1	2.5	0.6	5.6	1.7	55.1
2	1.6	0.5	1.1	2.1	0.4	22.2
3	0.3	0.3	0.0	0.5	0.2	77.6
4	0.0	0.0	0.0	0.0	0.0	90.3
Overall spatial change	5.0	2.5	2.4	7.5	1.7	34.9

Table 2. Raw estimates of change in Sierra Nevada Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.9	0.5	0.4	1.3	0.3	36.0	0.1
1980–1986	0.7	0.4	0.4	1.1	0.2	33.2	0.1
1986–1992	1.6	0.5	1.1	2.1	0.4	21.6	0.3
1992–2000	3.9	2.5	1.3	6.4	1.7	44.3	0.5
Estimate of change, in square kilometers							
1973–1980	454	241	213	695	164	36.0	65
1980–1986	400	196	205	596	133	33.2	67
1986–1992	868	276	592	1,144	188	21.6	145
1992–2000	2,059	1,344	715	3,404	913	44.3	257

Table 3. Estimated area (and margin of error) of each land-cover class in Sierra Nevada Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	1.1	0.5	0.2	0.3	0.4	0.3	0.1	0.2	2.7	1.5	73.5	4.6	19.2	4.0	0.3	0.4	2.2	1.2	0.2	0.0
1980	1.1	0.5	0.2	0.3	0.1	0.1	0.1	0.2	2.7	1.5	73.2	4.6	19.7	3.9	0.3	0.4	2.2	1.2	0.2	0.0
1986	1.1	0.5	0.2	0.3	0.3	0.2	0.1	0.2	2.7	1.5	73.1	4.6	19.9	3.9	0.3	0.4	2.2	1.2	0.0	0.2
1992	1.1	0.5	0.2	0.3	0.8	0.3	0.1	0.2	2.7	1.5	72.5	4.5	19.8	3.9	0.3	0.4	2.2	1.2	0.2	0.3
2000	1.1	0.5	0.3	0.3	0.4	0.2	0.1	0.2	2.7	1.5	70.1	4.6	20.4	3.8	0.3	0.4	2.2	1.2	2.4	0.1
Net change	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	-3.5	2.3	1.1	0.6	0.0	0.0	0.0	0.0	2.3	0.1
Gross change	0.0	0.1	0.0	0.0	1.9	0.7	0.0	0.0	0.0	0.0	4.5	2.3	2.6	0.9	0.0	0.0	0.0	0.0	3.2	0.8
Area, in square kilometers																				
1973	612	288	127	134	191	144	73	100	1,446	799	39,274	2,477	10,259	2,143	160	223	1,176	666	84	109
1980	606	287	127	134	65	39	73	100	1,446	799	39,104	2,466	10,534	2,093	160	223	1,175	665	114	152
1986	606	287	127	134	153	89	73	100	1,446	799	39,046	2,455	10,616	2,074	160	223	1,176	666	0	1
1992	592	287	129	137	411	156	73	100	1,446	799	38,741	2,384	10,550	2,093	160	223	1,176	666	125	127
2000	586	287	148	150	215	106	73	100	1,446	799	37,427	2,477	10,872	2,043	152	212	1,176	666	1,307	1,345
Net change	−26	30	21	23	23	129	0	0	0	0	−1,847	1,241	613	319	−8	12	0	0	1,223	1,354
Gross change	26	30	21	23	1,016	368	0	0	0	0	2,412	1,249	1,367	468	8	12	3	3	1,690	1,362

Table 4. Principal land-cover conversions in Sierra Nevada Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Mechanically disturbed	Grassland/Shrubland	191	144	98	0.4	42.1
	Forest	Nonmechanically disturbed	112	152	103	0.2	24.6
	Nonmechanically disturbed	Grassland/Shrubland	84	109	74	0.2	18.6
	Forest	Mechanically disturbed	58	38	26	0.1	12.9
	Water	Mechanically disturbed	6	9	6	0.0	1.4
	Other	Other	2	n/a	n/a	0.0	0.5
		Totals	454			0.9	100.0
1980–1986	Forest	Mechanically disturbed	146	89	60	0.3	36.5
	Nonmechanically disturbed	Grassland/Shrubland	110	152	103	0.2	27.4
	Grassland/Shrubland	Forest	81	78	53	0.2	20.3
	Mechanically disturbed	Grassland/Shrubland	54	37	25	0.1	13.5
	Mechanically disturbed	Forest	4	6	4	0.0	1.0
	Other	Other	4	n/a	n/a	0.0	1.1
		Totals	400			0.7	100.0
1986–1992	Forest	Mechanically disturbed	391	154	105	0.7	45.1
	Grassland/Shrubland	Forest	190	171	116	0.4	21.9
	Mechanically disturbed	Grassland/Shrubland	146	89	60	0.3	16.8
	Forest	Nonmechanically disturbed	102	96	65	0.2	11.8
	Grassland/Shrubland	Nonmechanically disturbed	23	32	22	0.0	2.6
	Other	Other	16	n/a	n/a	0.0	1.8
		Totals	868			1.6	100.0
1992–2000	Forest	Nonmechanically disturbed	1,190	1,230	835	2.2	57.8
	Mechanically disturbed	Grassland/Shrubland	361	135	92	0.7	17.6
	Forest	Mechanically disturbed	188	104	71	0.4	9.1
	Nonmechanically disturbed	Grassland/Shrubland	112	119	81	0.2	5.4
	Grassland/Shrubland	Nonmechanically disturbed	112	116	79	0.2	5.4
	Other	Other	96	n/a	n/a	0.2	4.7
		Totals	2,059			3.9	100.0
1973–2000 (overall)	Forest	Nonmechanically disturbed	1,404	1,244	845	2.6	37.1
	Forest	Mechanically disturbed	784	299	203	1.5	20.7
	Mechanically disturbed	Grassland/Shrubland	753	323	219	1.4	19.9
	Nonmechanically disturbed	Grassland/Shrubland	307	214	145	0.6	8.1
	Grassland/Shrubland	Forest	303	195	132	0.6	8.0
	Other	Other	231	n/a	n/a	0.4	6.1
		Totals	3,782			7.1	100.0

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Chapter 16

Blue Mountains Ecoregion

By Christopher E. Soulard

Ecoregion Description

The Blue Mountains Ecoregion encompasses approximately 65,461 km² (25,275 mi²) of land bordered on the north by the Columbia Plateau Ecoregion, on the east by the Northern Rockies Ecoregion, on the south by the Snake River Basin and the Northern Basin and Range Ecoregions, and on the west by the Cascades and the Eastern Cascades Slopes and Foothills Ecoregions (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). Most of the Blue Mountains Ecoregion is located within Oregon (83.5 percent); 13.8 percent is in Idaho, and 2.7 percent is in Washington. The Blue Mountains are composed of primarily Paleozoic volcanic rocks, with minor sedimentary, metamorphic, and granitic rocks. Lower mountains and numerous basin-and-range areas, as well as the lack of Quaternary-age volcanoes, distinguish the Blue Mountains from the adjacent Cascade Range (Thorson and others, 2003).

The Cascade Range to the west creates a rain-shadow effect in the Blue Mountains Ecoregion, which receives much less rain relative to the Cascade Range and the marine forests of the Pacific Northwest. The rain shadow is most dramatic in the southern reach of the Blue Mountains Ecoregion; the northern part of the ecoregion receives more moisture-bearing air, which passes across the Cascade Range by way of the Columbia Gorge (Heyerdahl and others, 2001). This interregional precipitation gradient contributes to significant vegetation variability across the Blue Mountains Ecoregion. In the northern part of the ecoregion, grasslands thrive at low elevations, and dense forests persist in moist ash soils at high elevations. Much of the southern part of the ecoregion is covered

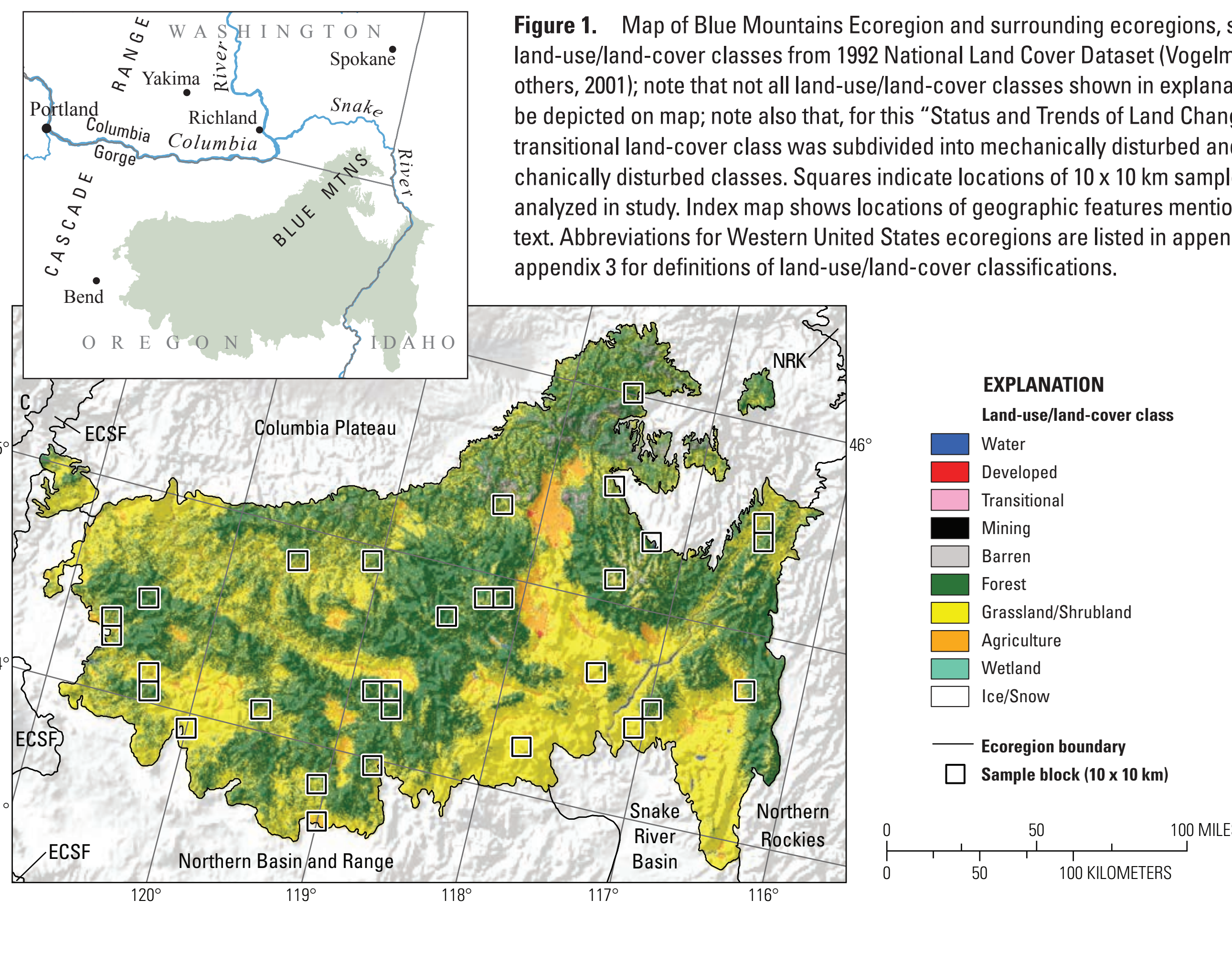

Figure 1. Map of Blue Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

by drought-tolerant sagebrush (*Artemisia* spp.), shrubland, and juniper woodland (*Juniperus* spp.).

The variety of land covers across the Blue Mountains Ecoregion drives a wide range of land-use patterns in the region. Fertile grasslands support large hay and livestock operations in the northern Blue Mountains Ecoregion where windblown silt has created thick soils. Smaller agricultural operations persist in the dry southern reach of region where soils are less developed (Busacca, 1991). Another contrast is the difference in anthropogenic land disturbances between the northern and southern parts of the Blue Mountains Ecoregion. All mechanical disturbances in the northern forests resulted from logging, but clearings in the southern Blue Mountains Ecoregion resulted primarily from the removal of juniper to improve rangeland. Perhaps the most consistent pattern of land-cover change across the Blue Mountains Ecoregion is that which is caused by nonmechanical disturbances such as fire. Fire has an established history in the Blue Mountains Ecoregion owing to the region's low-to-moderate precipitation and abundant fuel sources (Heyerdahl and others, 2001). However, fire now poses a larger threat in the Blue Mountains Ecoregion (and in the greater western United States) because of vegetation build-up following decades of fire suppression (McCullough and others, 1998). Prescribed burning and forest thinning became increasingly common within much of the Blue Mountains Ecoregion in the latter part of the 20th century to remove dense vegetation and neutralize the threat of large, unmanageable fires that jeopardize wildlife and human habitats.

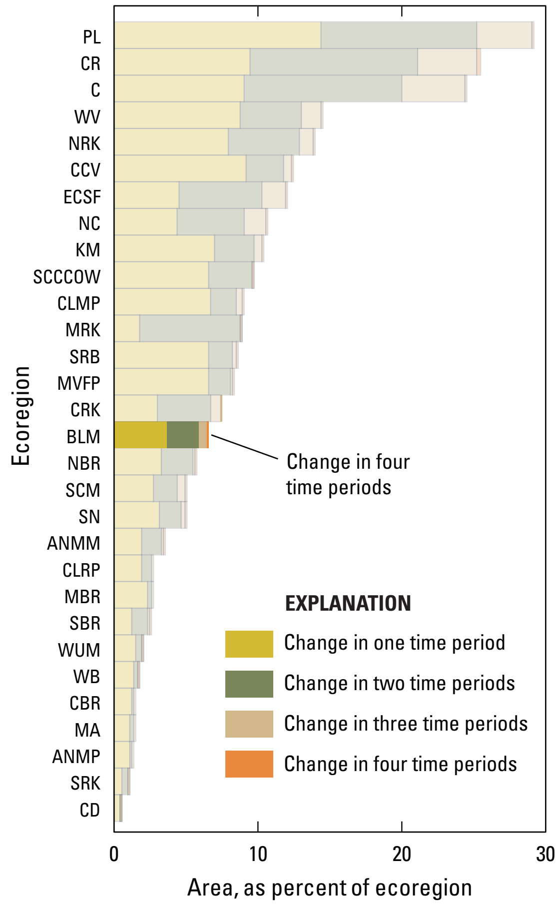

Figure 2. Overall spatial change in Blue Mountains Ecoregion (BLM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Blue Mountains Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the footprint (overall areal extent) of land-use/land-cover change in the Blue Mountains Ecoregion was 6.5 percent, or 4,275 km². The footprint of change can be interpreted as the area that experienced change during at least one of the four time periods that make up the 27-year study period. Of the total change, 2,476 km² (3.8 percent) of the ecoregion changed during one period, 1,367 km² (2.1 percent) changed during two periods, 425 km² (0.6 percent) changed during three periods, and roughly 5 km² (less than 0.1 percent) changed throughout all four periods (table 1). Overall, this level of spatial change is lower than that of most of the western United States ecoregions (fig. 2).

Between 1973 and 2000, the average annual rate of change in the Blue Mountains Ecoregion was roughly 0.4 percent. This measurement, which normalizes the results for each period to an annual scale, indicates that the region averaged roughly 0.4 percent (241 km²) of change each year in the 27-year study period (table 2). However, this annual change varied between each of the four time periods (fig. 3). Between 1973 and 1980, the annual rate of change in the Blue Mountains Ecoregion was 0.1 percent. The annual rate of change steadily increased in each of the following periods, to 0.3 percent between 1980 and 1986, to 0.4 percent between 1986 and 1992, and to 0.6 percent between 1992 and 2000 (table 2).

The results of this study illustrate the estimated dominance of four of the eleven land-use/land-cover classes in the Blue Mountains Ecoregion in 2000: forest (48.4 percent), grassland/shrubland (42.1 percent), agriculture (4.1 percent), and nonmechanically disturbed (2.4 percent). Although six other classes cumulatively made up the remaining 3.0 percent of the Blue Mountains Ecoregion landscape in 2000, each of these classes made up less than one percent of the ecoregion (table 3). Between 1973 and 2000, the land-use/land-cover classes that experienced a noteworthy net change in relation to the total Blue Mountains Ecoregion area include, in descending order, forest (7.9 percent decrease), grassland/shrubland (3.3 percent increase), and nonmechanically disturbed, which occupied no land in 1973 and only 0.2 percent of the total area in 1992 but expanded to 2.4 percent of the sampled area in 2000 (fig. 4).

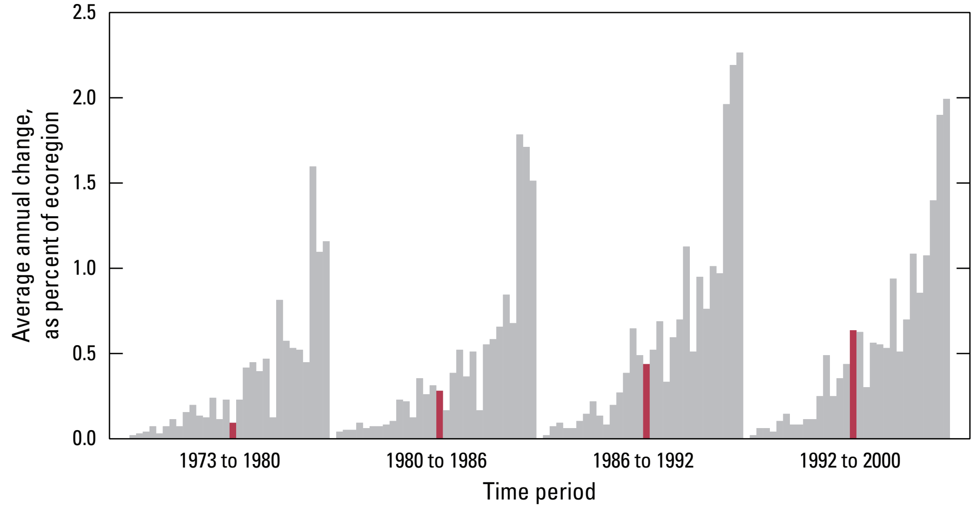

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Blue Mountains Ecoregion are represented by red bars in each time period.

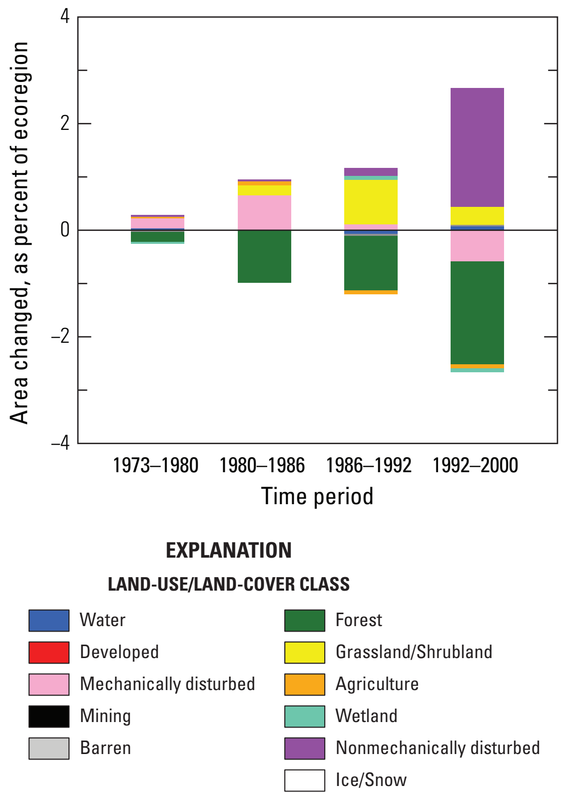

Figure 4. Normalized average net change in Blue Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

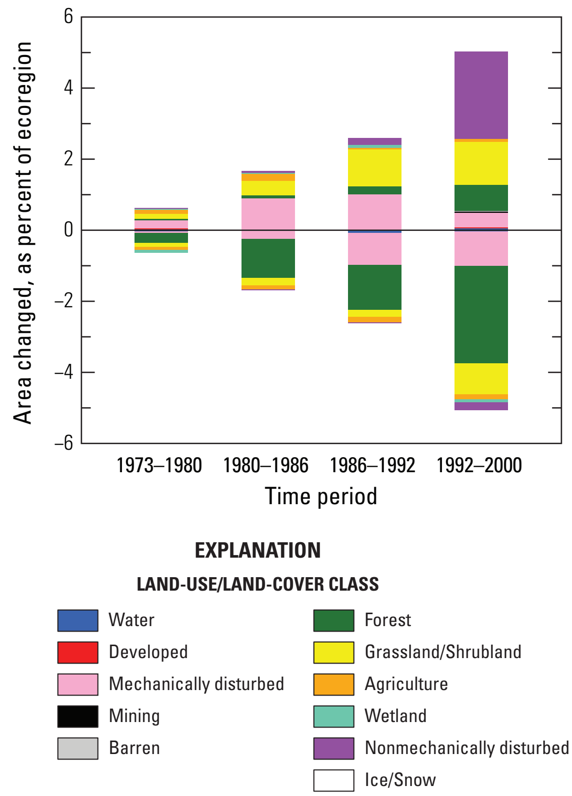

Figure 5. Gross change (as percent of ecoregion) in Blue Mountains Ecoregion by time period for each land-cover class. Diagram illustrates how net change can mask within-class fluctuations in each period and for entire 27-year study period. Bars above zero axis represent area gained, whereas bars below zero represent area lost. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Net change, however, may not necessarily be the best indicator of within-class variability for those classes experiencing spatiotemporal fluctuations. The net-change metric often masks dynamics of land-use/land-cover change, whereas analysis of gross change (area gained or lost) by individual land-use/land-cover classes by time period shows that classes have fluctuated throughout the 27-year study period to a greater degree than net-change values may indicate (Raumann and others, 2007) (fig. 5). In addition, land-cover classes may experience gains and losses in area both within and between time periods (fig. 5). For example, the mechanically disturbed class increased by more than 600 percent between 1973 and 2000, but gross change relating to mechanical disturbance affected an area greater than 40 times the size of the 1973 classification area. Figure 5 illustrates the dynamic nature of land-use/land-cover change in the Blue Mountains Ecoregion between 1973 and 2000.

The land-use/land-cover change information for each of the four time periods afforded by a postclassification comparison allowed the identification of land-use/land-cover class conversions and the ranking of these conversions according to their magnitude. Table 4 illustrates the most frequent conversions in the Blue Mountains Ecoregion between 1973 and 2000. The largest overall conversion and the largest conversion in each of the first three time periods represented the mechanical disturbance of forest by logging and rangeland improvement (fig. 6). Additionally, the second most common overall conversion and a major conversion in each of the last two time periods were connected to nonmechanical disturbance of forest by fire and to a significantly lesser degree, to insect damage from the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough), the western spruce budworm (*Choristoneura occidentalis* Freeman), and the mountain pine beetle (*Dendroctonus ponderosae*) (Wickman, 1992) (fig. 7). Insect damage to forest land cannot be separated out from other nonmechanical disturbances in the present study; however, it must be stressed that insect-caused declines in forest health are known to exacerbate the effects, spread, and intensity of wildfires (Wickman, 1992). The effect of mechanical disturbance on forest resulted in an estimated 1,663 km² of land-cover loss, whereas the impact of nonmechanical disturbance on grassland/shrubland and forest resulted in an estimated 1,760 km² of vegetated land-cover loss.

Most mechanical disturbances (74.1 percent) occurred between 1980 and 1992, and these changes declined significantly between 1992 and 2000. This decline coincided with the decline in timber harvest in Oregon in the 1990s, when a shift towards forest conservation caused the federal share of Oregon's timber harvest to decrease from approximately 50 percent in 1989 to 10 percent by 2000 (Brandt and others, 2006). Although mechanical forest clearing declined between 1992 and 2000, over 90 percent of all nonmechanical disturbances took place during this period.

Mechanical and nonmechanical disturbances are transitional by definition, so many of these disturbed areas experienced ecological succession, or regrowth, after each disturbance event. The cumulative regrowth following mechanical and nonmechanical disturbances accounts for 1,555 km² of vegetated land-cover gain through 2000; on the basis of field observations, disturbances that occurred in 2000 would also convert to one of the vegetation land-cover classes if mapping efforts had been extended to include a 2007 date. Conversions to and from the agriculture class represent another conversion in the Blue Mountains Ecoregion during the study period. Between 1973 and 2000, 273 km² converted from agriculture to grassland/shrubland and 219 km² converted from grassland/shrubland to agriculture.

The mechanical removal of forest in the Blue Mountains Ecoregion between 1973 and 2000 occurred in over half of the sample-block locations. Most of these conversions were associated with silviculture. Considerable research has been conducted, and policy has been implemented, to establish improved

Figure 6. Young stand of trees in formerly cleared part of Blue Mountains Ecoregion. Standing snags provide nesting and roosting sites for avian species. Land-use/land-cover classes shown are forest and grassland/shrubland.

Figure 7. Cut trees in Blue Mountains Ecoregion during precommercial thinning. Land-use/land-cover classes shown are mechanically disturbed and forest.

Figure 8. Forested area in early-stage succession (regrowth) following fire. Although grasses and shrubs tend to reestablish themselves quite soon after fire, trees take much longer to recover. Land-cover classes shown are grassland/shrubland and forest.

forestry practices such as sustainable stocking levels, thinning practices, and snag preservation (Cochran and others, 1994; Parker and others, 2006; U.S. Department of Agriculture, 1979) (figs. 6,8). The goal of many of these practices has been to replicate old-growth forest conditions and remedy the detrimental effects of logging on forest fauna. For example, protecting tree snags and select trees while cutting is intended to preserve nest and roost sites vital for breeding and winter survival of many avian species (Zarnowitz and Manuwal, 1985; Bryce, 2006; U.S. Department of Agriculture, 1979).

Nonmechanical disturbances, although comparable to mechanical disturbances in terms of the overall footprint of change across the Blue Mountains Ecoregion, were much less frequent than the mapped instances of forest cutting. Despite this lower frequency, nonmechanical disturbances caused by fire had a much larger patch size. Larger fires have become much more common in the Blue Mountains Ecoregion and can be largely attributed to fire-suppression practices that took place over much of 20th century. Fires not only pose an immediate threat to wildlife and human habitats, but they also contribute to future fires by altering forest composition and making damaged trees more vulnerable to insect pests (McCullough and others, 1998). In an effort to reduce the threat of forest fires, prescribed fires are being applied more regularly to remove built-up fuels and excess understory growth within the Blue Mountains Ecoregion (Mutch and others, 1993) (fig. 9).

Figure 9. Forested area during prescribed fire, showing warning sign (*A*) and scattered smoldering logs (*B*). Prescribed fires remove undergrowth and prevent large, unmanageable fires from occurring. Land-cover classes shown are nonmechanically disturbed and forest.

Table 1. Percentage of Blue Mountains Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (93.5 percent), whereas 6.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	3.8	1.9	1.8	5.7	1.3	34.7
2	2.1	0.8	1.3	2.9	0.5	25.8
3	0.6	0.4	0.3	1.0	0.2	38.3
4	0.0	0.0	0.0	0.0	0.0	67.8
Overall spatial change	6.5	2.2	4.3	8.8	1.5	23.0

Table 2. Raw estimates of change in Blue Mountains Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence levels.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.6	0.2	0.4	0.8	0.1	18.1	0.1
1980–1986	1.7	0.7	1.0	2.4	0.5	28.0	0.3
1986–1992	2.6	1.1	1.5	3.7	0.8	28.7	0.4
1992–2000	5.0	2.1	3.0	7.1	1.4	27.7	0.6
Estimate of change, in square kilometers							
1973–1980	399	107	292	506	72	18.1	57
1980–1986	1,094	453	641	1,548	306	28.0	182
1986–1992	1,714	727	988	2,441	491	28.7	286
1992–2000	3,300	1,353	1,947	4,653	915	27.7	413

Table 3. Estimated area (and margin of error) of each land-cover class in Blue Mountains Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.4	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.8	0.6	52.5	7.8	40.8	7.6	4.1	2.1	1.0	0.5	0.0	0.0
1980	0.4	0.3	0.2	0.2	0.2	0.1	0.0	0.0	0.8	0.6	52.3	7.7	40.8	7.6	4.1	2.1	0.9	0.5	0.0	0.0
1986	0.4	0.3	0.2	0.2	0.9	0.6	0.0	0.0	0.8	0.6	51.4	7.4	40.9	7.5	4.2	2.1	1.0	0.5	0.0	0.1
1992	0.4	0.3	0.2	0.2	1.0	0.5	0.0	0.0	0.8	0.6	50.3	7.3	41.8	7.3	4.1	2.0	1.0	0.5	0.2	0.2
2000	0.4	0.3	0.3	0.2	0.4	0.2	0.0	0.0	0.8	0.6	48.4	7.0	42.1	7.3	4.1	2.0	0.9	0.5	2.4	2.0
Net change	0.1	0.1	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.0	−4.2	1.9	1.3	0.7	0.0	0.2	0.0	0.1	2.4	2.0
Gross change	0.2	0.2	0.0	0.0	2.5	1.2	0.0	0.0	0.1	0.1	5.1	2.1	2.5	0.8	0.5	0.3	0.3	0.2	2.9	2.0
Area, in square kilometers																				
1973	250	205	144	99	40	21	26	22	539	420	34,399	5,076	26,677	4,958	2,694	1,360	639	316	0	0
1980	282	212	149	103	153	67	25	21	530	420	34,262	5,046	26,685	4,961	2,704	1,367	612	318	5	7
1986	285	212	157	106	580	404	25	21	530	420	33,626	4,876	26,799	4,892	2,750	1,364	625	325	31	44
1992	236	203	162	110	661	339	26	22	521	420	32,953	4,758	27,337	4,787	2,696	1,299	675	333	140	163
2000	284	210	168	114	284	137	29	27	539	420	31,671	4,573	27,546	4,780	2,667	1,285	618	321	1,602	1,281
Net change	33	34	24	18	244	132	4	4	0	0	−2,728	1,239	868	435	−27	155	−20	36	1,602	1,281
Gross change	140	121	25	18	1,604	811	7	7	36	52	3,363	1,395	1,646	533	329	166	166	112	1,888	1,299

Table 4. Principal land-cover conversions in Blue Mountains Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	152	67	45	0.2	38.0
	Agriculture	Grassland/Shrubland	52	47	32	0.1	13.1
	Grassland/Shrubland	Agriculture	51	49	33	0.1	12.9
	Wetland	Water	31	32	22	0.0	7.7
	Mechanically disturbed	Grassland/Shrubland	30	18	12	0.0	7.4
	Other	Other	83	n/a	n/a	0.1	20.9
		Totals	399			0.6	100.0
1980–1986	Forest	Mechanically disturbed	579	404	273	0.9	52.9
	Mechanically disturbed	Grassland/Shrubland	118	53	36	0.2	10.8
	Grassland/Shrubland	Agriculture	91	64	43	0.1	8.4
	Forest	Grassland/Shrubland	75	107	72	0.1	6.9
	Agriculture	Grassland/Shrubland	63	56	38	0.1	5.8
	Other	Other	168	n/a	n/a	0.3	15.3
		Totals	1,094			1.7	100.0
1986–1992	Forest	Mechanically disturbed	653	340	230	1.0	38.1
	Mechanically disturbed	Grassland/Shrubland	527	363	246	0.8	30.7
	Forest	Nonmechanically disturbed	139	163	110	0.2	8.1
	Grassland/Shrubland	Forest	96	78	53	0.1	5.6
	Agriculture	Grassland/Shrubland	90	111	75	0.1	5.2
	Other	Other	210	n/a	n/a	0.3	12.3
		Totals	1,714			2.6	100.0
1992–2000	Forest	Nonmechanically disturbed	1,471	1,170	791	2.2	44.6
	Mechanically disturbed	Grassland/Shrubland	566	293	198	0.9	17.1
	Grassland/Shrubland	Forest	397	251	170	0.6	12.0
	Forest	Mechanically disturbed	279	137	93	0.4	8.5
	Grassland/Shrubland	Nonmechanically disturbed	125	114	77	0.2	3.8
	Other	Other	462	n/a	n/a	0.7	14.0
		Totals	3,300			5.0	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	1,663	809	547	2.5	25.5
	Forest	Nonmechanically disturbed	1,632	1,178	797	2.5	25.1
	Mechanically disturbed	Grassland/Shrubland	1,240	630	426	1.9	19.0
	Grassland/Shrubland	Forest	554	293	198	0.8	8.5
	Agriculture	Grassland/Shrubland	273	247	167	0.4	4.2
	Other	Other	1,146	n/a	n/a	1.8	17.6
		Totals	6,508			9.9	100.0

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Mediterranean California Ecoregions

Status and Trends of Land Change in the Western United States—1973 to 2000
Edited by Benjamin M. Sleeter, Tamara S. Wilson, and William Acevedo
U.S. Geological Survey Professional Paper 1794–A, 2012

Chapter 17

Central California Valley Ecoregion

By Benjamin M. Sleeter

Ecoregion Description

The Central California Valley Ecoregion, which covers approximately 45,983 km^2 (17,754 mi^2), is an elongated basin extending approximately 650 km north to south through central California (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion is surrounded entirely by the Southern and Central California Chaparral and Oak Woodlands Ecoregion, which includes parts of the Coast Ranges to the west and which is bounded by the Sierra Nevada to the east. The Central California Valley Ecoregion accounts for more than half of California's agricultural production value and is one of the most important agricultural regions in the country, with flat terrain, fertile soils, a favorable climate, and nearly 70 percent of its land in cultivation (Kuminoff and others, 2000; Sumner and others, 2003). Commodities produced in the region include milk and dairy, cattle and calves, cotton, almonds, citrus, and grapes, among others (U.S. Department of Agriculture, 2004; Johnston and McCalla, 2004; Kuminoff and others, 2000) (figs. 2*A,B,C*). Six of the top eight agricultural-producing counties in California are located at least partly within the Central California Valley Ecoregion (Kuminoff and others, 2000) (table 1). The Central California Valley Ecoregion is also home to nearly 5 million people spread throughout the region, including the major cities of Sacramento (state capital), Fresno, Bakersfield, and Stockton, California (U.S. Census Bureau, 2000) (fig. 1).

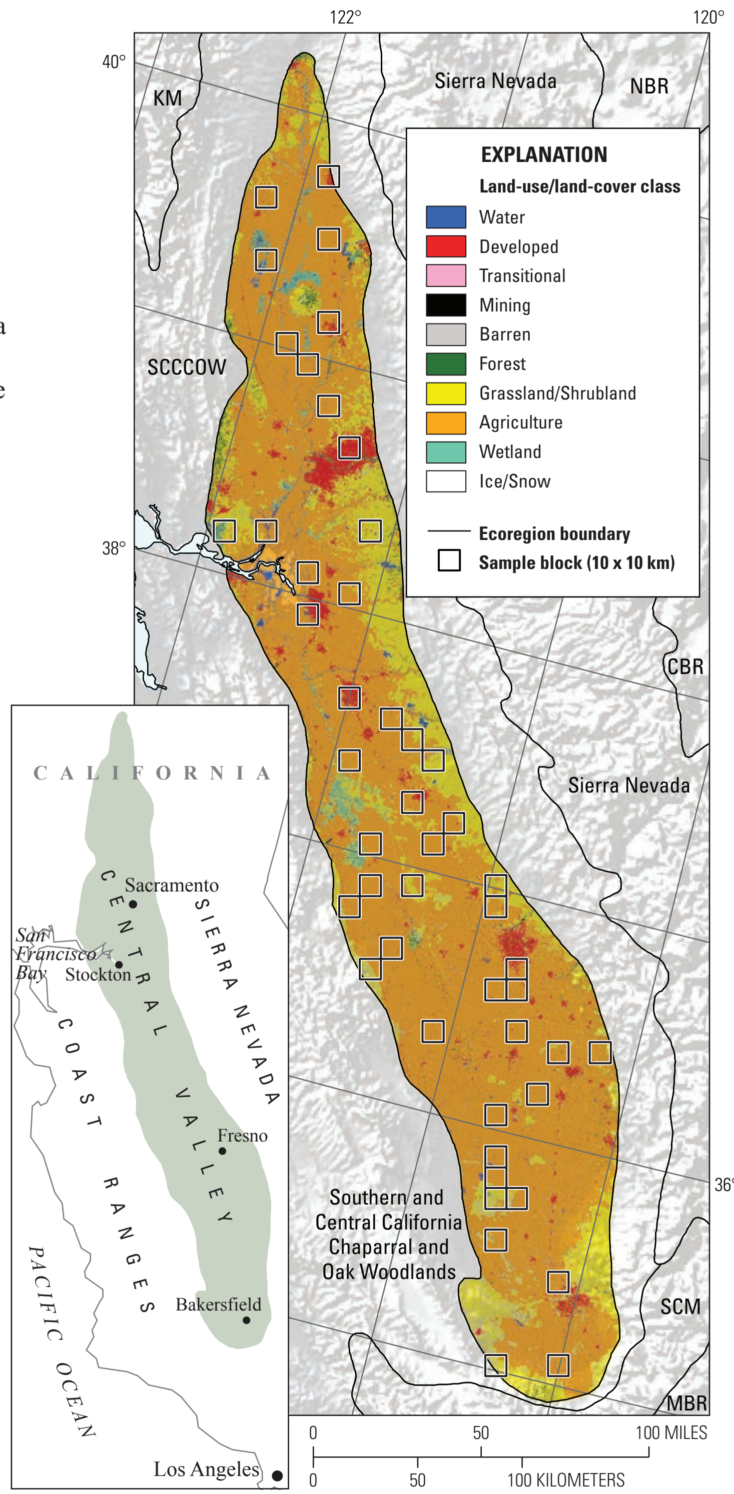

Figure 1. Map of Central California Valley Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

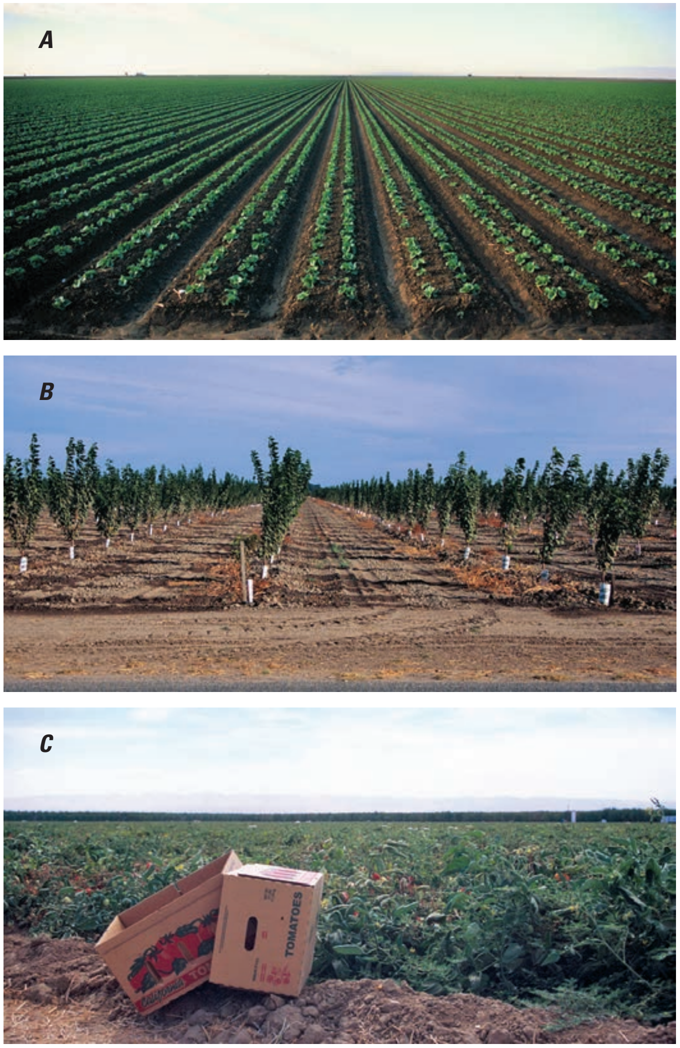

Figure 2. Agriculture in Central California Valley Ecoregion. *A*, Newly planted field. *B*, Young orchard. *C*, Tomato field.

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change in the Central California Valley Ecoregion (the percentage of area that changed at least one time between 1973 and 2000) was estimated at 12.9 percent (±3.1 percent at 85-percent confidence level) (table 2). Compared to other western ecoregions, change in the Central California Valley Ecoregion was above average (fig. 3). Total estimated change was highest in the first time period (1973–1980), when 5.7 percent of the ecoregion changed from one land cover to another (table 3). When change estimates are normalized to account for the varying lengths of the time periods, change is also highest in the first time period (at 0.8 percent per year) and then constant for the following three time periods at just greater than 0.5 percent per year (fig. 4).

The largest change in any one land-cover class between 1973 and 2000 was the loss of 1,782 km^2 of grassland/shrubland (20.2 percent of the area it occupied in 1973, table 4). The second largest change was the addition of 1,129 km^2 of developed land cover (an increase of 37.7 percent), increasing from 6.5 to 9.0 percent of the ecoregion area. Agricultural lands, which accounted for more than 70 percent of the Central California Valley Ecoregion, remained relatively stable throughout the study period with a net increase of 358 km^2 (1.1 percent increase). Estimates of percent cover for all land-cover classes by time period are found in table 4, and estimates of average annual change by class are found in figure 5.

The dominant land-cover conversion that occurred in the Central California Valley Ecoregion was from grassland/shrubland to agriculture. This conversion was most common near the ecoregion boundary (fig. 6), because historically open grazing lands were brought into agricultural production to

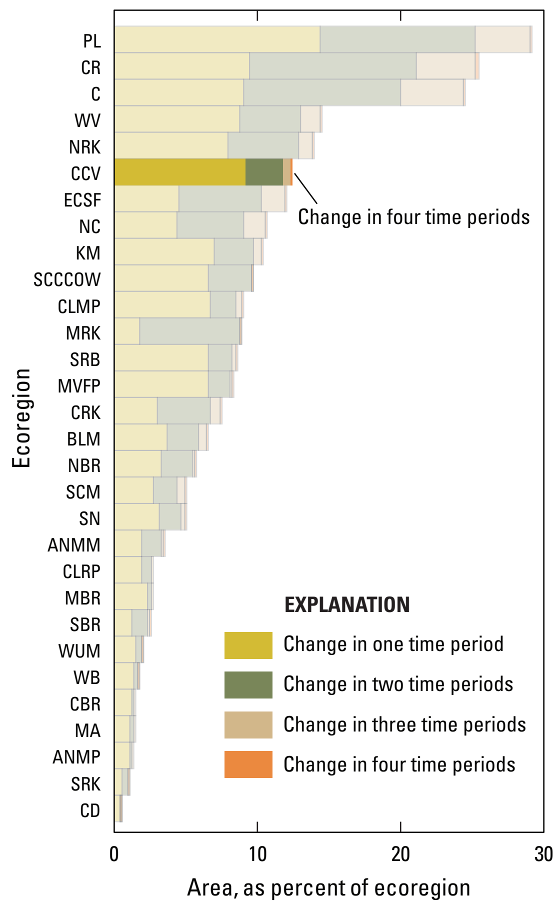

Figure 3. Overall spatial change in Central California Valley Ecoregion (CCV; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Central California Valley Ecoregion (four time periods) labeled for clarity. See table 3 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

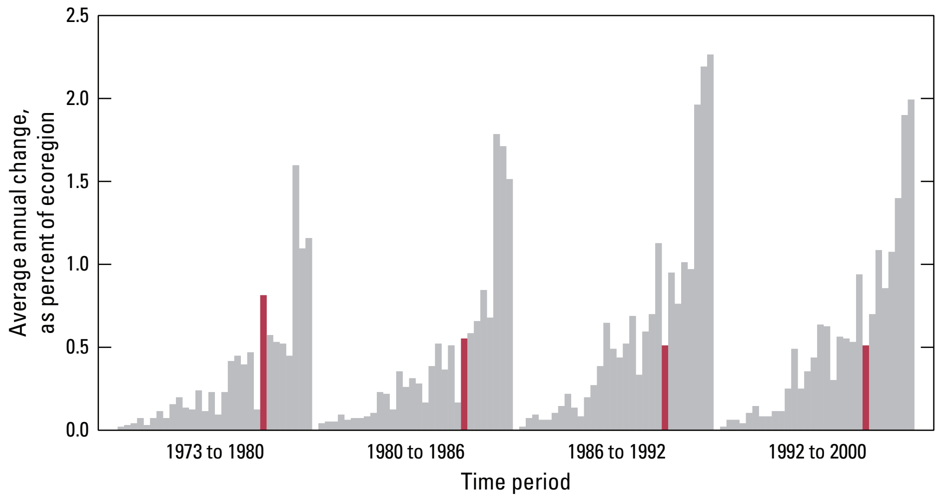

Figure 4. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Central California Valley Ecoregion are represented by red bars in each time period.

grow grapes, nut crops, and citrus. This change may also be attributed to the tilling cycle, when farmers allow parcels of land to revert to natural vegetation before eventually being returned to production. This particular conversion (grassland/shrubland to agriculture) accounted for 45.0 percent of all change in the ecoregion. The second most common conversion was from agriculture to grassland/shrubland (26.5 percent of all change). Again, a portion of this change can be attributed to the cycling of cropland into and out of production (fig. 7), although this conversion was also commonly observed at the edge of urban areas and new development. As urban areas expand, agricultural land is converted to developed land. In many instances, farmland converts to grassland/shrubland before being developed. The third and fourth most common conversions were from agriculture and grassland/shrubland to developed land (9.2 and 4.9 percent of ecoregion change, respectively). Combined, the top four conversions account for 88 percent of all land-cover change in the Central California Valley Ecoregion between 1973 and 2000. A detailed description of the most common land-cover conversions for the Central California Valley Ecoregion is found in table 5.

A major driver of change in the ecoregion is population growth. Population growth in the San Francisco Bay area and Los Angeles, as well as in the Central Valley itself, has resulted in a high demand for land for urban uses (figs. 8*A*,*B*). Within the ecoregion, as new development adjacent to existing urban areas converts agricultural land to homes, businesses, and other urban uses, farms are relocating to the ecoregion periphery and then converting traditional grazing lands (grassland/shrubland) into new agricultural uses. Annual climatic variability may also play a role in the conversion rates and, more importantly, in the types of land-cover conversions that occurred in the ecoregion. In all but the 1986 to 1992 period, the leading conversion was from grassland/shrubland

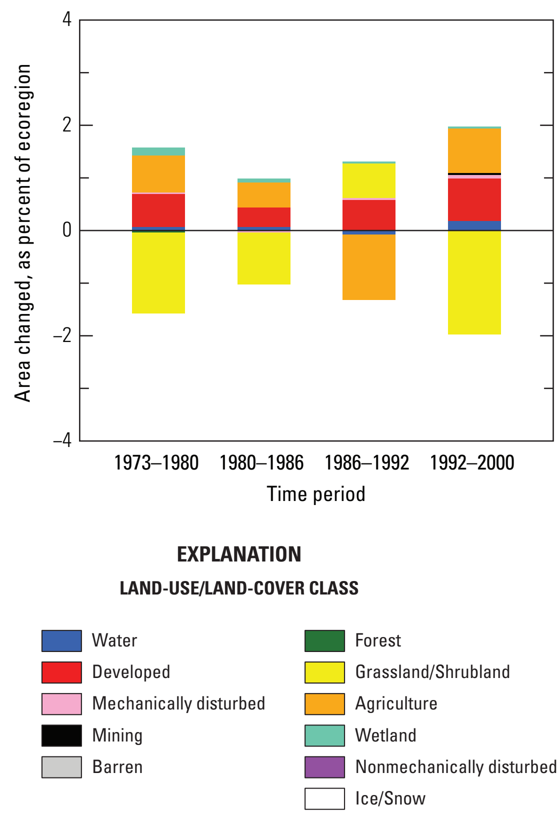

Figure 5. Normalized average net change in Central California Valley Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

to agriculture, and the second most common conversion was from agriculture to grassland/shrubland. This pattern was reversed during the 1986 to 1992 period, which also corresponded to a period of prolonged drought in California. During this period, irrigation-water-supply (figs. 9*A,B*) shortages coupled with increased cost and conservation efforts led to decreased production in some of the Central California Valley's primary crops, such as cotton and rice (U.S. Department of Agriculture, 1991). In response to the reduced surface-water supplies, producers who normally relied on irrigation increased groundwater usage, idled some land, sought to minimize waste, and shifted water to the production of higher value crops (U.S. Department of Agriculture, 1991). In 1991, conservation efforts alone resulted in widespread declines in irrigated lands, including 56,500 acres of corn, 36,000 acres of wheat, 12,600 acres of pasture, 9,200 acres of alfalfa, and

Figure 6. New asparagus fields planted along Central California Valley Ecoregion boundary.

Figure 7. Abandoned agricultural field near Kern National Wildlife Refuge, Kern County, California.

Figure 8. Development in Central California Valley Ecoregion. *A*, New home construction. *B*, New subdivision for-sale signs in a Fresno, California, suburb.

Figure 9. Irrigation systems in Central California Valley Ecoregion. *A*, Section of Delta-Mendota Canal, which runs 188 km through ecoregion. *B*, Single-field irrigation ditch.

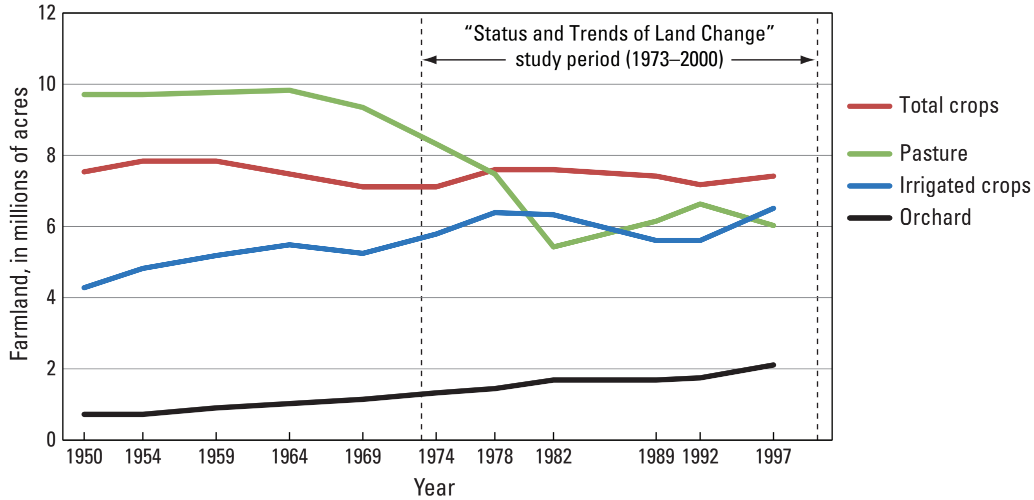

Figure 10. Changes in California agriculture (total crops, irrigated crops, pasture, and orchards) between 1950 and 1997 (U.S. Department of Agriculture, 2004).

9,100 acres of sugar beets, while surface water shortages resulted in an estimated 14-percent decrease in cotton production and a 23-percent decrease in rice production (U.S. Department of Agriculture, 1991).

The loss of farmland to urban uses is often assumed to be the single greatest threat to the Central California Valley Ecoregion (Hart, 2003). While significant amounts of high quality farmland are being converted to permanent urban uses (an estimated 684 km^2 between 1973 and 2000), agriculture is evolving and, in fact, increasing in scale (Hart, 2003; Johnston and McCalla, 2004; Sleeter, 2008). Farmers continue to make use of advances in irrigation technologies, such as drip systems, in an effort to cultivate lands once considered marginal for traditional crops (Charbonneau and Kondolf, 1993). Central California Valley Ecoregion agriculture continues its adaptation through investments in higher value, higher risk crops, such as almonds and grapes, instead of traditional field crops, such as alfalfa and grains (U.S. Department of Agriculture, 2004; Johnston and McCalla, 2004) (fig. 10). This is possible because these higher value crops can be successfully cultivated on slopes at the ecoregion periphery and on soils of significantly lower quality than those found on the fertile valley floor.

California has led the nation in agricultural cash receipts in every year since 1948 and, in 1999, recorded nearly $25 billion; California farmers have increased their national share from 9.5 percent in 1960 to 13.1 percent in 1999 (Kuminoff and others, 2000). For comparison, Australia and Canada each had approximately $18.5 billion in agricultural cash receipts in 1999 (Kuminoff and others, 2000). Due to the ecoregion’s economic importance, consequences of land-cover change are a significant concern at multiple scales and will require detailed analysis. As California’s population continues to increase, additional demands will be placed on the Central California Valley Ecoregion to support people and the agricultural complex they depend on, which will result in the continued evolution of the nation’s most diverse agricultural region.

Table 1. Gross value of agricultural production in 1999 by county in Central California Valley Ecoregion (California Agricultural Statistics Service, 2001; modified from Kuminoff and others, 2000).

California county rank (1999)	County[1]	Value of production[2] (millions of dollars)	Top commodities[3]
1	Fresno	3,559	Grapes, Poultry, Cotton, Tomatoes, Milk
2	Tulare	3,075	Milk, Grapes, Navel and Valencia Oranges, Cattle and Calves, Plums
4	Kern	2,128	Grapes, Cotton and Processed Cottonseed, Citrus, Milk, Almonds and By-Products
5	Merced	1,534	Milk, Chickens, Almonds, Tomatoes, Cotton
6	San Joaquin	1,352	Grapes, Milk, Tomatoes, Cherries, Almond Meats
8	Stanislaus	1,210	Milk, Almonds, Chickens, Cattle and Calves, Tomatoes
12	Kings	901	Milk, Cotton, Cattle and Calves, Turkeys, Alfalfa Hay
14	Madera	700	Grapes, Milk, Almonds, Pistachios, Nursery Stock
18	Colusa	351	Rice, Processing Tomatoes, Almond Meats, Cucumber Seed, Rice Seed
19	Sutter	347	Rice, Prunes, Peaches, Tomatoes, Walnuts
21	Yolo	339	Processing Tomatoes, Winegrapes, Seed Crops, Rice, Alfalfa
22	Sacramento	293	Winegrapes, Milk, Bartlett Pears, Processing Tomatoes, Ornamental Nursery Stock
23	Butte	257	Milling Rice, Almonds, Prunes, Walnuts, Kiwifruit
24	Glenn	253	Rice Paddy, Dairy Products, Almonds, Prunes, Cattle and Calves
28	Solano	195	Processing Tomatoes, Nursery Stock, Alfalfa Hay, Winegrapes, Cattle and Calves
34	Yuba	108	Rice, Peaches, Walnuts, Cattle and Calves, Prunes
35	Tehama	97	Cattle and Calves, Walnuts, Prunes, Milk, Olives
37	Contra Costa	86	Bedding Plants, All Milk, All Tomatoes, Grapes, Sweet Corn
39	Placer	58	Rice, Cattle and Calves, Nursery, Chickens, Pasture and Range, Walnuts
47	Amador	19	Winegrapes, Cattle and Calves, Pasture and Range, Grain Hay, Alfalfa Hay
49	Mariposa	18	Cattle and Calves, Range, Misc. Livestock/Poultry Products, All Poultry
51	Calaveras	15	Cattle and Calves, Winegrapes, Poultry, Livestock and Poultry Products, Walnuts

[1]Counties in California that intersect the boundary of Central California Valley Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997).

[2]Gross value of production includes all farm production, whether sold into usual marketing channels or used on farm where produced.

[3]Information reported by agricultural commissioners of each county. Level of detail reported differs by county. For example, some may report grapes (table, raisin, and wine) as an aggregate category, whereas others may report them as distinct categories.

Table 2. Percentage of Central California Valley Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (87.1 percent), whereas 12.9 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	9.7	2.0	7.7	11.7	1.4	14.4
2	2.4	1.1	1.3	3.6	0.8	31.7
3	0.7	0.3	0.4	0.9	0.2	26.7
4	0.1	0.0	0.0	0.1	0.0	48.8
Overall spatial change	12.9	3.1	9.7	16.0	2.1	16.6

Table 3. Raw estimates of change in Central California Valley Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	5.7	1.4	4.3	7.1	1.0	17.1	0.8
1980–1986	3.3	0.8	2.4	4.1	0.6	17.6	0.5
1986–1992	3.0	1.2	1.8	4.3	0.8	27.5	0.5
1992–2000	4.1	1.3	2.7	5.4	0.9	22.4	0.5
			Estimate of change, in square kilometers				
1973–1980	2,624	656	1,968	3,279	448	17.1	375
1980–1986	1,504	387	1,116	1,891	265	17.6	251
1986–1992	1,395	562	833	1,957	384	27.5	232
1992–2000	1,879	615	1,264	2,494	420	22.4	235

Table 4. Estimated area (and margin of error) of each land-cover class in Central California Valley Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	0.7	0.3	6.5	3.1	0.0	0.0	0.2	0.1	0.0	0.0	0.3	0.1	19.2	5.1	71.6	5.8	1.4	1.0	0.0	0.0
1980	0.7	0.3	7.2	3.4	0.1	0.0	0.2	0.1	0.0	0.0	0.3	0.1	17.7	4.9	72.3	5.7	1.6	1.1	0.0	0.0
1986	0.8	0.5	7.6	3.5	0.1	0.0	0.2	0.2	0.0	0.0	0.3	0.1	16.7	4.7	72.8	5.6	1.7	1.2	0.0	0.0
1992	0.7	0.3	8.2	3.7	0.1	0.1	0.2	0.2	0.0	0.0	0.3	0.1	17.3	5.0	71.5	5.8	1.7	1.2	0.0	0.0
2000	0.9	0.5	9.0	3.8	0.2	0.1	0.2	0.2	0.0	0.0	0.3	0.1	15.4	4.4	72.4	5.6	1.7	1.2	0.0	0.0
Net change	0.2	0.2	2.5	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	−3.9	1.9	0.8	2.3	0.3	0.5	0.0	0.0
Gross change	0.9	0.5	2.5	1.0	0.3	0.2	0.1	0.1	0.0	0.0	0.1	0.0	8.7	2.8	10.3	2.8	0.6	0.5	0.0	0.0
									Area, in square kilometers											
1973	300	146	2,996	1,446	17	14	80	65	2	2	156	64	8,841	2,359	32,934	2,678	658	464	0	0
1980	330	153	3,293	1,562	29	22	87	66	2	2	147	60	8,129	2,231	33,249	2,610	718	503	0	0
1986	359	209	3,475	1,611	24	16	86	69	2	3	146	60	7,671	2,160	33,457	2,560	761	539	0	0
1992	323	159	3,755	1,688	36	30	91	76	3	5	145	59	7,965	2,288	32,895	2,681	771	549	0	0
2000	413	217	4,124	1,751	74	39	96	82	2	3	142	58	7,060	2,044	33,292	2,564	780	564	0	0
Net change	112	101	1,129	455	57	37	16	18	0	0	−14	11	−1,782	860	358	1,039	122	214	0	0
Gross change	391	222	1,129	455	160	76	29	25	3	5	26	15	4,020	1,302	4,747	1,307	253	217	0	0

Table 5. Principal land-cover conversions in Central California Valley Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	1,305	462	316	2.8	49.7
	Agriculture	Grassland/Shrubland	748	351	240	1.6	28.5
	Agriculture	Developed	177	94	64	0.4	6.7
	Grassland/Shrubland	Developed	106	75	51	0.2	4.0
	Agriculture	Wetland	71	92	63	0.2	2.7
	Other	Other	217	n/a	n/a	0.5	8.3
		Totals	2,624			5.7	100.0
1980–1986	Grassland/Shrubland	Agriculture	734	275	188	1.6	48.8
	Agriculture	Grassland/Shrubland	316	179	122	0.7	21.0
	Agriculture	Developed	98	52	35	0.2	6.5
	Grassland/Shrubland	Developed	71	43	29	0.2	4.7
	Agriculture	Water	57	68	47	0.1	3.8
	Other	Other	227	n/a	n/a	0.5	15.1
		Totals	1,504			3.3	100.0
1986–1992	Agriculture	Grassland/Shrubland	675	460	314	1.5	48.4
	Grassland/Shrubland	Agriculture	271	119	81	0.6	19.5
	Agriculture	Developed	160	77	53	0.3	11.5
	Grassland/Shrubland	Developed	101	49	33	0.2	7.2
	Water	Agriculture	44	58	39	0.1	3.1
	Other	Other	144	n/a	n/a	0.3	10.3
		Totals	1,395			3.0	100.0
1992–2000	Grassland/Shrubland	Agriculture	1,024	536	366	2.2	54.5
	Agriculture	Developed	249	146	99	0.5	13.2
	Agriculture	Grassland/Shrubland	225	101	69	0.5	12.0
	Grassland/Shrubland	Developed	89	46	32	0.2	4.7
	Agriculture	Mechanically disturbed	62	37	26	0.1	3.3
	Other	Other	231	n/a	n/a	0.5	12.3
		Totals	1,879			4.1	100.0
1973–2000 (overall)	Grassland/Shrubland	Agriculture	3,334	1,160	792	7.3	45.0
	Agriculture	Grassland/Shrubland	1,965	960	656	4.3	26.5
	Agriculture	Developed	684	289	198	1.5	9.2
	Grassland/Shrubland	Developed	366	181	123	0.8	5.0
	Agriculture	Wetland	165	213	145	0.4	2.2
	Other	Other	887	n/a	n/a	1.9	12.0
		Totals	7,401			16.1	100.0

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Chapter 18

Southern California Mountains Ecoregion

By Christopher E. Soulard, Christian G. Raumann, and Tamara S. Wilson

This chapter has been modified from original material published in Soulard and others (2007), entitled “Land-cover trends of the Southern California Mountains ecoregion” (U.S. Geological Survey Scientific Investigations Report 2007–5235).

Ecoregion Description

The Southern California Mountains Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) encompasses approximately 17,871 km^2 (6,900 mi^2) of land located entirely within California. The ecoregion is bounded on the far north by the Sierra Nevada Ecoregion, on the east by the Mojave Basin and Range Ecoregion, on the southeast by the Sonoran Basin and Range Ecoregion, and on the west and north by Southern and Central California Chaparral and Oak Woodlands Ecoregion. In addition, the northern part of the ecoregion is separated from the Central California Valley Ecoregion by a narrow strip of the Southern and Central California Chaparral and Oak Woodlands Ecoregion (fig. 1).

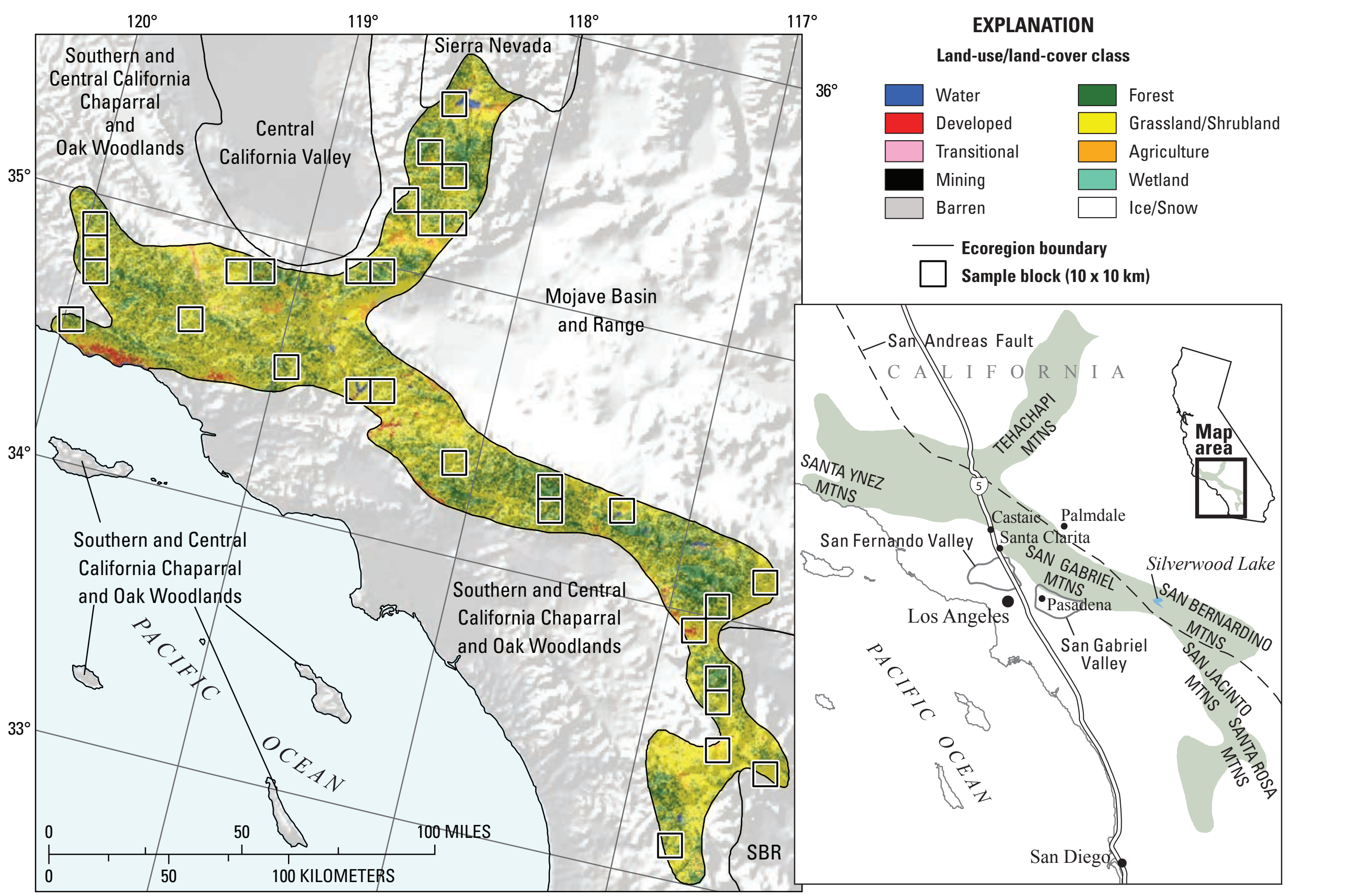

Figure 1. Map of Southern California Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

The Southern California Mountains Ecoregion includes several Pacific Coast mountain ranges. From northwest to southeast, these are the Santa Ynez Mountains, the Tehachapi Mountains, the San Gabriel Mountains, the San Bernardino Mountains, the San Jacinto Mountains, and the Santa Rosa Mountains. These mountain ranges are composed primarily of Mesozoic granitic and metamorphic rocks, in addition to Tertiary sedimentary rocks. The mountains are fractured and discontinuous, owing to movement on the San Andreas Fault and also the associated thrust faults that underlie the region. Additionally, the Santa Ynez Mountains, San Gabriel Mountains, and San Bernardino Mountains make up part of the geologic province known informally as the "Transverse Ranges Province," so-named because of its atypical east-west orientation, which differs from the more typical northwest-southeast orientation (roughly parallel to the San Andreas Fault) of most mountain ranges and valleys elsewhere in California.

The mountains of the Southern California Mountains Ecoregion act as a barrier between a coastal Mediterranean climate to the west and a dry desert climate to the east. This physiographic-barrier effect, along with the topographic gradient of rolling hills to mountains, plays a large role in dictating regional land-use patterns. For example, most urban and agricultural development (for example, irrigated pasture, hay fields, orchards) occurs at lower elevations in the more temperate parts of the ecoregion. Much of this land use is also connected to the suburban growth occurring in adjacent ecoregions; population pressure from cities along the periphery of the Southern California Mountains ecoregion—specifically, the San Fernando and San Gabriel Valleys in the greater Los Angeles, California, area, as well as the cities of Pasadena, Santa Clarita, and Palmdale, California —has caused a spillover in development into the Southern California Mountains Ecoregion's foothills. At higher elevations, development is less dense and is primarily associated with recreational activities and their supporting infrastructure (for example, campgrounds, vacation homes, ski resorts).

The physiographic barrier between the coastal and desert climates also sets the stage for the annual fire season, which occurs from late summer to early fall. Dry conditions on the ground, coupled with the seasonal strong, offshore Santa Ana winds (created from steep pressure gradients that develop between the desert and the coast), have fueled frequent major wildfires throughout the region for more than 500 years (Mensing and others, 1999). The increase in contemporary development, coupled with the long fire history, makes human populations in the region susceptible to fire hazards on a regular basis.

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the footprint (overall areal extent) of land-use/land-cover change in the Southern California Mountains Ecoregion was 5.1 percent, or 906 km². The footprint of change can be interpreted as the area that experienced land-cover change during at least one of the four multiyear time periods that make up the 27-year study period. Of the total change, 518 km² changed during one period, 268 km² changed during two periods, 107 km² changed during three periods, and less than 1 km² changed during all four periods (table 1). Compared to other western United States ecoregions, overall change was low (fig. 2).

The average annual rate of land-cover change in the Southern California Mountains Ecoregion between 1973 and 2000 was roughly 0.3 percent per year. This measurement, which normalizes the results for each period to an annual scale, means that the ecoregion averaged roughly 0.3 percent (50 km²) of change each year in the 27-year study period. However, this annual change varied between each of the four time periods (fig. 3). Between 1973 and 1980, the annual rate of change in the Southern California Mountains Ecoregion

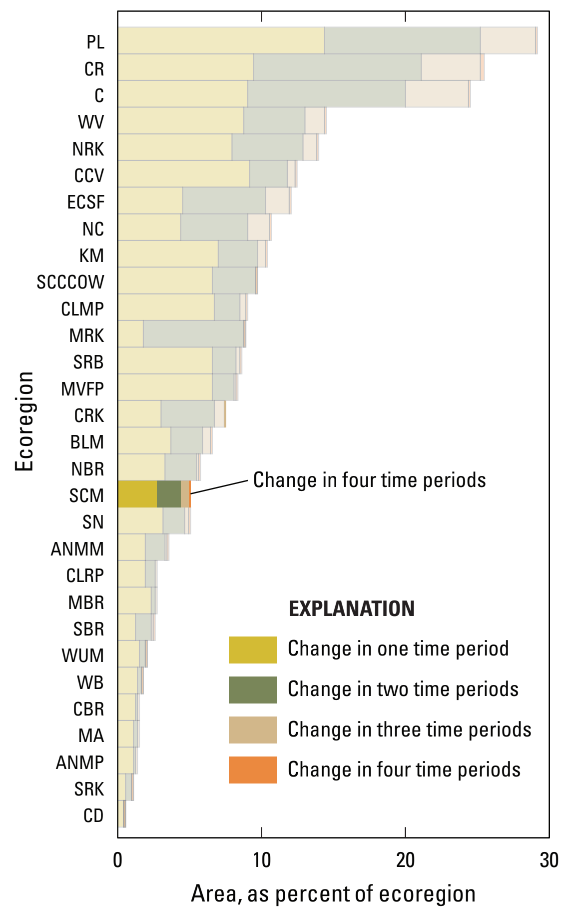

Figure 2. Overall spatial change in Southern California Mountains Ecoregion (SCM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Southern California Mountains Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

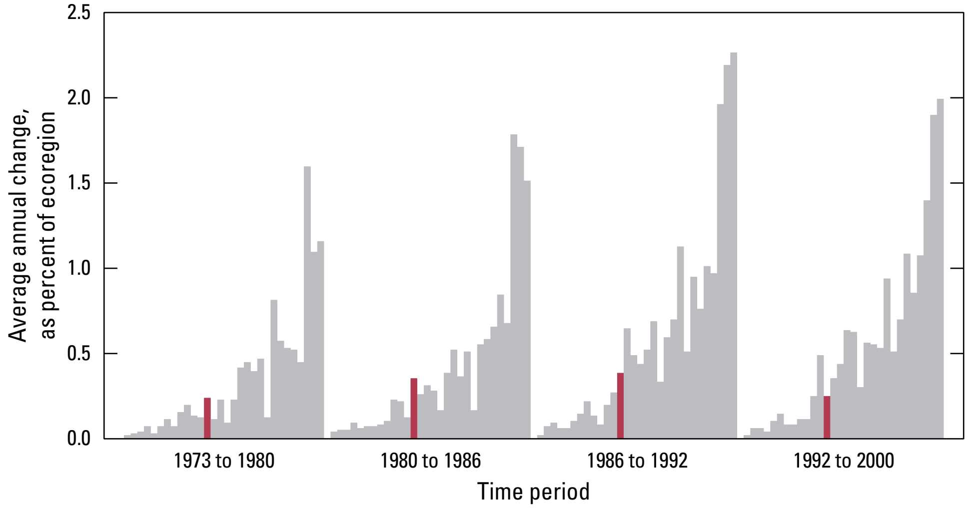

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Southern California Mountains Ecoregion are represented by red bars in each time period.

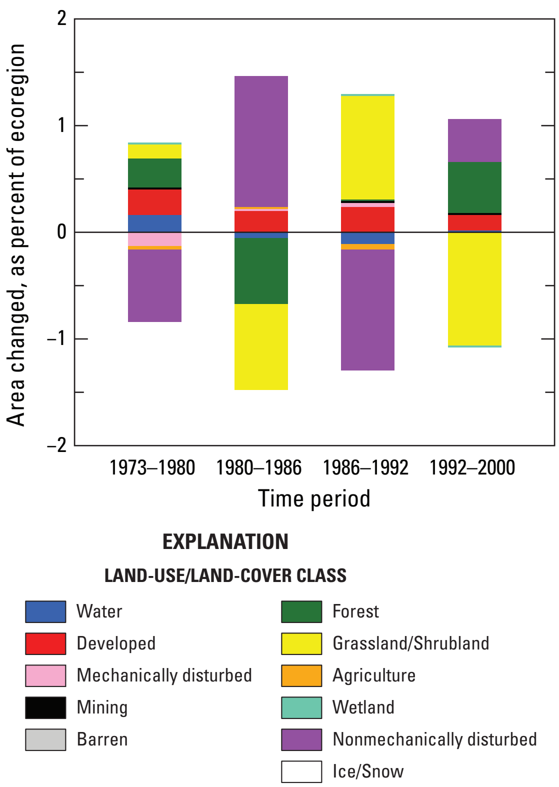

Figure 4. Normalized average net change in Southern California Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

was 0.2 percent per year, increasing to 0.3 percent per year between 1980 and 1986 and 0.4 percent per year between 1986 and 1992. The normalized annual rate dropped to 0.2 percent per year between 1992 and 2000 (table 2).

In 2000, 4 of the 11 land-cover classes occupied most of the Southern California Mountains Ecoregion: grassland/shrubland (65.9 percent), forest (27.5 percent), developed (2.6 percent), and agriculture (1.5 percent). Six other land-cover classes cumulatively made up the remaining 2.5 percent of the ecoregion in 2000, each making up less than 1.0 percent of the ecoregion (table 3).

Between 1973 and 2000, the land-cover classes that experienced a measurable net change in relation to the total Southern California Mountains Ecoregion area were, in descending order, developed (44.6 percent increase) and grassland/shrubland (1.1 percent decrease) (fig. 4). However, net change may not necessarily be the best indicator of change for individual land-cover classes as it can mask more complex land-use/land-cover dynamics. Analysis of gross change (that is, area gained or lost) by individual land-cover classes by time period shows that classes have fluctuated throughout the 27-year study period to a greater degree than net change values may indicate (fig. 5). Figure 5 illustrates how land-cover classes may experience gains and losses in area both within and between time periods. For example, the water class had no significant net change but experienced a gross change of nearly half its 1973 value. The nonmechanically disturbed class, which fluctuated greatly over the study period. underwent gross change totaling more than four times its original value.

The "from class–to class" information afforded by a postclassification comparison allows the identification of land-use/land-cover class conversions and the ranking of these conversions according to their magnitude. Table 4 illustrates the most frequent conversions between 1973 and 2000 in the Southern California Mountains Ecoregion. Five of the top ten

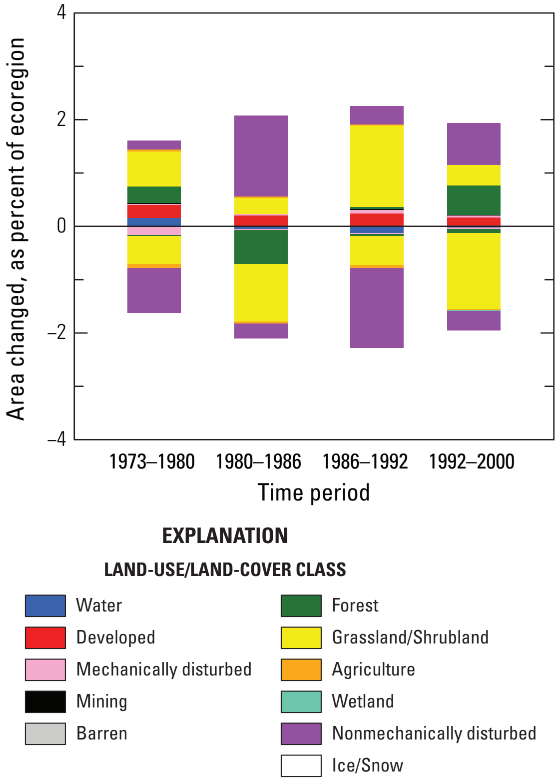

Figure 5. Gross change (area gained and lost) in Southern California Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications. Diagram illustrates that net change can mask within-class fluctuations within each time period and during entire 27-year study period.

Figure 6. Photograph taken in April 2005 of Silverwood Lake, California, and its surroundings, showing area undergoing regeneration following fire. Although grasses and shrubs tend to reestablish themselves quite soon after fire, trees take much longer to recover. Land-cover classes shown are grassland/shrubland and water.

most prominent conversions are connected to the nonmechanical disturbance of land cover by fire. Cumulatively, the effect of nonmechanical disturbance on grassland/shrubland and forest resulted in an estimated 501 km² of vegetated land-cover loss. However, much of this land experienced ecological succession, or regrowth, after each disturbance event (fig. 6). Regrowth accounted for 531 km² of vegetated land-cover gain; areas that were disturbed in consecutive periods account for an additional 21 km².

Conversions to the developed class also were common in the Southern California Mountains Ecoregion during the study period (146 km²) (fig. 7). The ecoregion is a geographically unique place, surrounded at lower elevations by human development and having few natural corridors that link its multiple mountain ranges. In the past, natural ignition sources such as lightning and wind dictated fire behavior in the Southern California Mountains Ecoregion, but today most of the fires are human-caused and are located at or near the interface between human development and wildlands (U.S. Department of Agriculture, 2005). These anthropogenic changes make predictions of future ecosystem health difficult as threats and outcomes

Figure 7. Photograph taken in April 2005 of new homes in Castaic, California, an unincorporated community in Los Angeles County located alongside Interstate 5. Land-use/land-cover classes shown are grassland/shrubland, forest, developed, and water.

cannot be measured against historical conditions. Topographic isolation, coupled with increased fragmentation of habitat by fire, poses significant threats to existing diversity and may ultimately drive species turnover in Southern California Mountains Ecoregion (Center for Biological Diversity, 2007). Protection of this designated biodiversity hotspot will become increasingly difficult given current land-use/land-cover trends (Myers and others, 2000). The consequences of land-use/land-cover change caused by nonmechanical disturbance and development, as well as the general loss of grassland/shrubland, do not necessarily follow managerial boundaries. On Federal lands, many agencies have adopted multiscale, integrated planning and management activities in an attempt to deal with these ecological processes within and across management units (Hann and Bunnell, 2001).

Table 1. Percentage of Southern California Mountains Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (94.9 percent), whereas 5.1 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	2.4	1.3	1.5	4.2	0.9	31.6
2	1.1	1.6	0.0	3.1	1.1	68.8
3	0.6	0.7	−0.1	1.4	0.5	78.1
4	0.0	0.0	0.0	0.0	0.0	52.2
Overall spatial change	5.1	2.5	2.6	7.5	1.7	32.8

Table 2. Raw estimates of change in Southern California Mountains Ecoregion land cover, computed for each of four time periods, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	1.6	1.0	0.6	2.6	0.7	41.6	0.2
1980–1986	2.1	1.5	0.6	3.5	1.0	47.4	0.3
1986–1992	2.3	1.6	0.6	3.9	1.1	48.4	0.4
1992–2000	1.9	1.1	0.8	3.0	0.7	38.4	0.2
Estimate of change, in square kilometers							
1973–1980	289	178	111	467	120	41.6	41
1980–1986	371	260	111	632	176	47.4	62
1986–1992	407	291	116	698	197	48.4	68
1992–2000	346	196	149	542	133	38.4	43

Table 3. Estimated area (and margin of error) of each land-cover class in Southern California Mountains Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.8	0.6	1.8	0.8	0.1	0.2	0.1	0.0	0.5	0.2	27.4	5.3	66.6	5.0	1.6	1.2	0.2	0.2	0.9	0.8
1980	1.0	0.7	2.1	0.9	0.0	0.0	0.1	0.1	0.5	0.2	27.7	5.3	66.7	5.0	1.5	1.2	0.2	0.2	0.3	0.2
1986	0.9	0.7	2.3	0.9	0.0	0.0	0.1	0.1	0.5	0.2	27.0	5.0	65.9	4.9	1.5	1.2	0.2	0.2	1.5	1.3
1992	0.8	0.6	2.5	1.0	0.1	0.1	0.1	0.1	0.5	0.2	27.0	5.0	66.9	4.8	1.5	1.2	0.2	0.2	0.4	0.4
2000	0.8	0.6	2.6	1.1	0.1	0.1	0.1	0.1	0.5	0.2	27.5	5.3	65.9	5.0	1.5	1.2	0.2	0.2	0.8	0.6
Net change	0.0	0.2	0.8	0.3	−0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.3	−0.7	0.8	−0.1	0.2	0.0	0.0	−0.2	1.0
Gross change	0.4	0.3	0.8	0.3	0.3	0.2	0.0	0.0	0.0	0.0	1.6	1.5	4.6	2.4	0.2	0.2	0.0	0.0	4.1	2.4
Area, in square kilometers																				
1973	143	100	327	146	26	28	11	7	92	44	4,893	940	11,902	897	279	214	30	29	169	143
1980	175	120	368	159	3	4	13	10	92	44	4,943	941	11,924	892	274	210	30	29	49	43
1986	167	119	404	167	7	5	14	10	92	44	4,830	886	11,781	884	276	209	31	29	269	234
1992	147	101	448	185	14	13	17	12	92	44	4,831	888	11,958	849	267	207	31	30	66	80
2000	151	102	473	194	16	14	19	14	92	44	4,916	939	11,769	892	265	207	31	29	139	106
Net change	8	32	146	62	−10	31	8	7	0	0	24	58	−133	148	−13	30	1	1	−30	172
Gross change	70	46	146	62	55	36	8	7	0	0	291	266	814	426	32	29	2	2	741	431

Table 4. Principal land-cover conversions in Southern California Mountains Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Nonmechanically disturbed	Grassland/Shrubland	98	89	60	0.5	33.7
	Nonmechanically disturbed	Forest	53	51	34	0.3	18.2
	Grassland/Shrubland	Nonmechanically disturbed	31	37	25	0.2	10.7
	Grassland/Shrubland	Developed	31	19	13	0.2	10.7
	Grassland/Shrubland	Water	24	20	13	0.1	8.4
	Other	Other	53	n/a	n/a	0.3	18.3
		Totals	289			1.6	100.0
1980–1986	Grassland/Shrubland	Nonmechanically disturbed	166	183	124	0.9	44.7
	Forest	Nonmechanically disturbed	103	132	89	0.6	27.9
	Nonmechanically disturbed	Grassland/Shrubland	48	43	29	0.3	12.8
	Grassland/Shrubland	Developed	21	9	6	0.1	5.8
	Forest	Developed	10	11	7	0.1	2.8
	Other	Other	23	n/a	n/a	0.1	6.1
		Totals	371			2.1	100.0
1986–1992	Nonmechanically disturbed	Grassland/Shrubland	262	232	157	1.5	64.3
	Grassland/Shrubland	Nonmechanically disturbed	62	76	51	0.3	15.3
	Grassland/Shrubland	Developed	30	14	9	0.2	7.3
	Water	Grassland/Shrubland	11	14	9	0.1	2.8
	Agriculture	Developed	10	13	9	0.1	2.3
	Other	Other	32	n/a	n/a	0.2	7.9
		Totals	407			2.3	100.0
1992–2000	Grassland/Shrubland	Nonmechanically disturbed	122	93	63	0.7	35.4
	Grassland/Shrubland	Forest	98	132	90	0.5	28.4
	Nonmechanically disturbed	Grassland/Shrubland	64	79	53	0.4	18.5
	Grassland/Shrubland	Developed	22	10	7	0.1	6.5
	Forest	Nonmechanically disturbed	14	19	13	0.1	4.1
	Other	Other	24	n/a	n/a	0.1	7.0
		Totals	346			1.9	100.0
1973–2000 (overall)	Nonmechanically disturbed	Grassland/Shrubland	471	377	255	2.6	33.3
	Grassland/Shrubland	Nonmechanically disturbed	382	344	233	2.1	27.0
	Forest	Nonmechanically disturbed	119	133	90	0.7	8.4
	Grassland/Shrubland	Developed	104	41	28	0.6	7.4
	Grassland/Shrubland	Forest	101	132	89	0.6	7.2
	Other	Other	236	n/a	n/a	1.3	16.7
		Totals	1,413			7.9	100.0

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Chapter 19

Southern and Central California Chaparral and Oak Woodlands Ecoregion

By Darrell E. Napton

Ecoregion Description

The Southern and Central California Chaparral and Oak Woodlands Ecoregion, which covers approximately 102,110 km² (39,425 mi²), is characterized by a Mediterranean climate with cool, moist winters and hot, dry summers (Omernik, 1987; U.S. Environmental Protection Agency, 1997). Natural vegetation includes chaparral (for example, manzanita, *Arctostaphylos* spp.) and oak (*Quercus* spp.) woodlands with extensive grassland and shrubland cover. The low mountains and foothills of the ecoregion border or parallel the Pacific Ocean from Mexico to Point Reyes, California, and continue inland surrounding the Central California Valley Ecoregion (fig. 1). These mountains and hills are interrupted by limited areas of flat land generally used for development or agriculture. The largest developed area in the ecoregion is the Los Angeles Basin, followed by the San Francisco Bay area and the San Diego metropolitan area (fig. 1). The largest agricultural area

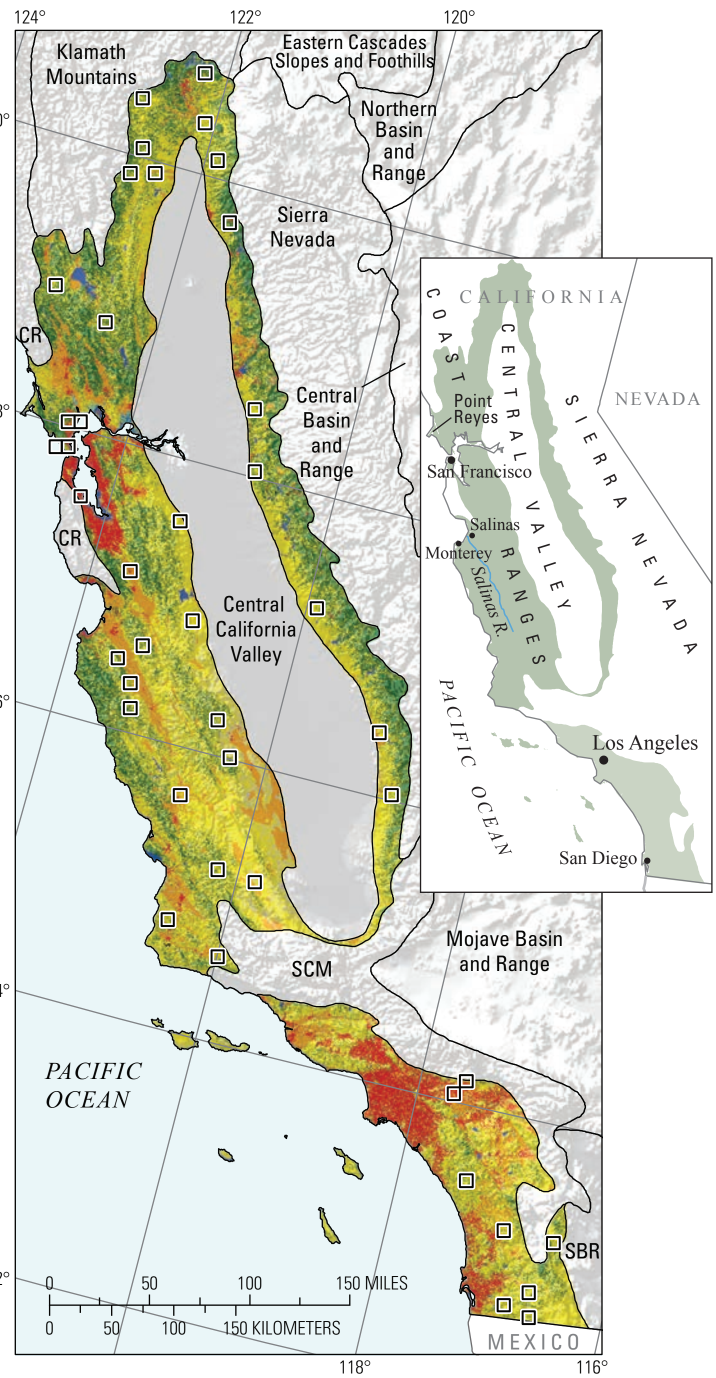

Figure 1. Map of Southern and Central California Chaparral and Oak Woodlands Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

EXPLANATION

Land-use/land-cover class

Water
Developed
Transitional
Mining
Barren
Forest
Grassland/Shrubland
Agriculture
Wetland
Ice/Snow

Ecoregion boundary
Sample block (10 x 10 km)

Figure 2. Typical Southern and Central California Chaparral and Oak Woodlands Ecoregion landscape, consisting of grassland/shrubland or forest land cover.

is the Salinas River valley south of Monterey, California. Most of the ecoregion consists of rangelands classified as grassland/shrubland and forest land covers (figs. 1,2).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change (that is, the percentage of area that changed at least one time between 1973 and 2000) in the ecoregion was estimated at 9.7 percent (table 1). The amount of change in the Southern and Central California Chaparral and Oak Woodlands Ecoregion was close to the median among the western United States ecoregions (fig. 3). Nearly seventy percent of the converted landscape changed land-cover class only one time, whereas thirty percent changed land cover twice (table 1). Fire, which produces a landscape classified as nonmechanically

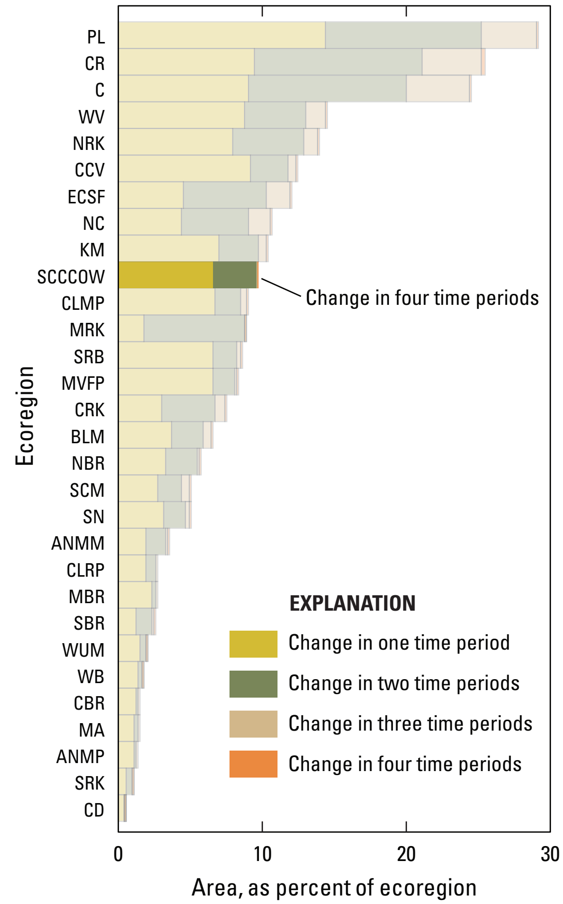

Figure 3. Overall spatial change in Southern and Central California Chaparral and Oak Woodlands Ecoregion (SCCCOW; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Southern and Central California Chaparral and Oak Woodlands Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

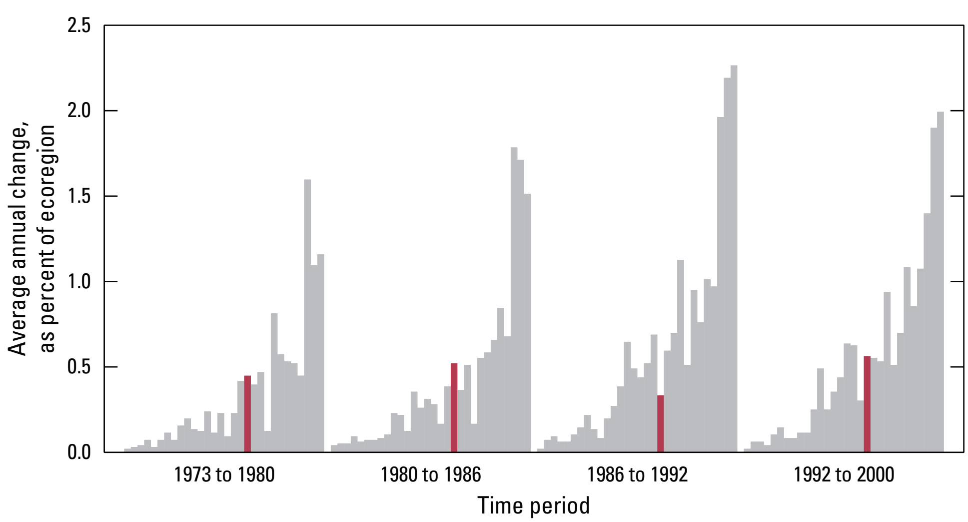

Figure 4. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Southern and Central California Chaparral and Oak Woodlands Ecoregion are represented by red bars in each time period.

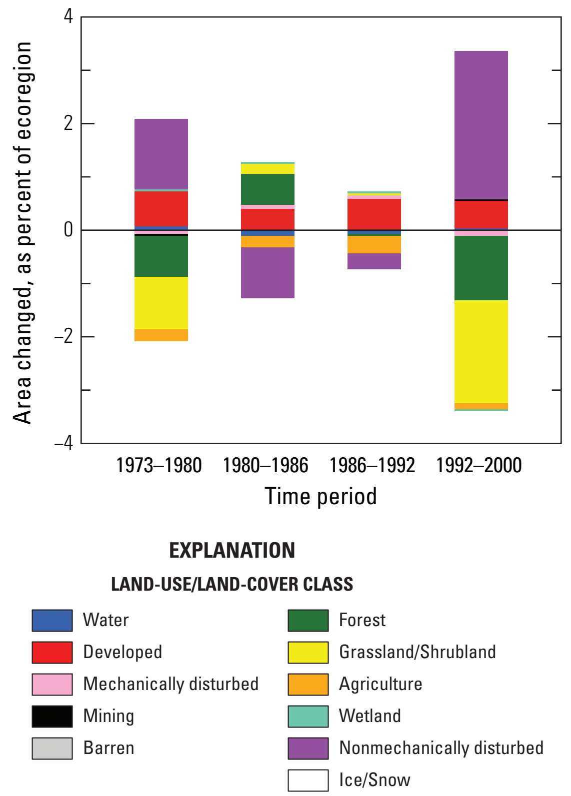

Figure 5. Normalized average net change in Southern and Central California Chaparral and Oak Woodlands Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

disturbed, was the primary cause of land-cover change in areas that experienced two or more changes during the study period. Land-conversion rates varied temporally with the fastest annual rates occurring between 1992 and 2000 (at 0.6 percent) and slowest rate between 1986 and 1992 (at 0.3 percent) (table 2; fig. 4).

Figure 5 provides an overview of the net land-cover change by time period. Forest and grassland/shrubland losses were associated with net increases in nonmechanical disturbances, a conversion normally attributed to fire, which is a major presence in the Southern and Central California Chaparral and Oak Woodlands Ecoregion. Cool, wet winters bring a growth of annual grasses providing the necessary fuel load for fires to spread during the ecoregion's hot, dry summers. Many of the endemic chaparral plant species here are adapted to survive low-frequency fires, and some species even depend on fire as part of their life-cycle strategy (fig. 6; see also, Halsey, 2005). Developed land cover increased throughout the study period and accounted for virtually all of the net change occurring between 1986 and 1992. A net loss of agriculture occurred during each time period in the study. As agriculture here typically occurs on flat, easily developed land, agriculture lands are often best suited for urban expansion (fig. 7).

Figure 6. Grassland/shrubland and forest in Southern and Central California Chaparral and Oak Woodlands Ecoregion, two land-cover classes that are prone to fires during dry summers associated with Mediterranean climate of ecoregion.

Figure 7. Conversion of grassland/shrubland to agriculture was most common nonfire land-cover change in Southern and Central California Chaparral and Oak Woodlands Ecoregion during study period.

Figure 8. Conversions of grassland/shrubland and agriculture to developed land were two common land-cover changes in Southern and Central California Chaparral and Oak Woodlands Ecoregion during study period.

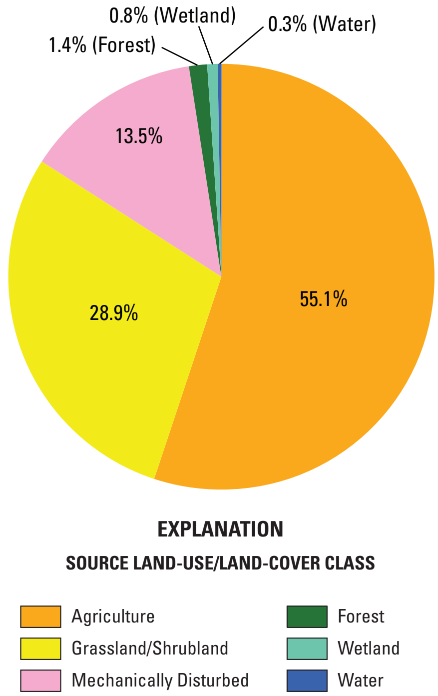

Figure 9. Areal percentages of sources of developed land in Southern and Central California Chaparral and Oak Woodlands Ecoregion during study period.

Grassland/shrubland land cover makes up the largest share of this ecoregion, followed by forest, agriculture, and developed lands (table 3). These four land-cover classes accounted for 96 percent of the ecoregion in 1973 but only 93.2 percent in 2000, largely because of the net increase in nonmechanically disturbed land cover coupled with a decrease in forest and grassland/shrubland land covers. Developed land increased 33 percent during the study period as population in the Southern and Central California Chaparral and Oak Woodlands Ecoregion increased from 14.5 to 22.2 million between 1970 and 2000 (U.S. Census Bureau, 2000). More than half of the land converted to developed land cover came from agriculture, and nearly thirty percent was converted from grassland/shrubland (figs. 8, 9).

Between 1973 and 2000, the five most common land conversions accounted for 73 percent (by area) of the change in the ecoregion (table 4). The most common land-cover conversion was grassland/shrubland to nonmechanically disturbed, accounting for nearly one-quarter of all area converted, whereas forest to nonmechanically disturbed accounted for an additional 19 percent. These conversions largely represent the impact of wildfire in the ecoregion. The third and fifth most common conversions (nonmechanically disturbed back to grassland/shrubland and nonmechanically disturbed back to forest) reflect the cyclic nature of landscape changes associated with wildfire and postfire vegetation recovery. The numbers do not balance because there is a lag time between fire occurrence and the conversion back to the original land cover, especially in the case of forests where an intermediate, successional vegetation cover is likely to occur. The conversion of agriculture to developed land was the fourth most common conversion and accounted for nearly 10 percent of the land-cover change in the ecoregion.

The Southern and Central California Chaparral and Oak Woodlands Ecoregion is the most populous of the nation's ecoregions. Many people find the ecoregion's Mediterranean climate desirable, but little accessible, flat land suitable for affordable housing is available. Additionally, water shortages and drought are common, and much of the ecoregion's water is imported from other ecoregions. Consequently, most of the ecoregion's landscape remains open rangeland with land covers of grassland/shrubland mixed with oak forest. The region's limited farmland is used for specialty crops such as wine grapes, table grapes, and strawberries. New development has resulted in the conversion of some agricultural land, but the largest driver of land-cover change has been the periodic burning of grassland/shrubland and forested land during the ecoregion's long, hot, and dry summers.

Table 1. Percentage of Southern and Central California Chaparral and Oak Woodlands Ecoregion that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (90.3 percent), whereas 9.7 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	6.7	2.3	4.4	9.0	1.5	23.1
2	2.9	1.6	1.3	4.5	1.1	37.9
3	0.1	0.1	0.0	0.1	0.0	50.5
4	0.0	0.0	0.0	0.0	0.0	87.5
Overall spatial change	9.7	2.9	6.7	12.6	2.0	20.8

Table 2. Raw estimates of change in Southern and Central California Chaparral and Oak Woodland. land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	3.1	1.7	1.5	4.8	1.1	36.1	0.4
1980–1986	3.1	1.6	1.5	4.7	1.1	35.8	0.5
1986–1992	2.0	0.9	1.1	2.9	0.6	29.6	0.3
1992–2000	4.5	2.2	2.3	6.8	1.5	33.8	0.6
			Estimate of change, in square kilometers				
1973–1980	3,216	1,704	1,512	4,921	1,161	36.1	459
1980–1986	3,149	1,653	1,496	4,802	1,126	35.8	525
1986–1992	2,037	. 885	1,151	2,922	. 603	29.6	339
1992–2000	4,607	2,286	2,321	6,893	1,557	33.8	576

Table 3. Estimated area (and margin of error) of each land-cover class in Southern and Central California Chaparral and Oak Woodlands Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	2.5	1.7	6.6	3.6	0.1	0.1	0.2	0.2	0.3	0.3	21.3	4.2	58.0	5.7	10.1	3.1	0.6	0.4	0.3	0.2
1980	2.5	1.7	7.3	4.0	0.1	0.1	0.2	0.2	0.3	0.3	20.5	4.0	57.0	5.7	9.9	3.1	0.6	0.4	1.6	1.6
1986	2.5	1.7	7.7	4.0	0.2	0.1	0.2	0.2	0.3	0.3	21.1	4.1	57.2	5.6	9.7	3.0	0.6	0.4	0.6	0.6
1992	2.4	1.7	8.3	4.2	0.2	0.1	0.2	0.2	0.3	0.3	21.0	4.0	57.2	5.7	9.4	3.0	0.6	0.4	0.3	0.2
2000	2.5	1.7	8.8	4.4	0.1	0.1	0.2	0.2	0.3	0.3	19.8	3.5	55.3	5.6	9.3	3.0	0.6	0.4	3.1	2.1
Net change	0.0	0.1	2.2	1.4	0.0	0.1	0.0	0.1	0.0	0.0	−1.5	1.6	−2.7	1.3	−0.8	1.1	0.0	0.0	2.8	2.0
Gross change	0.4	0.3	2.2	1.4	0.6	0.3	0.1	0.1	0.0	0.0	3.2	2.4	6.1	2.2	2.3	1.1	0.1	0.1	7.5	3.8
Area, in square kilometers																				
1,973	2,507	1,776	6,743	3,650	140	112	199	234	339	291	21,741	4,296	59,216	5,777	10,340	3,200	627	424	257	212
1,980	2,601	1,773	7,417	4,039	62	71	188	220	338	291	20,924	41,20	58,220	5,783	10,121	3,170	644	440	1,595	1,586
1,986	2,505	1,770	7,836	4,101	155	93	187	220	338	291	21,520	4,216	58,408	5,763	9,905	3,103	654	428	602	598
1,992	2,455	1,772	8,456	4,279	216	140	168	161	337	291	21,491	4,133	58,447	5816	9,563	3,069	663	432	315	221
2,000	2,502	1,773	8,977	4,443	116	71	214	169	346	291	20,234	3,611	56,471	5,707	9,478	3,043	626	416	3,146	2,097
Net change	−5	55	2,234	1,381	−25	99	15	88	7	15	−1,506	1,677	−2,746	1,326	−862	1,170	−1	31	2,889	2,057
Gross change	447	278	2,234	1,381	612	314	135	91	13	15	3,305	2,499	6,221	2,247	2,346	1,076	116	80	7,620	3,843

Table 4. Principal land-cover conversions in Southern and Central California Chaparral and Oak Woodlands Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Nonmechanically disturbed	825	990	674	0.8	25.6
	Grassland/Shrubland	Nonmechanically disturbed	755	803	547	0.7	23.5
	Agriculture	Developed	481	437	298	0.5	14.9
	Grassland/Shrubland	Agriculture	409	306	209	0.4	12.7
	Nonmechanically disturbed	Grassland/Shrubland	226	186	127	0.2	7.0
	Other	Other	520	n/a	n/a	0.5	16.2
		Totals	3,216			3.1	100.0
1980–1986	Nonmechanically disturbed	Grassland/Shrubland	810	841	573	0.8	25.7
	Nonmechanically disturbed	Forest	769	926	631	0.8	24.4
	Grassland/Shrubland	Nonmechanically disturbed	448	523	357	0.4	14.2
	Agriculture	Developed	210	184	125	0.2	6.7
	Agriculture	Grassland/Shrubland	156	141	96	0.2	5.0
	Other	Other	756	n/a	n/a	0.7	24.0
		Totals	3,149			3.1	100.0
1986–1992	Nonmechanically disturbed	Grassland/Shrubland	485	526	358	0.5	23.8
	Agriculture	Developed	327	328	224	0.3	16.1
	Grassland/Shrubland	Developed	210	124	85	0.2	10.3
	Grassland/Shrubland	Nonmechanically disturbed	169	123	84	0.2	8.3
	Forest	Nonmechanically disturbed	134	170	116	0.1	6.6
	Other	Other	712	n/a	n/a	0.7	34.9
		Totals	2,037			2.0	100.0
1992–2000	Grassland/Shrubland	Nonmechanically disturbed	1,771	1,230	838	1.7	38.4
	Forest	Nonmechanically disturbed	1,353	1,589	1,082	1.3	29.4
	Grassland/Shrubland	Agriculture	261	174	119	0.3	5.7
	Agriculture	Developed	213	147	100	0.2	4.6
	Grassland/Shrubland	Developed	183	107	73	0.2	4.0
	Other	Other	826	n/a	n/a	0.8	17.9
		Totals	4,607			4.5	100.0
1973–2000 (overall)	Grassland/Shrubland	Nonmechanically disturbed	3,144	1,643	1,119	3.1	24.2
	Forest	Nonmechanically disturbed	2,442	2,018	1,375	2.4	18.8
	Nonmechanically disturbed	Grassland/Shrubland	1,680	1,080	736	1.6	12.9
	Agriculture	Developed	1,230	931	634	1.2	9.5
	Nonmechanically disturbed	Forest	1,007	939	640	1.0	7.7
	Other	Other	3,506	n/a	n/a	3.4	27.0
		Totals	13,009			12.7	100.0

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Cold Deserts Ecoregions

Chapter 20

Central Basin and Range Ecoregion

By Christopher E. Soulard

This chapter has been modified from original material published in Soulard (2006), entitled “Land-cover trends of the Central Basin and Range Ecoregion” (U.S. Geological Survey Scientific Investigations Report 2006–5288).

Ecoregion Description

The Central Basin and Range Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) encompasses approximately 343,169 km² (132,498 mi²) of land bordered on the west by the Sierra Nevada Ecoregion, on the east by the Wasatch and Uinta Mountains Ecoregion, on the north by the Northern Basin and Range and the Snake River Basin Ecoregions, and on the south by the Mojave Basin and Range and the Colorado Plateaus Ecoregions (fig. 1). Most of the Central Basin and Range Ecoregion is located in Nevada (65.4 percent) and Utah (25.1 percent), but small segments are also located in Idaho (5.6 percent), California (3.7 percent), and Oregon (0.2 percent). Basin-and-range topography characterizes the Central Basin and Range Ecoregion: wide desert valleys are bordered by parallel mountain ranges generally oriented north-south. There are more than 33 peaks within the Central Basin and Range Ecoregion that have summits higher than 3,000 m

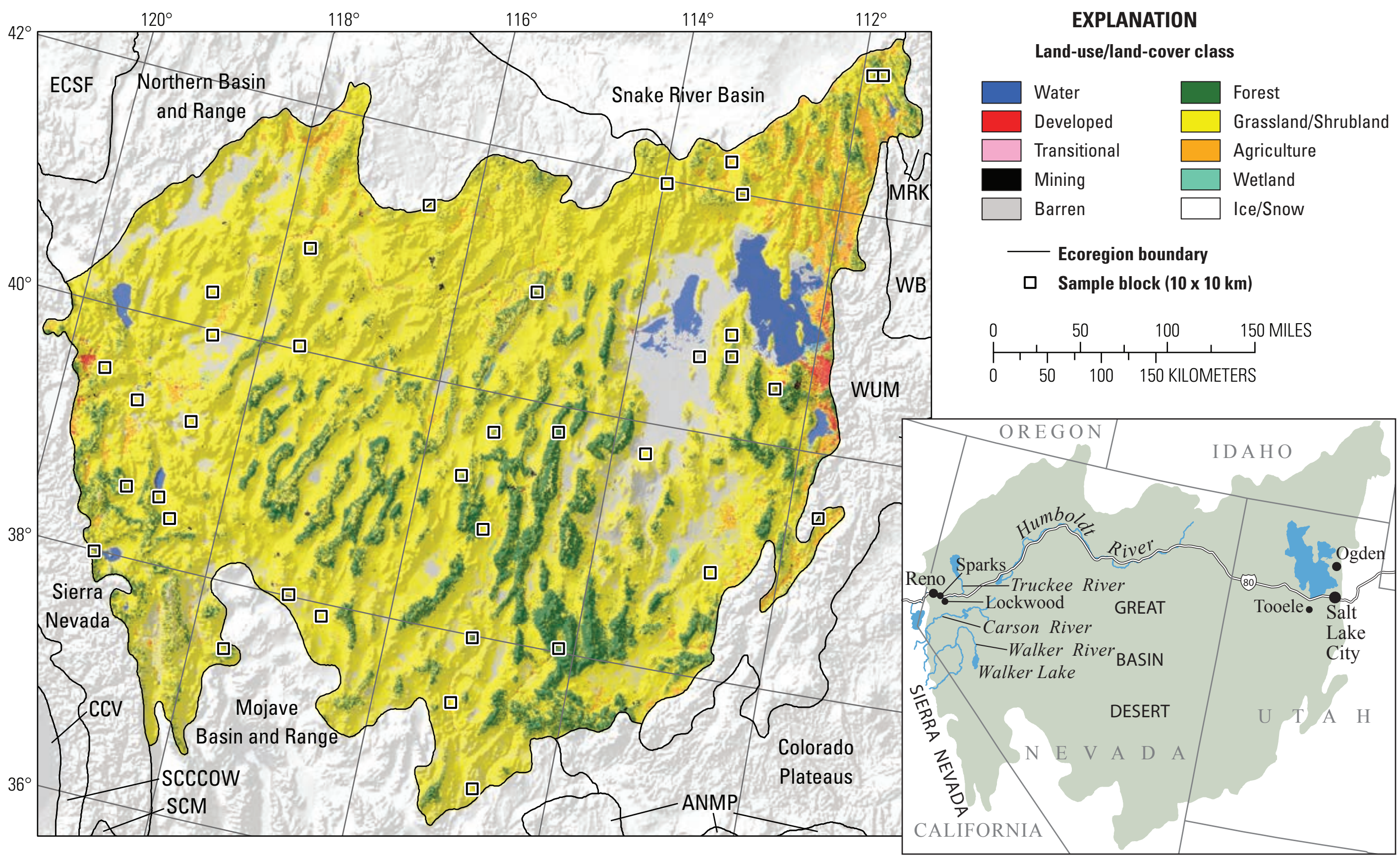

Figure 1. Map of Central Basin and Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

(10,000 ft), but valleys in the ecoregion are also high, most having elevations above 1,200 m (4,000 ft) (Grayson, 1993).

The Central Basin and Range Ecoregion's high elevation and location between mountain ranges influences regional climate. The Sierra Nevada to the west produces a rain shadow effect that blocks moisture from the Pacific Ocean, and the Rocky Mountains to the east creates a barrier effect that restricts moisture from the Gulf of Mexico (Rogers, 1982). This lack of moisture creates the Great Basin Desert (encompassed within the Central Basin and Range Ecoregion), which is one of the four biologically distinct deserts in North America, along with the Mojave, Sonoran, and Chihuahuan Deserts (Grayson, 1993). The Great Basin has the coldest climate of these deserts. As opposed to the other North American deserts, precipitation within the Great Basin regularly falls in winter as snow (Mac and others, 1998). Because no natural drainages exist within the Central Basin and Range Ecoregion, the little precipitation that does fall either drains to ephemeral or saline lakes by means of streams or disappears through evaporation and (or) absorption into the soil (Grayson, 1993).

Inhospitable conditions, such as harsh climate, infertile soils, and lack of viable resources, have been a formidable barrier to human land use in the Central Basin and Range Ecoregion. These conditions also restrict ecoregion resilience, which results in lasting impacts from most land-use practices. This ecoregion is very sensitive to those land-use changes that do occur (Mac and others, 1998; Pellant and others, 2004; Chambers and Miller, 2004). Much as with the historical land-use legacies of the ecoregion, factors that have driven contemporary change in the ecoregion have the potential to produce long-term consequences. For example, the poor soil quality and low rainfall characteristic of the ecoregion make successful farming difficult. As a way to overcome these obstacles, farmers either establish irrigation-dependent crops near rare riparian segments or rely on groundwater pumping and water diversions. Water diversions from the Carson, Humboldt, Truckee, and Walker Rivers have shifted to accommodate irrigation demand (particularly to support the ranching industry), municipal-water demand in regional cities (for example, Reno, Nevada), and government-mandated water conservation. Shifts in agricultural land use across the Central Basin and Range Ecoregion degrade ecosystems vital to the fitness of many vertebrates and invertebrates. This degradation is manifested as livestock trampling of native vegetation (in wetlands and grasslands) and lowered water tables in places like Walker Lake (Mac and others, 1998).

The arid climate and abundance of dry fuel sources also make the ecoregion naturally susceptible to fire. This susceptibility has been magnified since European settlement in the late 1800s. Early settlers changed the composition of grasslands and shrublands by introducing livestock grazing and fire-suppression practices within the sagebrush-dominated landscape. Grazing and fire suppression have continued to the present day and have shaped the grassland/shrubland landscape by degrading sagebrush plant communities and enabling nonnative annual grasses to invade much of the ecoregion (Miller and others, 2001). These grasses, most notably cheatgrass (*Bromus tectorum*), not only contribute to a rise in fire susceptibility across the ecoregion by increasing dry fuel sources but also reestablish themselves more easily than native plants following fires, thereby perpetuating and magnifying the cycle of fires (Pellant and others, 2004). Historical and contemporary land-use practices have produced lasting impacts in the Central Basin and Range Ecoregion by changing the fire regime and making the ecoregion more susceptible to fire. The increased probability of fire poses long-term risks for human and natural systems.

Contemporary Land-Cover Change (1973 to 2000)

Land-use/land-cover change between 1973 and 2000 that was discernable using a 60-m mapping unit was minimal, especially when compared to other ecoregions of the western

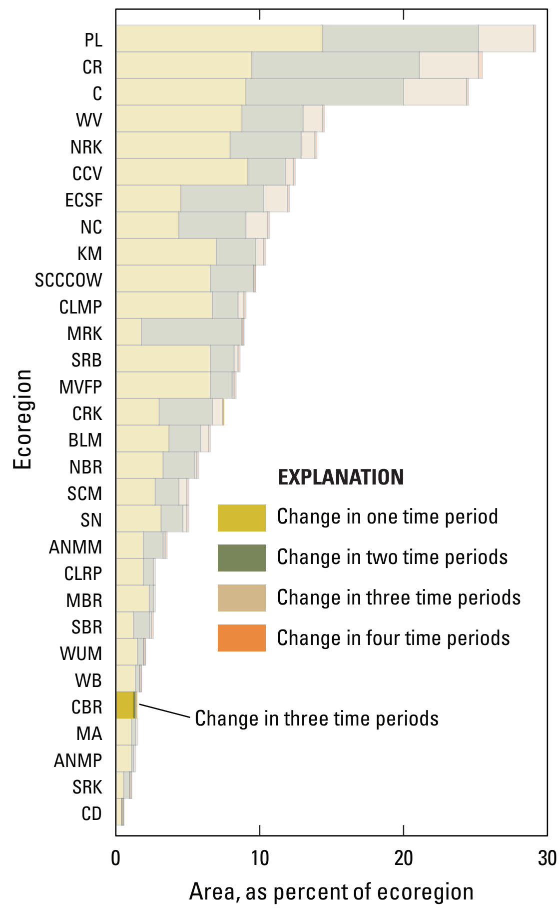

Figure 2. Overall spatial change in Central Basin and Range Ecoregion (CBR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Central Basin and Range Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

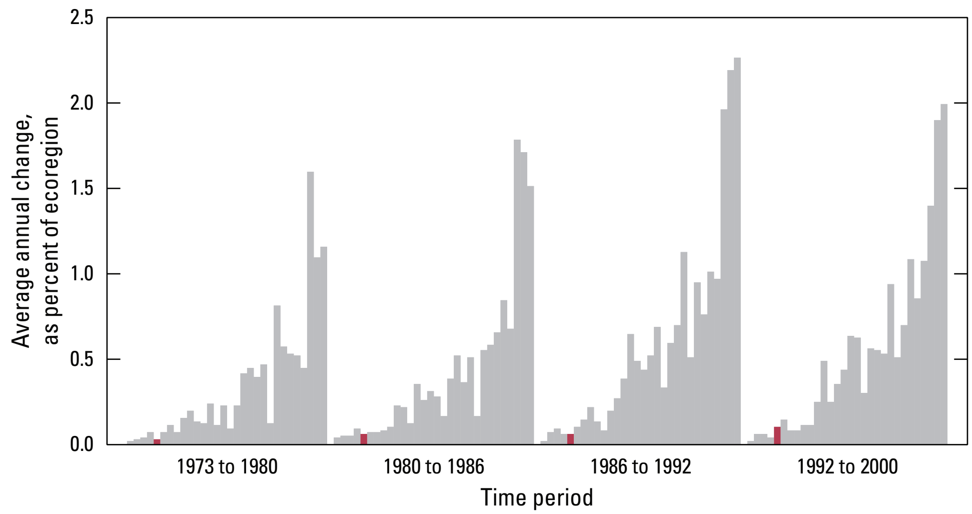

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Central Basin and Range Ecoregion are represented by red bars in each time period.

United States (fig. 2). Between 1973 and 2000, the footprint (overall areal extent) of land-cover change in the Central Basin and Range Ecoregion was only 1.5 percent, or 4,979 km². The footprint of change can be interpreted as the area in the Central Basin and Range Ecoregion that experienced change during at least one of the four multiyear periods that make up the 27-year study period; it does not account for the frequency of change in any given location. This overall spatial change translates to 4,461 km² that changed in one period, 343 km² that changed in two periods, and 166 km² that changed in three periods (table 1).

The normalized annual rate of land-cover change in the Central Basin and Range Ecoregion between 1973 and 2000 was less than 0.1 percent per year. This means that the ecoregion averaged less than 0.1 percent (206 km²) of change each year in the 27-year study period. Between 1973 and 1980, the annual rate of change in the Central Basin and Range Ecoregion was less than 0.1 percent per year, while the annual rate of change increased to about 0.1 percent per year between 1980 and 1986, 1986 and 1992, and 1992 and 2000 (table 2; fig. 3).

Of the 11 land-use/land-cover classes, 4 dominated the landscape of the Central Basin and Range Ecoregion in 2000: grassland/shrubland (75.4 percent), forest (15.3 percent), barren (3.9 percent), and agriculture (2.9 percent). The remaining seven classes cumulatively made up the remaining 2.5 percent of the Central Basin and Range Ecoregion landscape in 2000 (table 3).

Between 1973 and 2000, the land-cover classes that experienced a measurable net change include grassland/shrubland (0.8 percent decrease), forest (1.9 percent decrease), developed (43 percent increase), wetland (12.2 percent decrease), mining (159 percent increase, but still representing just 0.2 percent of the ecoregion), and nonmechanically disturbed (which was not present until the 2000 classification, when it occupied 0.5 percent of the sampled area). Net change by temporal period is illustrated in figure 4.

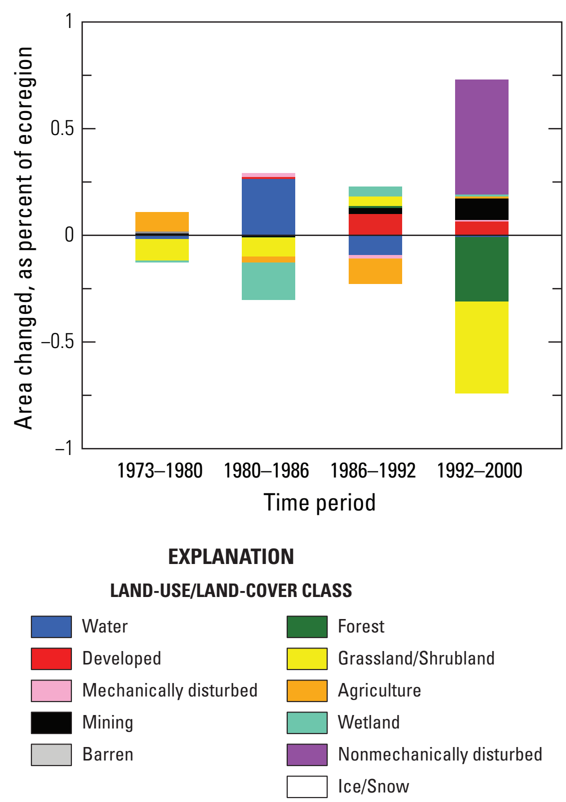

Figure 4. Normalized average net change in Central Basin and Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 2 for definitions of land-use/land-cover classifications.

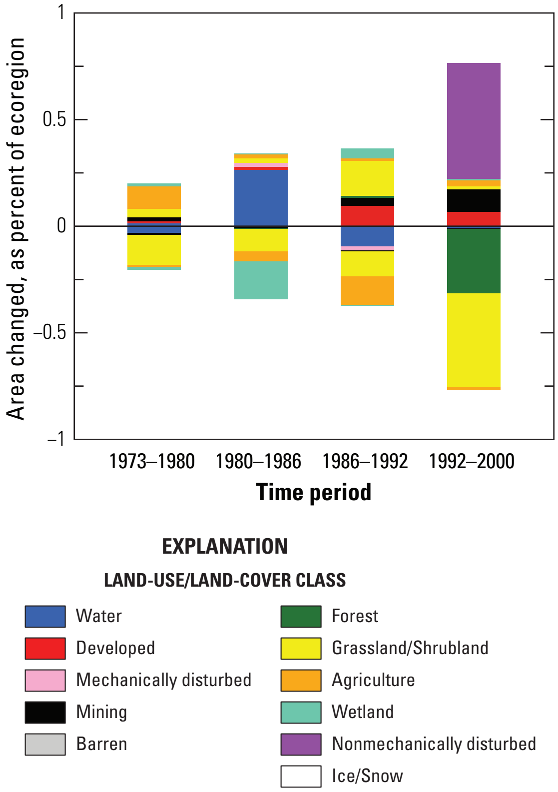

Figure 5. Gross change (area gained and lost) in Central Basin and Range Ecoregion by time period for each land-cover class. Area gained is shown by positive values, and area lost is shown by negative values. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 2 for definitions of land-use/land-cover classifications.

Figure 6. Instances of agriculture in Central Basin and Range Ecoregion. *A*, Livestock grazing on rangeland. *B*, Irrigated fields growing livestock feed.

Net change, however, is not necessarily the best indicator of within-class variability for those classes experiencing spatio-temporal fluctuations (fig. 5). For instance, areas classified as water fluctuated wildly between 259 km^2 (1980) and 1,168 km^2 (1986) because of the ephemeral nature of desert lakes. Between 1973 and 2000, a net areal gain of 172 percent (518 km^2) in water was measured, but gross change over the entire study period reached 1,420 km^2, nearly five times the area that water occupied in 1973.

The "from class–to class" information afforded by a postclassification comparison was used to identify land-cover class conversions and rank them according to their magnitude. Table 4 illustrates the most frequent conversions for each individual time period and also between 1973 and 2000. Although fieldwork confirmed the presence of many of the conversions listed in table 4, the ability to report these changes on the basis of interpretations was accomplished with varying degrees of uncertainty (as illustrated by the statistical error values in the table). In general, higher uncertainty arose where sampled changes were clustered within certain parts of the ecoregion rather than distributed evenly across the ecoregion.

The two most prominent conversions reflect the natural, or nonmechanical, disturbance of natural land cover by fire. Cumulatively, the effect of nonmechanical disturbance on grassland/shrubland and forest resulted in 1,872 km^2 (32.5 percent of all changes) loss of vegetated land cover. As discussed earlier, the increase in fire seen within the Central Basin and Range Ecoregion is largely attributable to the invasion of annual grasses like cheatgrass (*Bromus tectorum*), which has increased dry fuels on the landscape. The changes in the agriculture and water classes represent other common conversions. Prominent changes in agricultural lands include 527 km^2 of conversion from grassland/shrubland to agriculture and 503 km^2 from agriculture to grassland/shrubland (fig. 3). Similarly, the water class experienced a variety of conversions within the Central Basin and Range Ecoregion, including 640 km^2 from wetland to water, 255 km^2 from water to grassland/shrubland, 222 km^2 from grassland/shrubland to water, and 178 km^2 from water to wetland (note that water conversions account for changes in both natural and manmade water bodies). Ultimately, these land-use dynamics vary across the ecoregion and, as noted earlier, are associated with irrigation demand (to support the ranching industry), municipal-water demand in cities (for

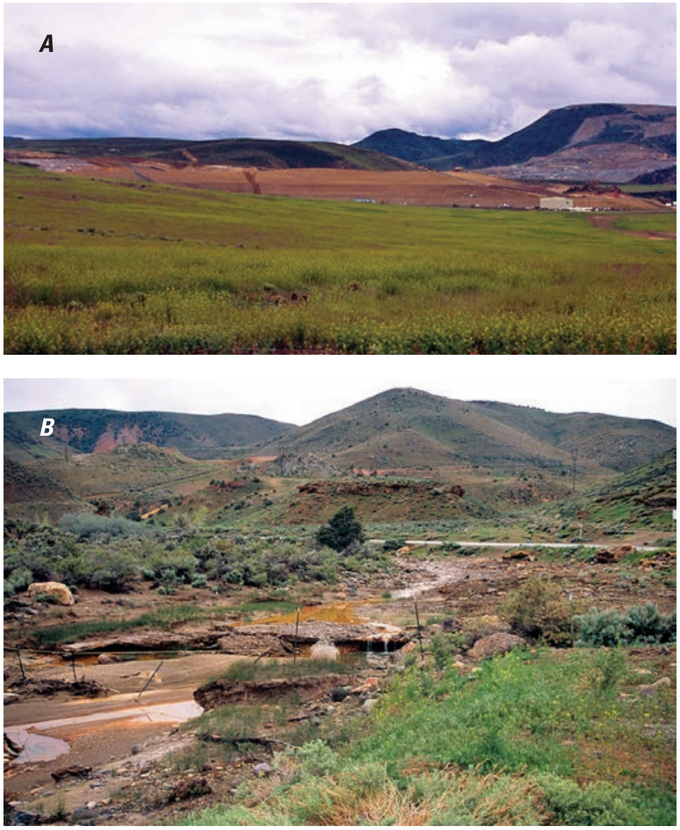

Figure 7. Hillside municipal-waste facility (*A*) and its downhill stream drainage (*B*) near Lockwood, Nevada.

example, Reno, Nevada), and government-mandated water conservation. Changes from grassland/shrubland to both developed (538 km²) and mining (526 km²) were predominantly unidirectional and permanent (figs. 6,7,8).

Contemporary land-use/land-cover change has been minimal throughout the Central Basin and Range Ecoregion. However, landscape changes that result from increased fire frequency, rising demand for water and mineral resources, and growing highway development can have far-reaching consequences despite the small spatial extent of change. For example, increased fire frequency in the Central Basin and Range Ecoregion has ultimately contributed to the loss of sagebrush plant communities in favor of invasive annual grasses (Miller and others, 2001), resulting in possible impacts on biological diversity and human health. Much of the wildlife that depends on this vegetated landscape may become more vulnerable as a result of loss of habitat following a fire. Fire also directly threatens human communities and indirectly affects humans by jeopardizing traditional ranging practices (U.S. Geological Survey, 2003). Agricultural and developed land-use changes also have possible impacts, including pollution from agricultural and municipal sources as well as mechanical disturbances associated with water and mineral-resource use. Although wildlife has proven to be resilient to anthropogenic land use, the loss of natural vegetation resulting

Figure 8. Different elements of mining in Central Basin and Range Ecoregion. *A*, Gravel-extraction site near Tooele, Utah. *B*, Piles of gravel aggregate awaiting transport. *C*, Mineral-processing facility along Interstate 80 near Reno, Nevada. *D*, Old tailings pile undergoing reestablishment of vegetation.

from the afore-mentioned changes has both eliminated and polluted ecosystems used by endangered species such as the Greater Sage Grouse (*Centrocercus urophasianus*).

The growth of human populations in the Reno–Sparks and Salt Lake City–Ogden metropolitan areas will likely dictate the rate of future land-use conversions in the Central Basin and Range Ecoregion. The findings from the present study can be used in conjunction with existing literature to explore how, and to what extent, current land-use/land-cover trends will affect the Central Basin and Range Ecoregion into the future, and they also can provide insights into how policy change may alter current landscape conditions.

Table 1. Percentage of Central Basin and Range Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (98.5 percent), whereas 1.5 percent changed at least once throughout study period. Two dashes (--) indicate that, because zero pixels changed four times during study period, relative error is not calculable]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.3	0.7	0.6	1.9	0.4	35.0
2	0.1	0.1	0.0	0.2	0.1	59.7
3	0.0	0.0	0.0	0.1	0.0	65.9
4	0.0	0.0	0.0	0.0	0.0	--
Overall spatial change	1.5	0.7	0.7	2.2	0.5	34.2

Table 2. Raw estimates of change in Central Basin and Range Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.2	0.1	0.1	0.3	0.1	48.2	0.0
1980–1986	0.3	0.3	0.0	0.7	0.2	69.5	0.1
1986–1992	0.4	0.2	0.2	0.5	0.1	34.1	0.1
1992–2000	0.8	0.6	0.2	1.3	0.4	49.4	0.1
Estimate of change, in square kilometers							
1973–1980	698	495	202	1,193	337	48.2	100
1980–1986	1,163	1,190	–27	2,354	808	69.5	194
1986–1992	1,254	629	624	1,883	428	34.1	209
1992–2000	2,638	1,918	721	4,556	1,303	49.4	330

Table 3. Estimated area (and margin of error) of each land-cover class in Central Basin and Range Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.1	0.1	0.4	0.4	0.0	0.0	0.1	0.1	3.9	3.6	15.6	5.1	75.9	5.7	2.9	2.1	1.0	0.7	0.0	0.0
1980	0.1	0.1	0.4	0.4	0.0	0.0	0.1	0.1	3.9	3.6	15.6	5.1	75.8	5.7	3.0	2.2	1.0	0.7	0.0	0.0
1986	0.3	0.4	0.5	0.4	0.0	0.0	0.1	0.1	3.9	3.6	15.6	5.1	75.8	5.7	3.0	2.2	0.8	0.7	0.0	0.0
1992	0.2	0.3	0.6	0.4	0.0	0.0	0.1	0.1	3.9	3.6	15.6	5.1	75.8	5.7	2.9	2.1	0.9	0.7	0.0	0.0
2000	0.2	0.3	0.6	0.4	0.0	0.0	0.2	0.2	3.9	3.6	15.3	4.8	75.4	5.6	2.9	2.1	0.9	0.7	0.5	0.6
Net change	0.2	0.3	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.0	−0.3	0.4	−0.6	0.5	0.0	0.1	−0.1	0.2	0.5	0.6
Gross change	0.4	0.5	0.2	0.1	0.0	0.1	0.2	0.1	0.0	0.0	0.3	0.4	1.0	0.5	0.3	0.2	0.2	0.3	0.5	0.6
Area, in square kilometers																				
1973	302	278	1,510	1,256	0	0	312	317	13,320	12,282	53,407	17,337	260,616	19,717	10,060	7,371	3,509	2,405	0	0
1980	259	246	1,530	1,261	0	0	345	307	13,323	12,282	53,407	17,337	260,266	19,706	10,401	7,401	3,506	2,403	0	0
1986	1,168	1,219	1,581	1,262	61	89	336	280	13,323	12,282	53,384	17,341	259,975	19,699	10,302	7,396	2,906	2,281	0	0
1992	847	968	1,922	1,308	0	0	454	328	13,323	12,282	53,400	17,343	260,129	19,580	9,905	7,150	3,055	2,281	0	0
2000	820	930	2,159	1,368	12	18	806	520	13,323	12,282	52,366	16,615	258,664	19,382	9,932	7,131	3,082	2,283	1,872	1,916
Net change	518	925	649	484	12	18	494	349	3	5	−1,041	1,471	−1,952	1,580	−128	434	−428	628	1,872	1,916
Gross change	1,420	1,575	649	484	134	179	570	375	3	5	1,074	1,470	3,311	1,578	1,150	629	782	1,133	1,872	1,916

Table 4. Principal land-cover conversions in Central Basin and Range Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	352	353	240	0.1	50.5
	Water	Grassland/Shrubland	101	148	101	0.0	14.5
	Grassland/Shrubland	Mining	62	51	34	0.0	8.9
	Wetland	Water	39	57	38	0.0	5.5
	Grassland/Shrubland	Wetland	37	55	37	0.0	5.3
	Other	Other	106	n/a	n/a	0.0	15.2
		Totals	698			0.2	100.0
1980–1986	Wetland	Water	600	874	594	0.2	51.6
	Grassland/Shrubland	Water	202	234	159	0.1	17.3
	Agriculture	Water	108	158	107	0.0	9.3
	Grassland/Shrubland	Agriculture	55	57	39	0.0	4.8
	Grassland/Shrubland	Developed	51	46	31	0.0	4.4
	Other	Other	147	n/a	n/a	0.0	12.7
		Totals	1,163			0.3	100.0
1986–1992	Agriculture	Grassland/Shrubland	399	320	218	0.1	31.8
	Grassland/Shrubland	Developed	243	193	131	0.1	19.4
	Water	Grassland/Shrubland	154	225	153	0.0	12.3
	Water	Wetland	149	214	145	0.0	11.9
	Grassland/Shrubland	Mining	126	117	79	0.0	10.1
	Other	Other	182	n/a	n/a	0.1	14.5
		Totals	1,254			0.4	100.0
1992–2000	Forest	Nonmechanically disturbed	1,005	1,471	1,000	0.3	38.1
	Grassland/Shrubland	Nonmechanically disturbed	867	1,269	862	0.3	32.9
	Grassland/Shrubland	Mining	328	252	171	0.1	12.4
	Grassland/Shrubland	Developed	224	198	135	0.1	8.5
	Grassland/Shrubland	Agriculture	85	124	84	0.0	3.2
	Other	Other	130	n/a	n/a	0.0	4.9
		Totals	2,638			0.8	100.0
1973–2000 (overall)	Forest	Nonmechanically disturbed	1,005	1,471	1,000	0.3	17.5
	Grassland/Shrubland	Nonmechanically disturbed	867	1,269	862	0.3	15.1
	Wetland	Water	640	932	633	0.2	11.1
	Grassland/Shrubland	Developed	538	386	262	0.2	9.4
	Grassland/Shrubland	Agriculture	527	413	281	0.2	9.2
	Other	Other	2,177	n/a	n/a	0.6	37.8
		Totals	5,753			1.7	100.0

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Chapter 21

Colorado Plateaus Ecoregion

By Michael P. Stier

Ecoregion Description

The Colorado Plateaus Ecoregion covers approximately 129,617 km^2 (50,045 mi^2) within southern and eastern Utah, western Colorado, and the extreme northern part of Arizona (fig. 1). The terrain of this ecoregion is characterized by broad plateaus, ancient volcanoes, and deeply dissected canyons (Booth and others, 1999; fig. 2). The ecoregion is bounded on the east by the Wyoming Basin and Southern Rockies Ecoregions in Colorado and on the northwest by the Wasatch and Uinta Mountains Ecoregion in northern and central Utah. To the south, the ecoregion borders the Arizona/New Mexico Plateau Ecoregion, which has a higher elevation and more grasslands than the Colorado Plateaus Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997).

The climate in the ecoregion is arid to semiarid, with only 15 to 40 cm of annual precipitation. Higher elevation areas such as the La Sal Mountains receive more precipitation and support a mixed forest of ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), quaking aspen (*Populus tremuloides*), and Engelmann spruce (*Picea engelmannii*). Most other locations of the ecoregion are covered by an extensive woodland zone, which is dominated by a “pygmy forest” of pinyon pine (*Pinus edulis*) and several species of juniper (*Juniperus* spp.; fig. 3). The ground between these trees is sparsely covered by blue grama (*Bouteloua gracilis*), shrubs such as big sagebrush (*Artemisia tridentata*) and alderleaf cercocarpus (*Cercocarpus montanus*), and various herbs (McGinley, 2007). Grassland/shrubland land cover accounts for approximately 63 percent of the

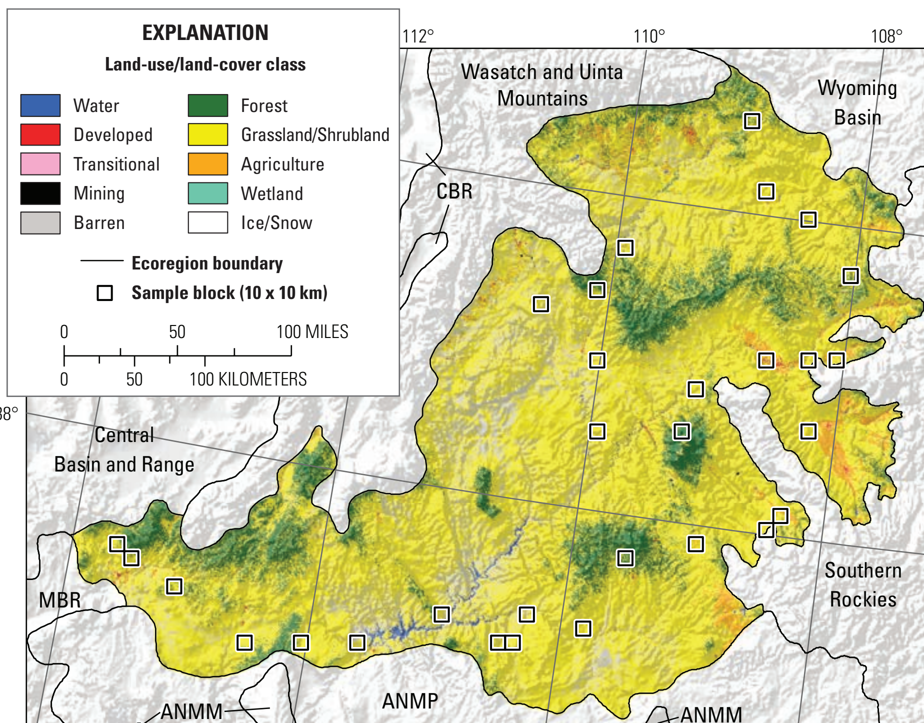

Figure 1. Map of Colorado Plateaus Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. Shrubland plateau dissected by canyons in Colorado Plateaus Ecoregion.

Figure 3. Mix of junipers and pinyon pine in eastern part of Colorado Plateaus Ecoregion.

ecoregion, whereas the remainder is covered by forest (25 percent), agriculture (6 percent), barren (4 percent), developed (1 percent), water (0.5 percent), wetland (0.4 percent), and mining (0.1 percent). The land-cover makeup of the ecoregion is summarized in table 3, which shows the percent land cover by type in the year 2000 (see appendix 3 for definitions of land-cover classifications).

From the Paleozoic into the Mesozoic era (600 to 300 million years ago), thick layers of limestone, sandstone, siltstone, and shale were deposited in shallow marine waters and then overlain by eolian deposits. Layers of sediment accumulated for millions of years on a thick crustal block that became the foundation of the Colorado Plateaus Ecoregion. As the plateau started to rise because of tectonic activity about 10 million years ago, streams that would become the present-day Colorado and Green Rivers carved down through the colorful (reds, purples, and oranges, stained by iron and other minerals) sedimentary rocks (Booth and others, 1999). Erosional processes created the arroyos, canyons, mesas, buttes, monuments, towers, and cliffs that make up the dramatic landscape we see today (fig. 4).

Because the Colorado Plateaus Ecoregion has been stable geologically (in other words, little rock deformation by faulting and folding) within the last 500 million years, conditions were ideal to create, preserve, and then reveal the unique rock formations and landforms (Wheeler, 1990). As a result of extensive conservation efforts, numerous U.S. National Parks, Forests, and Monuments have been established to protect, and preserve access to, these unique features. These extensive federal lands, coupled with Bureau of Land Management rangelands, account for nearly 55 percent of the ecoregion area. The remaining public land in the ecoregion is tribal land (24 percent) or held by state and local governments (6 percent). Private lands account for an estimated 15 percent of the entire ecoregion (Booth and others, 1999).

Today (2012), with the easy access provided by Interstate Highways 15 and 70 and secondary roads through the ecoregion to numerous wilderness areas and National Parks and Monuments, the area has become a tourist mecca. National Park visits increased 94 percent between 1981 and 1994, and recreation and tourism has become one of the ecoregion's largest industries (Hecox and Ack, 1996). Other major economic activities include ranching, farming, timber harvesting, and mining. From the late 1800s to the 1950s, gold, silver, and uranium mining were the major economic drivers in the region. Since the 1970s, increased demands have made coal, oil, and

Figure 4. Mesas, towers, and monuments just east of Moab, Utah.

Figure 5. Coal power plant in eastern part of Colorado Plateaus Ecoregion near Grand Junction, Colorado.

gas the primary targets of mining and energy exploration in the Colorado Plateaus Ecoregion (fig. 5).

As the tourism and energy-exploration industries grew, the number of new jobs increased 225 percent between 1970 and 2000, 140 percent faster than the national average (van Riper and Mattson, 2005). Approximately 95 percent of all new jobs were service based. Resource-based employment in farming and mining only made up 2 percent of this growth (8,728 jobs), whereas manufacturing provided the remaining 3 percent (14,038 jobs) during this period (van Riper and Mattson, 2005). Service-based employment accounted for nearly 90 percent of all jobs within the Colorado Plateaus Ecoregion by 2000. All these factors indicate a rapid conversion from resource-extractive to service-based industries in the ecoregion during the study period.

Contemporary Land-Cover Change (1973 to 2000)

An estimated 2.6 percent of the land cover in the Colorado Plateaus Ecoregion changed at least once between 1973 and 2000 (table 1). Overall, the ecoregion experienced a low amount of land-cover conversion when compared to other western ecoregions (fig. 6). An estimated 0.6 percent of the ecoregion experienced change in more than one of the four time periods analyzed (table 2). Much of the land-cover change involved the expansion of developed land that accompanied employment increases and population growth. Change within the four individual time periods ranged from a low of 0.6 percent between 1980 and 1986 to a high of 1.1 percent between 1973 and 1980 (table 2). When the estimates are normalized to an annual average, accounting for varying lengths of study periods, the period between 1973 and 1980 experienced the highest normalized annual rate of change, at 0.15 percent (196 km^2; fig. 7). The other three time periods were relatively stable, at approximately 0.1 percent change per year.

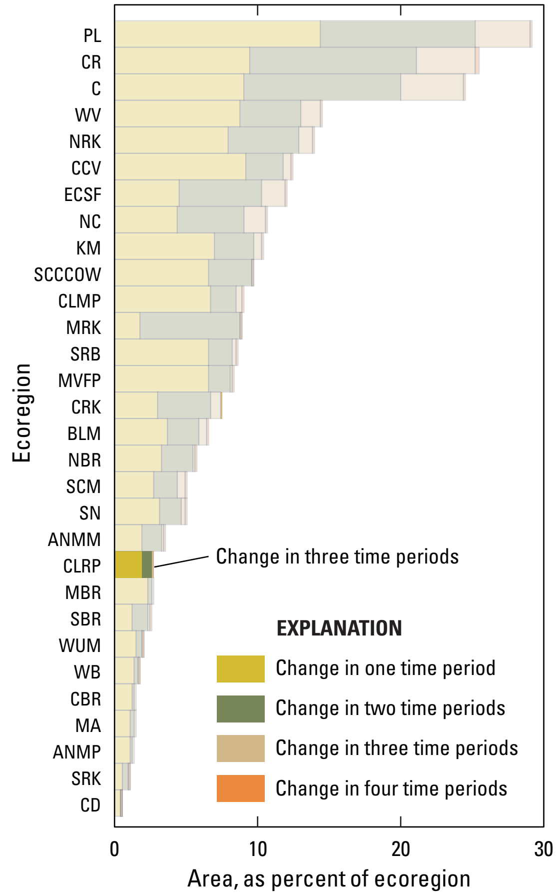

Figure 6. Overall spatial change in Colorado Plateaus Ecoregion (CLRP; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Colorado Plateaus Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

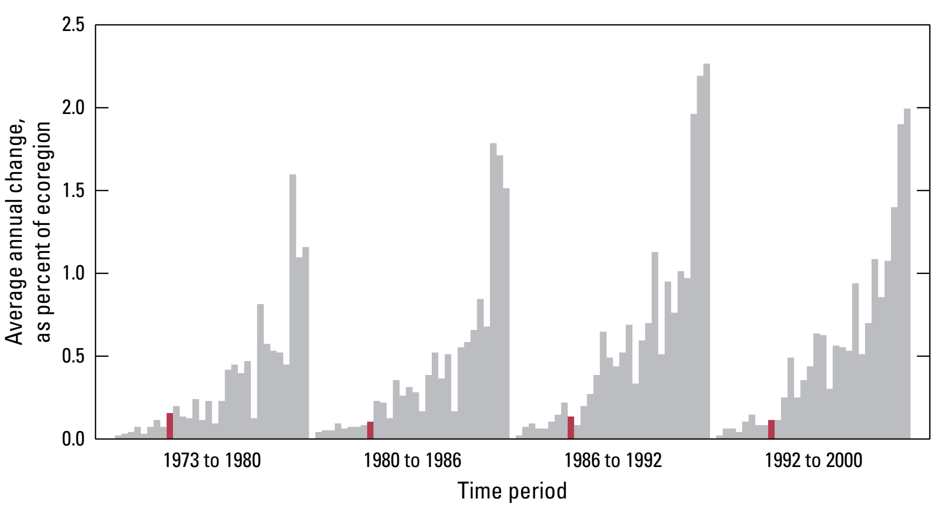

Figure 7. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Colorado Plateaus Ecoregion are represented by red bars in each time period.

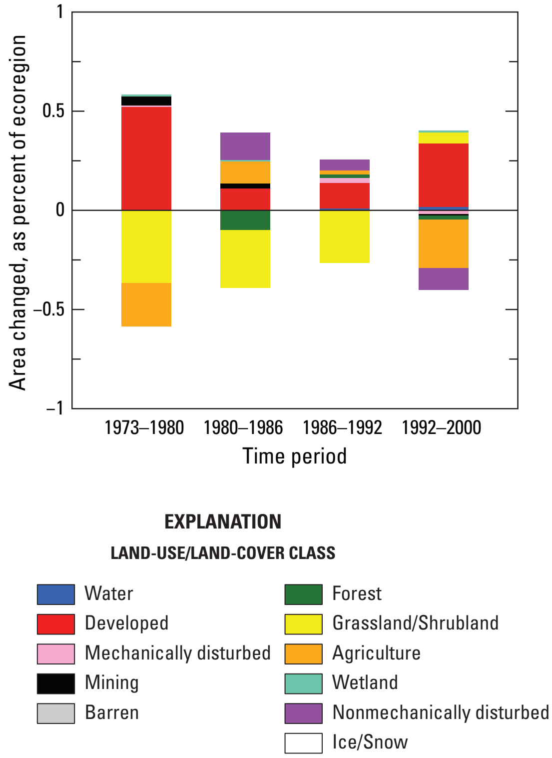

Figure 8. Normalized average net change in Colorado Plateaus Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

The largest amounts of net change that occurred over the entire study period (1973–2000) were an estimated 430 percent (1,408 km^2) increase in developed land and a 1.3 percent (1,121 km^2) decrease in grassland/shrubland (table 3). The largest net change in developed land occurred between 1973 and 1980 (fig. 8), almost all new developed land resulting from losses in either agriculture (756 km^2) or grassland/shrubland (644 km^2; table 4).

Although developed land only accounted for a small percentage of the ecoregion, nearly 43 percent of the land that changed became new developed land. Developed land is estimated to account for 0.3 percent (326 km^2) of the ecoregion in 1973, increasing to just over 1.3 percent (1,735 km^2) by 2000 (table 3). New developed land primarily was found near the ecoregion's urban centers of Saint George, Utah, and Grand Junction, Colorado, which had respective population estimates of 49,663 and 41,986 in 2000 (U.S. Census Bureau, 2000). Both of these cities have seen substantial population increases because of flourishing tourism and energy-mining industries. For example, Saint George's population increased 600 percent, from 7,097 in 1970 to 49,728 in 2000, whereas Grand Junction's increased 108 percent, from 20,170 in 1970 to 41,986 in 2000 (U.S. Census Bureau, 2000). The Interstate 15 and 70 corridors near these two cities also attracted new development, especially north from Saint George along Interstate 15 to Cedar City, Utah, and west from Grand Junction along Interstate 70 to Fruita, Colorado (fig. 9).

The grassland/shrubland land-cover class had the largest net loss in the ecoregion, decreasing by approximately 1,121 km^2. New developed land accounted for most of this decline, but land-cover conversions between agriculture and grassland/shrubland between 1973 and 2000 also affected the net change of grassland/shrubland. Considerable areas of land fluctuated between these two classes in all time periods between 1973 and 2000 (table 4). The overall trend from 1973 to 1992 indicated that more grassland/shrubland converted to agriculture than agriculture to grassland/shrubland. As a result, a net loss of grassland/shrubland to agriculture of approximately 327 km^2 occurred between 1973 and 1992. Irrigation needed to grow crops in the Colorado Plateaus Ecoregion's arid and relatively warm climate expanded in the counties of southeastern Utah and southwestern Colorado, causing agricultural lands to increase at the expense of grassland/shrubland. Irrigation water was drawn from the Dakota–Glen Canyon aquifer and the Colorado, White, San Juan, and Green Rivers to grow corn, wheat, barley, dry beans, hay, and alfalfa (U.S. Department of Agriculture, 2002). From 1992 to 2000, the exchange between grassland/shrubland and agricultural lands was balanced.

Even though agricultural lands increased at the expense of grassland/shrubland, the increase was not enough to offset agricultural lands lost to new developed land and mining between 1973 and 2000. As a result, agricultural lands in the Colorado Plateaus Ecoregion had a net decrease of 5.6 percent. Agricultural lands were estimated to account for 6.2 percent (8,004 km^2) of the ecoregion in 1973, decreasing to 5.8 percent (7,555 km^2) by 2000 (table 3). The largest net loss in agricultural lands occurred between 1992 and 2000, at 321 km^2, most of which went to developed land and grassland/shrubland (table 3). Increased municipal-water demands, as well as water scarcity in the arid Colorado Plateaus Ecoregion, may leave limited water available to farmers growing irrigated

Figure 9. Development in Redlands, between Fruita and Grand Junction, Colorado.

crops, further contributing to this decline. Additionally, because of cyclic changes in the extent of grassland/shrubland and agricultural lands, the gross land-cover change for agriculture and grassland/shrubland were the greatest among the other land-cover categories, totaling 1.2 percent (1,606 km^2) and 1.7 percent (2,204 km^2) of the ecoregion, respectively (table 3).

Periodic wildfires (classified as nonmechanically disturbed) affected nearly 1 percent (983 km^2) of the ecoregion's land between from 1973 and 2000 (table 3). These fires created common land-cover conversions involving forest and grassland/shrubland categories, especially between 1980 and 1986 and between 1986 and 1992. Between 1980 and 1986, conversion from forest to nonmechanically disturbed was the second greatest land change, whereas conversion from grassland/shrubland to nonmechanically disturbed was the top land-cover change between 1986 and 1992 (table 4). As burned areas recovered, land-cover conversion from nonmechanically disturbed to grassland/shrubland was common. For example, between 1986 and 1992, approximately 253 km^2 of grassland/shrubland burned, becoming nonmechanically disturbed, and then, by 2000, returned to grassland/shrubland. Because of this sequence of events, the return of nonmechanically disturbed lands to grassland/shrubland was the fifth most common conversion between 1973 and 2000, at 434 km^2 (table 4). As some burned areas have recovered by 2000, nonmechanically disturbed lands covered an estimated 115 km^2 of the ecoregion in 2000 (table 3).

Forest, the second most common land-cover class at approximately 25 percent of the Colorado Plateaus Ecoregion, generally was confined to the higher elevations of the ecoregion in the La Sal, Abajo, and Henry Mountains. Changes associated with forests were relatively small in the Colorado Plateaus Ecoregion. Forests had a small net decrease of 132 km^2 between 1973 and 2000 (table 3). Much of the forest loss is attributed to wildfires that occurred between 1980 and 1986, which caused an estimated loss of 178 km^2 in forest land to nonmechanically disturbed. Forest areas did expand in some locations of the ecoregion between 1980 and 1986 but not enough to make up for losses caused by wildfires. Slight forest gains in the ecoregion may be a result of the forest-management practice of fire suppression, as well as the dissemination of juniper seeds by grazing cattle while they simultaneously remove the competing grasses that inhibit juniper expansion (Allen, 1998). Both factors caused grasses to decline, whereas dense woodlands of pinyon pine and juniper expanded.

Other land-cover classes that changed very little are water, mining, and mechanically disturbed. Gross and net land change between 1973 and 2000 for each of these land categories affected no more than 0.1 percent (approximately 100 km^2) of the ecoregion. Mining lands had a net increase of 91 km^2 between 1973 and 2000 (table 3).

In Grand Junction and in many locations of the western slope of Colorado, new development expanded at a brisk pace, especially between 1973 and the early 1980s as people came to work in the energy-exploration business. An economic boom occurred during this time as major oil companies began investing large sums of money in the oil-shale industry (Gulliford, 2003). Grand Junction had its largest population increase (approximately 39 percent) between 1970 and 1980 (U.S. Census Bureau, 2000). This increase likely contributed to the large expansion of developed land in Colorado Plateaus Ecoregion between 1973 and 1980 (table 2).

As oil and gas exploration increased in the eastern part of the Colorado Plateaus Ecoregion during the energy crisis of the mid-1970s, the amount of new mining land increased between 1973 and 1992 (71 km^2 to 175 km^2, respectively; table 3). Mining of aggregate for the new Interstate 70 also accelerated mining land expansion in the 1970s. Nearly 78 percent of all new mining land was converted from grassland/shrubland. After 1982, however, the energy industry declined dramatically as the value of oil, coal, and uranium decreased, causing a "bust" economic condition in many small communities (notably, the towns of Rifle and Parachute, Colorado) that relied on the energy industry in the Colorado Plateaus Ecoregion (Gulliford, 2003). Mining land stabilized between 1986 and 1992 before decreasing from 175 km^2 in 1992 to 162 km^2 in 2000 (table 3).

Population gains continued in the Grand Junction area following the departure of major oil companies, causing a continuation of new developed lands. The economy in this part of the ecoregion became more diversified as a stable health care industry, tourism, agriculture (orchards and vineyards), livestock, and oil-and-gas extraction became major economic contributors. As oil and natural-gas prices increased in the 1990s, major energy companies once again invested large amounts of money into the area (van Riper and Mattson, 2005). In the 1990s, many Americans, especially well-educated retirees, were attracted to the western slope area of Colorado near Grand Junction because of outdoor amenities such as access to public lands and high mountain meadows. New developed land expanded as numerous second homes were built for the retirees (Gulliford, 2003).

The Saint George, Utah, area (known informally as "Utah's Dixie") also expanded for similar reasons. Outdoor recreational areas and nearby Zion and Bryce Canyon National Parks helped the tourism and recreation industry to grow there, attracting workers. The mild climate, access to high-quality health care, and natural amenities in the Saint George area attracted numerous retirees from other parts of the country. In addition, some large corporations such as SkyWest Airlines and Intermountain Health Care made their home in Saint George (Hecox and Ack, 1996). All these factors played an important role in expanding developed lands within the Colorado Plateaus Ecoregion.

Consequences of land change within the Colorado Plateaus Ecoregion became especially apparent between 1973 and 2000. Many agents of change are related to population growth in the ecoregion. As new development, tourism, mining, and heavy grazing increased, habitats that support wildlife and native plants have been greatly degraded. Approximately 85 percent of the ecoregion's habitat has been altered by human activity

(McGinley, 2007). Hardest-hit areas include riparian ecosystems and areas where mineral resources have been extracted. Habitat destruction caused by dam building (fig. 10) and other forms of development threaten native fish, including the humpback chub (*Gila cypha*), bluehead sucker (*Catostomus discobolus*), and the Colorado pikeminnow (*Ptychocheilus lucius*) (McGinley, 2007). Demand for water by growing municipalities also is having an effect on riparian areas as the water needs of wildlife, vegetation, and riparian systems become secondary (Booth and others, 1999). Today (2012), land managers are charged with accommodating land uses that can be sustained without degrading the health of the land and water. As a result, timber harvesting, mining, and livestock grazing all have been reduced in the ecoregion (Booth and others, 1999). Land managers increasingly are relying on science to balance commodity extraction and public recreation use while, at the same time, protecting ecosystem health within the Colorado Plateaus Ecoregion.

Figure 10. Glen Canyon Dam in southwestern part of Colorado Plateaus Ecoregion, near Page, Arizona.

Table 1. Percentage of Colorado Plateaus Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (97.4 percent), whereas 2.6 percent changed at least once throughout study period. Two dashes (--) indicate that, because zero pixels changed four times during study period, relative error is not calculable]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	2.0	1.7	0.2	3.7	1.2	59.2
2	0.6	0.4	0.2	1.1	0.3	47.6
3	0.0	0.0	0.0	0.0	0.0	82.3
4	0.0	0.0	0.0	0.0	0.0	--
Overall spatial change	2.6	2.1	0.6	4.7	1.4	53.2

Table 2. Raw estimates of change in Colorado Plateaus Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	1.1	1.2	−0.2	2.3	0.8	78.4	0.2
1980–1986	0.6	0.3	0.3	0.9	0.2	37.0	0.1
1986–1992	0.8	0.5	0.4	1.3	0.3	37.5	0.1
1992–2000	0.9	0.7	0.1	1.6	0.5	56.2	0.1
Estimate of change, in square kilometers							
1973–1980	1,369	1,589	−219	2,958	1,074	78.4	196
1980–1986	738	404	334	1,142	273	37.0	123
1986–1992	1,053	584	469	1,637	395	37.5	175
1992–2000	1,135	943	191	2,078	638	56.2	142

Table 3. Estimated area (and margin of error) of each land-cover class in Colorado Plateaus Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.4	0.3	0.3	0.3	0.0	0.0	0.1	0.1	4.3	2.5	24.9	6.8	63.5	7.5	6.2	3.7	0.4	0.2	0.0	0.0
1980	0.4	0.3	0.8	1.0	0.0	0.0	0.1	0.1	4.3	2.5	24.9	6.8	63.1	7.5	6.0	3.5	0.4	0.2	0.0	0.0
1986	0.4	0.3	0.9	1.1	0.0	0.0	0.1	0.1	4.3	2.5	24.8	6.7	62.8	7.6	6.1	3.6	0.4	0.2	0.1	0.2
1992	0.4	0.3	1.0	1.2	0.0	0.0	0.1	0.1	4.3	2.5	24.8	6.7	62.6	7.6	6.1	3.6	0.4	0.2	0.2	0.3
2000	0.5	0.3	1.3	1.7	0.0	0.0	0.1	0.1	4.3	2.5	24.8	6.7	62.6	7.7	5.8	3.5	0.4	0.2	0.1	0.1
Net Change	0.0	0.0	1.1	1.4	0.0	0.0	0.1	0.1	0.0	0.0	−0.1	0.3	-0.9	0.6	−0.3	1.2	0.0	0.0	0.1	0.1
Gross Change	0.1	0.1	1.1	1.4	0.1	0.1	0.1	0.1	0.0	0.0	0.3	0.2	1.7	0.8	1.2	1.1	0.0	0.0	0.8	0.8
Area, in square kilometers																				
1973	547	389	326	394	0	0	71	72	5,545	3,186	32,302	8,771	82,281	9,680	8,004	4,750	541	268	0	0
1980	547	387	1,011	1,360	2	3	135	127	5,542	3,186	32,306	8,767	81,815	9,754	7,718	4,524	541	271	0	0
1986	546	386	1,155	1,450	2	3	175	163	5,544	3,186	32,173	8,702	81,437	9,837	7,859	4,650	546	275	181	265
1992	561	390	1,319	1,612	43	40	175	188	5,544	3,186	32,194	8,698	81,097	9,888	7,876	4,696	555	281	253	370
2000	589	409	1,735	2,189	18	27	162	169	5,544	3,186	32,170	8,689	81,161	9,928	7,555	4,599	568	281	115	168
Net Change	42	54	1,408	1,795	18	27	91	97	−1	5	−132	328	−1,121	840	−449	1,513	27	23	115	168
Gross Change	69	71	1,408	1,795	112	82	168	148	9	8	332	318	2,204	1,091	1,606	1,456	42	22	983	999

Table 4. Principal land-cover conversions in Colorado Plateaus Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Developed	343	478	323	0.3	25.0
	Agriculture	Developed	342	489	331	0.3	24.9
	Grassland/Shrubland	Agriculture	305	198	134	0.2	22.3
	Agriculture	Grassland/Shrubland	246	349	236	0.2	18.0
	Grassland/Shrubland	Mining	57	52	35	0.0	4.1
	Other	Other	77	n/a	n/a	0.1	5.7
		Totals	1,369			1.1	100.0
1980–1986	Grassland/Shrubland	Agriculture	235	202	136	0.2	31.8
	Forest	Nonmechanically disturbed	178	0	0	0.1	24.1
	Grassland/Shrubland	Developed	92	82	56	0.1	12.4
	Grassland/Shrubland	Forest	50	69	47	0.0	6.7
	Agriculture	Developed	50	65	44	0.0	6.7
	Other	Other	138	n/a	n/a	0.1	18.8
		Totals	738			0.6	100.0
1986–1992	Grassland/Shrubland	Nonmechanically disturbed	253	266	180	0.2	24.1
	Nonmechanically disturbed	Grassland/Shrubland	181	265	179	0.1	17.2
	Grassland/Shrubland	Agriculture	162	153	103	0.1	15.4
	Grassland/Shrubland	Developed	102	95	65	0.1	9.7
	Agriculture	Grassland/Shrubland	76	71	48	0.1	7.3
	Other	Other	278	n/a	n/a	0.2	26.4
		Totals	1,053			0.8	100.0
1992–2000	Agriculture	Developed	305	445	301	0.2	26.9
	Nonmechanically disturbed	Grassland/Shrubland	253	370	250	0.2	22.3
	Grassland/Shrubland	Developed	108	130	88	0.1	9.5
	Agriculture	Grassland/Shrubland	98	103	70	0.1	8.6
	Grassland/Shrubland	Agriculture	90	83	56	0.1	8.0
	Other	Other	280	n/a	n/a	0.2	24.7
		Totals	1,135			0.9	100.0
1973–2000 (overall)	Grassland/Shrubland	Agriculture	793	534	361	0.6	18.5
	Agriculture	Developed	756	1,085	733	0.6	17.6
	Grassland/Shrubland	Developed	644	711	481	0.5	15.0
	Agriculture	Grassland/Shrubland	466	533	360	0.4	10.9
	Nonmechanically disturbed	Grassland/Shrubland	434	448	303	0.3	10.1
	Other	Other	1,201	n/a	n/a	0.9	28.0
		Totals	4,295			3.3	100.0

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Chapter 22

Columbia Plateau Ecoregion

By Benjamin M. Sleeter

Ecoregion Description

Located in eastern Washington and northern Oregon, the Columbia Plateau Ecoregion is characterized by sagebrush steppe and grasslands with extensive areas of dryland farming and irrigated agriculture. The ecoregion, which is approximately 90,059 km^2 (34,772 mi^2), is surrounded on all sides by mountainous ecoregions: to the west, the North Cascades Ecoregion and the Eastern Cascades Slopes and Foothills Ecoregion (and to the west of it, the Cascades Ecoregion); to the south, the Blue Mountains Ecoregion; and to the east, the Northern Rockies Ecoregion (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The climate is Mediterranean, with cool wet winters and hot dry summers.

The ecoregion was formed by Miocene (17 to 6 million year old) flood basalts covering approximately 200,000 km^2 in what is currently central and eastern Washington, northern Oregon, and western Idaho (Hooper, 1982). Other notable processes

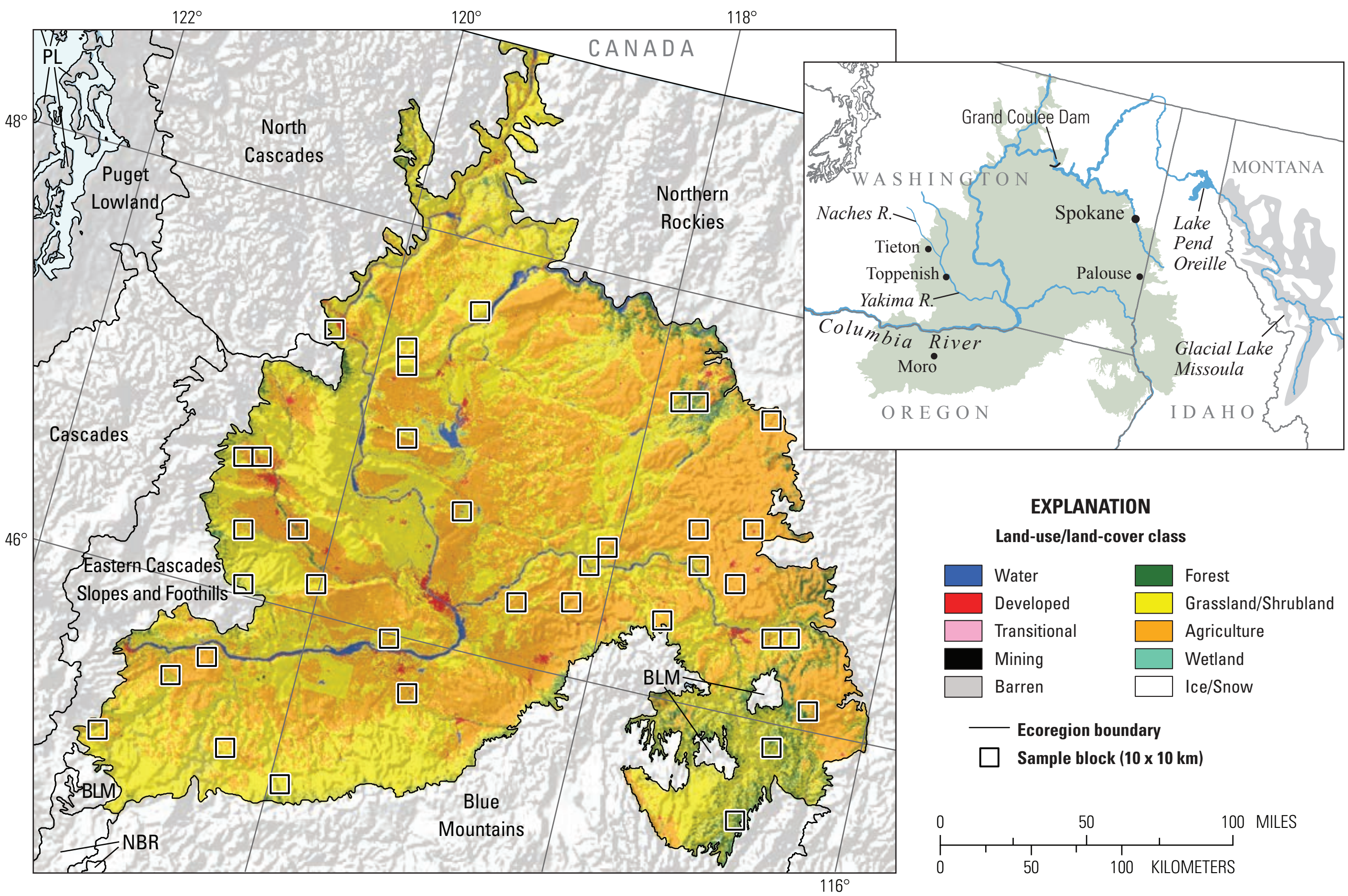

Figure 1. Map of Columbia Plateau Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

that shaped the Columbia Plateau Ecoregion were the great Missoula floods caused by catastrophic failures of glacial dams that blocked Montana's Glacial Lake Missoula 10 to 15 thousand years ago. Massive amounts of water rushing westward from the vicinity of the present-day east end of Lake Pend Oreille, Idaho, transformed a dendritic preglacial drainage pattern into the channeled scablands of today (Bretz, 1969; Smith, 2006). The great floods resulted in the loss of loess soils that covered much of the region. The only areas spared were those not in the path of flood waters or that had high enough elevations, such as the fertile Palouse region in eastern Washington. Today (2012) these areas support vast amounts of grain farming.

Since European settlement in the mid-19th century, the region has been heavily used for agricultural production. Much of the Columbia Plateau Ecoregion is used for dryland winter wheat production (fig. 2), the typical pattern being winter-wheat, followed by summer-fallow, cultivation. Soil moisture is accumulated throughout the winter; most growth occurs in the spring, and the harvest takes place in the summer. The hot and dry summer climate is ideal for maturation of dryland grains and cereals, but without irrigation little else can flourish (Schillinger and Papendick, 2008).

The Columbia Basin Project, a large engineered irrigation network serving eastern Washington, began in the 1930s with the construction of Grand Coulee Dam, originally designed to provide irrigation to the region's farmers. World War II caused the project to shift its focus to providing hydroelectric power; the irrigation component was not functional again until the 1950s. In 2009 alone, water from the Columbia Basin Project irrigated approximately 670,000 acres of crops valued at over $600 million annually (U.S. Bureau of Reclamation, 2009) (fig. 3).

Figure 2. Wheat fields near Moro, Oregon (*A*) and outside of Spokane, Washington (*B*).

Figure 3. Hops planted in Yakima Valley, Washington (*A*) and corn field near Toppenish, Washington (*B*).

Development in the Columbia Plateau Ecoregion generally is rural with only a few major urban areas. Population growth was slow in the 1980s, increasing only 4.9 percent. In the 1990s the ecoregion population increased by 20 percent to just under one million people (U.S. Census Bureau, 2000) (table 1).

Contemporary Land-Cover Change (1973 to 2000)

An estimated 9.2 percent of the Columbia Plateau Ecoregion land cover changed at least once between 1973 and 2000 (table 2). Compared to other ecoregions, change in the

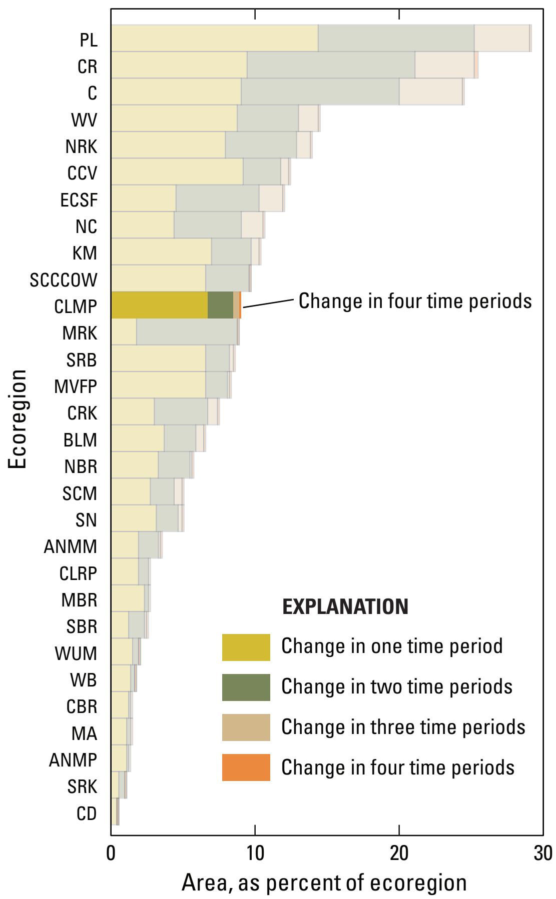

Figure 4. Overall spatial change in Columbia Plateau Ecoregion (CLMP; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Columbia Plateau Ecoregion (four time periods) labeled for clarity. See table 3 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

Columbia Plateau Ecoregion is considered modest (fig. 4). Of the total area, 2.3 percent changed in more than one of the four time periods analyzed (table 3), mostly a result of farmland cycling in and out of production. Changes to ecoregion land cover were not spread evenly throughout the entire 27-year study period. As is the case in many other agricultural regions, the period between 1986 and 1992 experienced the greatest amount of change, owing, in large part, to the conversion of marginal agricultural lands to grassland/shrubland (see appendix 3 for definitions of land-cover classes). The average annual rate of change during this period was 0.7 percent, whereas the other three periods experienced rates roughly one-half that amount (table 3; fig. 5).

Agricultural lands made up approximately 48.8 percent of the ecoregion in 1973 (table 4). By 1986 the agriculture land-cover class had increased an estimated 1,475 km^2 to make up 50.4 percent of the ecoregion. Between 1986 and 1992, agricultural lands declined by an estimated 1,531 km^2 (fig. 6), decreasing to approximately 48.7 percent of total ecoregion land cover. By 2000, agriculture had once again increased to account for 49.4 percent of the ecoregion (table 4). The Conservation Reserve Program (CRP), a federal policy to encourage landowners to convert marginal farmlands to native vegetation, played an important role in the Columbia Plateau Ecoregion. After the onset of the program, the ecoregion reversed the prior trend of increasing agricultural land use, and by 1997 enrollment in the CRP program totaled 3,311 km^2 (U.S. Department of Agriculture, 1999). Expiration of 10-year CRP contracts in the late 1990s contributed to 0.6 percent of the ecoregion converting back into agricultural land use by 2000. During the study period, dryland wheat farming experienced a sharp decline, whereas other areas of agriculture intensified with the addition of new irrigated lands. Historical levels of dryland wheat, irrigated cropland, and CRP enrollments are summarized in figure 7.

Trends in grassland/shrubland mirrored those of the agriculture class. Grassland/shrubland made up 41.0 percent of the ecoregion in 1973 and 39.9 percent in 2000, a net

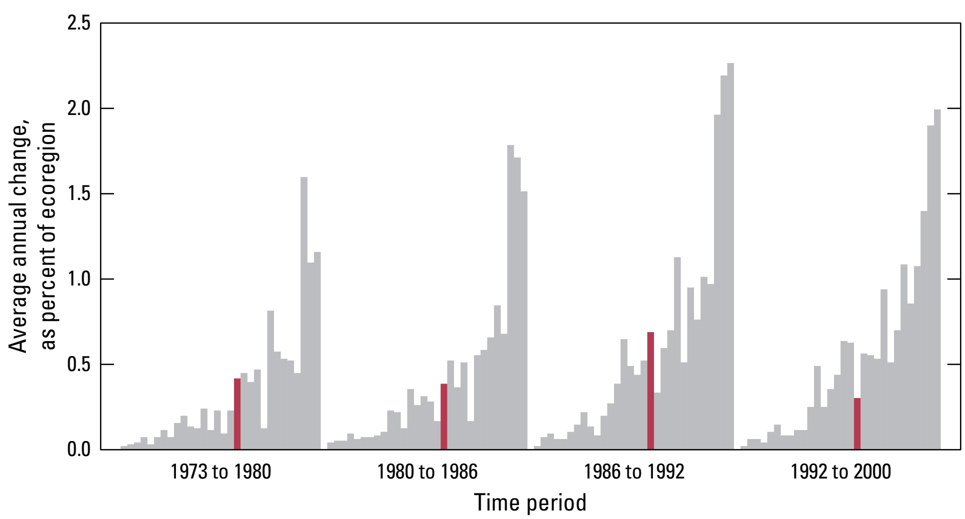

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Columbia Plateau Ecoregion are represented by red bars in each time period.

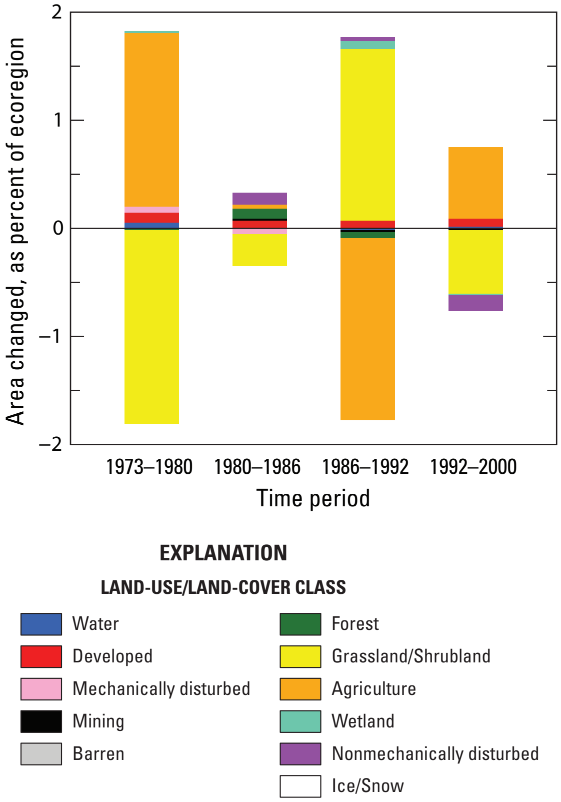

Figure 6. Normalized average net change in Columbia Plateau Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

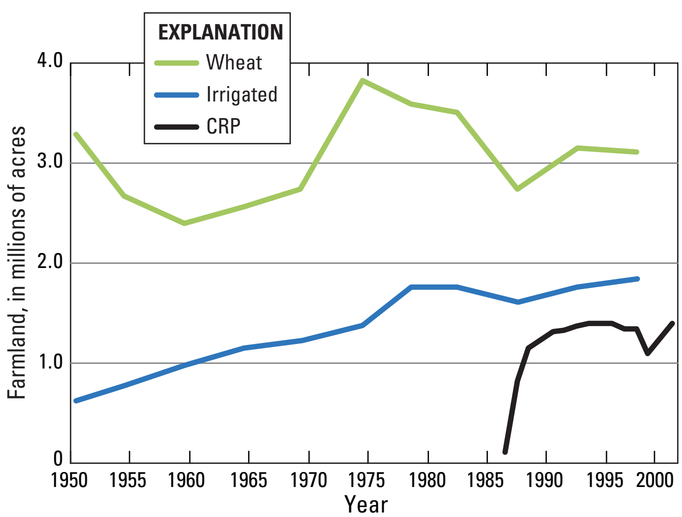

Figure 7. Historical trends in acreage for irrigated agriculture, dryland wheat, and Conservation Reserve Program enrollments (CRP). Total annual values were summed for all counties that have their centroid within Columbia Plateau Ecoregion. Data from United States Department of Agriculture's agriculture census (U.S. Department of Agriculture, 1999).

loss of 973 km^2. Developed land accounted for a very small proportion of the ecoregion (about 1.0 percent), an estimated net increase of approximately 284 km^2 over the 27-year period. All other land-cover classes remained relatively stable (table 4).

As expected, the most common land-cover conversions were between the agriculture and grassland/shrubland classes. In all four time periods, these were the two most common land-cover conversions. In three of the four periods, increases in conversions from agriculture to grassland/shrubland outpaced losses. The exception was between 1986 and 1992, when 2,342 km^2 changed from agriculture to grassland/shrubland, and only 886 km^2 converted from grassland/shrubland to agriculture. Other conversions of note were grassland/shrubland to nonmechanically disturbed (by fire) and agriculture to developed (table 5).

Irrigation technology, infrastructure development, federal conservation efforts, and population growth all acted as drivers of change on Columbia Plateau Ecoregion land cover. In the 1960s and 1970s, the spread of center-pivot irrigation technology enhanced the ability to bring marginal lands into agricultural production. The spread of irrigation was facilitated by the expansion and utilization of water-delivery infrastructure from the Columbia Basin Project, designed to irrigate more than 1 million acres of marginal lands. Estimates indicate that this period resulted in the greatest rate of change from sagebrush steppe (grassland/shrubland class) to new agriculture, adding an average of 290 km^2 per year between 1973 and 1980.

Whereas new lands were being added to the Columbia Plateau Ecoregion's agriculture mosaic in each time period, in only one period, 1986 to 1992, were these additions outpaced by the reversion back to natural vegetative conditions, largely as a result of the CRP (fig. 8). In the western United States, CRP had its most substantial effect in the Columbia Plateau Ecoregion. Estimates reveal that this period (1986–1992) experienced the only net decline in agriculture land cover during the 27-year land-cover study.

Figure 8. Agricultural land converted to grassland/shrubland under Conservation Reserve Program.

Regional population growth also has had an effect on regional land-cover change. Although developed land-cover areas accounted for approximately 1 percent of the total ecoregion area, a measured increase in developed lands of approximately 32 percent occurred between 1973 and 2000. Demand for new housing and infrastructure to support an additional 200,000 people resulted in the conversion of a relatively small amount of agricultural land and, to a lesser extent, grassland/shrubland to new developed uses (fig. 9).

Figure 9. New home construction and orchard near Naches River and town of Tieton, Washington.

Table 1. Columbia Plateau Ecoregion population estimates by state for 1980, 1990, and 2000 censuses (U.S. Census Bureau, 2000). Population estimates are calculated using census tracts that have their centroid within ecoregion. Total population estimates are sums of all three states for each year.

[--, no significant change]

Census year	State	Population	Percent change from previous decade
1980	Total	777,166	
	Oregon	90,051	
	Washington	618,055	
	Idaho	69,060	
1990	Total	814,979	+4.9
	Oregon	90,861	--
	Washington	654,062	+5.8
	Idaho	70,056	+1.4
2000	Total	978,069	+20.0
	Oregon	107,212	+18.0
	Washington	792,260	+21.1
	Idaho	78,597	+12.2

Table 2. Percentage of Columbia Plateau Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (90.8 percent), whereas 9.2 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	7.0	2.3	4.8	9.3	1.6	22.2
2	1.7	0.6	1.2	2.3	0.4	22.2
3	0.4	0.2	0.2	0.5	0.1	32.0
4	0.0	0.1	0.0	0.1	0.0	84.6
Overall spatial change	9.2	2.7	6.3	11.9	1.8	20.4

Table 3. Raw estimates of change in Columbia Plateau Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	2.9	1.4	1.5	4.3	1.0	32.8	0.4
1980–1986	2.3	0.6	1.7	3.0	0.4	18.9	0.4
1986–1992	4.1	1.4	2.7	5.5	0.9	23.0	0.7
1992–2000	2.4	0.7	1.7	3.2	0.5	21.0	0.3
Estimate of change, in square kilometers							
1973–1980	2,641	1,275	1,366	3,915	866	32.8	377
1980–1986	2,080	579	1,501	2,659	393	18.9	347
1986–1992	3,702	1,251	2,451	4,954	850	23.0	617
1992–2000	2,174	671	1,504	2,845	456	21.0	272

Table 4. Estimated area (and margin of error) of each land-cover class in Columbia Plateau Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechani-cally dis-turbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.8	0.4	1.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	7.6	3.1	41.0	6.4	48.8	7.4	0.9	0.3	0.0	0.0
1980	0.8	0.4	1.1	0.7	0.0	0.1	0.0	0.0	0.0	0.0	7.6	3.0	39.2	6.1	50.4	7.3	0.9	0.3	0.0	0.0
1986	0.8	0.4	1.1	0.7	0.0	0.0	0.0	0.1	0.0	0.0	7.7	3.1	38.9	5.9	50.4	7.1	0.9	0.3	0.1	0.2
1992	0.8	0.4	1.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	7.6	3.0	40.5	6.1	48.7	7.2	0.9	0.3	0.1	0.2
2000	0.8	0.4	1.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	7.6	3.0	39.9	6.1	49.4	7.2	0.9	0.3	0.0	0.0
Net change	0.1	0.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	−1.1	2.5	0.6	2.5	0.1	0.1	0.0	0.0
Gross change	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.4	0.4	7.6	2.4	7.3	2.4	0.1	0.1	0.5	0.5
Area, in square kilometers																				
1973	680	360	878	580	0	0	7	8	1	1	6,836	2,754	36,943	5,742	43,946	6,674	768	291	0	0
1980	730	390	967	612	41	59	18	18	0	1	6,817	2,728	35,331	5,455	45,387	6,532	768	288	0	0
1986	738	394	1,025	647	0	0	40	46	1	2	6,894	2,779	35,068	5,350	45,421	6,435	775	288	96	139
1992	718	387	1,095	682	8	9	36	43	1	1	6,847	2,679	36,495	5,464	43,889	6,447	840	291	131	189
2000	740	388	1,162	734	5	5	29	28	4	5	6,843	2,678	35,970	5,486	44,480	6,525	826	289	0	0
Net change	61	71	284	172	5	5	21	25	3	4	7	224	-973	2,270	534	2,223	58	63	0	0
Gross change	113	83	284	172	94	118	57	61	5	7	381	325	6,881	2,166	6,561	2,144	111	74	455	463

Table 5. Principal land-cover conversions in Columbia Plateau Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	1,960	1,139	774	2.2	74.2
	Agriculture	Grassland/Shrubland	440	301	204	0.5	16.7
	Agriculture	Developed	61	50	34	0.1	2.3
	Grassland/Shrubland	Water	51	73	50	0.1	1.9
	Forest	Mechanically disturbed	41	59	40	0.0	1.5
	Other	Other	88	n/a	n/a	0.1	3.3
		Totals	2,641			2.9	100.0
1980–1986	Grassland/Shrubland	Agriculture	944	363	246	1.0	45.4
	Agriculture	Grassland/Shrubland	822	419	285	0.9	39.5
	Grassland/Shrubland	Nonmechanically disturbed	94	135	92	0.1	4.5
	Agriculture	Developed	47	37	25	0.1	2.3
	Agriculture	Forest	42	60	41	0.0	2.0
	Other	Other	132	n/a	n/a	0.1	6.3
		Totals	2,080			2.3	100.0
1986–1992	Agriculture	Grassland/Shrubland	2,342	1,155	785	2.6	63.3
	Grassland/Shrubland	Agriculture	880	470	319	1.0	23.8
	Forest	Nonmechanically disturbed	131	189	129	0.1	3.5
	Nonmechanically disturbed	Grassland/Shrubland	96	138	94	0.1	2.6
	Grassland/Shrubland	Forest	89	76	52	0.1	2.4
	Other	Other	165	n/a	n/a	0.2	4.5
		Totals	3,702			4.1	100.0
1992–2000	Grassland/Shrubland	Agriculture	1,276	527	358	1.4	58.7
	Agriculture	Grassland/Shrubland	634	313	212	0.7	29.1
	Nonmechanically disturbed	Grassland/Shrubland	131	188	128	0.1	6.0
	Agriculture	Developed	49	44	30	0.1	2.3
	Wetland	Water	19	20	14	0.0	0.9
	Other	Other	66	n/a	n/a	0.1	3.0
		Totals	2,174			2.4	100.0
1973–2000 (overall)	Grassland/Shrubland	Agriculture	5,060	2,075	1,410	5.6	47.7
	Agriculture	Grassland/Shrubland	4,238	1,621	1,101	4.7	40.0
	Nonmechanically disturbed	Grassland/Shrubland	226	230	156	0.3	2.1
	Agriculture	Developed	211	149	102	0.2	2.0
	Forest	Nonmechanically disturbed	134	189	129	0.1	1.3
	Other	Other	729	n/a	n/a	0.8	6.9
		Totals	10,597			11.8	100.0

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Chapter 23

Northern Basin and Range Ecoregion

By Christopher E. Soulard

Ecoregion Description

The Northern Basin and Range Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) is located in eastern Oregon (58.7 percent), northern Nevada (20.6 percent), southwestern Idaho (14.8 percent), and northeastern California (5.9 percent), encompassing the northern extent of the hydrographic Great Basin (Grayson, 1993). The ecoregion, which covers approximately 110,039 km² (42,486 mi²) of land, is bordered on the west by the Eastern Cascades Slopes and Foothills and the Sierra Nevada Ecoregions, on the north by the Blue Mountains and the Snake River Basin Ecoregions, and on the south by the Central Basin and Range Ecoregion (fig. 1). Much like the other Basin and Range ecoregions in the western United States (for example, Central Basin and Range, Mojave Basin and Range, and Sonoran Basin and Range Ecoregions), the Northern Basin and Range Ecoregion is characterized by basin-and-range topography. The ecoregion contains several wide basins bordered by scattered low mountains. Big sagebrush (*Artemisia tridentata*), the predominant vegetation, is intermixed with grasslands. Despite regional aridity, natural springs and spring-fed wetlands

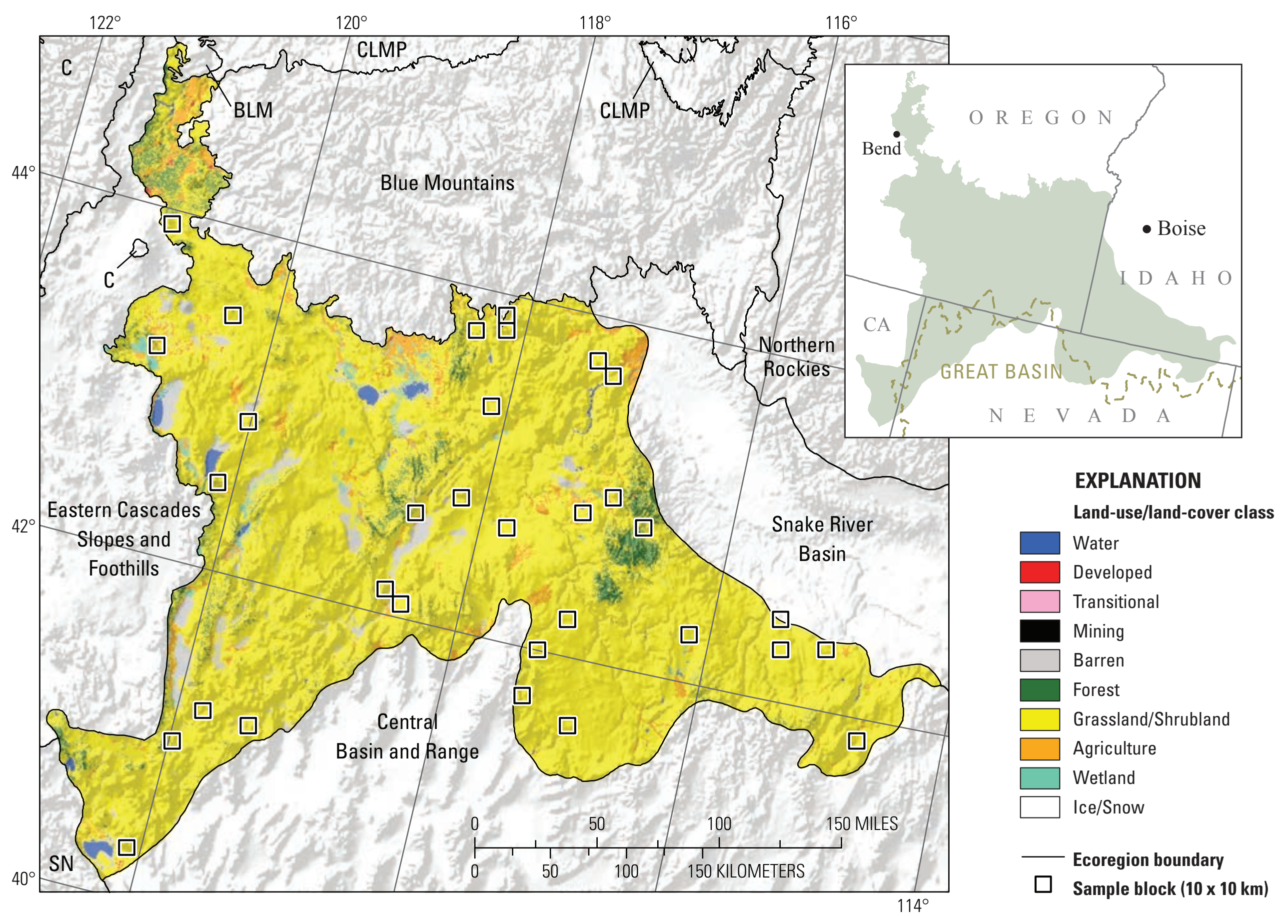

Figure 1. Map of Northern Basin and Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

are scattered around the landscape, sustaining much of the region's wildlife (Oregon Department of State Lands, 2000).

Because most of the Northern Basin and Range Ecoregion is arid and soil development generally is poor, viable economic land uses are limited. Livestock (cattle and sheep) grazing, the predominant land use, occurs mostly in the grassland/shrubland landscapes (fig. 2). Some agriculture (mostly hay farming) occurs where reservoirs have been constructed along regional waterways. Mining and recreation also account for small fragments of local economy. Ultimately, the scarcity of economic activity explains the absence of any large municipalities and the general lack of developed land across the ecoregion's landscape.

Land-cover change in the ecoregion is caused primarily by livestock grazing. Grazing activity has effectively modified the contemporary fire regime, contributing to the loss of native-plant communities in the region (Miller and others, 2001) (fig. 3). Historical land-management practices of unregulated grazing and fire suppression have led to increased fuel loads and nonnative-species invasion of rangelands (Oregon Department of State Lands, 2000). The most notable of these invasive species is cheatgrass (*Bromus tectorum*), which was introduced by settlers intending to feed domestic livestock by seeding areas devoid of native vegetation (Pellant and others, 2004). Cheatgrass and other introduced annuals not only outcompete native plants but also alter the fire regime by providing a denser, more continuous fuel source, which can extend the fire season (Pyke, 2002). Increased fire frequency eliminates native sagebrush in the short term, as the highly prolific seed-production capability of cheatgrass allows it to reestablish before sagebrush can take hold (Keeley, 2006; Pellant and others, 2004). Cheatgrass has ultimately created a positive-feedback mechanism for its own colonization, quickly expanding its range owing to frequent fires and its early reestablishment success in burned landscapes formerly occupied by sagebrush.

Figure 2. Area undergoing livestock grazing and hay farming in Northern Basin and Range Ecoregion. Land-use/land-cover classes shown are grassland/shrubland and agriculture.

Figure 3. Shrubland being used as open rangeland for cattle in Northern Basin and Range Ecoregion. Charred shrubs illustrate nonmechanical disturbance of land cover by fire. Land-use/land-cover classes shown are grassland/shrubland and nonmechanically disturbed.

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, the footprint (overall areal extent) of land-use/land-cover change in the Northern Basin and Range Ecoregion was 5.8 percent, or 6,430 km². This can be interpreted as the amount of land that experienced change during at least one of the four time periods that make up the entire 27-year study period. This footprint of change translates to an estimated 3,631 km² of land that changed during one time period, 2,421 km² that changed during two time periods, 110 km² that changed during three time periods, and 220 km² that changed throughout all four time periods (table 1; fig. 4).

The average annual rate of change between 1973 and 2000 was 0.3 percent per year. This measurement, which normalizes the results for the 27-year study period to an annual scale, means that the region averaged 363 km² of change each year between 1973 and 2000 (table 2); however, this annual change varied between each of the four time periods. Between 1973 and 1980, the annual rate of change was 0.1 percent per year; this rate increased to 0.3 percent annually between 1980 and 1986 and 0.6 percent annually between 1986 and 1992. The normalized annual rate dropped back to 0.3 percent between 1992 and 2000 (table 2). Compared to the other ecoregions in the western United States, land-cover change in the Northern Basin and Range Ecoregion was relatively low (fig. 5).

In 2000, five of the eleven land-use/land-cover classes made up the majority of the Northern Basin and Range Ecoregion: grassland/shrubland (89.3 percent), forest (3.7 percent), nonmechanically disturbed (2.5 percent), agriculture (2.3 percent), and wetland (1.1 percent). Five other classes cumulatively made up the remaining 1 percent of the Northern Basin and Range Ecoregion landscape in 2000 (table 3).

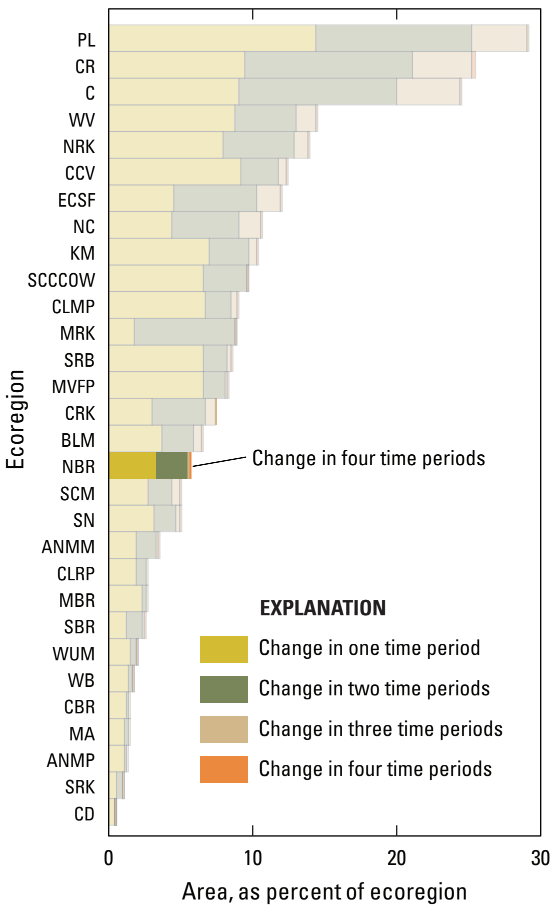

Figure 4. Overall spatial change in Northern Basin and Range Ecoregion (NBR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during time periods 1, 2, 3, or 4; highest level of spatial change in Northern Basin and Range Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

Between 1973 and 2000, the land-cover classes that experienced a measurable net change in relation to total ecoregion area include grassland/shrubland (2.6 percent decrease) and nonmechanically disturbed (which occupied 194 km^2 in 1973 and 2,713 km^2 in 2000, owing to fires) (fig. 6).

The "from class–to class" information afforded by a postclassification comparison was used to identify land-cover class conversions and to rank these conversions from highest to lowest (table 4). Although fieldwork confirmed the presence of many of the conversions listed in table 4, the ability to report these changes on the basis of interpretations was accomplished with varying degrees of uncertainty (as illustrated by the statistical error values in the table). In general, higher uncertainty arose where sampled changes were clustered spatially within the ecoregion rather than distributed evenly across the ecoregion.

Four of the top ten most prominent conversions are connected to nonmechanical disturbance of land cover by fire (fig. 7). Cumulatively, nonmechanical disturbance of grassland/shrubland resulted in the loss of an estimated 5,016 km^2; however, much of this land experienced ecological succession, or regrowth, and by the end of the study period, 2,530 km^2 had converted back to grassland/shrubland (fig. 7; table 4). Areas that experienced fires in consecutive periods accounted for an additional 1,491 km^2 (table 4). The conversions to and from the water class also were common in the Northern Basin and Range Ecoregion (1,016 km^2 of gross change). Less common were the conversions from grassland/shrubland to agriculture and to mining.

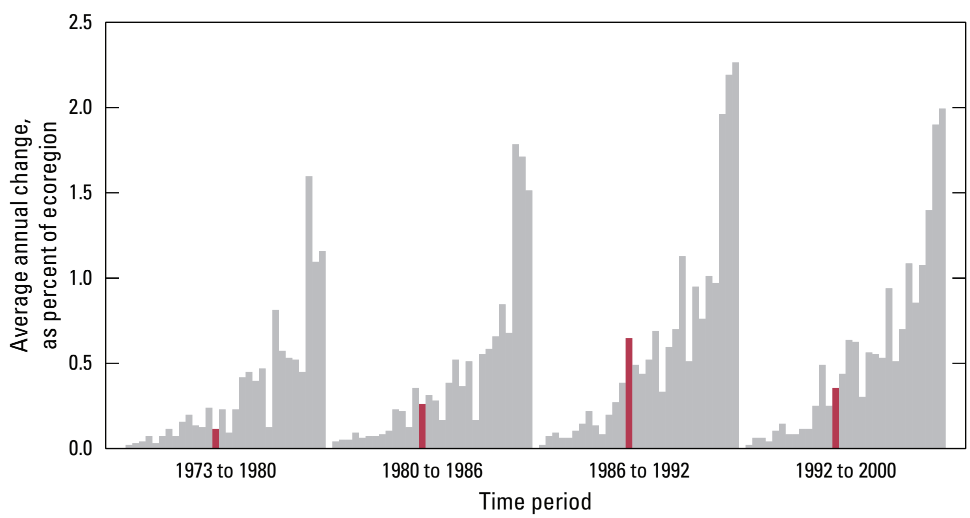

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Northern Basin and Range Ecoregion are represented by red bars in each time period.

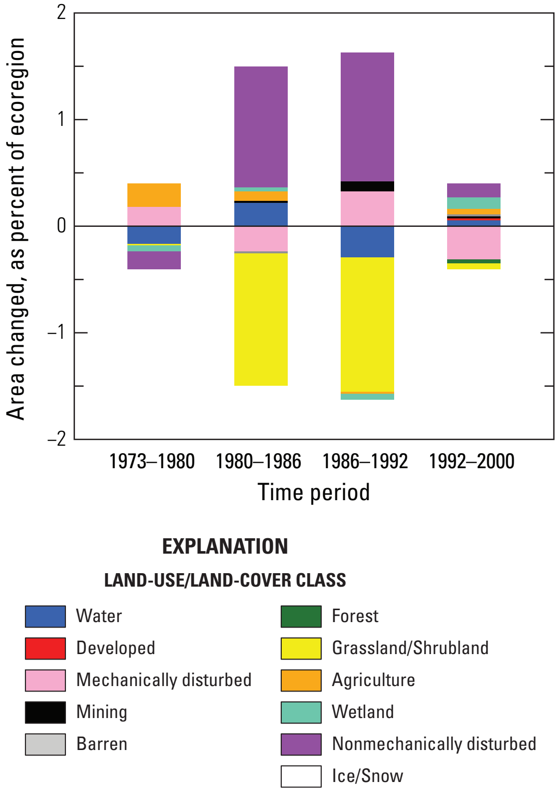

Figure 6. Normalized average net change in Northern Basin and Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 7. Area experiencing active nonmechanical disturbance of land cover by fire in Northern Basin and Range Ecoregion. Land-use/land-cover classes shown are grassland/shrubland, forest, and nonmechanically disturbed.

Table 1. Percentage of Northern Basin and Range Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (94.2 percent), whereas 5.8 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	3.3	3.2	0.0	6.5	2.2	67.0
2	2.2	2.1	0.1	4.4	1.5	65.3
3	0.1	0.1	0.0	0.3	0.1	52.7
4	0.2	0.3	−0.1	0.5	0.2	97.7
Overall spatial change	5.8	3.9	2.0	9.7	2.6	44.7

Table 2. Raw estimates of change in Northern Basin and Range Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.8	0.5	0.3	1.2	0.3	42.8	0.1
1980–1986	1.6	1.0	0.6	2.6	0.7	43.3	0.3
1986–1992	3.9	2.7	1.2	6.5	1.8	47.2	0.6
1992–2000	2.8	2.1	0.7	4.8	1.4	50.2	0.3
Estimate of change, in square kilometers							
1973–1980	828	523	305	1,351	354	42.8	118
1980–1986	1,727	1,104	624	2,831	748	43.3	288
1986–1992	4,249	2,957	1,292	7,207	2,004	47.2	708
1992–2000	3,055	2,263	792	5,319	1,533	50.2	382

Table 3. Estimated area (and margin of error) of each land-cover class in Northern Basin and Range Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.5	0.4	0.1	0.0	0.1	0.1	0.1	0.1	0.4	0.2	3.8	2.5	91.9	2.6	2.0	0.9	1.0	0.5	0.2	0.3
1980	0.3	0.2	0.1	0.0	0.2	0.3	0.1	0.1	0.4	0.2	3.8	2.5	91.9	2.7	2.2	1.0	1.0	0.5	0.0	0.0
1986	0.6	0.4	0.1	0.0	0.0	0.0	0.1	0.1	0.4	0.2	3.8	2.5	90.7	2.7	2.3	1.0	1.0	0.5	1.1	1.0
1992	0.3	0.2	0.1	0.0	0.3	0.3	0.2	0.1	0.4	0.2	3.8	2.5	89.4	3.2	2.2	1.0	1.0	0.5	2.3	2.4
2000	0.3	0.2	0.1	0.1	0.0	0.0	0.2	0.1	0.4	0.2	3.7	2.5	89.3	3.9	2.3	1.1	1.1	0.5	2.5	3.2
Net change	−0.2	0.3	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	−2.6	3.3	0.3	0.3	0.1	0.2	2.3	3.3
Gross change	0.9	0.9	0.0	0.0	1.2	1.2	0.1	0.1	0.0	0.0	0.0	0.1	6.7	4.5	0.4	0.3	0.3	0.4	6.1	4.6
Area, in square kilometers																				
1973	551	401	62	49	59	84	73	57	463	183	4,156	2,792	101,150	2,908	2,177	964	1,152	526	194	282
1980	374	223	64	50	267	342	79	58	461	182	4,158	2,792	101,139	2,947	2,401	1,070	1,091	524	5	8
1986	619	386	68	53	1	1	97	65	458	182	4,157	2,791	99,752	2,974	2,492	1,132	1,145	523	1,250	1,060
1992	307	215	69	53	372	337	188	118	449	181	4,157	2,790	98,361	3,527	2,474	1,127	1,078	523	2,584	2,616
2000	378	229	80	65	30	25	219	133	451	181	4,111	2,783	98,309	4,301	2,538	1,178	1,210	548	2,713	3,571
Net change	−173	356	18	16	−29	89	146	116	−12	10	−45	60	−2,841	3,589	361	348	58	179	2,519	3,582
Gross change	1,016	997	18	16	1,305	1,340	152	116	28	21	48	60	7,387	4,965	444	342	381	404	6,670	5,066

Table 4. Principal land-cover conversions in Northern Basin and Range Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Water	Mechanically disturbed	256	341	231	0.2	30.9
	Grassland/Shrubland	Agriculture	226	183	124	0.2	27.2
	Nonmechanically disturbed	Grassland/Shrubland	193	280	190	0.2	23.3
	Mechanically disturbed	Water	59	84	57	0.1	7.2
	Wetland	Grassland/Shrubland	44	50	34	0.0	5.3
	Other	Other	51	n/a	n/a	0.0	6.1
		Totals	828			0.8	100.0
1980–1986	Grassland/Shrubland	Nonmechanically disturbed	1,250	1,060	718	1.1	72.4
	Mechanically disturbed	Water	237	315	213	0.2	13.7
	Grassland/Shrubland	Agriculture	95	96	65	0.1	5.5
	Grassland/Shrubland	Wetland	34	40	27	0.0	2.0
	Grassland/Shrubland	Mining	21	28	19	0.0	1.2
	Other	Other	90	n/a	n/a	0.1	5.2
		Totals	1,727			1.6	100.0
1986–1992	Grassland/Shrubland	Nonmechanically disturbed	2,482	2,528	1,713	2.3	58.4
	Nonmechanically disturbed	Grassland/Shrubland	1,139	961	651	1.0	26.8
	Water	Mechanically disturbed	313	330	224	0.3	7.4
	Wetland	Grassland/Shrubland	70	68	46	0.1	1.6
	Grassland/Shrubland	Mechanically disturbed	49	72	49	0.0	1.2
	Other	Other	195	n/a	n/a	0.2	4.6
		Totals	4,249			3.9	100.0
1992–2000	Grassland/Shrubland	Nonmechanically disturbed	1,279	1,558	1,055	1.2	41.9
	Nonmechanically disturbed	Grassland/Shrubland	1,193	1,669	1,131	1.1	39.0
	Mechanically disturbed	Wetland	152	220	149	0.1	5.0
	Mechanically disturbed	Grassland/Shrubland	144	127	86	0.1	4.7
	Grassland/Shrubland	Agriculture	73	104	70	0.1	2.4
	Other	Other	215	n/a	n/a	0.2	7.0
		Totals	3,055			2.8	100.0
1973–2000 (overall)	Grassland/Shrubland	Nonmechanically disturbed	5,016	4,243	2,875	4.6	50.9
	Nonmechanically disturbed	Grassland/Shrubland	2,530	2,450	1,660	2.3	25.7
	Water	Mechanically disturbed	569	662	449	0.5	5.8
	Grassland/Shrubland	Agriculture	407	345	234	0.4	4.1
	Mechanically disturbed	Water	354	345	234	0.3	3.6
	Other	Other	983	n/a	n/a	0.9	10.0
		Totals	9,860			9.0	100.0

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Chapter 24

Snake River Basin Ecoregion

By Benjamin M. Sleeter

Ecoregion Description

Located in south-central Idaho, the Snake River Basin Ecoregion spans 66,063 km^2 (25,507 mi^2) of mostly sagebrush-steppe (*Artemisia tridentata*) with some areas of saltbush-greasewood (*Atriplex* spp. and *Sarcobatus* spp.) and barren lava fields (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The Snake River is the dominant hydrographic feature extending the full length (east to west) of the ecoregion. Elevation ranges from approximately 640 m in the "Treasure Valley" (Canyon County, near Nampa, Idaho) to 2,000 m in the semiarid foothills and eastern Snake River Plain. Mean annual precipitation ranges from 15 to 50 cm annually, and highest precipitation occurs in the high elevations of the dissected plateaus and Teton Basin along the eastern edge of the ecoregion. Mean January temperatures range from –14 to 4°C, with mean July temperatures ranging from 8 to 32°C.

Land cover in the Snake River Basin Ecoregion is dominated by grassland/shrubland, which covered approximately two-thirds of the landscape in 2000 (fig. 2). The sagebrush-steppe ecosystems of the Snake River Plain consist of a mosaic of sagebrush and perennial grass species, including Wyoming big sagebrush (*Artemisia tridentata*), bluebunch wheatgrass (*Pseudoroegneria spicata*), basin wildrye (*Leymus cinereus*), rabbitbrush (*Chrysothamnus viscidiflorus*), Thurber needlegrass (*Achnatherum thurberianum*), Idaho fescue (*Festuca*

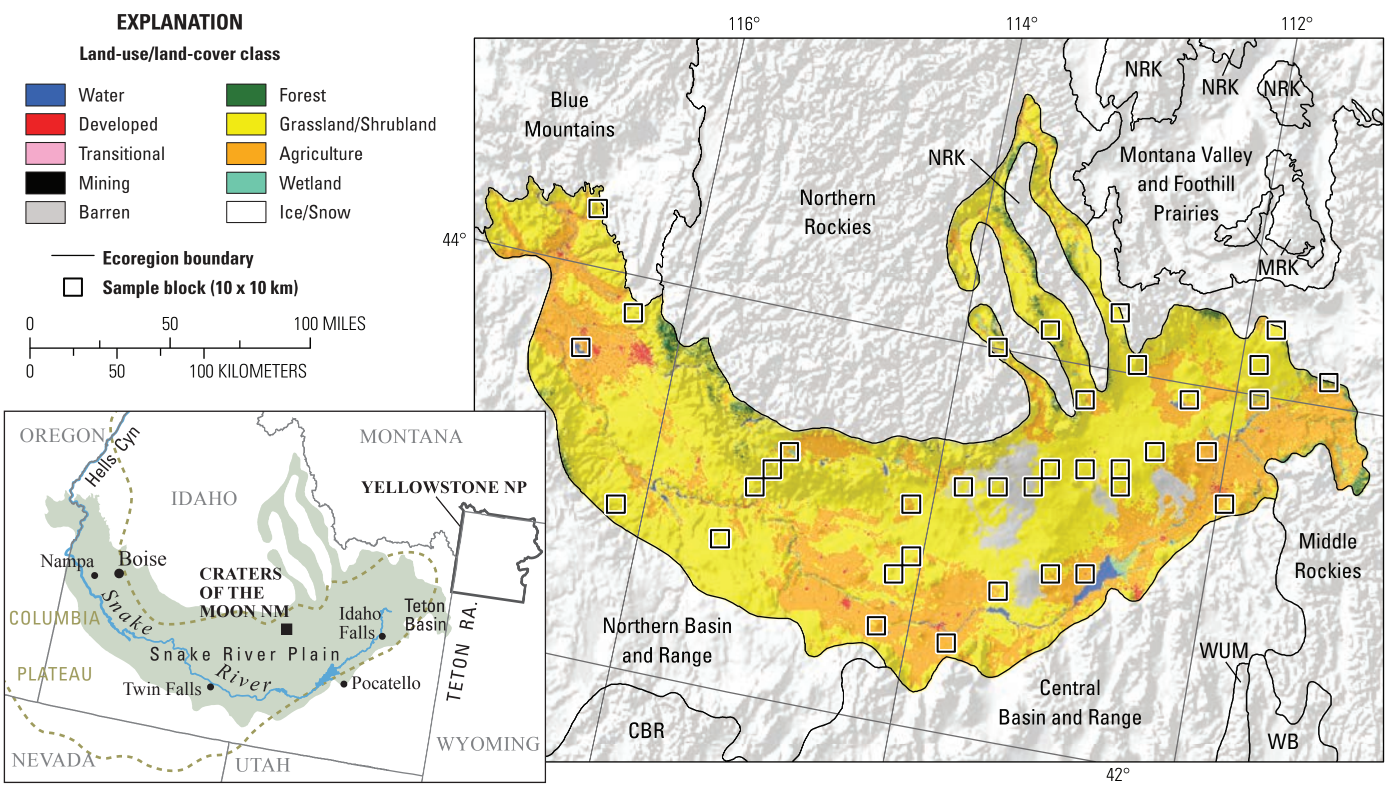

Figure 1. Map of Snake River Basin Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. Sagebrush steppe, which characterizes Snake River Basin Ecoregion.

Figure 3. Road serving as fire break in Snake River Basin Ecoregion. Area on right recently burned and has been revegetated with grasslands. Area to left of road was not burned and is dominated by sagebrush steppe.

idahoensis), threetip sagebrush (*Artemisia tripartita*), Gardner's saltbush (*Atriplex gardneri*), black greasewood (*Sarcobatus vermiculatus*), Indian ricegrass (*Achnatherum hymenoides*), fourwing saltbush (*Atriplex canescens*), crested wheatgrass (*Agropyron cristatum*), alkali sagebrush (*Artemisia longiloba*), and cheatgrass (*Bromus tectorum*) (McGrath and others, 2001). Disturbance from fire occurs at relatively long periods with low severity burns most common. However, due to the introduction of exotic species, such as cheatgrass, and managed burns to clear sagebrush for rangeland improvements, fire regimes have been altered, resulting in decreased fire-return periods with higher severity (fig. 3). Whisenant (1990) found fire-return periods had decreased from more than 75 years to as little as 5 to 10 years in some areas. The result on the landscape is a reduced ability of sagebrush species to recover postdisturbance, which may impact the long-term viability of sage-dependent species (Knick and Rotenberry, 1995).

Agriculture was the second most common land-use/land-cover type, accounting for approximately one-quarter of the ecoregion's area (fig. 4). Barren lands, primarily volcanic basalt flows, cover 2.6 percent of the ecoregion (fig. 5), and wetlands cover an additional 1.9 percent. Developed lands accounted for only 0.5 percent of the Snake River Basin Ecoregion. Whereas developed lands were limited, five of Idaho's largest cities are found within the Snake River Basin Ecoregion, including Boise (population 185,787), Nampa (population 51,867), Pocatello (population 51,466), Idaho Falls (population 50,730), and Twin Falls (population 34,469) (U.S. Census Bureau, 2010).

The high-elevation mountains surrounding the eastern Snake River Basin Ecoregion provide abundant high-quality water to the region. The absence of large settlements and industry contribute to the high quality of the water entering the basin. The Snake River derives as much as 50 percent of its annual flow from natural spring discharge (Miller and others, 2003). Surface water feeds the Snake River Basin aquifer, which is as much as 400 m thick, underlies 26,000 km^2 of the ecoregion, and contains about 1.23×10^{12} m^3 (100 million acre-ft) of water (Smith, 2004). Johnson and Cosgrove (1997) estimated that total groundwater storage declined on average about 350,000 acre-ft per year between 1975 and 1995, a cumulative decrease of 7 million acre-ft. Drought conditions caused declines in spring discharge and subsequent declines in groundwater levels as recharge capability dropped while withdrawals continued (Kjelstrom, 1986). However, in certain areas of the ecoregion, declines may be predominantly the result of a single factor (Idaho Department of Water Resources, 1999). For example, groundwater declines of 10 ft or more in Minidoka County were attributed to increased groundwater pumping in that area (Lindholm and others, 1988). Agricultural activities, urban runoff, and historical disposal practices at the Idaho National Engineering and Environmental Laboratory are major threats to groundwater quality (Smith, 2004).

Base flow of the Snake River was reduced, in part, owing to the introduction of more efficient irrigation technologies and a conversion from surface water to groundwater irrigation sources (Idaho Department of Water Resources, 1999; Miller and others, 2003). The net effect of efficiency improvements and pumpage by 1992 was an annual decrease in aquifer recharge of more than 2.1 million acre-ft, leading to groundwater-level and springflow declines (Idaho Department of Water Resources, 1999). Demands for Snake River water are diverse and include competition among agriculture, municipal users, industry, hydroelectric-power-generating utilities, recreation, and fish and wildlife. Federal and state management agencies are attempting to adjust to changing values while maintaining most of the traditional demands (Miller and others, 2003).

Contemporary Land-Cover Change (1973 to 2000)

Overall spatial change in the Snake River Basin Ecoregion, or the area that changed at least one time between 1973 and 2000, was 8.5 percent (5,604 km^2) (table 1). Compared to other western ecoregions, the Snake River Basin Ecoregion experienced a modest amount of change (fig. 6). Of the

Figure 4. Irrigated potato field near Twin Falls, Idaho.

Figure 5. Lava field at Craters of the Moon National Monument and Preserve, Idaho.

total area that changed, 6.6 percent of the ecoregion changed in only one time period, while 1.8 percent of the ecoregion changed in two periods. Changes in multiple dates are primarily attributed to fire disturbance and subsequent revegetation in following periods.

Change by time period ranged from 1.0 percent to 5.0 percent (table 2). When the time periods are normalized to account for the varying lengths of time, the highest rate of change was an estimated 411 km^2 of change per year between 1992 and 2000. The second highest rate of change was 343 km^2 per year between 1986 and 1992. The first two periods (1973–1980, 1980–1986) were relatively stable at an estimated 0.2 percent change per year. Rates of overall land-cover change in the Snake River Basin Ecoregion are unique from surrounding ecoregions (fig. 7). Ecoregions to the north are characterized by changes associated with forest disturbance from both natural and anthropogenic sources, whereas to the south change was relatively low in the basin-and-range ecoregions. The Snake River Basin Ecoregion contains a mix of land-cover changes that are generally associated with three themes: rangeland fire, agricultural expansion and contraction, and urbanization.

Grassland/shrubland declined 2.3 percent over the 27-year period, from 66.3 percent of the ecoregion in 1973 to 64.8 percent of the ecoregion in 2000. This amounts to a loss of 988 km^2. The period of greatest decline was between 1992 and 2000—an estimated loss of 1,232 km^2 over the 8-year period. The first three time periods were relatively stable in terms of net changes in grassland/shrubland (table 3; fig. 8). The large loss of grassland/shrubland between 1992 and 2000 was primarily a result of fire disturbance. During that period, an estimated 1,907 km^2 of grassland/shrubland were disturbed by fire, whereas 500 km^2 converted from a disturbed state back to grassland/shrubland (table 4).

The Snake River Basin Ecoregion is one of five key agricultural regions in the western United States along with the Columbia Plateau, Willamette Valley, Central California Valley, and Southern and Central California Chaparral and Oak Woodlands Ecoregions. Compared to these other agricultural

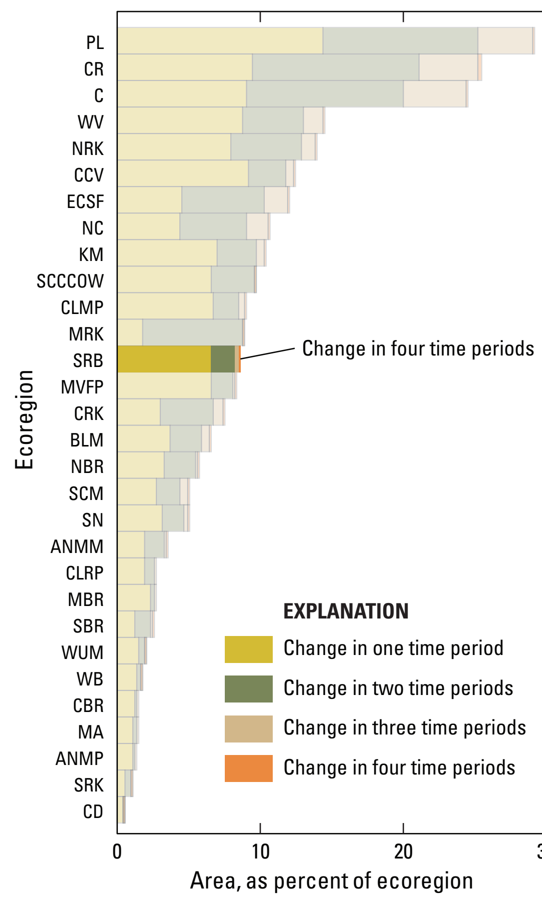

Figure 6. Overall spatial change in Snake River Basin Ecoregion (SRB; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Snake River Basin Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

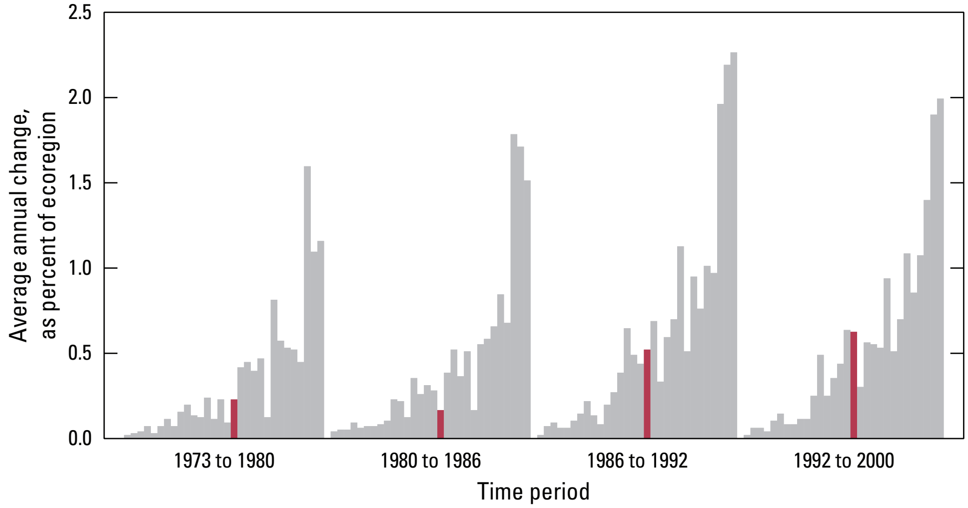

Figure 7. Estimates of land-cover change per time period normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Snake River Basin Ecoregion are represented by red bars in each time period.

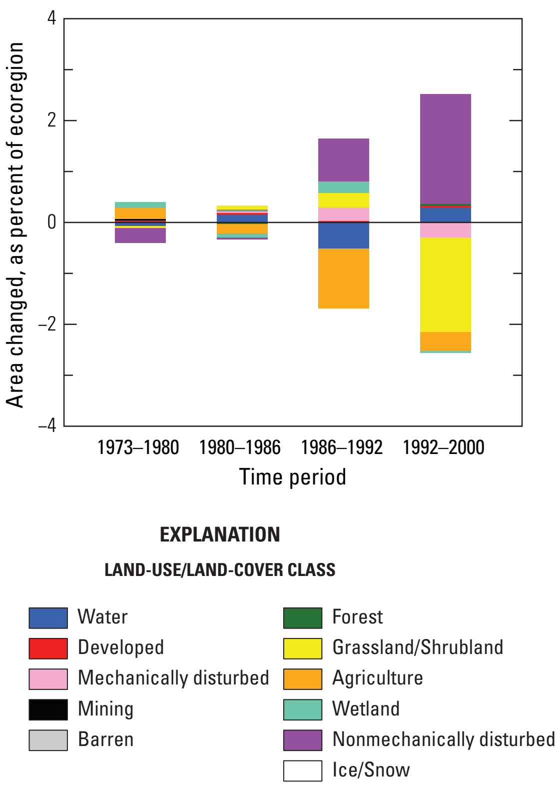

Figure 8. Normalized average net change in Snake River Basin Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

ecoregions, the Snake River Basin Ecoregion had the lowest overall spatial change but lost the largest amount of agriculture over the 27-year period (table 5).

The 1973 to 1980 period was the only period that realized a net increase (153 km^2) of agricultural land. Following 1980, agriculture began to decline and reached its largest period of loss between 1986 and 1992—a net loss of 773 km^2. Between 1992 and 2000, there was a net decline of 260 km^2 of agriculture. Driving the high amount of net loss in agriculture between 1986 and 1992 was the establishment of the Conservation Reserve Program (CRP). CRP enrollments began in 1986 and provided incentives for landowners to convert marginal and highly erodible croplands into natural vegetation. Based on county data from the U.S. Department of Agriculture (1999), counties in the Snake River Basin Ecoregion enrolled a total of 147,787 acres (598 km^2) into CRP by 1992. The main counties in Idaho that contributed to the program were Clark, Elmore, Madison, Teton, Bingham, and Twin Falls. Combined, they accounted for over three-quarters of all Snake River Basin Ecoregion CRP enrollments in 1992 (fig. 9).

Over the 27-year study period, developed land increased 47 percent. However, developed land uses make up less than 1 percent of the total ecoregion area. In 1973, an estimated 0.4 percent of the ecoregion was developed land, including the largest developed areas in the western part of the ecoregion associated with the cities of Boise and Nampa, Idaho. By 2000, developed land had increased to account for approximately 0.5 percent of the ecoregion—a gain of 112 km^2. Over the same three-decade period, population of counties that intersect the Snake River Basin Ecoregion increased from 561,641 in 1970 to 1,041,398 in 2000, an increase of 85 percent (U.S. Census Bureau, 2010).

Wetlands accounted for slightly less than 2 percent of the ecoregion and experienced a statistically significant

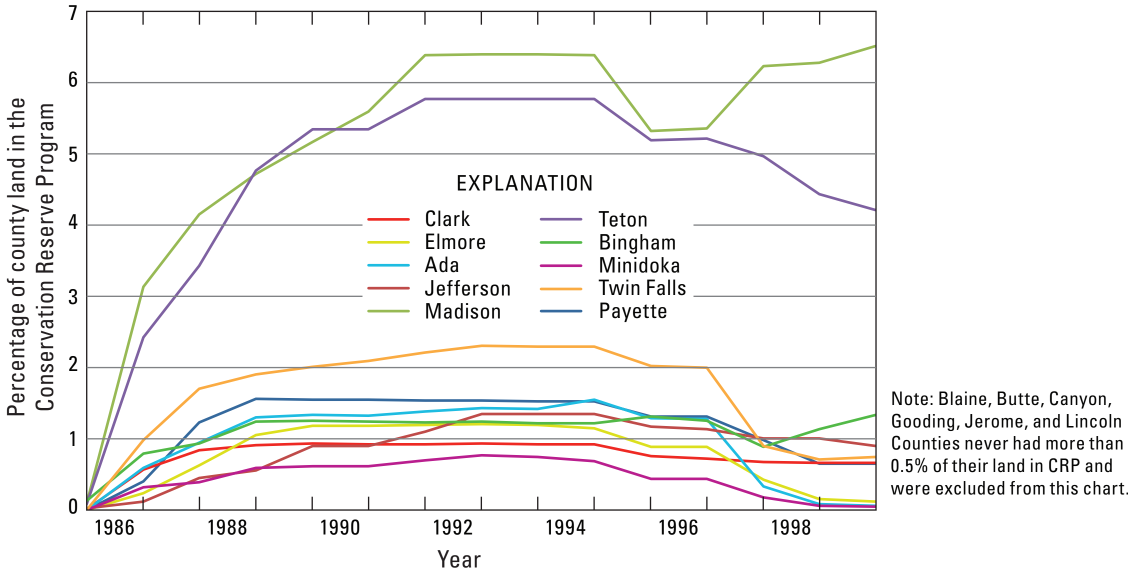

Figure 9. Enrollments in Conservation Reserve Program (CRP) for counties in Idaho that intersect Snake River Basin Ecoregion.

increasing trend throughout the study period. In 1973, wetlands accounted for 1.7 percent of the ecoregion, and by 2000 they accounted for 1.9 percent, an increase of 156 km^2.

As with many western ecoregions, ecosystem disturbance played an important role in the Snake River Basin Ecoregion. Nonmechanical disturbance, primarily from fire, accounted for an estimated 2,517 km^2 over the 27-year study period (table 4). Between 1973 and 1992, fire disturbance was relatively low with less than one percent of the ecoregion experiencing a disturbance in any of the periods. However, between 1992 and 2000, fire disturbance affected an estimated 3.0 percent of the ecoregion. Introduction of nonnative species and managed burns to remove sagebrush for range improvement are largely the cause of increased fire frequency (Pellant, 1990; Whisenant, 1990; Billings, 1994).

Land-cover change in the Snake River Basin Ecoregion generally involved land conversions into and out of the grassland/shrubland class (table 4). Conversions from grassland/shrubland to and from agriculture were most common and ranked in the top five conversions in each of the four time periods. Conversion from agricultural land to grassland/shrubland between 1980 and 1992 were especially common and were the top-ranked conversion during that time. From 1973 to 1980 and 1980 to 1986, conversion of grassland/shrubland to agriculture was the first and second most common conversion, respectively. Irrigation projects and technology advances, such as the adoption of center-pivot irrigation, likely resulted in the increase in agricultural land during this time. Changes associated with fire were most common in the last two time periods. Between 1992 and 2000 an estimated 1,907 km^2 converted from grassland/shrubland to nonmechanically disturbed, whereas an additional 500 km^2 of area classified as nonmechanically disturbed in the previous time period converted back to grassland/shrubland.

Drivers of land-cover and land-use change in the Snake River Basin Ecoregion are primarily associated with anthropogenic alteration of the sagebrush-steppe ecosystem. In the 1970s, areas of new agriculture outpaced areas converted out of agriculture by a 2:1 margin. With the implementation of the federal CRP program in the late 1980s, the trend reversed and nearly six times as much land ceased to be used for agriculture as there was new agricultural land. Historic management practices and the introduction of cheatgrass have influenced land change by promoting a change in historic fire regimes to more frequent and higher intensity burns. Managed burning to remove sagebrush for range improvement has also contributed to changes in land cover.

Table 1. Percentage of Snake River Basin Ecoregion land cover that changed at least one time during study period (1973–2000) and associated error.

[Most sample pixels remained unchanged (91.5 percent), whereas 8.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	6.6	2.7	3.8	9.3	1.9	28.4
2	1.8	1.1	0.6	2.9	0.8	43.5
3	0.2	0.1	0.1	0.2	0.1	29.5
4	0.0	0.0	0.0	0.0	0.0	61.2
Overall spatial change	8.5	3.0	5.5	11.5	2.1	24.3

Table 2. Raw estimates of change in Snake River Basin Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	1.6	0.4	1.1	2.0	0.3	18.6	0.2
1980–1986	1.0	0.4	0.6	1.4	0.3	27.7	0.2
1986–1992	3.1	1.6	1.6	4.7	1.1	33.9	0.5
1992–2000	5.0	2.6	2.4	7.6	1.8	35.9	0.6
			Estimate of change, in square kilometers				
1973–1980	1,024	280	744	1,305	190	18.6	146
1980–1986	665	271	394	936	184	27.7	111
1986–1992	2,056	1,026	1,030	3,082	697	33.9	343
1992–2000	3,292	1,738	1,553	5,030	1,181	35.9	411

Table 3. Estimated area (and margin of error) of each land-cover class in Snake River Basin Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/Shrubland		Agriculture		Wetland		Nonmechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
										Area, in percent stratum										
1973	1.0	0.9	0.4	0.2	0.0	0.0	0.1	0.0	2.6	1.9	3.1	2.7	66.3	8.3	24.5	7.5	1.7	1.2	0.4	0.3
1980	1.0	0.9	0.4	0.3	0.0	0.0	0.1	0.1	2.6	1.9	3.1	2.7	66.2	8.4	24.7	7.5	1.8	1.3	0.1	0.1
1986	1.1	0.9	0.4	0.3	0.1	0.1	0.1	0.1	2.6	1.9	3.1	2.6	66.3	8.4	24.5	7.5	1.7	1.2	0.0	0.0
1992	0.7	0.5	0.5	0.3	0.3	0.3	0.1	0.1	2.6	1.9	3.1	2.6	66.6	8.2	23.3	7.3	1.9	1.4	0.9	1.1
2000	0.9	0.8	0.5	0.3	0.0	0.0	0.1	0.1	2.6	1.9	3.2	2.7	64.8	8.2	22.9	7.2	1.9	1.4	3.0	2.6
Net change	−0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−1.5	2.9	−1.5	1.5	0.2	0.2	2.7	2.4
Gross change	1.1	0.9	0.2	0.1	0.7	0.7	0.0	0.0	0.0	0.0	0.1	0.1	7.8	3.5	3.3	1.5	0.6	0.5	5.0	3.4
										Area, in square kilometers										
1973	678	592	237	138	27	27	41	30	1,704	1,272	2,074	1,755	43,775	5,491	16,154	4,964	1,126	818	248	181
1980	644	591	277	166	23	20	48	35	1,698	1,269	2,072	1,752	43,764	5,561	16,307	4,981	1,191	866	42	59
1986	758	618	297	178	41	42	56	43	1,699	1,269	2,063	1,735	43,825	5,577	16,177	4,961	1,148	823	0	0
1992	429	337	329	198	206	229	51	35	1,704	1,270	2,065	1,735	44,019	5,441	15,404	4,812	1,288	925	569	711
2000	622	555	349	213	27	24	56	41	1,706	1,270	2,089	1,767	42,787	5,385	15,144	4,787	1,282	917	2,000	1,718
Net change	−56	69	112	91	1	32	15	15	2	7	15	16	−988	1,930	−1,009	1,010	156	140	1,752	1,613
Gross change	732	568	116	90	476	450	33	29	14	14	46	57	5,160	2,299	2,154	1,016	409	343	3,319	2,256

Table 4. Principal land-cover conversions in Snake River Basin Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	382	157	107	0.6	37.3
	Nonmechanically disturbed	Grassland/Shrubland	248	180	123	0.4	24.2
	Agriculture	Grassland/Shrubland	169	102	69	0.3	16.5
	Water	Wetland	54	54	36	0.1	5.2
	Grassland/Shrubland	Nonmechanically disturbed	42	59	40	0.1	4.1
	Other	Other	130	n/a	n/a	0.2	12.7
		Totals	1,024			1.6	100.0
1980–1986	Agriculture	Grassland/Shrubland	200	124	84	0.3	30.1
	Grassland/Shrubland	Agriculture	151	83	56	0.2	22.6
	Wetland	Water	109	129	88	0.2	16.4
	Agriculture	Wetland	49	71	48	0.1	7.4
	Nonmechanically disturbed	Grassland/Shrubland	42	59	40	0.1	6.2
	Other	Other	114	n/a	n/a	0.2	17.1
		Totals	665			1.0	100.0
1986–1992	Agriculture	Grassland/Shrubland	890	721	490	1.3	43.3
	Grassland/Shrubland	Nonmechanically disturbed	569	711	483	0.9	27.7
	Water	Mechanically disturbed	182	225	153	0.3	8.8
	Grassland/Shrubland	Agriculture	143	122	83	0.2	7.0
	Water	Wetland	138	137	93	0.2	6.7
	Other	Other	134	n/a	n/a	0.2	6.5
		Totals	2,056			3.1	100.0
1992–2000	Grassland/Shrubland	Nonmechanically disturbed	1,907	1,635	1,111	2.9	57.9
	Nonmechanically disturbed	Grassland/Shrubland	500	706	480	0.8	15.2
	Agriculture	Grassland/Shrubland	375	261	177	0.6	11.4
	Mechanically disturbed	Water	178	225	153	0.3	5.4
	Grassland/Shrubland	Agriculture	173	71	48	0.3	5.3
	Other	Other	158	n/a	n/a	0.2	4.8
		Totals	3,292			5.0	100.0
1973–2000 (overall)	Grassland/Shrubland	Nonmechanically disturbed	2,517	1,831	1,244	3.8	35.8
	Agriculture	Grassland/Shrubland	1,634	1,030	700	2.5	23.2
	Grassland/Shrubland	Agriculture	849	276	187	1.3	12.1
	Nonmechanically disturbed	Grassland/Shrubland	789	720	489	1.2	11.2
	Mechanically disturbed	Water	208	229	156	0.3	3.0
	Other	Other	1,039	n/a	n/a	1.6	14.8
		Totals	7,036			10.7	100.0

Table 5. Overall spatial change and net agricultural change in five main agricultural ecoregions of western United States.

Ecoregion	Overall spatial change (percent of ecoregion)	Agricultural change (km^2)	Agricultural change (percent ecoregion)
Snake River Basin	8.5	−1,022	−1.6
Southern and Central California Chaparral and Oak Woodlands	9.7	−862	−0.8
Willamette Valley	14.5	−322	−2.2
Central California Valley	12.4	+358	+0.8
Columbia Plateau	9.0	+534	+0.6

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Chapter 25

Wyoming Basin Ecoregion

By Todd J. Hawbaker

Ecoregion Description

The Wyoming Basin Ecoregion (Omernik 1987; U.S. Environmental Protection Agency, 1999) covers approximately 128,914 km^2 (49,774 mi^2) in Wyoming and parts of northwestern Colorado, northeastern Utah, southeastern Idaho, and southern Montana (fig. 1). The ecoregion is bounded on the east by the Northwestern Great Plains Ecoregion; on the south and east by the Southern Rockies Ecoregion; on the south by the Colorado Plateaus Ecoregion; on the south and west by the Wasatch and Uinta Mountains Ecoregion; and on the north by the Middle Rockies Ecoregion and parts of the Montana Valley and Foothill Prairies Ecoregion (fig. 1). The ecoregion generally consists of broad intermountain basins dominated by arid

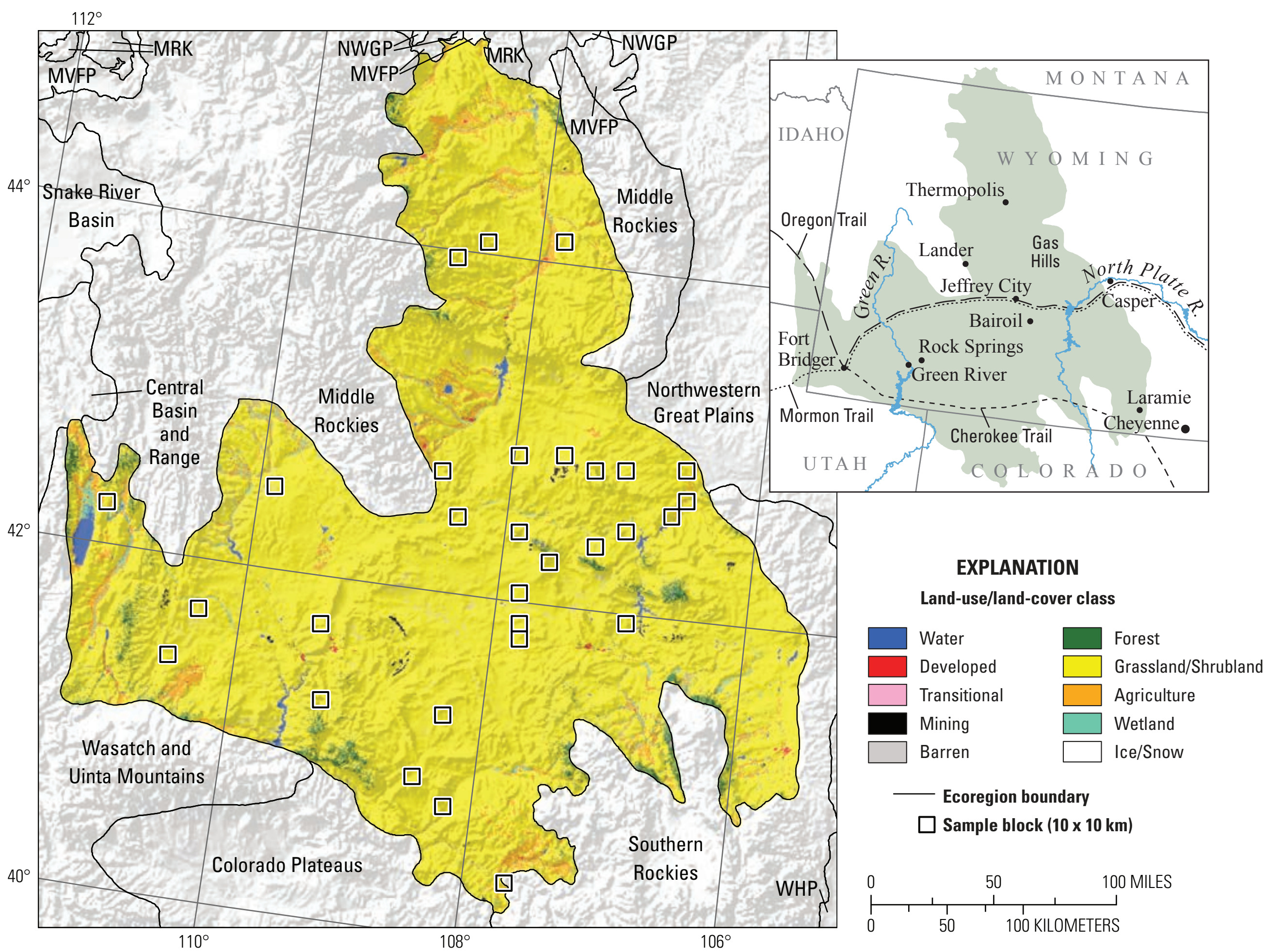

Figure 1. Map of Wyoming Basin Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map are parts of two Great Plains ecoregions: Northwestern Great Plains (NWGP) and Western High Plains (WHP). See appendix 3 for definitions of land-use/land-cover classifications.

grasslands and shrublands, as well as isolated hills and low mountains that merge to the south into a dissected plateau.

The climate in the Wyoming Basin Ecoregion is semi-arid continental, and it is drier and windier than most places in the United States. The average annual precipitation from rain is 20 cm in Green River, Wyoming, 28 cm in Thermopolis, Wyoming, and 30 cm in Casper, Wyoming. The average annual snowfall is 74 cm in Green River, 76 cm in Thermopolis, and 198 cm in Casper. Average maximum monthly temperatures range from 32°C and above in July to near −17°C in January (Desert Research Institute, 2011). Nearly surrounded by forest-covered mountains, the region is somewhat drier than the Northwestern Great Plains Ecoregion to the northeast.

Vegetation consists of grasses interspersed among big sagebrush (*Artemisia tridentata*). Higher elevations harbor some quaking aspen (*Populus tremuloides*) and patches of coniferous forest. Open water is rare in this ecoregion, consisting mainly of reservoirs on the North Platte and Green Rivers, as well as on smaller rivers that traverse the area. Many minor waterways have been dammed to provide water for livestock. Stream beds are often dry in these riparian areas. Wetlands are especially rare and typically are riparian.

This ecoregion has a rich history in the settlement of the American West. Several major trails cross through the ecoregion, as it provides a low pass across the Rocky Mountains (fig. 1). The Oregon Trail was used by settlers heading west during the 1840s to 1890s. The northern route of the Cherokee Trail, which crosses through southern Wyoming, was used primarily by travelers heading west to the California gold fields. The Mormon Trail was used between 1846 and 1857 by Mormons fleeing to Utah after persecution in the Midwest (Hill, 1987). The short-lived Pony Express also had stations lining an east-to-west route near the Oregon Trail (Di Certo, 2002). Evidence of many of these old trails is still visible. The Pony Express and overland movement along wagon trails started to decline with the increase in rail travel and telegraph use starting in the mid- to late-1800s.

Human population in the Wyoming Basin Ecoregion is sparse. The largest cities in the ecoregion are Casper (population, 49,644 in 2000), Laramie (27,204), and Rock Springs (18,708), Wyoming (U.S. Census Bureau, 2011). Much of the ecoregion is used for cattle and sheep grazing, often in managed pastures, and ranches are common, but many areas lack sufficient vegetation to support grazing. Agriculture is limited primarily to irrigated hay, corn, and sugar beets along river bottoms (fig. 2). Much of the land is owned by the Bureau of Land Management and is leased to ranches for cattle grazing.

The Wyoming Basin Ecoregion has a long history of energy development, as it holds large reserves of minerals, oil, and natural gas (fig. 3). Wyoming accounts for roughly 40 percent of all coal production in the United States, the most of any state (Freme, 2009). Much of the coal mined in Wyoming is shipped to the Midwest, producing approximately 30 percent of the electricity consumed in the United States.

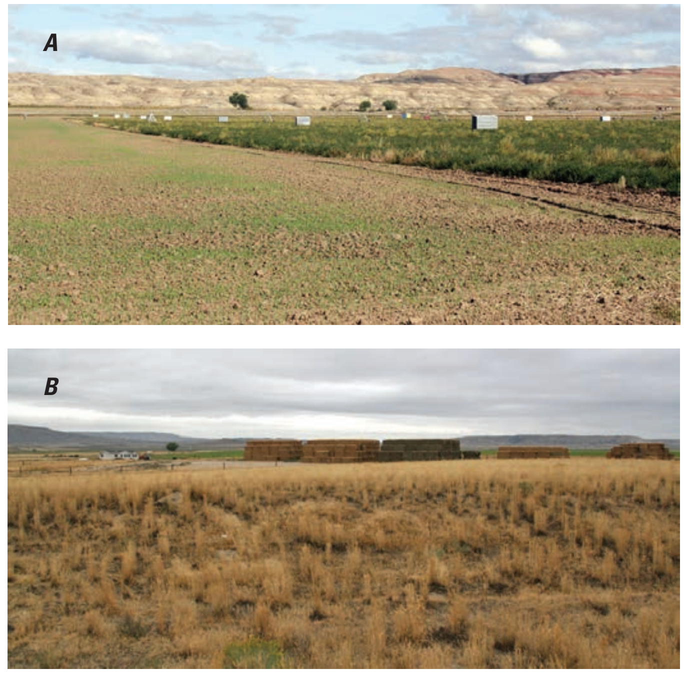

Figure 2. Agriculture in Wyoming Basin Ecoregion. *A*, Irrigated crops. *B*, Hay production.

Figure 3. Energy development in south-central Wyoming.

Figure 4. Reclaimed mine in Gas Hills District of Wyoming.

Figure 5. Oil well near Bairoil, Wyoming, and warning sign for hydrogen-sulfide gas.

Coal-fired power plants are scattered throughout the ecoregion, and large transmission lines radiate from them. Uranium mining once was common but decreased in the 1980s after the incidents at Three Mile Island and Chernobyl nuclear power plants. Many of those once-active mines have been reclaimed (fig. 4). Towns associated with uranium mining, such as Jeffrey City, Wyoming, are largely deserted. Today, uranium is mined in place using chemicals to dissolve the minerals before pumping them to the surface (Gregory, 2011).

Wyoming's first oil well was drilled in 1885, just southeast of Lander, Wyoming (Roberts, 2011). As of 2006, Wyoming ranked second in the United States for proven natural-gas reserves and fourth for proven crude-oil reserves (fig. 5). The most recent period of energy development started in the late 1990s and has intensified with rising energy prices during the 2000s. In some places, the density of recent energy development has produced a nearly continuous matrix of wells and their associated transportation networks. There is growing concern about how intensifying energy development will affect the populations and migration patterns of wildlife species that use parts of the Wyoming Basin Ecoregion (Bowen and others, 2009).

Contemporary Land-Cover Change (1973 to 2000)

Between 1973 and 2000, 1.8 percent of the Wyoming Basin Ecoregion changed land-use/land-cover classes at least once (table 1; fig. 6). In 1.4 percent of the ecoregion, change occurred in land-use/land-cover in one time period. Overall, the average annual rate of land-cover change in the Wyoming Basin Ecoregion was very low, at only 0.1 percent (fig. 7; table 2). Rates of change varied little among the different time periods analyzed. Even though the rate of change appeared low, the Wyoming Basin Ecoregion's size meant that it amounted to nearly 92 to 181 km^2 per year of total change, depending on the time period (table 2). Overall, this ecoregion's level of change was one of the lowest among western United States ecoregions (table 1).

The extent of agriculture increased until 1986 and then started to decline, although it remained at 2 percent of ecoregion in 2000. The extent of grassland/shrubland was negatively correlated to agriculture, and it was at its lowest point in 1986. In contrast, the amount of area classified as water, wetland, and mechanically disturbed (primarily reservoir drawdown) fluctuated during each time period (table 3). Conversions between grassland/shrubland and agriculture and between water, wetland, and mechanically disturbed account for the majority of change observed in the ecoregion (table 4).

During the 27-year study period, the extent of urban developed land increased from 39 km^2 to 61 km^2, with most expansion occurring near cities such as Cheyenne and Rock Springs, Wyoming. The amount of forest land decreased by

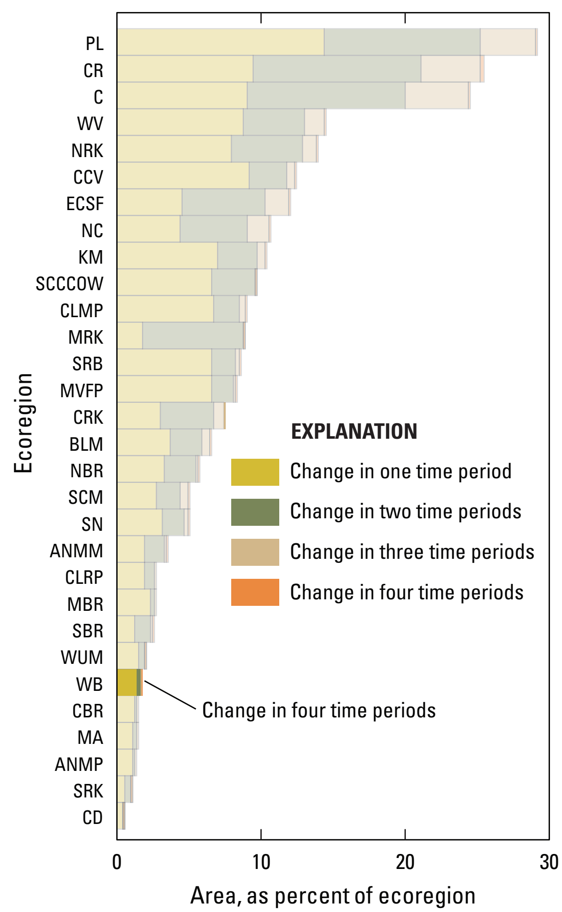

Figure 6. Overall spatial change in Wyoming Basin Ecoregion (WB; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Wyoming Basin Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

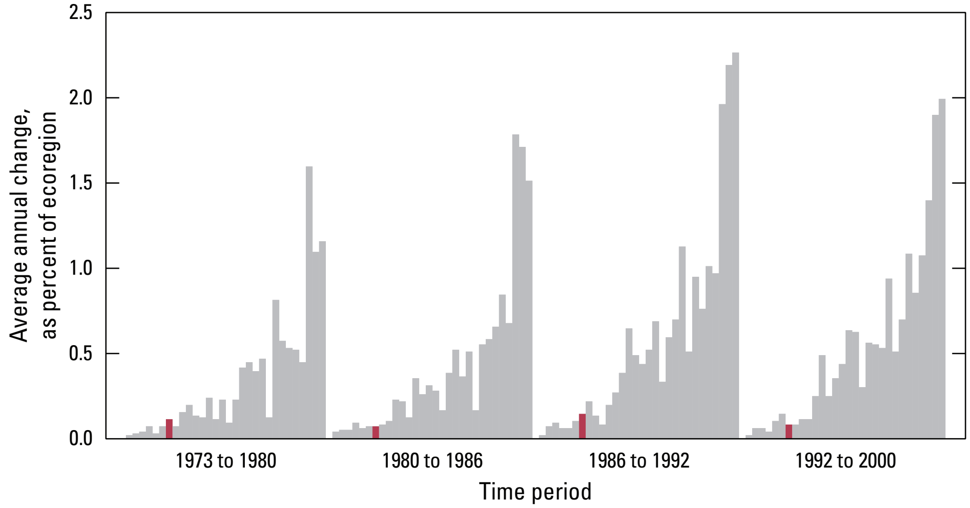

Figure 7. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Wyoming Basin Ecoregion are represented by red bars in each time period.

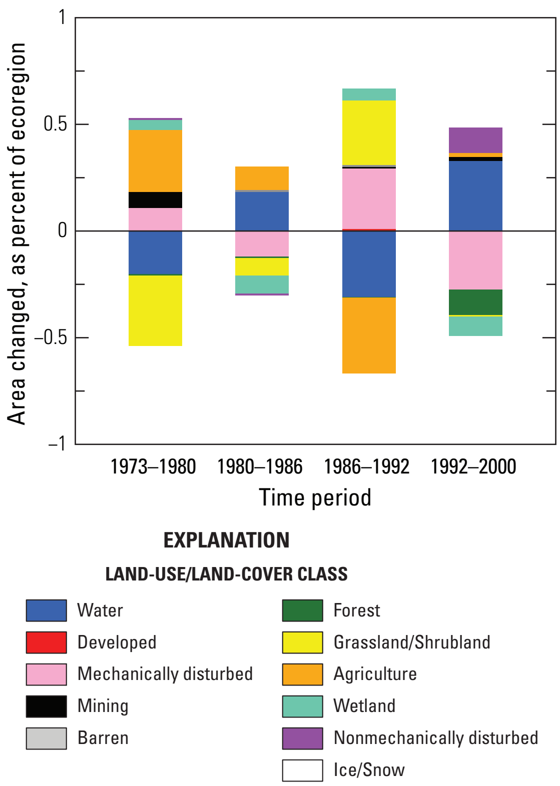

Figure 8. Normalized average net change in Wyoming Basin Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

4.2 percent, from 4,205 km^2 in 1973 to 4,027 km^2 in 2000. Nonmechanical disturbances were rare (table 3; figure 8).

The area covered by energy-related development (mining land-cover class) also was relatively low (0.3 percent in 2000; table 3); however, this area increased substantially, from 301 km^2 in 1973 to 435 km^2 in 2000 (table 3). Thus, a 44 percent increase occurred in the area impacted by energy development during the 27-year study period. Most of the mining increases took place between 1973 and 1980, during which time mining land cover is estimated to have increased by nearly 30 percent (fig. 8) following the energy boom that occurred in the 1970s.

The amount of area affected by mining may be underestimated, owing to the study's sampling design and the random sample-block selection process, as well as the 60-m resolution of the data. Almost all of the blocks fell outside areas experiencing major energy development. Some sample blocks (143, 533, 622) contained some energy development, but major oil and gas fields such as the Jonah and Pinedale fields were not sampled in the random selection process. Many oil- and gas-well pads are less than 60 m^2 and, thus, did not meet the minimum mapping-unit size in this study. Additionally, the extensive transportation networks required to access the oil- and gas-well pads have not been mapped. Thus, the measures of area in the mining and developed land-use/land-cover classes can be interpreted as highly conservative estimates of the true area affected.

Today (2012), Wyoming is in the midst of another energy boom. High demand and increasing prices for oil and gas since 2000 have rapidly transformed Wyoming's economy and landscape. Information from this project and other USGS projects that are examining the impacts of energy development, as well as from anecdotal accounts, indicates that the current rate of energy development is greatly outpacing past rates.

The fact that a large proportion of the Wyoming Basin Ecoregion is public land will constrain certain types of land-use/land-cover change. Energy exploration and grazing are extensive on both public and private lands, but intensive agricultural and urban development is limited to private lands. This constraint, in addition to a harsh and dry climate, generally limits agriculture to riparian areas where water is directly available for irrigation. The extent of agriculture fluctuated during the study period and is likely to continue to fluctuate as demand for agricultural products changes over time.

Urban development also will be both constrained and driven by land-ownership patterns. On the one hand, public lands preclude housing and urban development. On the other hand, public lands provide natural amenities that often attract low-density-housing development. The greatest increases in developed land occurred between 1986 and 1992, following the energy boom of the mid-1970s, and between 1992 and 2000 (fig. 8). Just as this study provides a conservative estimate of the area impacted by mining, it is probably providing a highly conservative estimate of the area impacted by development.

Most of the Wyoming Basin Ecoregion has not experienced substantial land-use/land-cover change during the past three decades. Large expanses of land remain largely free of development and agriculture; however, Wyoming's mineral resources are abundant, and the only limit to energy development may be the cost of extraction. As demands for energy increase with population growth, energy-related landscape change in the Wyoming Basin Ecoregion will increase. The overall footprint of energy development may be small, but the impacts on wildlife and water quality from mines, well pads, and related transportation infrastructure may extend out for some distance. Balancing wildlife and habitat conservation with the economic and social benefits of agricultural land uses and energy development will become increasingly challenging as the landscape in the Wyoming Basin Ecoregion continues to change.

Table 1. Percentage of Wyoming Basin Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (98.2 percent), whereas 1.8 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.4	0.7	0.6	2.1	0.5	35.6
2	0.3	0.2	0.1	0.5	0.1	41.9
3	0.0	0.0	0.0	0.0	0.0	56.4
4	0.2	0.3	−0.1	0.5	0.2	97.5
Overall spatial change	1.8	0.9	1.0	2.7	0.6	32.0

Table 2. Raw estimates of change in Wyoming Basin Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.8	0.4	0.4	1.2	0.3	34.7	0.1
1980–1986	0.4	0.3	0.1	0.7	0.2	47.1	0.1
1986–1992	0.8	0.7	0.2	1.5	0.5	54.0	0.1
1992–2000	0.7	0.5	0.2	1.1	0.3	46.5	0.1
Estimate of change, in square kilometers							
1973–1980	1,018	523	495	1,541	354	34.7	145
1980–1986	550	383	167	933	259	47.1	92
1986–1992	1,087	868	219	1,955	587	54.0	181
1992–2000	858	591	267	1,449	399	46.5	107

Table 3. Estimated area (and margin of error) of each land-cover class in Wyoming Basin Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.5	0.4	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.5	3.3	1.9	92.3	2.4	1.9	1.4	1.2	0.5	0.0	0.0
1980	0.3	0.2	0.0	0.0	0.1	0.2	0.3	0.3	0.6	0.5	3.3	1.9	92.0	2.5	2.2	1.5	1.2	0.5	0.0	0.0
1986	0.5	0.4	0.0	0.0	0.0	0.0	0.3	0.3	0.6	0.5	3.2	1.9	91.9	2.5	2.3	1.5	1.1	0.5	0.0	0.0
1992	0.2	0.1	0.0	0.0	0.3	0.3	0.3	0.3	0.6	0.5	3.2	1.9	92.2	2.3	2.0	1.1	1.2	0.5	0.0	0.0
2000	0.5	0.4	0.0	0.0	0.0	0.0	0.3	0.3	0.6	0.5	3.1	1.7	92.2	2.3	2.0	1.2	1.1	0.5	0.1	0.2
Net change	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	−0.1	0.2	−0.1	0.7	0.1	0.7	−0.1	0.1	0.1	0.2
Gross change	1.1	1.4	0.0	0.0	0.8	0.9	0.1	0.1	0.0	0.0	0.1	0.2	1.1	0.6	0.9	0.6	0.5	0.4	0.1	0.2
Area, in square kilometers																				
1973	659	576	39	40	6	9	301	289	749	581	4,205	2,426	118,962	3,124	2,511	1,812	1,483	642	0	0
1980	403	276	40	40	152	219	390	371	751	581	4,193	2,423	118,539	3,192	2,886	1,917	1,548	620	13	19
1986	638	545	42	41	1	1	397	369	755	581	4,184	2,421	118,426	3,206	3,028	1,967	1,444	608	0	0
1992	234	164	57	43	362	397	416	371	759	581	4,183	2,421	118,825	2,958	2,570	1,476	1,508	603	0	0
2000	660	566	61	44	10	7	435	380	760	581	4,027	2,229	118,822	2,947	2,595	1,498	1,388	586	157	229
Net change	1	21	23	13	4	11	134	95	10	16	−178	230	−140	857	85	845	−96	69	157	229
Gross change	1,412	1,769	23	13	1,033	1,221	140	101	22	16	179	231	1,422	807	1,113	831	589	560	183	231

Table 4. Principal land-cover conversions in Wyoming Basin Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	423	339	229	0.3	41.6
	Water	Mechanically disturbed	150	219	148	0.1	14.8
	Water	Wetland	122	170	115	0.1	11.9
	Grassland/Shrubland	Mining	89	84	57	0.1	8.7
	Agriculture	Grassland/Shrubland	82	109	74	0.1	8.1
	Other	Other	152	n/a	n/a	0.1	14.9
		Totals	1,018			0.8	100.0
1980–1986	Grassland/Shrubland	Agriculture	135	88	59	0.1	24.6
	Mechanically disturbed	Water	133	195	132	0.1	24.3
	Wetland	Water	107	155	105	0.1	19.5
	Grassland/Shrubland	Wetland	43	41	28	0.0	7.9
	Wetland	Grassland/Shrubland	40	29	19	0.0	7.2
	Other	Other	91	n/a	n/a	0.1	16.6
		Totals	550			0.4	100.0
1986–1992	Agriculture	Grassland/Shrubland	498	716	484	0.4	45.8
	Water	Mechanically disturbed	333	397	269	0.3	30.6
	Water	Wetland	82	113	77	0.1	7.5
	Grassland/Shrubland	Agriculture	39	33	22	0.0	3.6
	Grassland/Shrubland	Mechanically disturbed	23	32	22	0.0	2.1
	Other	Other	112	n/a	n/a	0.1	10.3
		Totals	1,087			0.8	100.0
1992–2000	Mechanically disturbed	Water	336	397	268	0.3	39.2
	Forest	Nonmechanically disturbed	157	229	155	0.1	18.3
	Wetland	Water	88	121	82	0.1	10.3
	Grassland/Shrubland	Agriculture	77	75	50	0.1	9.0
	Agriculture	Grassland/Shrubland	59	54	37	0.0	6.8
	Other	Other	141	n/a	n/a	0.1	16.5
		Totals	858			0.7	100.0
1973–2000 (overall)	Grassland/Shrubland	Agriculture	675	456	309	0.5	19.2
	Agriculture	Grassland/Shrubland	641	874	591	0.5	18.3
	Water	Mechanically disturbed	486	611	413	0.4	13.8
	Mechanically disturbed	Water	472	587	397	0.4	13.4
	Wetland	Water	217	277	187	0.2	6.2
	Other	Other	1,022	n/a	n/a	0.8	29.1
		Totals	3,513			2.7	100.0

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Chapter 26

Arizona/New Mexico Plateau Ecoregion

By Jana Ruhlman, Leila Gass, and Barry Middleton

Ecoregion Description

Situated between ecoregions of distinctly different topographies and climates, the Arizona/New Mexico Plateau Ecoregion represents a large area of approximately 192,869 km^2 (74,467 mi^2) that stretches across northern Arizona, central and northwestern New Mexico, and parts of southwestern Colorado; in addition, a small part extends into southeastern Nevada (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). Forested, mountainous terrain borders the ecoregion on the northeast (Southern Rockies Ecoregion) and southwest (Arizona/New Mexico Mountains Ecoregion). Warmer and drier climates exist to the south (Chihuahuan Deserts Ecoregion) and west (Mojave Basin and Range Ecoregion). The semiarid grasslands of the western Great Plains are to the east (Southwestern Tablelands Ecoregion), and the tablelands of the Colorado Plateau in Utah and western Colorado lie to the north (Colorado Plateaus Ecoregion). The Arizona/New Mexico Plateau Ecoregion occupies a significant portion of the southern half of the Colorado Plateau.

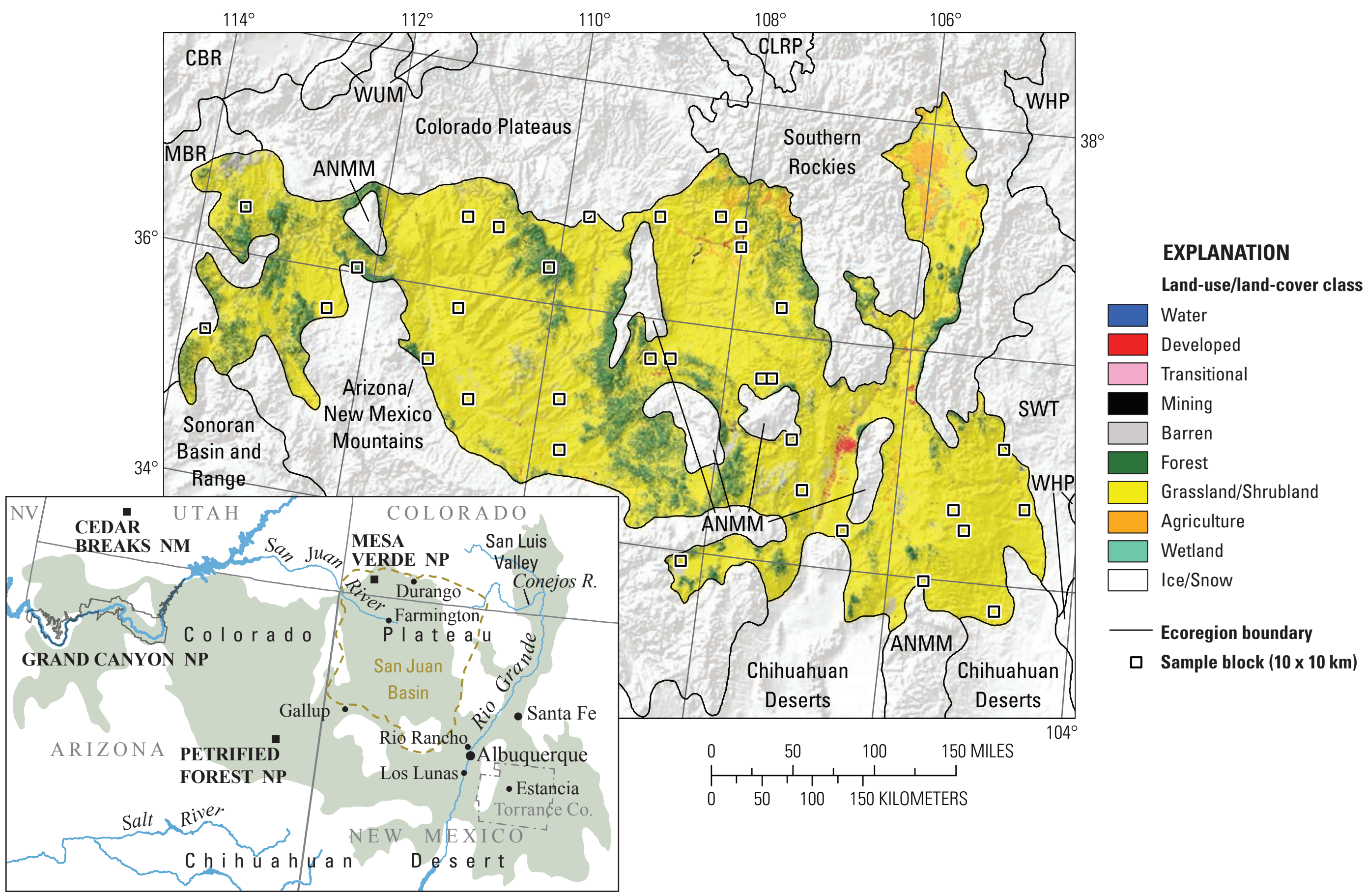

Figure 1. Map of Arizona/New Mexico Plateau Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map are parts of two Great Plains ecoregions: Southwestern Tablelands (SWT) and Western High Plains (WHP). See appendix 3 for definitions of land-use/land-cover classifications.

The Arizona/New Mexico Plateau Ecoregion is covered predominantly in a mosaic of sparse semiarid grassland and desert-scrub species. Major washes and river courses often contain riparian canopies of cottonwood (*Populus deltoides*), desert willow (*Chilopsis linearis*), and salt cedar (*Tamarix* spp.). Juniper (*Juniperus* spp.) and pinyon (*Pinus* spp.) trees are located in the upland areas, with ponderosa pine (*Pinus ponderosa*) forests present at the highest elevations. The climate in the ecoregion is mostly semiarid, but regional topography causes annual precipitation to vary substantially, ranging from 127 to 890 mm (Daly and others, 2002). Most of the ecoregion, however, averages between 152 and 254 mm of precipitation from southwestern monsoonal summer thunderstorms and winter frontal storms. The coldest areas can dip below −17.8°C in winter, and the hottest summer temperatures can exceed 36°C (Western Regional Climate Center, 2009).

Albuquerque, New Mexico, is the largest urban area, with a 2000 census population of 448,607, followed by Santa Fe, New Mexico, with a population of 62,203. Numerous smaller communities exist within the ecoregion, but only five municipalities had a 2000 census count greater than 10,000: Rio Rancho, Farmington, Gallup, and Los Lunas, New Mexico, and Durango, Colorado (U.S. Census Bureau, 2001a, 2001b). Over 55 percent of the ecoregion is federal land, with the majority occupying one of 29 different Indian reservations and pueblos. The largest of these tribal lands is the Navajo Nation, with 41,562 km^2 within the Arizona/New Mexico Plateau Ecoregion. The next largest federal landholders in the ecoregion are the Bureau of Land Management, Forest Service, and National Park Service. There are 15 National Park Service areas within the ecoregion; many of the national parks and monuments are dedicated to preserving the rich history and remnants from the Southwest's ancient native cultures. Prominent national parks in the ecoregion are the Grand Canyon and the Petrified Forest in Arizona and Mesa Verde in Colorado.

Because of limited rainfall in the ecoregion, crop production is found primarily in close proximity to natural water sources such as the Rio Grande, San Juan River, and Conejos River. The high mountains surrounding the fertile San Luis Valley in south-central Colorado and northern New Mexico provide snowmelt, which supports extensive farming in that area (McNoldy and Doesken, 2007). Likewise, there is considerable agriculture in the closed Estancia basin region in Torrance County, New Mexico, which is "one of the most productive agricultural counties in the United States" (Torrance County, New Mexico, 2009).

With over 33 percent of the Arizona/New Mexico Plateau Ecoregion designated as tribal lands, sheep ranching, cattle ranching, and farming (dry and some irrigated) continue to be the primary traditional economic activities for many Native Americans (Grahame and Sisk, 2002). The effect of low regional precipitation levels that can support only scant forage has been exacerbated by a long-term trend toward aridity in this part of the ecoregion (Karl and others, 2009). Combined with historical overgrazing and desertification, the condition of the rangeland in many areas is poor. As early as 1933, the Bureau of Indian Affairs determined that two-thirds of the Navajo rangeland had been overgrazed (Grahame and Sisk, 2002). Increases in wind erosion and sand-dune mobility that have resulted from current drought conditions across northeastern Arizona have further degraded rangelands (Ferguson and Crimmins, 2009).

Mining also contributes to local economies in parts of the Arizona/New Mexico Plateau Ecoregion. The San Juan Basin in northwestern New Mexico and southwestern Colorado was at one time the second largest natural-gas reserve in the United States (La Plata County Energy Council, 2009), having 20,000 producing wells (Ortega, 2009). Additionally, the Peabody Western Coal Company mines about 8.5 million tons of coal annually through lease agreements with the Navajo Nation and Hopi Tribe (U.S. Office of Surface Mining, 2008). As the ecoregion's largest city, Albuquerque is also its largest economy. Located at the crossroads of Interstate Highways 25 and 70, Albuquerque has a "diverse economic base consisting of government, services, trade, agriculture, tourism, manufacturing, and research and development" (City-Data.com, 2009). Kirtland Air Force Base is the largest employer in the Albuquerque metropolitan area (Albuquerque Economic Development, Inc., 2010).

Contemporary Land-Cover Change (1973 to 2000)

The Arizona/New Mexico Plateau Ecoregion experienced very little land-cover change during the study period (fig. 2). An estimated 1.2 percent of the ecoregion (2,380 km^2) converted to other land-cover classes during the study period. Estimates reveal that 1.1 percent of the ecoregion changed only once during the study period, and 0.1 percent changed twice (table 1). However, standard error is high as a proportion of overall spatial change, which is not unusual for an ecoregion with little change. Compared to other western United States ecoregions, the Arizona/New Mexico Plateau Ecoregion had the lowest amount of change other than the Chihuahuan Deserts Ecoregion and the Southern Rockies Ecoregion. Low estimates of land-cover change are consistent with other ecoregions in the Southwest (figs. 2, 3).

Estimated land-cover change per time period started with 0.2 percent between 1973 and 1980, and it increased 0.1 percent each time period thereafter, to reach 0.5 percent between 1992 and 2000. When the change estimates are normalized to account for the varying lengths of time between satellite imagery dates, the average rate of change per year was less than 100 km^2 between 1973 and 1980 and between 1980 and 1986, 131 km^2 between 1986 and 1990, and 111 km^2 between 1992 and 2000 (table 2; fig. 3).

Results showed that grassland/shrubland and forest were the predominant land-cover classes within the ecoregion. Grassland/shrubland encompassed approximately 78 percent of the land cover in each time period, whereas forest covered

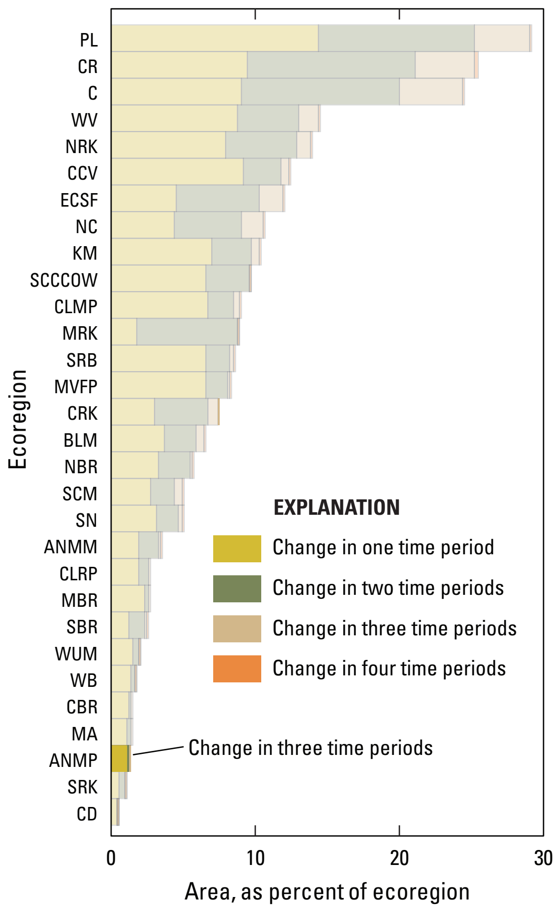

Figure 2. Overall spatial change in Arizona/New Mexico Plateau Ecoregion (ANMP; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Arizona/New Mexico Plateau Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

19 percent (table 3). The barren class accounted for 1.7 percent of the land cover, and the water, developed, mining, agriculture, wetland, and nonmechanically disturbed classes collectively made up the remaining land cover.

The developed and grassland/shrubland classes had the greatest net change during the study period. Grassland/shrubland declined by 0.5 percent (810 km^2), from 78.0 to 77.6 percent of the ecoregion. The developed class increased by 144 percent during the study period but remained only 0.7 percent of the ecoregion in 2000. The remaining classes experienced minimal net change (table 3).

Examination of net-change values alone can mask land-cover dynamics that occur within a given study period. Figure 4 illustrates the fluctuations that occurred in land-cover classes between time periods. Changes in grassland/shrubland occurred at variable rates over the study period; a slight increase occurred between 1986 and 1992, and the greatest decrease occurred between 1992 and 2000. The developed class increased the most between 1980 and 1986 but consistently gained over the entire study period. Mobility in active sand dunes was mapped during the study period, and it is conceivable the intense drought that began in this area in 1996 allowed for more sand deposition and active transport than in previous years, possibly explaining the 80 km^2 growth of the barren class over the study period. Research by U.S. Geological Survey scientists confirmed that drought conditions on the Navajo Nation Reservation have accelerated destabilization and mobility of sand dunes, owing to the detrimental effect on stabilizing vegetation (Redsteer and Block, 2004).

The most common land-cover conversions between 1973 and 2000 involved the grassland/shrubland, agriculture, and developed classes (table 4). Grassland/shrubland to developed (533 km^2) was the primary conversion between 1973 and 2000, followed by agriculture reverting to grassland/shrubland (470 km^2). Fire caused the next most common conversion of grassland/shrubland to nonmechanically disturbed, which occurred between 1992 and 2000 (393 km^2). Agriculture to

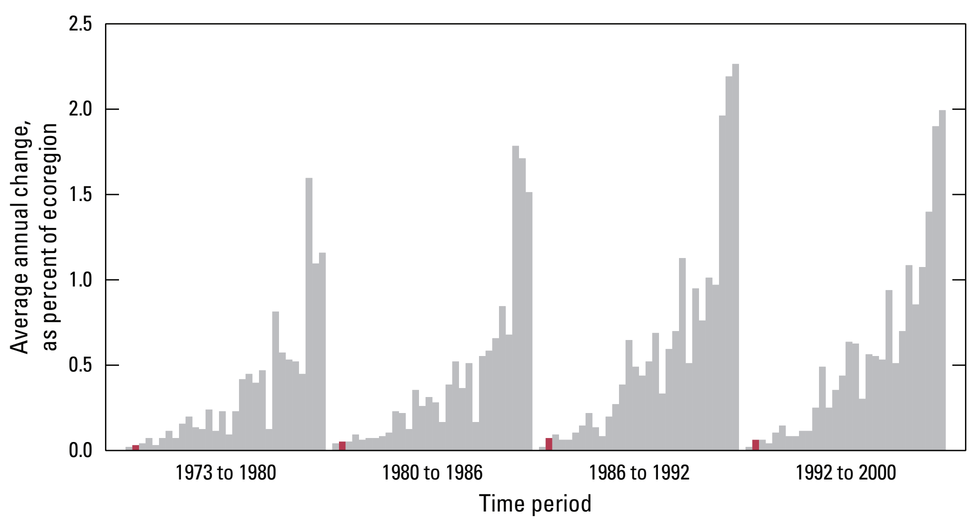

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Arizona/New Mexico Plateau Ecoregion are represented by red bars in each time period.

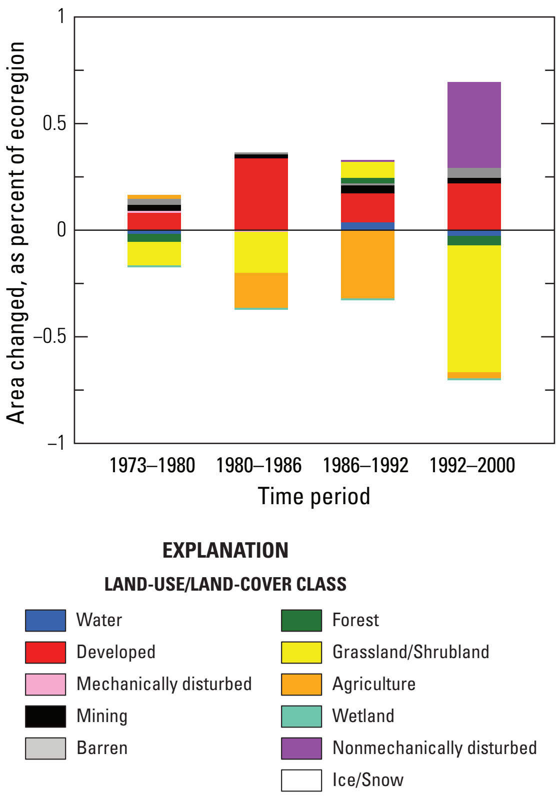

Figure 4. Normalized average net change in Arizona/New Mexico Plateau Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

developed was the fourth most common land-cover conversion. The overall net loss in agriculture (to grassland/shrubland and developed) was 30.8 percent of the area occupied by agriculture in 1973. However, although fieldwork confirmed the presence of many of the conversions listed in table 4, the margins of error in the table demonstrate the high degree of uncertainty derived from this study's interpretations.

The Arizona/New Mexico Plateau Ecoregion experienced little change in major land-cover classes between 1973 and 2000. Except for the Albuquerque metropolitan area, the ecoregion is sparsely populated, consisting mainly of large expanses of grassland/shrubland devoted to grazing (fig. 5). In an ecoregion where 78 percent of the land cover is grassland/shrubland, most land-cover change would be expected to occur in that dominant class. Change in grassland/shrubland class was distributed throughout the ecoregion, occurring in 26 out of 32 study blocks.

Change in the agriculture class occurred mainly in study blocks located along the San Juan River or in or near the Estancia basin region of central New Mexico. The largest observed area of former agricultural lands had evidence of abandoned canals leading from the nearby river. Statistics for the ecoregion's largest agricultural area, the San Luis Valley, indicated a small decrease (1.5 percent) in acreage devoted to farming between 1987 and 2002 (U.S. Department of Agriculture, 1992, 2002).

The Albuquerque metropolitan area is the location of most of the growth of developed land in the ecoregion. In 2000, Albuquerque's population was 448,607 (U.S. Census Bureau, 2001b), having grown from 243,751 in 1970 (U.S. Census Bureau, 1973). This 84 percent growth rate is substantial; moreover, the entire Albuquerque metropolitan area grew 125.7 percent within this same time frame (U.S. Census Bureau, 1973, 2001b). This population growth is reflected in the continually increasing acreage devoted to urban development. A 1997 U.S. Geological Survey study that mapped urban land use from aerial photographs noted that the Albuquerque metropolitan area had grown from 49,746 to 84,889 acres between 1973 and 1991, a 71 percent increase in area (Braun and others, 1998). Growth of the Albuquerque metropolitan area is expected to continue, with population projected to hit one million by 2021 or before (Siemers, 2007).

Coal mining in the Navajo Nation and the prolific amount of coal-bed methane available in the San Juan Basin will remain important and have many potential impacts on the Arizona/New Mexico Plateau Ecoregion. The area occupied by mining more than doubled during the study period (although the area remained as roughly 0.1 percent of ecoregion area). This small reported area might be attributable to the fact that no areas of coal mining were captured in our study blocks, as well as the fact that the footprint of new oil or gas wells mapped in study blocks within the San Juan Basin was minimal. Increased mining activity in the future may cause more land-cover change in the ecoregion, especially in the San Juan Basin.

The small land-cover changes that did occur during the study period were mainly due to increased urbanization, at the expense of natural grassland/shrubland and agricultural lands, as well as agricultural abandonment. It is important to keep in mind, however, that these land-cover changes were minor, and they represent a small percentage of the overall land cover of the ecoregion.

Figure 5. Rangeland southwest of Albuquerque, New Mexico.

Table 1. Percentage of Arizona/New Mexico Plateau Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (98.8 percent), whereas 1.2 percent changed at least once throughout study period. Two dashes (--) indicate that, because zero pixels changed four times during study period, relative error is not calculable]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.1	0.6	0.5	1.8	0.4	38.9
2	0.1	0.0	0.0	0.1	0.0	34.3
3	0.0	0.0	0.0	0.0	0.0	39.2
4	0.0	0.0	0.0	0.0	0.0	--
Overall spatial change	1.2	0.7	0.6	1.9	0.5	36.9

Table 2. Raw estimates of change in Arizona/New Mexico Plateau Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.2	0.1	0.1	0.3	0.1	40.2	0.0
1980–1986	0.3	0.3	0.0	0.5	0.2	66.4	0.0
1986–1992	0.4	0.3	0.1	0.7	0.2	44.6	0.1
1992–2000	0.5	0.3	0.1	0.8	0.2	49.2	0.1
Estimate of change, in square kilometers							
1973–1980	422	250	171	672	170	40.2	60
1980–1986	513	503	10	1,016	341	66.4	85
1986–1992	789	520	269	1,308	352	44.6	131
1992–2000	891	647	245	1,538	438	49.2	111

Table 3. Estimated area (and margin of error) of each land-cover class in Arizona/New Mexico Plateau Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.1	0.0	0.3	0.2	0.0	0.0	0.1	0.0	1.7	1.6	18.8	6.1	78.0	6.0	0.8	0.8	0.3	0.3	0.0	0.0
1980	0.1	0.0	0.3	0.3	0.0	0.0	0.1	0.1	1.7	1.6	18.8	6.1	78.0	6.0	0.8	0.7	0.3	0.3	0.0	0.0
1986	0.1	0.0	0.5	0.4	0.0	0.0	0.1	0.1	1.7	1.6	18.8	6.1	77.9	6.0	0.7	0.6	0.3	0.3	0.0	0.0
1992	0.1	0.1	0.6	0.5	0.0	0.0	0.1	0.1	1.7	1.6	18.8	6.1	77.9	6.0	0.6	0.6	0.2	0.3	0.0	0.0
2000	0.1	0.0	0.7	0.6	0.0	0.0	0.1	0.1	1.7	1.6	18.8	6.1	77.6	5.9	0.5	0.6	0.2	0.3	0.2	0.3
Net change	0.0	0.0	0.4	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	−0.4	0.5	−0.2	0.3	0.0	0.0	0.2	0.3
Gross change	0.1	0.0	0.4	0.5	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.9	0.5	0.3	0.3	0.0	0.0	0.2	0.3
Area, in square kilometers																				
1973	111	83	524	463	0	0	102	93	3,289	2,999	36,322	11,852	150,513	11,487	1,523	1,447	486	529	0	0
1980	99	82	606	518	8	9	129	120	3,313	2,998	36,283	11,843	150,403	11,487	1,543	1,423	485	529	0	0
1986	104	85	934	856	3	5	147	122	3,318	2,998	36,282	11,842	150,212	11,506	1,385	1,231	484	526	0	0
1992	138	106	1,067	964	8	7	180	135	3,330	2,998	36,305	11,838	150,281	11,536	1,073	1,151	481	521	6	9
2000	116	79	1,277	1,187	3	4	212	155	3,369	2,996	36,265	11,833	149,703	11,471	1,053	1,130	475	514	396	580
Net change	5	40	753	900	3	4	110	76	80	76	−57	68	−810	981	−470	517	−10	16	396	580
Gross change	168	96	753	900	27	20	110	76	102	86	178	148	1685	967	590	512	13	16	409	580

Table 4. Principal land-cover conversions in Arizona/New Mexico Plateau Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Agriculture	104	101	68	0.1	24.7
	Agriculture	Grassland/Shrubland	62	66	45	0.0	14.7
	Grassland/Shrubland	Developed	59	73	50	0.0	14.0
	Forest	Grassland/Shrubland	38	53	36	0.0	9.0
	Grassland/Shrubland	Barren	31	33	22	0.0	7.4
	Other	Other	127	n/a	n/a	0.1	30.1
		Totals	422			0.2	100.0
1980–1986	Grassland/Shrubland	Developed	172	214	145	0.1	33.6
	Agriculture	Developed	151	221	150	0.1	29.5
	Agriculture	Grassland/Shrubland	49	55	37	0.0	9.5
	Grassland/Shrubland	Agriculture	40	39	27	0.0	7.8
	Grassland/Shrubland	Water	22	12	8	0.0	4.2
	Other	Other	79	n/a	n/a	0.0	15.4
		Totals	513			0.3	100.0
1986–1992	Agriculture	Grassland/Shrubland	327	445	302	0.2	41.4
	Grassland/Shrubland	Developed	113	116	79	0.1	14.4
	Grassland/Shrubland	Forest	96	133	90	0.0	12.2
	Forest	Grassland/Shrubland	61	83	56	0.0	7.8
	Grassland/Shrubland	Water	55	60	41	0.0	7.0
	Other	Other	137	n/a	n/a	0.1	17.3
		Totals	789			0.4	100.0
1992–2000	Grassland/Shrubland	Nonmechanically disturbed	393	575	390	0.2	44.1
	Grassland/Shrubland	Developed	188	212	143	0.1	21.1
	Forest	Grassland/Shrubland	53	77	52	0.0	6.0
	Grassland/Shrubland	Barren	42	43	29	0.0	4.8
	Agriculture	Grassland/Shrubland	32	35	24	0.0	3.6
	Other	Other	182	n/a	n/a	0.1	20.4
		Totals	891			0.5	100.0
1973–2000 (overall)	Grassland/Shrubland	Developed	533	598	405	0.3	20.4
	Agriculture	Grassland/Shrubland	470	467	316	0.2	18.0
	Grassland/Shrubland	Nonmechanically disturbed	393	575	390	0.2	15.0
	Agriculture	Developed	201	293	198	0.1	7.7
	Grassland/Shrubland	Agriculture	197	151	102	0.1	7.5
	Other	Other	821	n/a	n/a	0.4	31.4
		Totals	2,615			1.4	100.0

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Warm Deserts Ecoregions

Status and Trends of Land Change in the Western United States—1973 to 2000
Edited by Benjamin M. Sleeter, Tamara S. Wilson, and William Acevedo
U.S. Geological Survey Professional Paper 1794–A, 2012

Chapter 27

Chihuahuan Deserts Ecoregion

By Jana Ruhlman, Leila Gass, and Barry Middleton

Ecoregion Description

The Chihuahuan Desert is the largest of the North American deserts, extending from southern New Mexico and Texas deep into Mexico, with approximately 90 percent of its area falling south of the United States–Mexico border (Lowe, 1964, p. 24). The Chihuahuan Deserts Ecoregion covers approximately 174,472 km^2 (67,364 mi^2) within the United States, including much of west Texas, southern New Mexico, and a small portion of southeastern Arizona (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion is generally oriented from northwest to southeast, with the Madrean Archipelago Ecoregion to the west; the Arizona/New Mexico Mountains, Arizona/New Mexico Plateau, Southwestern Tablelands, and Western High Plains Ecoregions to the north; and the Edwards Plateau and Southern Texas Plains Ecoregions to the east (fig. 1).

The Chihuahuan Desert is distinguished from other hot deserts in the Southwest by its higher elevation and summer-dominant rainfall. The terrain consists of broad basins and valleys bordered by sloping alluvial fans and terraces, along with isolated mesas and mountains. The alluvial fans and basins

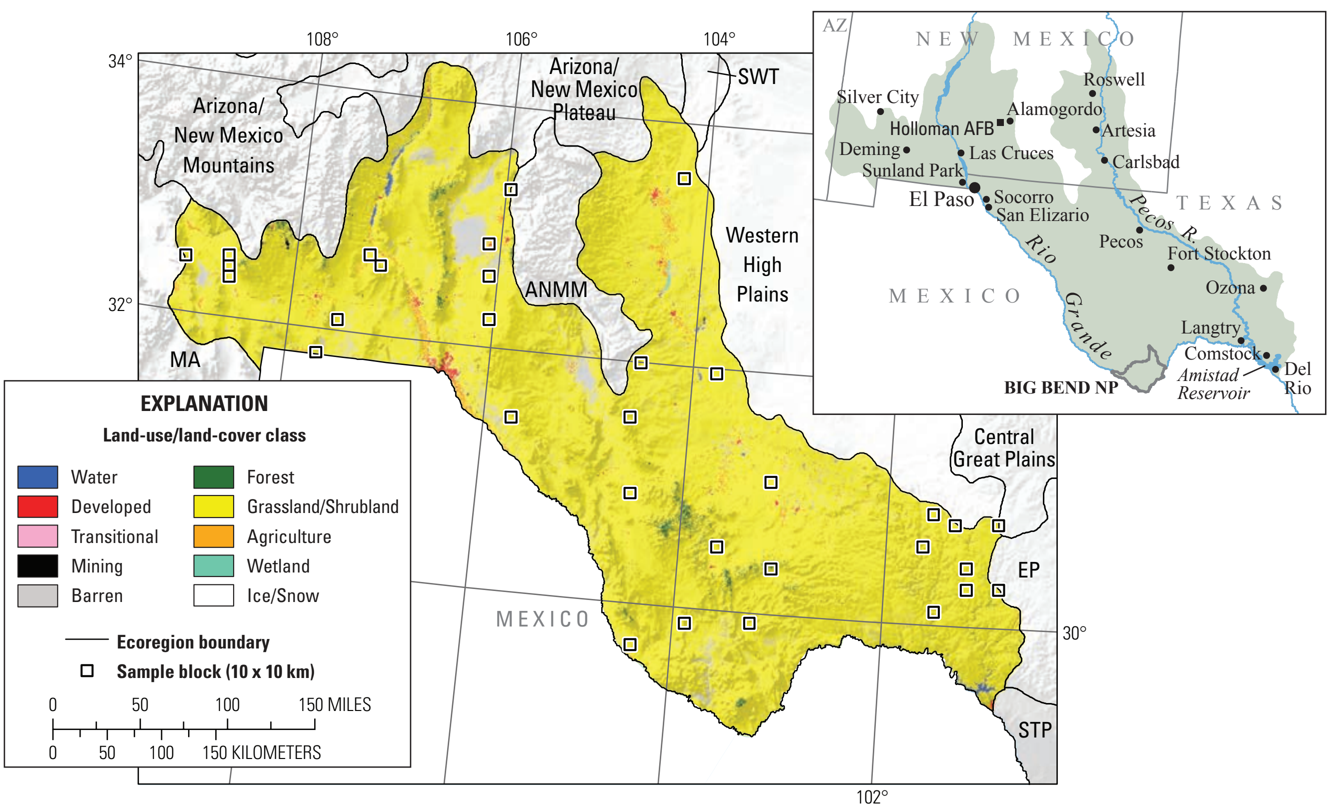

Figure 1. Map of Chihuahuan Deserts Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. Also shown on map are parts of five Great Plains Ecoregions: Central Great Plains, Edwards Plateau (EP), Southern Texas Plains (STP), Southwestern Tablelands (SWT), and Western High Plains. See appendix 3 for definitions of land-use/land-cover classifications.

play an important role in groundwater recharge of the alluvial-basin aquifer systems that supply water to human populations along the Texas–Mexico border.

In the northern Chihuahuan Desert, annual precipitation averages 245 to 265 mm, with most of the precipitation falling in the summer (Gucker, 2006; Schmidt, 1983). Annual mean temperatures range from less than 12°C to greater than 20°C throughout the part of the Chihuahuan Desert that is north of the border (Daly and others, 2002). January minimum temperatures reach near or below freezing except along parts of the Rio Grande in Texas, where July maximum temperature. exceed 36°C (National Park Service, 2007).

Unique in its diversity of yucca (*Yucca* spp.) and agave (*Agave* spp.) species (fig. 2), the Chihuahuan Desert replaces the large cacti, creosote bush (*Larrea tridentata*), and bursage (*Asteraceae* spp.) communities of the Sonoran Desert to the west with large yuccas amid a sea of sparse grass and shrubs. Much of the Chihuahuan Deserts Ecoregion was once covered by healthy semidesert grasslands, but heavy livestock grazing coupled with frequent droughts during the 20th century transformed thousands of acres to desert shrubland, a process that still continues (Hoyt, 2002). Extensive areas of Chihuahuan semidesert grasslands are now dominated by creosote bush (*Larrea tridentata*), tarbush (*Flourensia cernua)*, and mesquite (*Prosopis* spp.) (Buffington and Herbel, 1964, p. 139). McClaran and Van Devender (1995, p. 250–251) stated that livestock grazing and range-management programs since the 1870s have “led to soil erosion, destruction of those plants most palatable to livestock, changes in grassland fire ecology, the spread of nonnative plants, and a steady increase in the density of woody shrubs and brush.” However, some have challenged these prevailing interpretations of influences on environmental degradation, highlighting the significance of climate variability as a catalyst and the need for a more stakeholder-driven research approach when evaluating ecological stewardship (West and Vásquez-León, 2008).

Water in the ecoregion is limited, which makes its major rivers, the Rio Grande (fig. 3) and the Pecos River (fig. 4), precious resources. These river valleys create large riparian areas, and major pockets of development are located along their corridors (New Mexico State University, 2007). Most of the water in the Chihuahuan Deserts Ecoregion is associated with the Rio Grande and the Pecos River and their tributaries. Reservoirs on these rivers provide water for the ecoregion’s limited irrigated agriculture, as well as supply water for its major cities, including Las Cruces and Roswell, New Mexico, and El Paso, Texas.

Livestock, oil and gas production, and tourism are all important to the economy of the Chihuahuan Deserts Ecoregion (Conservation History Association of Texas, 2009). The Natural Resources Conservation Service reported that, in the Chihuahuan Desert Resource Conservation and Development area of Texas, 89 percent of the area was rangeland, and beef cattle, dairy cattle, pecans, onions, and various other crops were the major agricultural products (U.S. Department of Agriculture, 2008). Wheat (mostly irrigated), hay, sorghum,

Figure 2. Soaptree yucca (*Yucca elata*) near Texas–New Mexico border, south of Carlsbad, New Mexico. This is one of many types of yuccas and agaves indigenous to Chihuahuan Deserts Ecoregion.

Figure 3. View of Rio Grande from scenic overlook in Big Bend National Park, looking southwest into Mexico at Santa Elena Mountains.

Figure 4. View looking north over Pecos River, between Langtry and Comstock, Texas. This part of river contains water impounded by Amistad Reservoir, located farther downstream.

cotton, and a variety of fruits, nuts, and vegetables, as well as livestock, are important to the economy of all New Mexico counties in the ecoregion (U.S. Department of Agriculture, 2007). Farmers in the ecoregion also grow many varieties of chili peppers in the fertile fields along the Rio Grande in both New Mexico and Texas.

Federal lands make up approximately 28 percent of the Chihuahuan Deserts Ecoregion, with the majority managed by the Bureau of Land Management and the Department of Defense (for example, White Sands Missile Range, Holloman Air Force Base, and Fort Bliss); these military installations are a vital part of the local economies (Las Cruces and Alamogordo, New Mexico, and El Paso, Texas, respectively). Approximately 4,460 km^2 are managed by the National Park Service within seven park units, and these represent the nation's most significant areas of preserved Chihuahuan Desert landscape (National Park Service, 2005). White Sands National Monument and Carlsbad Caverns National Park in New Mexico and Big Bend National Park in Texas are three of the more notable parks within the ecoregion.

Contemporary Land-Cover Change (1973 to 2000)

The Chihuahuan Deserts Ecoregion had very little land-cover change during the study period (fig. 5). An estimated 0.5 percent of the ecoregion (822 km^2) was converted to other land-cover types (table 1). The standard error of 0.2 percent is high in proportion to the overall change of 0.5 percent but is not unusual for an ecoregion with so little change. Compared to other western ecoregions, change in the Chihuahuan Deserts Ecoregion was the lowest (figs. 5,6). Low change is consistent with that of other ecoregions in the arid Southwest. The estimated change in land cover was 0.2 percent between 1980 and 1986 and between 1992 and 2000; it was 0.1 percent between 1973 and 1980 and between 1986 and 1992. When

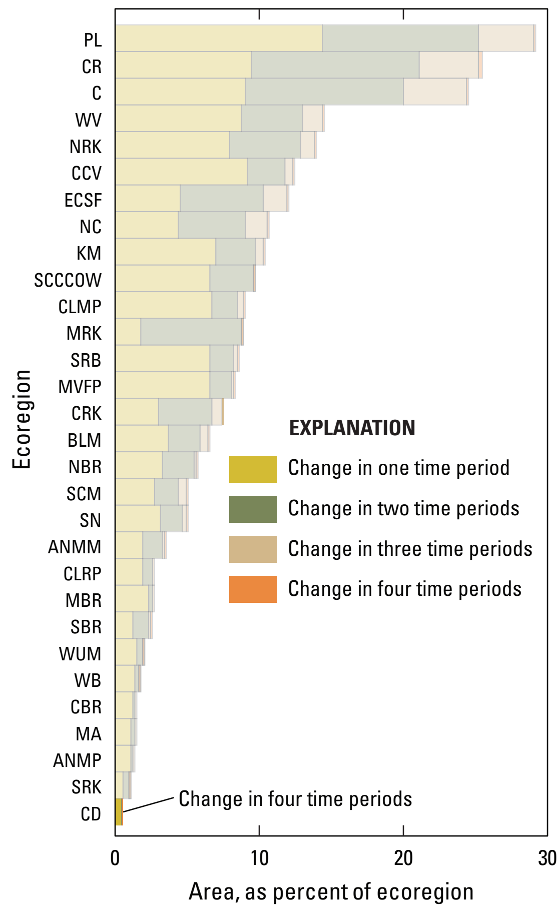

Figure 5. Overall spatial change in Chihuahuan Deserts Ecoregion (CD; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Chihuahuan Deserts Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

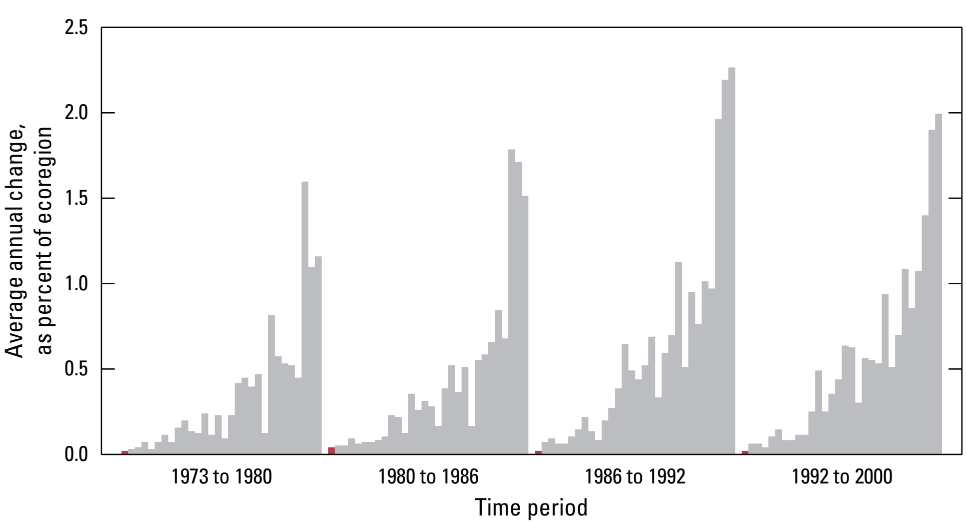

Figure 6. Estimates of land-cover change per time period normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Chihuahuan Deserts Ecoregion are represented by red bars in each time period.

the change estimates are normalized to account for the varying lengths of study periods, annual change ranged from 25 km^2 (1986–1992) to 57 km^2 (1980–1986) (table 2).

Grassland/shrubland was the predominant land cover, covering 95.6 percent of the Chihuahuan Deserts Ecoregion in 2000 (table 3; fig. 7). Forest (both riparian and higher elevation) was the second largest land cover in 2000 (2.4 percent), followed by developed lands at 1.0 percent. Water, mining, barren land, and agriculture contributed to the remaining 1.0 percent of the ecoregion's land-cover types.

Four classes changed by at least 100 km^2 during the study period: developed, mining, grassland/shrubland, and agriculture (table 3). The other classes experienced almost no change. Statistically significant, increasing trends of 11.2 percent over the study period were observed for the developed class, and the mining class nearly quadrupled in size, whereas a statistically significant, decreasing trend of 0.1 percent occurred in the grassland/shrubland class (fig. 8). No trend was apparent for agriculture, which fluctuated in gains and losses throughout the study period and had a net loss of 11.2 percent (fig. 8).

The most common conversions were grassland/shrubland to mining (217 km^2), grassland/shrubland to developed (187 km^2), and agriculture to grassland/shrubland (158 km^2) (table 4). The conversion from grassland/shrubland to mining, which occurred in each time period, was attributable to increased oil and gas extraction in the eastern part of the ecoregion (fig. 9). This type of conversion was evident in nine of the Chihuahuan Deserts Ecoregion's study blocks, which are located near the eastern border of the ecoregion and which overlie the Permian Basin, a geological province located in several counties in southeastern New Mexico and western Texas (fig. 10). More than half of the oil and gas production from Texas comes from the Permian Basin, making it the most prolific oil-producing province in United States history (Bureau of Economic Geology, 2005).

Conversion from grassland/shrubland to developed also took place during each time period, and it was the leading

Figure 7. Chihuahuan Desert grasslands south of Fort Stockton, Texas.

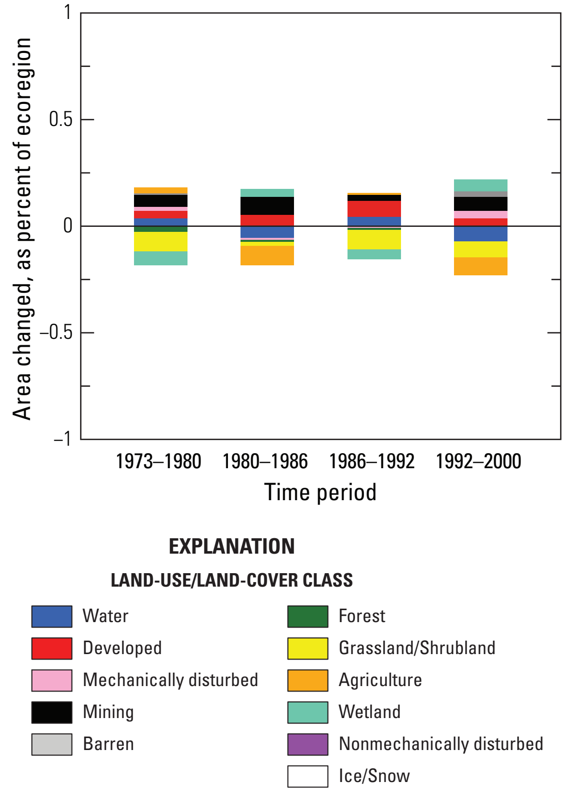

Figure 8. Normalized average net change in Chihuahuan Deserts Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

conversion between 1986 and 1992. The majority of mapped development increases, which were captured in three study blocks, took place in or near cities and near Holloman Air Force Base, New Mexico. Overall, developed land is estimated to have increased by 174 km^2 between 1973 and 2000.

Mining in the Chihuahuan Deserts Ecoregion is likely to continue to increase. In 2007, the U.S. Geological Survey estimated that 41 trillion ft^3 of undiscovered natural gas and 1.3 billion barrels of undiscovered oil are in the Permian Basin Province (Schenk and others, 2008). A decision in 2005 by the Bureau of Land Management allowed for oil and gas leasing and development on public lands in southern New Mexico's Sierra and Otero Counties. Publicized as one of the most restrictive plans ever developed for oil and gas leasing on federal lands, the plan provided for a variety of environmental protections and reclamation efforts for Chihuahuan Desert grasslands within the planning area (U.S. Bureau of Land Management, 2006).

Conversion of grassland/shrubland to developed is also likely to continue within the ecoregion. Areal interpolation of census-block data was used to obtain population totals for the Chihuahuan Deserts Ecoregion (U.S. Census Bureau, 2000). Using this technique, population in the ecoregion

Figure 9. Hydrocarbon-extraction facility southwest of Ozona, Texas.

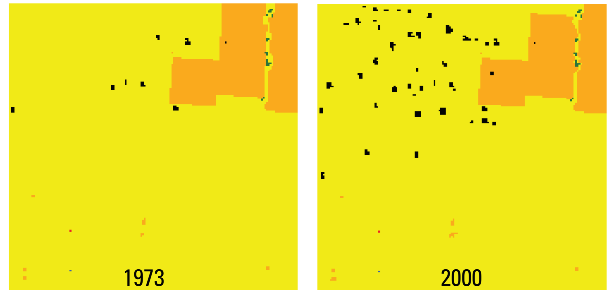

Figure 10. Sample block 24-1094, located between Pecos and Fort Stockton, Texas, showing land-use/land-cover data in 1973 (left) and 2000 (right). Between 1973 and 2000, oil and gas exploration and production increased in Permian Basin, part of Chihuahuan Deserts Ecoregion. Sample blocks show conversion between 1973 and 2000 of grassland/shrubland (yellow) to mining (black) associated with energy production; also shown are small areas of grassland/shrubland converting to agriculture (orange).

grew from 851,797 in 1980 to 1,178,626 in 2000, an increase of 38.4 percent. The population of the largest cities showed an overall increase of 67.1 percent between the 1970 and 2000 census (table 5).

A major concern in the Chihuahuan Deserts Ecoregion is the ongoing transformation of semidesert grassland into shrubland and a more desertlike ecosystem. The change in composition of the Chihuahuan grasslands has changed dramatically in the last century and continues to be observed (Brown, 1994, p. 169). Desert-scrub communities, which now make up nearly one half of the total vegetation in the Chihuahuan Desert, may have grown to their present extent through invasion of eroded grasslands (Chihuahuan Desert Research Institute, 2009). Scientists disagree, however, on the relative importance of factors such as livestock grazing, fire, and climate change as drivers of this transformation (McClaran and Van Devender, 1995, p. 265). (Note that the desertification of the Chihuahuan Desert grasslands is not reflected in the statistics of this report because capturing change within land-cover classes is not part of the Status and Trends of Land Change project design.)

Major land-cover classes changed very little in the Chihuahuan Deserts Ecoregion between 1973 and 2000. The small changes that did occur were due to increased oil and gas extraction and some urban growth, but these localized changes accounted for a small fraction of the overall ecoregion area. Except for its major cities, the ecoregion remains sparsely populated and consists mainly of large expanses of grassland and shrubland that are devoted to grazing. Little rainfall and a scarcity of both surface water and groundwater inhibit anthropogenic change in much of the ecoregion and will continue to be a challenge to future growth.

Table 1. Percentage of Chihuahuan Deserts Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (99.5 percent), whereas 0.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	0.4	0.2	0.2	0.6	0.1	29.8
2	0.0	0.0	0.0	0.1	0.0	45.9
3	0.0	0.0	0.0	0.0	0.0	85.3
4	0.0	0.0	0.0	0.0	0.0	99.1
Overall spatial change	0.5	0.2	0.2	0.7	0.2	32.1

Table 2. Raw estimates of change in Chihuahuan Deserts Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.1	0.1	0.0	0.2	0.0	38.2	0.0
1980–1986	0.2	0.1	0.1	0.3	0.1	39.7	0.0
1986–1992	0.1	0.1	0.0	0.2	0.0	51.6	0.0
1992–2000	0.2	0.1	0.1	0.3	0.1	33.6	0.0
Estimate of change, in square kilometers							
1973–1980	198	112	87	310	76	38.2	28
1980–1986	341	200	141	541	135	39.7	57
1986–1992	151	115	36	266	78	51.6	25
1992–2000	299	148	151	447	100	33.6	37

Table 3. Estimated area (and margin of error) of each land-cover class in Chihuahuan Deserts Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.1	0.1	0.9	1.0	0.0	0.0	0.0	0.0	0.2	0.1	2.4	1.3	95.8	2.3	0.6	0.6	0.0	0.1	0.0	0.0
1980	0.1	0.1	0.9	1.0	0.0	0.0	0.1	0.0	0.2	0.1	2.4	1.3	95.7	2.3	0.6	0.6	0.0	0.0	0.0	0.0
1986	0.1	0.1	0.9	1.0	0.0	0.0	0.1	0.1	0.2	0.1	2.4	1.3	95.7	2.3	0.6	0.5	0.0	0.0	0.0	0.0
1992	0.1	0.1	1.0	1.0	0.0	0.0	0.1	0.1	0.2	0.1	2.4	1.3	95.7	2.3	0.6	0.5	0.0	0.0	0.0	0.0
2000	0.1	0.0	1.0	1.0	0.0	0.0	0.2	0.1	0.2	0.1	2.4	1.3	95.6	2.3	0.6	0.5	0.0	0.0	0.0	0.0
Net change	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	−0.1	0.1	−0.1	0.1	0.0	0.0	0.0	0.0
Gross change	0.1	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Area, in square kilometers																				
1973	123	122	1,553	1,659	5	7	73	38	266	205	4,159	2,316	167,127	4,034	1,084	961	81	105	0	0
1980	160	175	1,581	1,675	22	26	124	65	271	205	4,139	2,298	167,043	4,050	1,107	969	25	26	0	0
1986	114	109	1,627	1,709	11	8	201	99	271	205	4,138	2,299	167,024	4,005	1,029	925	57	70	0	0
1992	153	163	1,692	1,746	5	7	227	104	271	205	4,131	2,299	166,941	4,022	1,032	926	18	19	0	0
2000	93	79	1,727	1,752	35	29	283	124	300	210	4,127	2,297	166,879	4,014	963	909	66	83	0	0
Net change	−30	46	174	116	30	28	210	98	34	49	−33	30	−249	151	−122	110	−15	22	0	0
Gross change	189	264	174	116	77	61	218	102	34	49	36	31	512	168	188	155	175	256	0	0

Table 4. Principal land-cover conversions in Chihuahuan Deserts Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Mining	51	34	23	0.0	25.8
	Wetland	Water	37	54	36	0.0	18.5
	Grassland/Shrubland	Developed	28	24	16	0.0	14.1
	Grassland/Shrubland	Agriculture	23	27	18	0.0	11.9
	Wetland	Grassland/Shrubland	20	29	20	0.0	10.0
	Other	Other	39	n/a	n/a	0.0	19.7
		Totals	198			0.1	100.0
1980–1986	Grassland/Shrubland	Mining	85	47	32	0.0	24.9
	Agriculture	Grassland/Shrubland	85	89	61	0.0	24.8
	Grassland/Shrubland	Developed	63	61	42	0.0	18.4
	Water	Wetland	32	47	32	0.0	9.4
	Developed	Grassland/Shrubland	19	28	19	0.0	5.6
	Other	Other	57	n/a	n/a	0.0	16.8
		Totals	341			0.2	100.0
1986–1992	Grassland/Shrubland	Developed	62	44	30	0.0	41.1
	Wetland	Water	41	59	40	0.0	27.0
	Grassland/Shrubland	Mining	27	18	12	0.0	18.1
	Forest	Grassland/Shrubland	7	11	7	0.0	4.8
	Mechanically disturbed	Developed	3	5	3	0.0	2.1
	Other	Other	10	n/a	n/a	0.0	6.9
		Totals	151			0.1	100.0
1992–2000	Agriculture	Grassland/Shrubland	71	67	46	0.0	23.8
	Grassland/Shrubland	Mining	53	33	23	0.0	17.8
	Water	Wetland	48	70	48	0.0	16.1
	Grassland/Shrubland	Developed	34	23	16	0.0	11.3
	Grassland/Shrubland	Mechanically disturbed	29	28	19	0.0	9.8
	Other	Other	63	n/a	n/a	0.0	21.2
		Totals	299			0.2	100.0
1973–2000 (overall)	Grassland/Shrubland	Mining	217	101	68	0.1	21.9
	Grassland/Shrubland	Developed	187	134	91	0.1	18.9
	Agriculture	Grassland/Shrubland	158	133	90	0.1	15.9
	Water	Wetland	82	120	81	0.0	8.3
	Wetland	Water	77	113	77	0.0	7.8
	Other	Other	269	n/a	n/a	0.2	27.2
		Totals	989	n/a	n/a	0.6	100.0

Table 5. Populations of largest cities in Chihuahuan Deserts Ecoregion that had both 1970 and 2000 census data. Cities of Socorro and San Elizario, Texas, and Sunland Park, New Mexico, had 2000 populations greater than 10,000, but no 1970 census data was available (U.S. Census Bureau, 2000).

City	State	1970 population	2000 population	County	Percent increase
El Paso	TX	322,261	563,662	El Paso	74.91
Las Cruces	NM	37,857	74,267	Dona Ana	96.18
Roswell	NM	33,908	45,293	Chaves	33.58
Alamogordo	NM	23,035	35,582	Otero	54.47
Del Rio	TX	21,330	33,867	Val Verde	58.78
Carlsbad	NM	21,297	25,625	Eddy	20.32
Deming	NM	8,343	14,116	Luna	69.20
Artesia	NM	10,315	10,692	Eddy	3.65
Silver City	NM	8,557	10,545	Grant	23.23
	Total	486,903	813,649		
	Total increase:		67.11%	Average increase:	48.26%

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Chapter 28

Madrean Archipelago Ecoregion

By Jana Ruhlman, Leila Gass, and Barry Middleton

Ecoregion Description

The Madrean Archipelago Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997), also known as the "Madrean Sky Islands" or "Sky Islands," covers an area of approximately 40,536 km^2 (15,651 mi^2) in southeastern Arizona and southwestern New Mexico (fig. 1). The ecoregion is bounded on the west by the Sonoran Basin and Range Ecoregion, on the east by the Chihuahuan Deserts Ecoregion, and on the north by the Arizona/New Mexico Mountains Ecoregion. This area of basin-and-range topography is one of the most biologically diverse in the world (Koprowski, 2005; Skroch, 2008). Although the mountains in the ecoregion bridge the Rocky Mountains to the north and the Sierra Madre Occidental in Mexico to the south (U.S. Environmental Protection Agency, 1997), the lower elevations act as a barrier to species dispersal. Nevertheless, the geographic convergence of these two major continental mountain ranges, as well as of the Chihuahuan Desert to the east and the Sonoran Desert to the west, forms the foundation for ecological interactions found nowhere else on Earth (Skroch, 2008).

A rise in elevation, from approximately 600 m in the lowlands to over 3,000 m in the mountains (Mount Graham summit, 3,267 m), is accompanied by dramatic gradients in temperature and precipitation, coinciding with at least eight distinct life zones (Skroch, 2008). Lower, hot and dry plains support desert and semiarid grasslands vegetation. Woodlands of oak (*Quercus* spp.) and juniper (*Juniperus* spp.) grow on lower slopes. Colder and wetter climates at higher elevations support ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and Engelmann spruce (*Picea engelmannii*) (figs. 2–4).

Climate summaries for 10 urban areas in the lowlands indicate that they average annual minimum and maximum

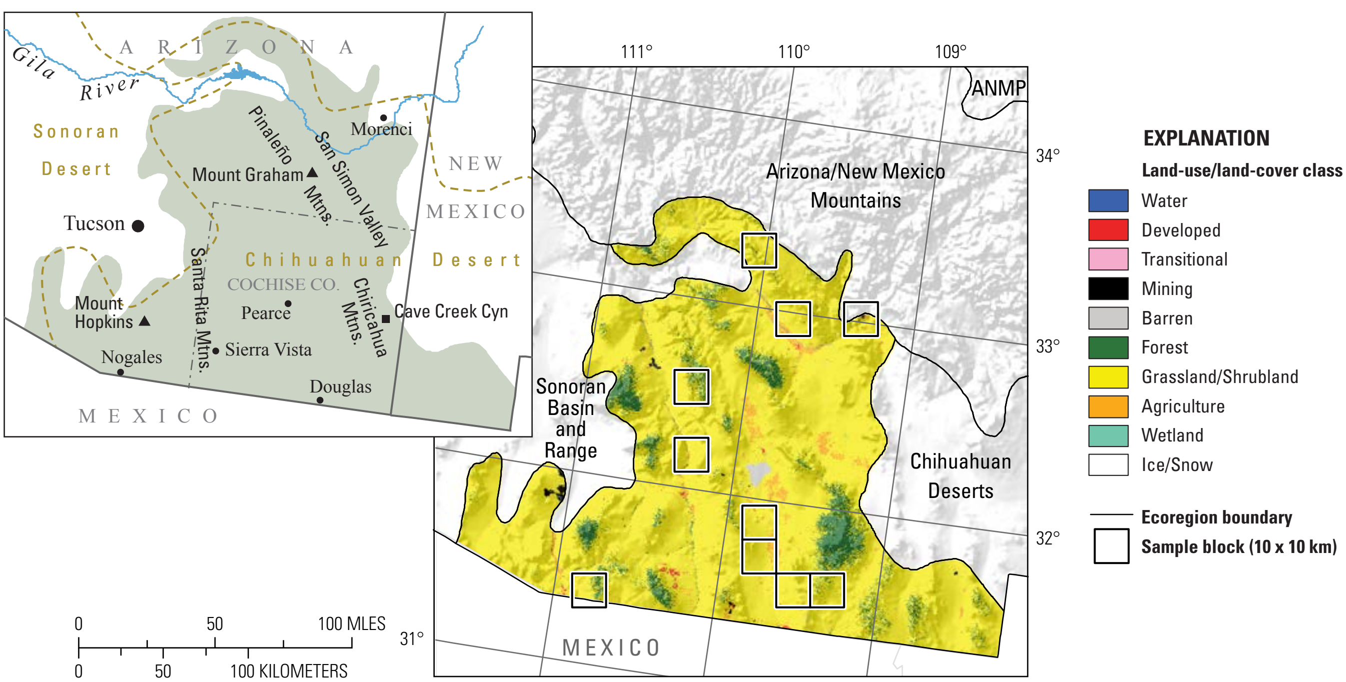


Figure 1. Map of Madrean Archipelago Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 20 x 20 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 2. View southeast toward San Simon Valley from Mount Graham, in Pinaleño Mountains in Arizona, showing diverse topography of Madrean Archipelago Ecoregion.

Figure 3. Whipple Observatory (elevation 2,623 m) on Mount Hopkins, in Santa Rita Mountains, south of Tucson, Arizona. Land cover includes grassland, oak woodland, and montane forest.

Figure 4. Grassland park near Cave Creek Canyon, in Chiricahua Mountains, Arizona.

temperatures of 7.9ºC and 25.7ºC, respectively (Western Regional Climate Center, 2009). Lowe (1964) described decreases in temperature of 2.2ºC and increases in precipitation of 100 to 125 mm for every 305 m gain in elevation. Estimates from the Parameter-elevation Regressions on Independent Slopes Model (Daly and others, 2002) indicate that as much as 1,118 mm of annual precipitation is received on mountaintops (fig. 5). The ecoregion receives a biseasonal rainfall regime, with frontal precipitation in winter and convective thunderstorms in summer. The large elevation and precipitation gradients caused by topography, coupled with the north-south convergence of multiple floral and faunal realms, are both important geographic factors that contribute to the high biodiversity in the Madrean Archipelago Ecoregion (Coblentz and Riitters, 2005).

The Madrean Archipelago Ecoregion is sparsely populated. Sierra Vista, Arizona, is the largest city in the ecoregion, having a 2000 census population of 37,775. Nogales and Douglas, Arizona, are the next largest cities, having populations of 20,878 and 14,312, respectively (U.S. Census Bureau, 2000). Farming and ranching are the principal industries of the ecoregion (fig. 6). Primary irrigated crops are corn, wheat, grain, alfalfa hay, and cotton (U.S. Department of Agriculture, 2004).

Contemporary Land-Cover Change (1973 to 2000)

As measured by the project methodology, the Madrean Archipelago Ecoregion experienced little land-cover change during the study period. An estimated 1.4 percent (575 km^2) of the ecoregion converted to other land-cover classes during the study period (table 1). The relative error is high at 33.7 percent, which is not unusual for an ecoregion with very little change. Compared to other western United States ecoregions, change in the Madrean Archipelago Ecoregion was low (figs. 7,8). However, change in this ecoregion is consistent with that of other ecoregions in the southwestern United States.

Total estimated change in land cover per time period varied from a high of 0.5 percent between 1973 and 1980 and between 1980 and 1986 to a low of 0.3 percent between 1992 and 2000 (table 2). When the total change estimates were normalized to account for the varying lengths of the time periods between satellite imagery dates, the period between 1992 and 2000 had a near 0 percent rate of change per year, while the other three time periods had 0.1 percent change per year (table 2).

A closer look at the net-change estimates reveals that each time period experienced a net increase for the mining and developed classes, although the size of the gains varied between time periods (fig. 9). Grassland/shrubland was the predominant land cover of the ecoregion (estimated at 87.9 percent in 2000), and this class experienced the greatest absolute amount of net change, with a net loss of 0.7 percent (271 km^2) during the study period (table 3). Analysis of this

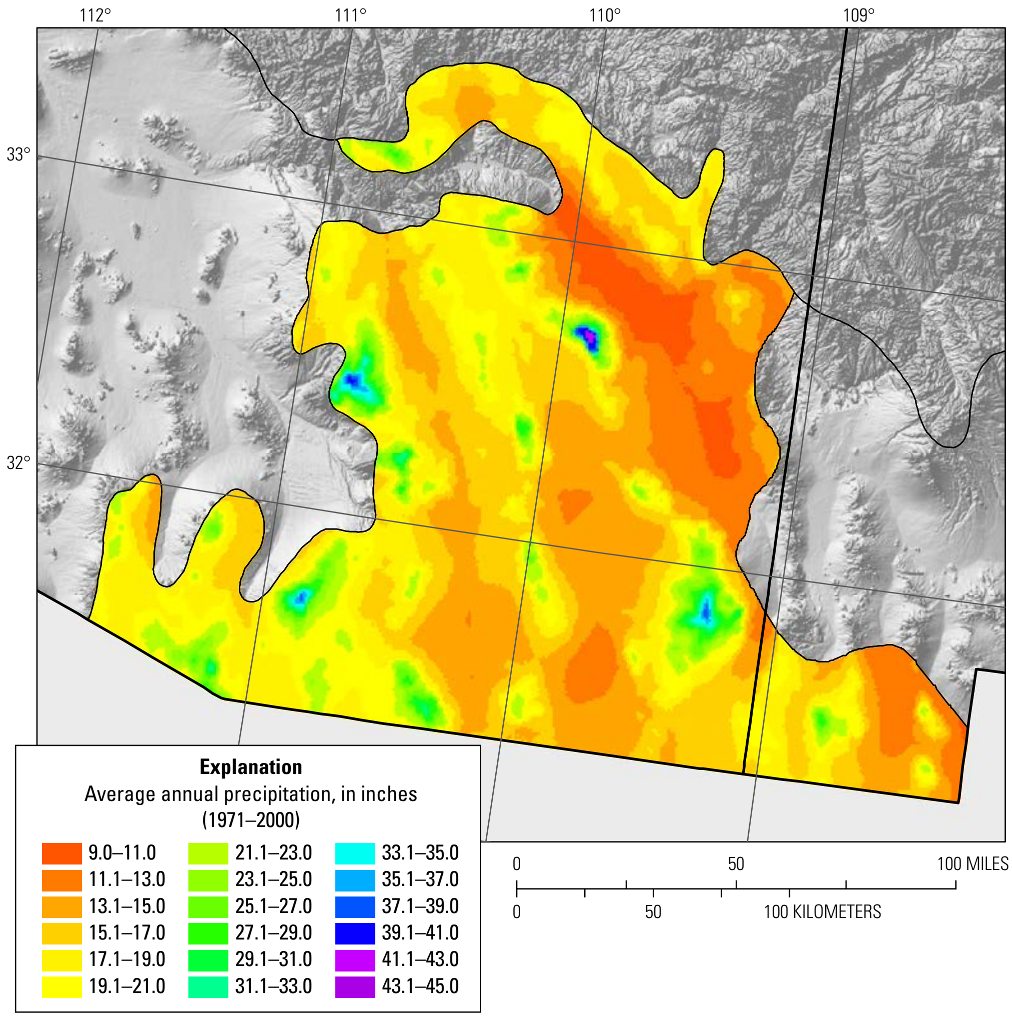


Figure 5. Estimated average annual precipitation in Madrean Archipelago Ecoregion between 1971 and 2000. Highest precipitation rates (shades of green, blue, purple) on mountaintops sustain evergreen woodlands and montane forests, whereas more arid lowland areas are covered in grassland and desert vegetation.

Figure 6. Harvested cotton field in Gila River valley, Arizona.

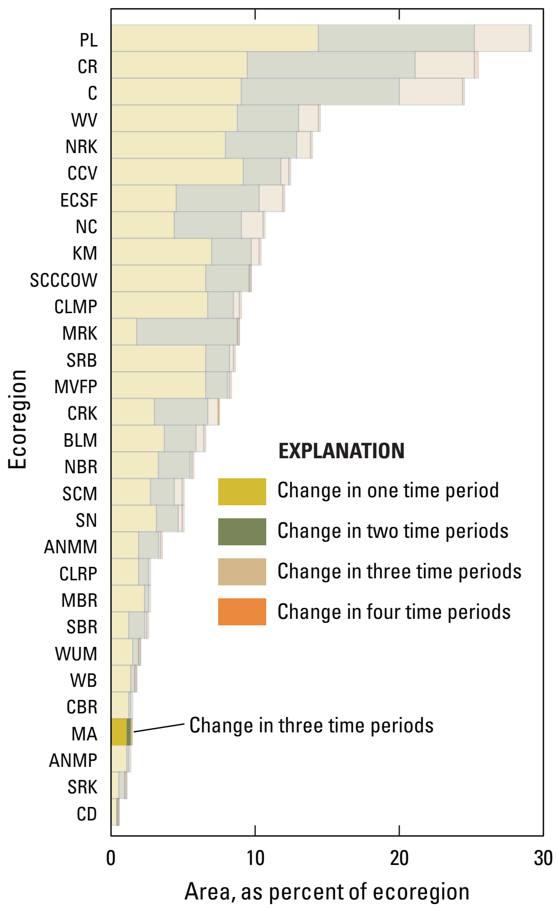


Figure 7. Overall spatial change in Madrean Archipelago Ecoregion (MA; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Madrean Archipelago Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

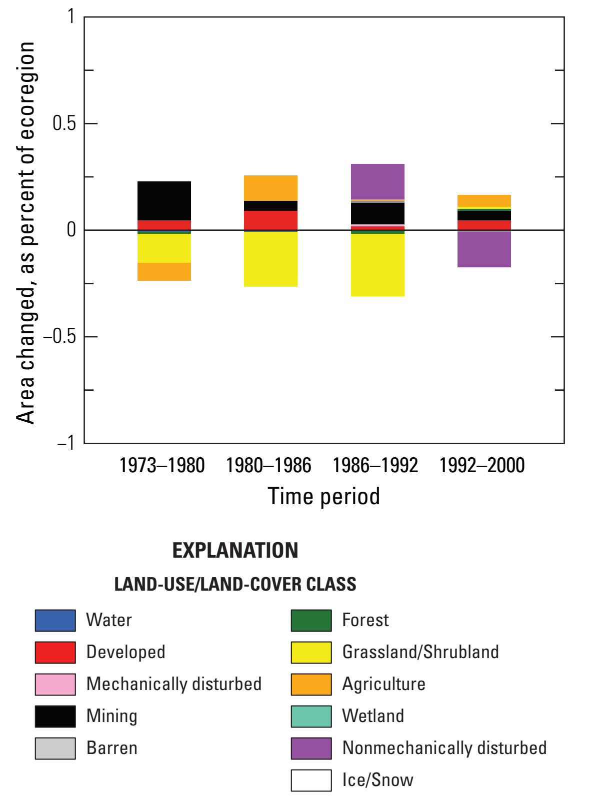
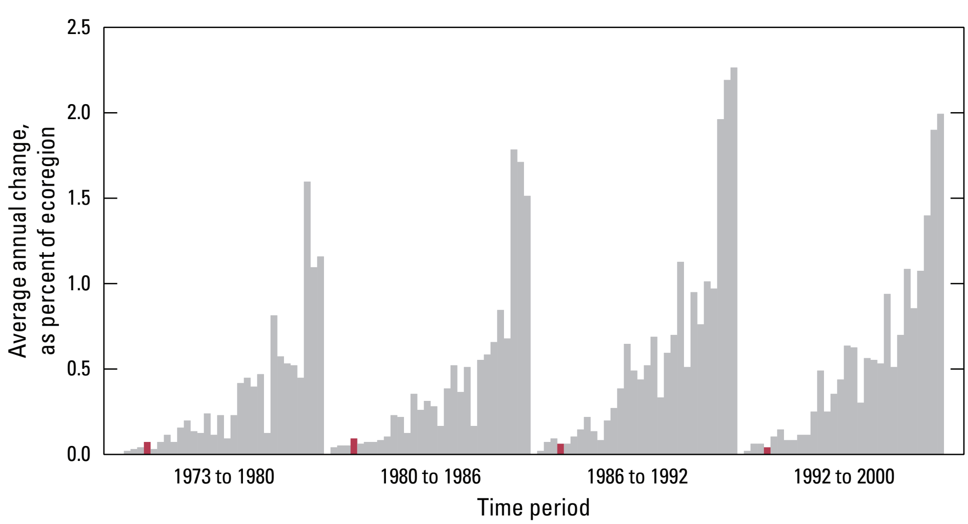


Figure 9. Normalized average net change in Madrean Archipelago Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 8. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Madrean Archipelago Ecoregion are represented by red bars in each time period.



class per time period shows net losses for the first three time periods but a slight gain between 1992 and 2000 (fig. 9).

The second and third most common land-cover types in 2000 were forest (5.3 percent) and agriculture (3.9 percent), followed by mining (1.1 percent). Although developed land was estimated at just 1.0 percent in 2000, it expanded 34 percent (98 km^2) over the course of the study; its increases were associated with small declines in grassland/shrubland. Overall, no statistically significant trends were observed during the study period.

The two most common conversions from 1973 to 2000 were grassland/shrubland to mining and grassland/shrubland to agriculture (table 4). Grassland/shrubland to developed land was the third most common conversion in all time periods except between1986 and 1992, when it ranked fourth. The conversion of 65 km^2 from grassland/shrubland to nonmechanically disturbed between 1986 and 1992 and its reversion back to grassland in the following period (1992–2000) was probably due to a fire event, followed by quick revegetation of the area.

This study's analysis clearly indicates that the Madrean Archipelago Ecoregion experienced very little land-cover change between 1973 and 2000. Reasons for this stability are diverse, but the principal factor is probably the sparse population of the region. Other possible contributing factors include the high percentage of federal land in the ecoregion (approximately 48 percent), the scarcity of water, and the mountainous terrain, all of which inhibit large amounts of anthropogenic change. The lack of statistically significant trends and the high levels of uncertainty prohibit drawing clear-cut conclusions, but each time period experienced an increase in the developed and mining land-cover classes. The increase in developed land between 1973 and 2000 is shown on fig. 10.

The steady increase in developed land may be correlated to increased population in the Madrean Archipelago Ecoregion. U.S. Census Bureau (2000) figures show that the population of the three Arizona counties that form most of the Madrean Archipelago Ecoregion grew an average of 122 percent between 1970 and 2000, an increase of 97,163 persons. Population growth is predicted to continue, both in the currently populated areas and in the rural parts of the ecoregion (Carreira, 2005). In rural Cochise County alone, the population increased 11.5 percent between 2000 and 2010, from 117,755 persons in 2000 to 131,346 persons in 2010 (U.S. Census Bureau, 2010), likely owing to its proximity to a major highway, railroads, and the United States–Mexico border, as well as its amenable climate, cultural history, growing golf-course communities, outdoor-recreation opportunities, and fertile agricultural lands (Cochise County, 2012).

The land-cover transformation from grassland/shrubland to mining in all four time periods was primarily attributable to the observed growth of the massive open-pit copper mine at Morenci, Arizona, one of five major copper mines located within the ecoregion (Arizona Department of Mines and Mineral Resources, 2008). The gains in the developed and mining classes all came at the expense of the grassland/shrubland class, but the total converted area totaled only 271 km^2 over entire the study period.

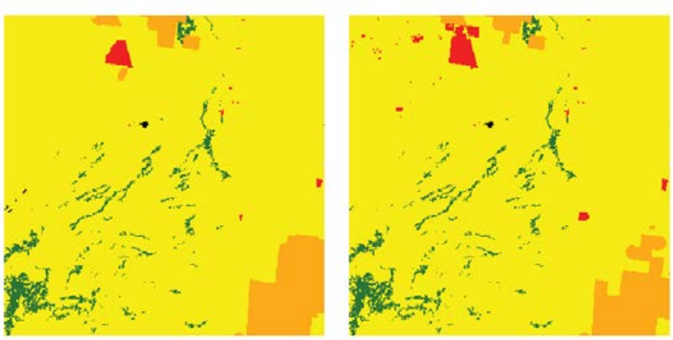


Figure 10. Sample block 79-6, centered over Pearce, Arizona, showing land-use/land-cover data in 1973 (left) and 2000 (right). Sample blocks show expansion of developed land (red) between 1973 and 2000, especially in Sunsites, Arizona, which is a growing, unincorporated retirement and golf community in northern part of sample block. Also shown are areas of agricultural land (orange) that reverted back to grassland/shrubland (yellow).

Table 1. Percentage of Madrean Archipelago Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (98.6 percent), whereas 1.4 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.2	0.7	0.4	1.9	0.5	39.9
2	0.2	0.2	0.0	0.5	0.1	61.9
3	0.0	0.0	0.0	0.0	0.0	63.3
4	0.0	0.0	0.0	0.0	0.0	0.0
Overall spatial change	1.4	0.8	0.7	2.2	0.5	33.7

Table 2. Raw estimates of change in Madrean Archipelago Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	0.5	0.3	0.1	0.8	0.2	47.2	0.1
1980–1986	0.5	0.3	0.2	0.9	0.2	41.8	0.1
1986–1992	0.4	0.3	0.1	0.6	0.2	46.1	0.1
1992–2000	0.3	0.2	0.1	0.6	0.1	45.4	0.0
			Estimate of change, in square kilometers				
1973–1980	185	137	47	322	87	47.2	26
1980–1986	210	138	72	348	88	41.8	35
1986–1992	145	105	40	251	67	46.1	24
1992–2000	132	95	38	227	60	45.4	17

Table 3. Estimated area (and margin of error) of each land-cover class in Madrean Archipelago Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	0.1	0.1	0.7	0.4	0.0	0.0	0.7	1.0	0.6	0.4	5.3	2.5	88.5	4.3	3.8	2.5	0.2	0.3	0.0	0.0
1980	0.1	0.1	0.8	0.4	0.0	0.0	0.9	1.3	0.6	0.4	5.3	2.5	88.4	4.4	3.7	2.5	0.2	0.3	0.0	0.0
1986	0.1	0.1	0.9	0.4	0.0	0.0	0.9	1.4	0.6	0.4	5.3	2.5	88.2	4.5	3.8	2.7	0.2	0.3	0.0	0.0
1992	0.1	0.1	0.9	0.4	0.0	0.0	1.0	1.5	0.6	0.4	5.3	2.5	87.9	4.4	3.8	2.7	0.2	0.3	0.2	0.2
2000	0.1	0.1	1.0	0.4	0.0	0.0	1.1	1.6	0.6	0.4	5.3	2.5	87.9	4.5	3.9	2.8	0.2	0.3	0.0	0.0
Net change	0.0	0.0	0.2	0.1	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.0	−0.7	0.7	0.1	0.4	0.0	0.0	0.0	0.0
Gross change	0.0	0.0	0.2	0.1	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.0	1.3	0.8	0.6	0.5	0.0	0.0	0.3	0.5
									Area, in square kilometers											
1973	41	41	298	155	6	9	289	417	259	178	2,154	1,015	35,891	1,744	1,528	1,033	70	104	0	0
1980	40	41	319	165	6	9	364	527	255	176	2,151	1,016	35,838	1,775	1,493	1,006	70	104	0	0
1986	38	41	357	164	6	9	381	554	258	177	2,151	1,016	35,735	1,814	1,541	1,098	70	104	0	0
1992	40	41	366	164	6	9	424	616	260	177	2,144	1,018	35,615	1,791	1,546	1,099	70	104	65	97
2000	40	41	387	169	6	9	443	644	256	176	2,146	1,018	35,620	1,837	1,569	1,121	70	104	0	0
Net change	−1	3	89	59	0	0	153	227	−2	6	−8	15	−271	269	41	157	0	0	0	0
Gross change	6	6	90	60	1	1	158	226	19	16	18	13	538	309	230	198	0	0	129	194

Table 4. Principal land-cover conversions in Madrean Archipelago Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Mining	73	108	69	0.2	39.6
	Agriculture	Grassland/Shrubland	59	59	38	0.1	32.0
	Grassland/Shrubland	Developed	21	23	14	0.1	11.1
	Grassland/Shrubland	Agriculture	19	16	10	0.0	10.4
	Barren	Agriculture	4	7	4	0.0	2.4
	Other	Other	8	n/a	n/a	0.0	4.5
		Totals	185			0.5	100.0
1980–1986	Grassland/Shrubland	Agriculture	92	137	87	0.2	43.8
	Agriculture	Grassland/Shrubland	37	42	27	0.1	17.8
	Grassland/Shrubland	Developed	34	32	20	0.1	16.0
	Grassland/Shrubland	Mining	24	34	21	0.1	11.6
	Mining	Grassland/Shrubland	8	9	6	0.0	4.1
	Other	Other	14	n/a	n/a	0.0	6.8
		Totals	210			0.5	100.0
1986–1992	Grassland/Shrubland	Nonmechanically disturbed	65	97	61	0.2	44.6
	Grassland/Shrubland	Mining	39	56	36	0.1	27.1
	Grassland/Shrubland	Agriculture	10	10	6	0.0	6.9
	Grassland/Shrubland	Developed	6	7	4	0.0	4.4
	Grassland/Shrubland	Barren	5	7	4	0.0	3.1
	Other	Other	20	n/a	n/a	0.0	13.9
		Totals	145			0.4	100.0
1992–2000	Nonmechanically disturbed	Grassland/Shrubland	65	97	61	0.2	48.9
	Grassland/Shrubland	Agriculture	23	27	17	0.1	17.4
	Grassland/Shrubland	Developed	21	13	8	0.1	15.6
	Grassland/Shrubland	Mining	19	28	18	0.0	14.1
	Barren	Grassland/Shrubland	3	5	3	0.0	2.5
	Other	Other	2	n/a	n/a	0.0	1.5
		Totals	132			0.3	100.0
1973–2000 (overall)	Grassland/Shrubland	Mining	155	226	144	0.4	23.1
	Grassland/Shrubland	Agriculture	144	177	112	0.4	21.4
	Agriculture	Grassland/Shrubland	100	92	59	0.2	15.0
	Grassland/Shrubland	Developed	81	56	36	0.2	12.1
	Grassland/Shrubland	Nonmechanically disturbed	65	97	61	0.2	9.6
	Other	Other	126	n/a	n/a	0.3	18.8
		Totals	672			1.7	100.0

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Chapter 29

Mojave Basin and Range Ecoregion

By Benjamin M. Sleeter and Christian G. Raumann

This chapter has been modified from original material published in Sleeter and Raumann (2006), entitled “Land-cover trends in the Mojave Basin and Range Ecoregion” (U.S. Geological Survey Scientific Investigations Report 2006–5098).

Ecoregion Description

The Mojave Basin and Range Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 130,922 km^2 (50,549 mi^2) in the southwestern United States. The ecoregion, which encompasses parts of four states, includes the Mojave Desert and much of the other desert areas in southeastern California, as well as a large part of the southern Nevada desert (fig. 1). The ecoregion is bounded on the north by the Central Basin and Range Ecoregion, on the east by the Colorado Plateaus and the Arizona/New Mexico Plateau Ecoregions, on the south by the Sonoran Basin and Range Ecoregion, and on the west by the Southern California Mountains and the Sierra Nevada Ecoregions.

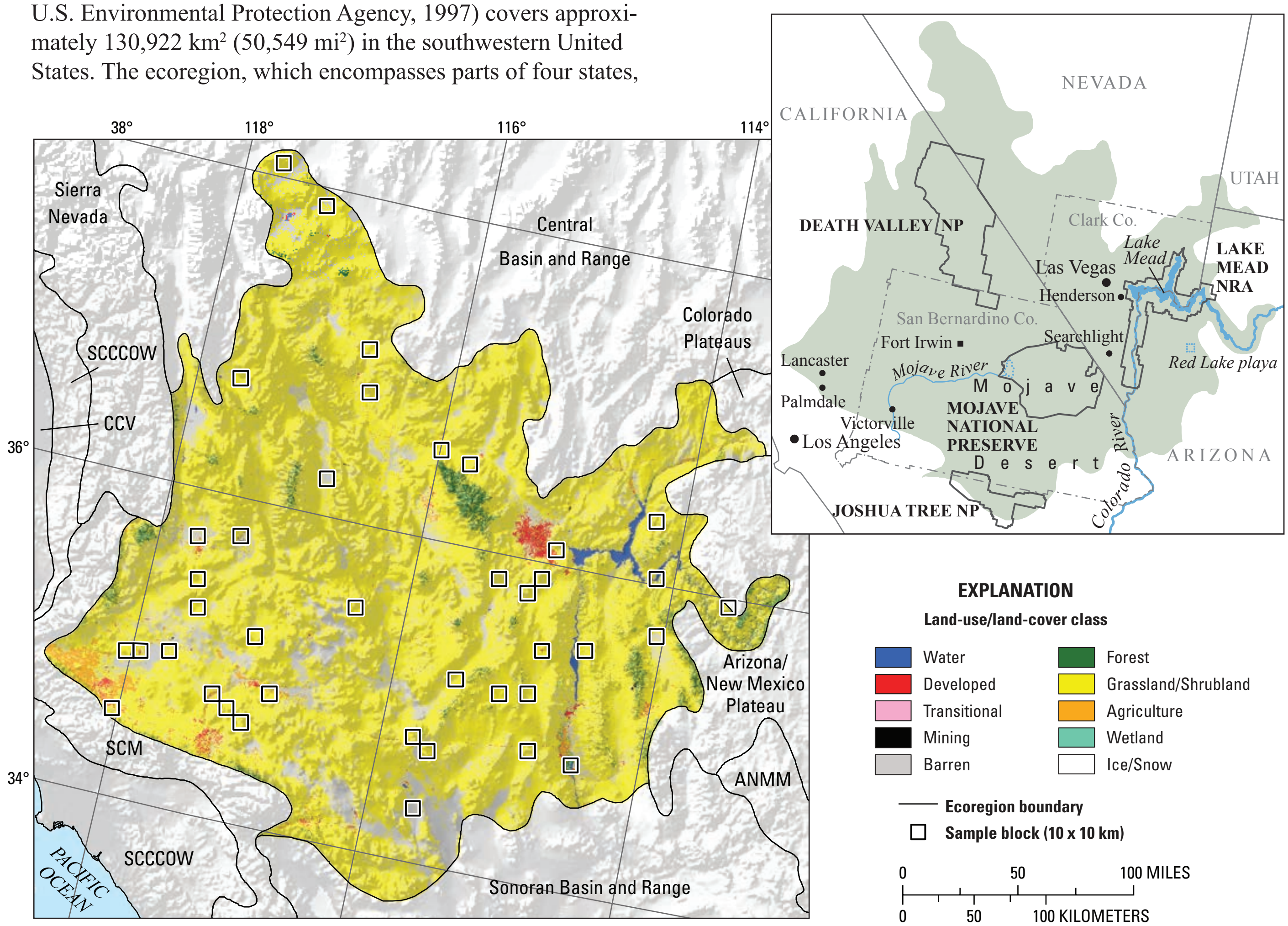

Figure 1. Map of Mojave Basin and Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and Trends of Land Change” study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

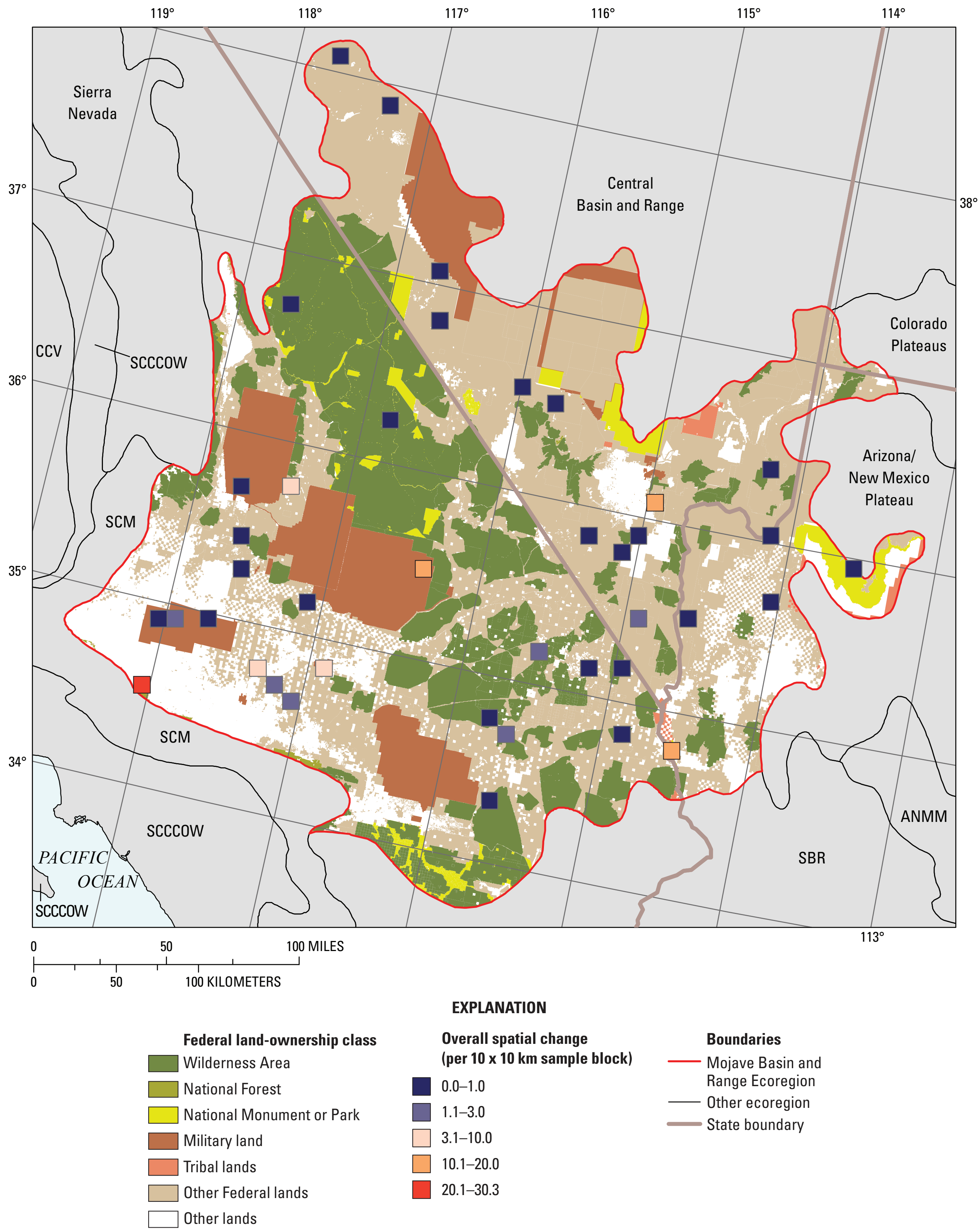

Figure 2. Federal land ownership and cumulative land-use/land-cover change (as percent of sample-block area) from 1973 to 2000 in Mojave Basin and Range Ecoregion. Land-ownership data from National Atlas of the United States (2006). See appendix 2 for abbreviations for Western United States ecoregions.

Figure 3. Construction of new hotel, resort, and lake (Lake Las Vegas) outside of Henderson, Nevada.

The Mojave Basin and Range Ecoregion is characterized by distinct fault-bounded mountain ranges that typically run northeast to southwest. The ecoregion receives very little annual precipitation (50–250 mm in the valleys), which, when combined with high temperatures during summer months, results in an ecoregion slow to recover from anthropogenic disturbances (Hunter and others, 2003). Federal lands constitute approximately 81 percent of the total land area (fig. 2), with major holdings under the jurisdiction of the Bureau of Land Management, National Park Service, and Department of Defense. Grasslands and shrublands dominate the ecoregion, whereas developed land accounts for only 1.5 percent of total land area (Vogelmann and others, 2001). Although developed land is limited, the two major urban areas found in the ecoregion are among the fastest growing locales in the western United States. Las Vegas, Nevada, is the major urban center within the ecoregion (fig. 3), although the cities of Palmdale and Lancaster, California, also had significant growth between 1973 and 2000.

The Mojave Basin and Range Ecoregion has long supported human activities such as livestock grazing, mining, military training, and recreation, all of which have had some effect on the desert landscape (Lovich and Bainbridge, 1999). Agriculture, although not extensive, takes place along the Colorado and Mojave Rivers. Mining, which historically has been an important land-use activity, is found throughout the ecoregion wherever mineral resources are available (fig. 4). Recreation activities have become increasingly important in the ecoregion, with millions of people each year visiting Death Valley National Park, Mojave National Preserve, and Lake Mead National Recreation Area, as well as numerous open-access Bureau of Land Management lands (fig. 5).

Figure 4. Abandoned mine shaft outside Searchlight, Nevada.

Figure 5. Staging and camping area for off-highway-vehicle users near Red Lake playa, Arizona, located about 30 km southeast of Lake Mead.

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change (that is, the percentage of area that changed at least one time between 1973 and 2000) in the Mojave Basin and Range Ecoregion is estimated at 2.7 percent (3,474 km^2), which is low when compared to other western United States ecoregions (fig. 6). The ecoregion also showed low rates of change across all time periods when compared to other western United States ecoregions (fig. 7). The period between 1986 and 1992 had the highest estimated rate of change, at 1.3 percent. In addition, when change estimates are normalized to account for the varying lengths of the time periods, change remained highest between 1986 and 1992, at 0.2 percent per year, whereas the other three time periods (1973–1980, 1980–1986, and 1992–2000) are estimated at 0.07 to 0.08 percent per year (table 2).

The largest change in any one land-cover class was the estimated loss of 2,387 km^2 of grassland/shrubland, a 2.0

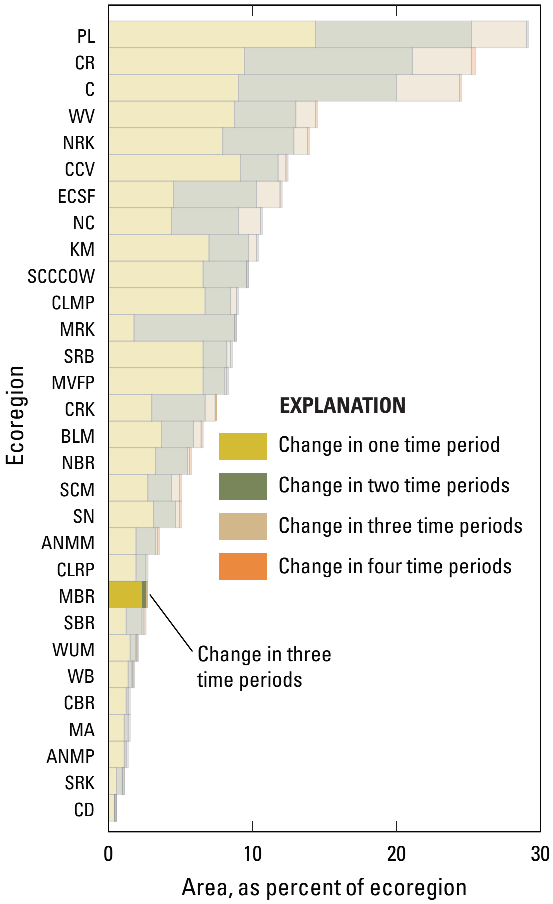

Figure 6. Overall spatial change in Mojave Basin and Range Ecoregion (MBR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Mojave Basin and Range Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

percent decline. In 1973, grassland/shrubland is estimated to account for 89.2 percent of the ecoregion. In 2000, grassland/shrubland accounted for 87.4 percent of the ecoregion. The second largest change was the addition of 1,673 km^2 of developed land, which increased from 1.5 percent of the ecoregion in 1973 to 2.8 percent of the ecoregion in 2000. Estimates of land-cover composition for all classes for each time period can be found in table 3. Normalized net change values for all classes for each time period can be found in figure 8.

The dominant land-cover change that occurred in the Mojave Basin and Range Ecoregion was the conversion of grassland/shrubland to developed land. An estimated 1,426 km^2 of grassland/shrubland were converted to developed land between 1973 and 2000, with 52.7 percent (751 km^2) converting between 1986 and 1992. Grassland/shrubland converting to mechanically disturbed and mining, forest converting to mechanically disturbed, and mechanically disturbed converting to developed were the other top land-cover conversions between 1973 and 2000 (table 4). Combined, these conversions account for an estimated 78.5 percent of all changes in the ecoregion.

Population growth in the Mojave Basin and Range Ecoregion, much of it spillover from the Los Angeles, California, metropolitan area, was the primary driver of change in the ecoregion. In three of the four time periods (1973–1980, 1980–1986, and 1986–1992), grassland/shrubland converting directly to developed land was the most common conversion and, between 1992 and 2000, the second most common conversion. New developed land was added to the ecoregion at an average rate of 62 km^2 per year, an estimated total of 1,680 km^2 over the 27-year study period. Development was not dispersed evenly across the ecoregion. On the basis of field observations, increases in developed land appeared to be concentrated in two main regions, the Las Vegas, Nevada, metropolitan area and the cities of Victorville, Lancaster, and Palmdale, California, in the western

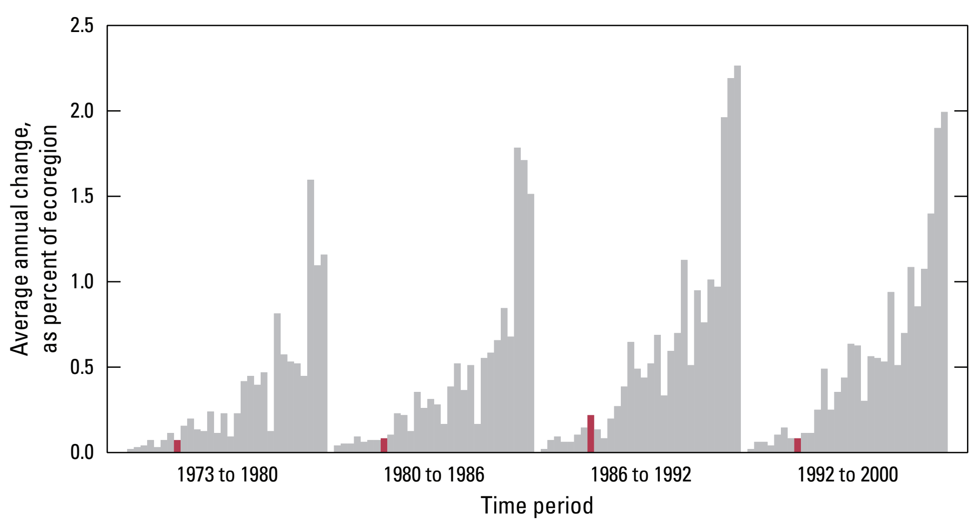

Figure 7. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Mojave Basin and Range Ecoregion are represented by red bars in each time period.

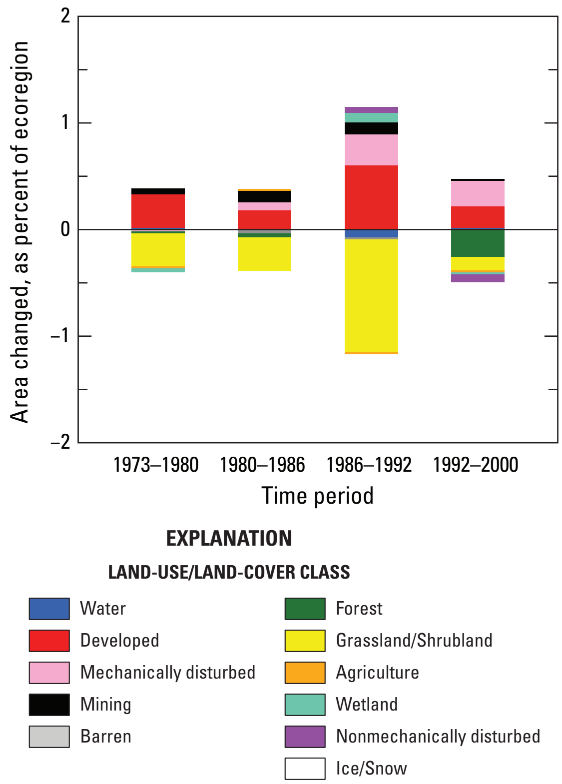

Figure 8. Normalized average net change in Mojave Basin and Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Mojave Desert; Las Vegas is one of the fastest growing cities in the United States, whereas Palmdale and Lancaster both have populations larger than 100,000 (U.S. Census Bureau, 2001). Population statistics show that Clark County, Nevada, added more than 1.3 million residents between 1970 and 2000, whereas San Bernardino County, California, has added more than 1.175 million people during the same time period (fig. 9) (U.S. Census Bureau, 2001). Figure 10 shows land-use/land-cover data for a sample site near Palmdale, California, which has experienced rapid urbanization.

Land ownership is another driving force of land-cover change. As previously noted, the Federal Government owns a large percentage of land within the ecoregion, the largest landholder being the Bureau of Land Management, and each federal agency manages public lands to meet distinct goals and objectives. For instance, Bureau of Land Management lands are often open for public use and recreation such as off-highway-vehicle (OHV) activities (Lovich and Bainbridge, 1999). In most cases, OHV disturbances such as single vehicle tracks were not detected in image interpretations because of the coarse size of the minimum mapping unit (60 m) and are, therefore, not described by the change estimates. However, image interpretations did identify several OHV staging areas where relatively large areas of grassland/shrubland have been gradually stripped of vegetation. Continued use of these areas has resulted in soil compaction, which has prevented the reestablishment of vegetation. The growth of OHV activity in the ecoregion can be attributed largely to the open-access policy of the Bureau of Land Management lands, as well as the close proximity of these lands to major urban areas (Sheridan, 1979).

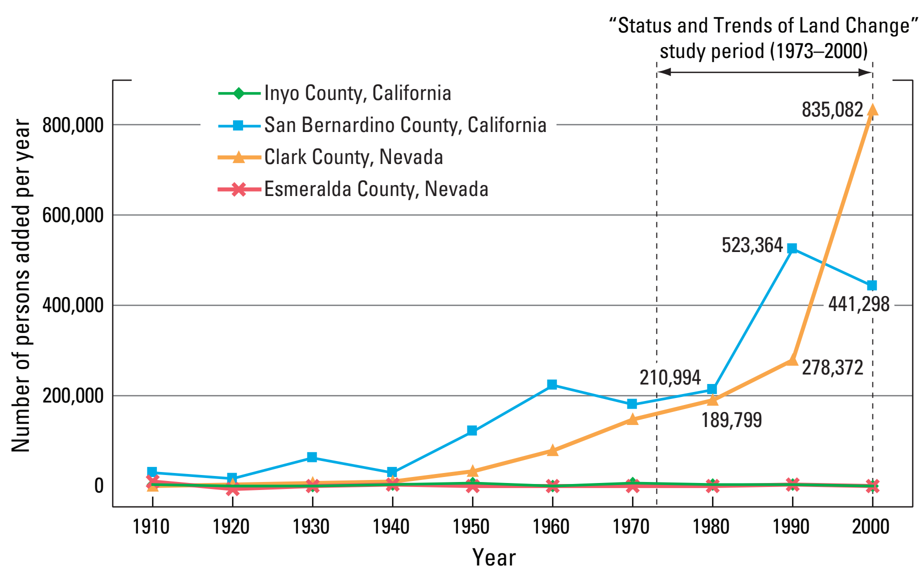

Figure 9. Population trends between 1910 and 2000 of selected counties in Mojave Basin and Range Ecoregion. Numbers of persons added to each county are from U.S. Census data at 10-year intervals (U.S. Census Bureau, 2001). San Bernardino County, California, and Clark County, Nevada, have experienced highest growth of any counties in ecoregion, each adding more than 175,000 persons in each decade since 1980.

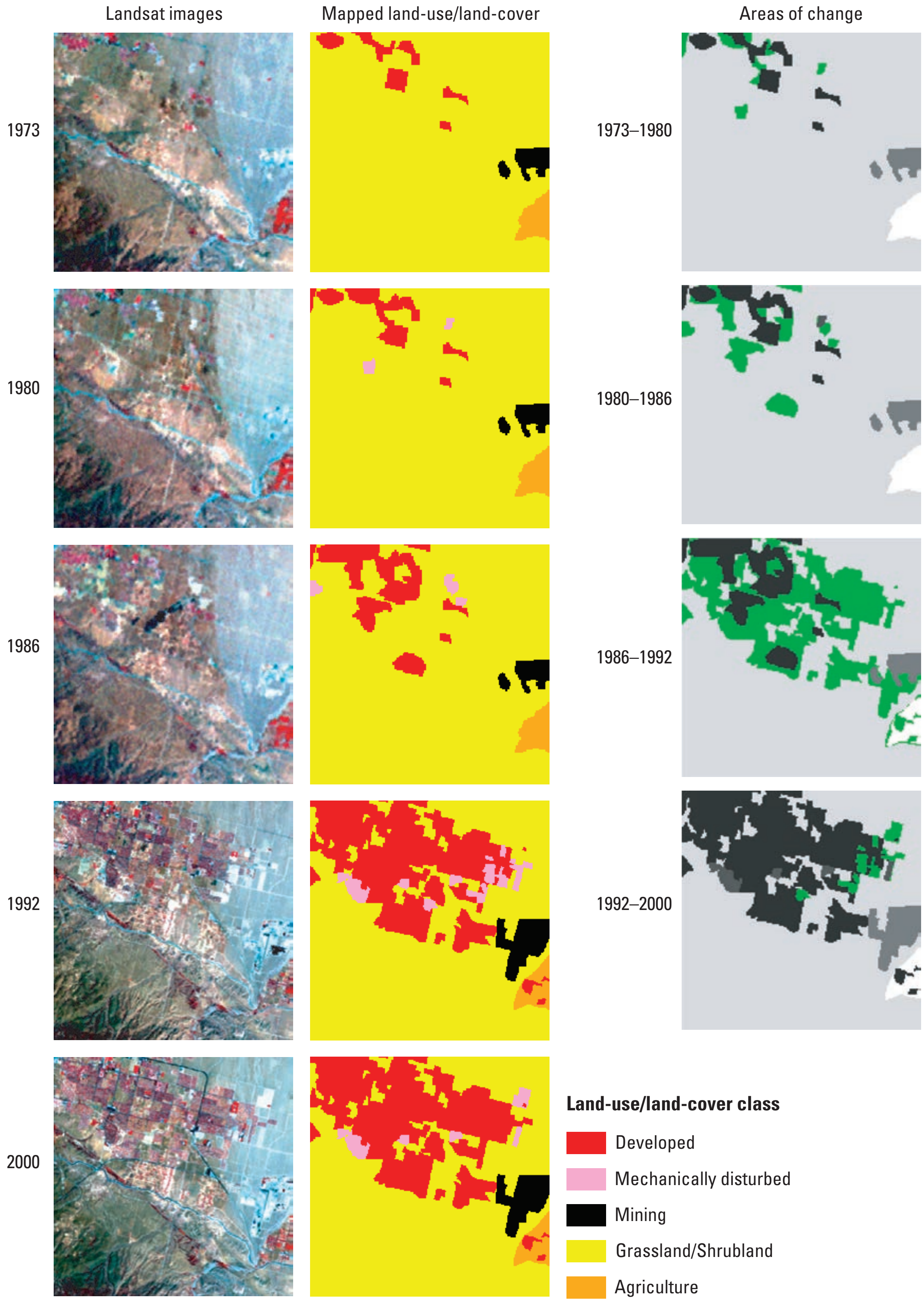

Figure 10. Data for sample block 14-1009, located near Palmdale, California, illustrating urbanization taking place in Mojave Basin and Range Ecoregion. Left column is satellite imagery collected for each of five years analyzed in study, used to map land-use/land-cover change in four time periods between study years (imagery sources for study years: 1973, 1980, and 1986 are Landsat Multispectral Scanner (MSS) images; 1992 is Landsat Thematic Mapper (TM) image; 2000 is Landsat Enhanced Thematic Mapper (ETM) image). Center column is mapped land-use/land-cover data for each study year. Right column shows areas that changed (green areas) in each of four time periods between study years; light- and dark-gray-shaded areas do not change between study years but, rather, represent overall land-use/land-cover footprint throughout study period.

Figure 11. Mechanical disturbance (vehicle tracks) observed at Fort Irwin National Training Center, California, site of intensive military training that includes live-fire exercises.

The Department of Defense has a substantially different mandate pertaining to its land ownership and management policies. The Department of Defense manages vast areas of the ecoregion (fig. 2) for conducting military training activities. The largest of the facilities that lie entirely within the ecoregion is Fort Irwin National Training Center, California (2,369 km^2), which is used for desert-warfare training that includes live-fire exercises. Tracked and wheeled vehicles, which operate throughout the facility, can have a major impact on the health and composition of desert flora and fauna (Prose and Wilshire, 2000). Recent studies have estimated that several hundred years will be needed for desert soils and vegetation to recover once exposed to these intensive land-use practices (Prose and Wilshire, 2000; Steiger and Webb, 2000). This phenomenon was observe. in the eastern part of Fort Irwin, which was heavily used for tracked- and wheeled-vehicle operations training (fig. 11). Evidence of this destruction includes compacted and rutted soils, low shrub density, and stunted growth of creosote bush (*Larrea tridentata*) and other vegetation.

Unlike the Bureau of Land Management and Department of Defense, the National Park Service attempts to preserve natural desert lands while promoting low-impact public recreation such as camping, hiking, and sightseeing. The largest holding of the National Park Service within the ecoregion is Death Valley National Park (12,759 km^2). Other National Park Service areas include Mojave National Preserve and Joshua Tree National Park. With the exception of small, tourism-supported development such as visitor centers, boardwalks, campgrounds, hiking trails, and unimproved roads, no land-cover changes were detected on National Park Service lands, further illustrating the significant role that land-ownership and -management goals play in regards to the spatial distribution of contemporary land-cover change.

Results show that change between land-cover classes in the Mojave Basin and Range Ecoregion is relatively rare and highly localized. Urbanization is the primary source of change, although other human-use activities such as military training and recreation are significant contributors to change within the ecoregion.

Table 1. Percentage of Mojave Basin and Range Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (97.3 percent), whereas 2.7 percent changed at least once throughout study period. Two dashes (--) indicate that, because zero pixels changed four times during study period, relative error is not calculable]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	2.4	1.3	1.1	3.8	0.9	37.0
2	0.2	0.1	0.1	0.3	0.1	45.9
3	0.0	0.0	0.0	0.0	0.0	98.5
4	0.0	0.0	0.0	0.0	0.0	--
Overall spatial change	2.7	1.4	1.2	4.1	1.0	36.5

Table 2. Raw estimates of change in Mojave Basin and Range Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
			Estimate of change, in percent stratum				
1973–1980	0.5	0.3	0.2	0.8	0.2	37.0	0.1
1980–1986	0.5	0.2	0.2	0.7	0.2	36.4	0.1
1986–1992	1.3	0.9	0.3	2.2	0.6	50.6	0.2
1992–2000	0.6	0.5	0.2	1.1	0.3	50.5	0.1
			Estimate of change, in square kilometers				
1973–1980	675	366	308	1,041	250	37.0	96
1980–1986	605	323	282	928	220	36.4	101
1986–1992	1,660	1,232	428	2,892	839	50.6	277
1992–2000	841	624	217	1,466	425	50.5	105

Table 3. Estimated area (and margin of error) of each land-cover class in Mojave Basin and Range Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
									Area, in percent stratum											
1973	0.9	0.9	1.5	0.9	0.1	0.1	1.1	1.2	4.7	3.9	2.0	1.6	89.2	4.6	0.2	0.2	0.3	0.3	0.0	0.0
1980	0.9	0.9	1.8	1.0	0.1	0.1	1.1	1.2	4.7	3.9	2.0	1.6	88.9	4.6	0.2	0.2	0.2	0.3	0.0	0.0
1986	0.9	0.9	2.0	1.0	0.2	0.1	1.3	1.3	4.7	3.9	1.9	1.6	88.6	4.6	0.2	0.2	0.2	0.3	0.0	0.0
1992	0.8	0.9	2.6	1.4	0.5	0.4	1.4	1.4	4.7	3.9	1.9	1.6	87.5	4.7	0.2	0.2	0.3	0.4	0.1	0.1
2000	0.9	0.9	2.8	1.5	0.7	0.6	1.4	1.4	4.7	3.9	1.7	1.5	87.4	4.7	0.2	0.2	0.3	0.4	0.0	0.0
Net change	0.0	0.1	1.3	1.0	0.6	0.6	0.3	0.2	−0.1	0.1	−0.3	0.4	−1.8	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Gross change	0.2	0.2	1.3	1.0	0.8	0.6	0.3	0.2	0.1	0.1	0.3	0.4	2.0	1.3	0.1	0.1	0.1	0.2	0.1	0.2
									Area, in square kilometers											
1973	1,164	1,183	1,958	1,184	152	104	1,394	1,604	6,196	5,097	2,581	2,119	116,844	5,984	303	270	331	419	0	0
1980	1,198	1,209	2,349	1,263	124	96	1,482	1,627	6,196	5,096	2,570	2,113	116,430	6,001	277	243	296	370	0	0
1986	1,198	1,209	2,594	1,303	216	185	1,638	1,707	6,153	5,094	2,522	2,097	116,013	5,991	293	250	296	370	0	0
1992	1,108	1,123	3,386	1,784	609	587	1,776	1,777	6,123	5,093	2,520	2,106	114,622	6,096	287	250	408	530	82	118
2000	1,139	1,140	3,638	1,908	925	790	1,813	1,783	6,123	5,093	2,189	1,903	114,457	6,150	270	228	369	474	0	0
Net change	−25	106	1,680	1,329	773	745	418	281	−73	110	−392	493	−2,387	1,646	−33	50	38	55	0	0
Gross change	224	274	1,680	1,329	1,073	785	422	281	93	109	417	528	2,611	1,649	73	67	185	267	163	236

Table 4. Principal land-cover conversions in Mojave Basin and Range Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for "other" class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Developed	314	241	164	0.2	46.5
	Grassland/Shrubland	Mining	90	94	64	0.1	13.3
	Mechanically disturbed	Developed	52	56	38	0.0	7.7
	Wetland	Water	34	50	34	0.0	5.1
	Barren	Grassland/Shrubland	34	49	34	0.0	5.0
	Other	Other	151	n/a	n/a	0.1	22.4
		Totals	675			0.5	100.0
1980–1986	Grassland/Shrubland	Developed	202	192	131	0.2	33.3
	Grassland/Shrubland	Mechanically disturbed	115	132	90	0.1	19.0
	Grassland/Shrubland	Mining	110	103	70	0.1	18.1
	Barren	Mining	49	70	48	0.0	8.0
	Mechanically disturbed	Developed	38	35	24	0.0	6.2
	Other	Other	92	n/a	n/a	0.1	15.3
		Totals	605			0.5	100.0
1986–1992	Grassland/Shrubland	Developed	751	851	580	0.6	45.2
	Grassland/Shrubland	Mechanically disturbed	435	421	287	0.3	26.2
	Water	Wetland	125	180	123	0.1	7.5
	Grassland/Shrubland	Mining	110	97	66	0.1	6.6
	Grassland/Shrubland	Nonmechanically disturbed	82	118	80	0.1	4.9
	Other	Other	158	n/a	n/a	0.1	9.5
		Totals	1,660			1.3	100.0
1992–2000	Forest	Mechanically disturbed	324	467	318	0.2	38.5
	Grassland/Shrubland	Developed	160	183	124	0.1	19.1
	Mechanically disturbed	Developed	89	80	54	0.1	10.5
	Nonmechanically disturbed	Grassland/Shrubland	82	118	80	0.1	9.7
	Grassland/Shrubland	Mechanically disturbed	77	58	40	0.1	9.1
	Other	Other	110	n/a	n/a	0.1	13.1
		Totals	841			0.6	100.0
1973–2000 (overall)	Grassland/Shrubland	Developed	1,426	1,191	811	1.1	37.7
	Grassland/Shrubland	Mechanically disturbed	651	591	403	0.5	17.2
	Grassland/Shrubland	Mining	345	245	167	0.3	9.1
	Forest	Mechanically disturbed	340	488	332	0.3	9.0
	Mechanically disturbed	Developed	205	138	94	0.2	5.4
	Other	Other	814	n/a	n/a	0.6	21.5
		Totals	3,781			2.9	100.0

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Chapter 30

Sonoran Basin and Range Ecoregion

By James P. Calzia and Tamara S. Wilson

Ecoregion Description

The Sonoran Basin and Range Ecoregion covers approximately 116,364 km^2 (44,928 mi^2) of desert landscape in southeastern California and southwestern Arizona (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). This ecoregion is bounded on the west by the Southern and Central California Chaparral and Oak Woodlands and the Southern California Mountains Ecoregions; on the north by the Mojave Basin and Range, the Arizona/New Mexico Plateaus, and the Arizona/New Mexico Mountains Ecoregions; and on the east by the Madrean Archipelago Ecoregion (fig.1). The Sonoran Basin and Range Ecoregion extends far southward into both mainland Mexico and northeastern Baja California peninsula; however, those international parts were not included in the present study. The largest concentrations of population in the ecoregion include the Palm Springs–Coachella Valley area (population 332,485 in 2000) in California's Riverside County, as well as the Phoenix and Tucson metropolitan areas (metropolitan populations of approximately 4.2 million and 1 million, respectively) in Arizona (U.S. Census Bureau, 2011).

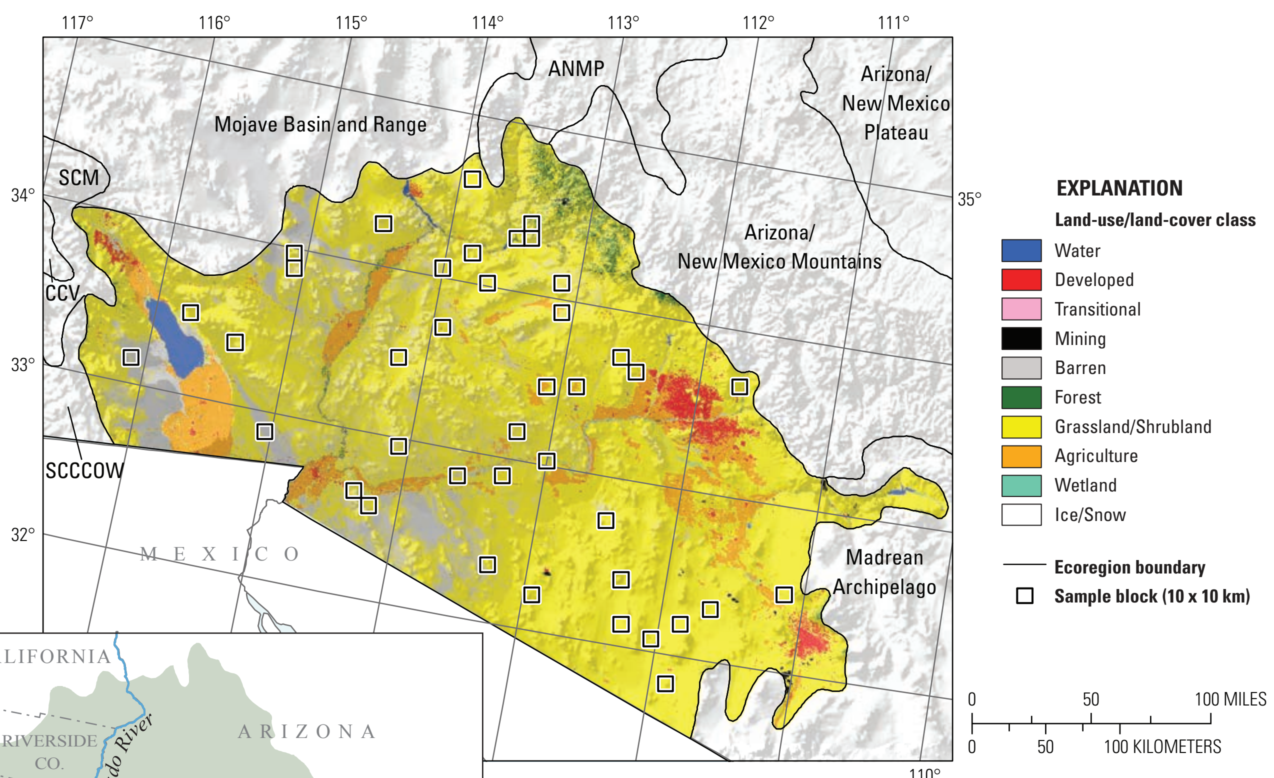

Figure 1. Map of Sonoran Basin and Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends of Land Change" study, transitional land-cover class was subdivided into mechanically disturbed and nonmechanically disturbed classes. Squares indicate locations of 10 x 10 km sample blocks analyzed in study. Index map shows locations of geographic features mentioned in text. Abbreviations for Western United States ecoregions are listed in appendix 2. See appendix 3 for definitions of land-use/land-cover classifications.

The geography of the Sonoran Basin and Range Ecoregion is characterized by discontinuous mountain ranges separated by wide alluvial plains. The mountains are composed of igneous, sedimentary, and metamorphic rocks that vary in age from Precambrian to Tertiary (Jennings, 1977; Arizona Geological Survey and Bureau of Land Management, 1993). Elevations range from 20 to 1,830 m. The largest rivers include the Colorado River along the boundary between California and Arizona, as well as the Gila and Salt Rivers in Arizona. The Salton Sea at the northern end of the Salton Trough is located near the ecoregion's western border.

The Sonoran Basin and Range Ecoregion is characterized by a warm, arid climate. During winter months, daytime temperatures can average 21°C, and overnight temperatures can drop to below freezing in some low-lying desert valleys (Climate Assessment for the Southwest, 2010). In summer months, temperatures often climb above 38°C during the day. Daily temperature variation can exceed 15°C (Climate Assessment for the Southwest, 2010). Annual precipitation varies from 7.5 to 43 cm, with slightly more rainfall at higher elevations (Arizona Fish and Game Department, 2006; McGinnies, 1976) and a gradient of increasing precipitation from west to east. The western Sonoran Desert receives most of its precipitation in winter, whereas summer precipitation totals farther east are greater because of the influence of monsoon rains fed by higher temperatures and moisture pumped in from the Gulf of California and the Gulf of Mexico (Comrie and Glenn, 1998).

The bimodal precipitation pattern contributes to the surprisingly diverse range of vegetation within the Sonoran Basin and Range Ecoregion. More than 2,500 species, including both annual and perennial trees and shrubs, as well as succulents and cacti (Turner and others, 1995), are found here. Vast expanses of cholla (*Opuntia* spp.) cactus in California are joined by the giant saguaro (*Carnegia gigantea*) cactus in Arizona. The saguaro is cold-intolerant and highly susceptible to winter freeze mortality; it cannot survive in the California part of the ecoregion (Steenbergh and Lowe, 1977). Creosote (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), ocotillo (*Fouquieria splendens*), and brittlebush (*Encelia farinosa*) shrubs dominate plant communities in the hottest, driest areas; palo verde (*Parkinsonia* spp.), mesquite (*Prosopis* spp.), and ironwood (*Olneya tesota*) trees are common on slopes and near the heads of alluvial fans.

Land ownership in the ecoregion is primarily Federal, managed by the Bureau of Land Management, Department of Defense, and National Park Service, and some of the remainder is occupied by tribal lands. Major land uses include urban and rural settlement, agriculture and livestock grazing, mining, and military training. Agriculture was established where water was available, but in recent years it has given way to urban growth. The dry climate makes this ecoregion a favored destination for relocation and retirement (Arizona Fish and Game, 2006).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change of land cover in the Sonoran Basin and Range Ecoregion between 1973 and 2000 was estimated at 2.6 percent (table 1). Although the overall change is small when compared to other ecoregions in the western United States, the amount of change is high relative to the adjacent Chihuahuan Deserts (0.5 percent; CD, on fig. 2) and Madrean Archipelago (1.4 percent; MA, on fig. 2) Ecoregions. Our estimates indicate that between 1973 and 2000, 1.3 percent of the ecoregion changed at least once, and 1.1 percent changed at least two times (table 1).

The normalized annual rates of land-cover change, which account for varying lengths of time between imagery dates (table 2), show that the rate of land-cover change in the

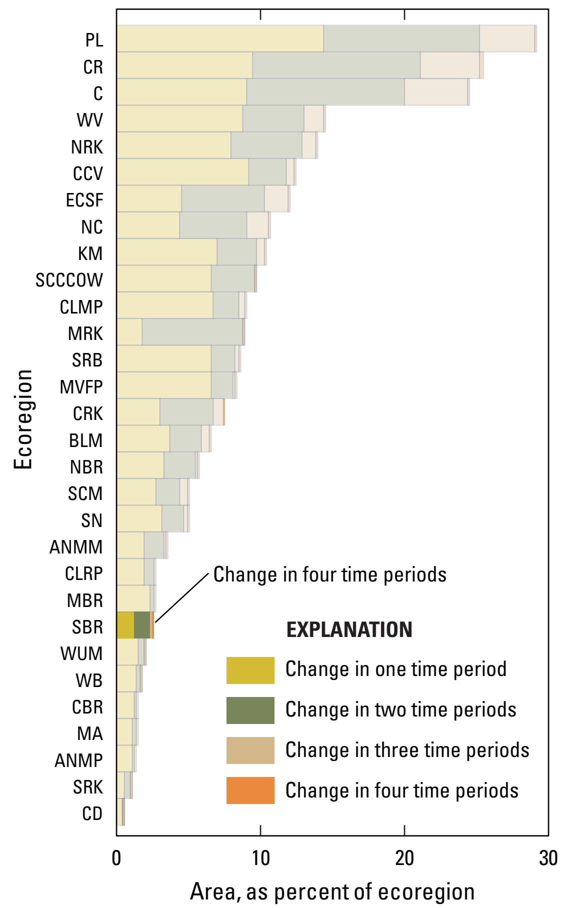

Figure 2. Overall spatial change in Sonoran Basin and Range Ecoregion (SBR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Sonoran Basin and Range Ecoregion (four time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

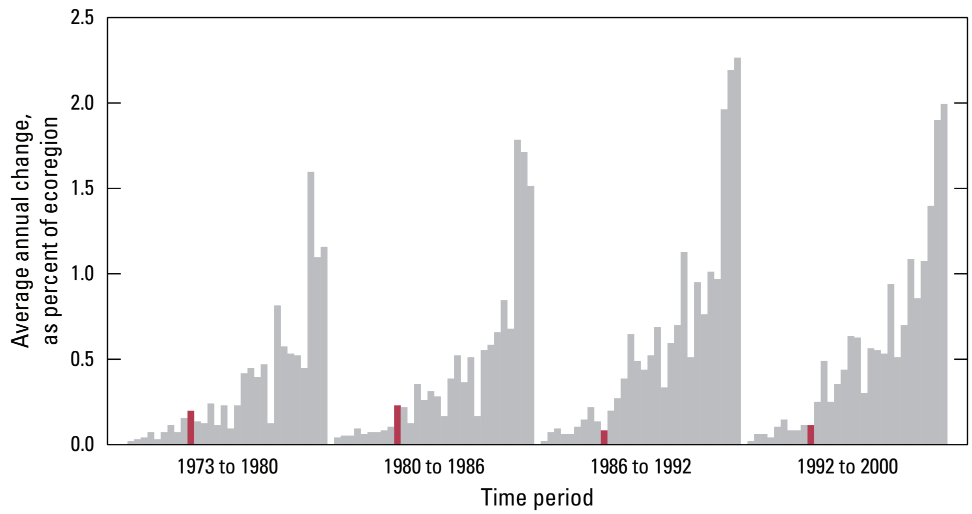

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Sonoran Basin and Range Ecoregion are represented by red bars in each time period.

Sonoran Basin and Range Ecoregion was very low compared to that in other ecoregions in the western United States (fig. 2). Within the Sonoran Basin and Range Ecoregion itself, the fastest rate of land-cover change occurred between 1980 and 1986, when approximately 264 km² changed land-cover classes per year, followed closely by 221 km² annually between 1973 and 1980. These rates were nearly twice as fast as between 1986 and 1992 and were approximately 50 percent faster than the rate of change between 1992 and 2000. It is worth noting that, because considerable error is associated with these rates, they may not be significantly different (table 2).

Net change in land-cover classes per time period is presented in figure 4. Between 1973 and 1980, a large net increase in water coupled with a large net decrease in grassland/shrubland was observed, whereas between 1980 and 1986 this trend reversed, with a large increase in grassland/shrubland and wetland coupled with a large decrease in water. These changes in land cover were in response to short-term climate fluctuations that resulted in widely varied reservoir levels. Grassland/shrubland changes were also influenced by an increase in developed land, which expanded by 173 percent over the study period, from 278 to 759 km².

Grassland/shrubland dominates the Sonoran Basin and Range Ecoregion, followed distantly by agriculture. In 2000 the grassland/shrubland class covered 92.9 percent (108,139 km²) of the ecoregion, while agriculture covered 3.2 percent of the ecoregion (3,698 km²) (table 3). Between 1973 and 1980, 617 km² of grassland/shrubland and 264 km² of wetland were converted to water, and another 257 km² of grassland/shrubland was converted to agriculture (table 4). Nearly the same area of water changed back to grassland/shrubland and wetland between 1980 and 1986. In addition, 147 km² of grassland/shrubland was converted to agriculture, and 96 km² was

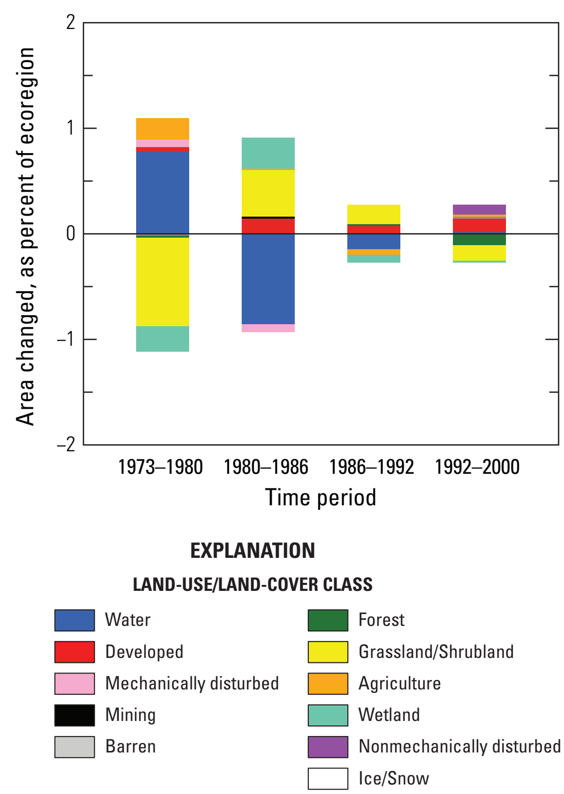

Figure 4. Normalized average net change in Sonoran Basin and Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

reclassified as developed. These changes continued between 1986 and 2000, during which time the Sonoran Basin and Range Ecoregion experienced net losses of 461 km^2 of grassland/shrubland and 245 km^2 of water, as well as net gains of 244 km^2 of agricultural land and 481 km^2 of developed land (fig. 4).

Estimates suggest that, between 1973 and 2000, land-cover change in the Sonoran Basin and Range Ecoregion was small, and it also occurred at a slow rate relative to other ecoregions in the western United States. However, as in the Mojave Basin and Range Ecoregion to the north, a seemingly small, yet significant change was occurring in developed land (fig. 5). Although development is sparse, all three major metropolitan regions in the Sonoran Basin and Range Ecoregion experienced unprecedented rates of population growth both during and since the study period. Between 1990 and 2000 alone, the population of the Coachella Valley grew at more than twice the rate of any other region in California. This growth has continued since the end of the study: between 2000 and 2005, the population of the Coachella Valley grew to 410,974 (an increase of 23.6 percent) (U.S. Census Bureau, 2011); by 2008, the Phoenix metropolitan area added nearly a million more people, a 31.7 percent increase since 2000. The greater Tucson region grew from 531,443 residents in 1980 to 666,880 in 1990 (a 25.5 percent increase) and to an estimated 843,746 people in 2000 (a 26.5 percent increase since 1990) (U.S. Census, 2011). In 1990, the Sonoran Basin and Range Ecoregion included 6.9 million residents; by 2020, the population is expected to reach 12 million (U.S. Census Bureau, 2011). Land-cover data suggest that urbanization of the Sonoran Basin and Range Ecoregion comes primarily at the expense of grassland/shrubland. As the population grows, water resources may become limited as human uses draw down regional water tables by groundwater pumping and also tax the Colorado River's finite water resources and its long-distance water delivery systems (for example, the Central Arizona Project canal) (fig. 6).

Figure 5. Changing landscape of Sonoran Basin and Range Ecoregion. *A,* Typical grassland/shrubland land cover within ecoregion. *B*, Result of change from grassland/shrubland to developed land-cover classes.

Figure 6. Increased use of water (*A*), coupled with decreasing water supplies (*B*), has controlled, and will continue to control, rate of land-cover change in Sonoran Basin and Range Ecoregion.

Table 1. Percentage of Sonoran Basin and Range Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

[Most sample pixels remained unchanged (97.4 percent), whereas 2.6 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.3	0.7	0.6	2.0	0.5	35.4
2	1.1	0.8	0.2	1.9	0.6	53.1
3	0.2	0.2	0.0	0.4	0.1	84.0
4	0.0	0.0	0.0	0.0	0.0	85.9
Overall spatial change	2.6	1.4	1.2	3.9	0.9	36.4

Table 2. Raw estimates of change in Sonoran Basin and Range Ecoregion land cover, computed for each of four time periods between 1973 and 2000, and associated error at 85-percent confidence level.

[Estimates of change per period normalized to annual rate of change for each time period]

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	1.3	0.9	0.4	2.2	0.6	45.4	0.2
1980–1986	1.4	1.1	0.3	2.5	0.7	55.0	0.2
1986–1992	0.5	0.4	0.1	0.8	0.2	50.2	0.1
1992–2000	0.8	0.5	0.4	1.3	0.3	38.8	0.1
Estimate of change, in square kilometers							
1973–1980	1,544	1,029	515	2,574	701	45.4	221
1980–1986	1,583	1,277	306	2,861	870	55.0	264
1986–1992	558	411	147	969	280	50.2	93
1992–2000	985	560	424	1,545	382	38.8	123

Table 3. Estimated area (and margin of error) of each land-cover class in Sonoran Basin and Range Ecoregion, calculated five times between 1973 and 2000. See appendix 3 for definitions of land-cover classifications.

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	2.1	2.9	0.8	0.4	93.3	3.4	3.0	2.0	0.2	0.3	0.0	0.0
1980	1.1	1.1	0.3	0.1	0.1	0.1	0.0	0.0	2.1	2.9	0.8	0.4	92.5	3.6	3.2	2.1	0.0	0.0	0.0	0.0
1986	0.2	0.2	0.4	0.2	0.0	0.0	0.0	0.0	2.1	2.9	0.8	0.4	92.9	3.5	3.2	2.1	0.3	0.4	0.0	0.0
1992	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.0	2.1	2.9	0.9	0.4	93.1	3.4	3.2	2.0	0.2	0.3	0.0	0.0
2000	0.1	0.0	0.7	0.4	0.0	0.0	0.0	0.0	2.1	2.9	0.8	0.3	92.9	3.5	3.2	2.1	0.2	0.3	0.1	0.1
Net change	−0.2	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	−0.1	0.1	−0.4	0.6	0.2	0.4	0.0	0.1	0.1	0.1
Gross change	1.9	1.9	0.4	0.3	0.1	0.2	0.0	0.0	0.0	0.0	0.2	0.2	2.3	1.4	0.8	0.5	0.7	0.9	0.1	0.1
Area, in square kilometers																				
1973	308	402	278	143	8	7	8	6	2,449	3,332	981	478	108,599	4,012	3,454	2,355	280	387	0	0
1980	1,224	1,321	328	172	88	90	9	6	2,428	3,326	962	489	107,615	4,175	3,696	2,398	14	13	0	0
1986	218	224	511	257	14	11	14	9	2,431	3,324	973	490	108,115	4,033	3,724	2,388	366	511	0	0
1992	43	42	604	313	15	13	14	10	2,435	3,323	995	495	108,315	4,010	3,674	2,381	269	368	0	0
2000	62	56	759	426	20	16	19	14	2,439	3,324	876	376	108,139	4,048	3,698	2,400	239	321	113	163
Net change	−245	396	481	310	12	11	11	13	−10	9	−104	130	−461	717	244	500	−42	67	113	163
Gross change	2,173	2,267	482	310	164	178	12	13	51	37	282	220	2,719	1,666	987	565	757	1,083	113	163

Table 4. Principal land-cover conversions in Sonoran Basin and Range Ecoregion, showing amount of area changed (and margin of error, calculated at 85-percent confidence level) for each conversion during each of four time periods and also during overall study period. See appendix 3 for definitions of land-cover classifications.

[Values given for “other” class are combined totals of values for other land-cover classes not listed in that time period. Abbreviations: n/a, not applicable]

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Water	617	608	414	0.5	40.0
	Wetland	Water	264	381	260	0.2	17.1
	Grassland/Shrubland	Agriculture	257	188	128	0.2	16.6
	Grassland/Shrubland	Forest	90	120	82	0.1	5.8
	Grassland/Shrubland	Mechanically disturbed	80	90	61	0.1	5.2
	Other	Other	236	n/a	n/a	0.2	15.3
		Totals	1,544			1.3	100.0
1980–1986	Water	Grassland/Shrubland	657	738	503	0.6	41.5
	Water	Wetland	344	496	338	0.3	21.7
	Grassland/Shrubland	Agriculture	147	112	76	0.1	9.3
	Grassland/Shrubland	Developed	96	75	51	0.1	6.1
	Agriculture	Grassland/Shrubland	90	108	74	0.1	5.7
	Other	Other	249	n/a	n/a	0.2	15.7
		Totals	1,583			1.4	100.0
1986–1992	Wetland	Grassland/Shrubland	158	227	155	0.1	28.3
	Water	Grassland/Shrubland	147	160	109	0.1	26.4
	Grassland/Shrubland	Developed	91	63	43	0.1	16.3
	Agriculture	Grassland/Shrubland	49	44	30	0.0	8.7
	Grassland/Shrubland	Wetland	47	67	46	0.0	8.4
	Other	Other	67	n/a	n/a	0.1	12.0
		Totals	558			0.5	100.0
1992–2000	Grassland/Shrubland	Agriculture	245	264	180	0.2	24.9
	Agriculture	Grassland/Shrubland	207	161	110	0.2	21.0
	Grassland/Shrubland	Developed	135	99	68	0.1	13.7
	Forest	Nonmechanically disturbed	113	163	111	0.1	11.5
	Wetland	Grassland/Shrubland	89	128	87	0.1	9.0
	Other	Other	195	n/a	n/a	0.2	19.8
		Totals	985			0.8	100.0
1973–2000 (overall)	Water	Grassland/Shrubland	833	809	551	0.7	17.8
	Grassland/Shrubland	Water	682	620	422	0.6	14.6
	Grassland/Shrubland	Agriculture	651	427	291	0.6	13.9
	Agriculture	Grassland/Shrubland	360	241	164	0.3	7.7
	Water	Wetland	358	514	350	0.3	7.7
	Other	Other	1,786	n/a	n/a	1.5	38.2
		Totals	4,671			4.0	100.0

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Appendixes 1–4

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Appendix 1. Map of Ecoregions in Conterminous United States

This volume—U.S. Geological Survey Professional Paper 1794–A, which covers 30 ecoregions in the Western United States—provides an assessment of the rates and causes of land-use and land-cover change in the Western United States region between 1973 and 2000. The other three volumes of this Professional Paper (1794–B, 1794–C, and 1794–D) provide similar analyses for the Great Plains, the Midwest–South Central United States, and the Eastern United States regions, respectively.

The map contained in this appendix (fig. 1.1) shows all 84 ecoregions in the conterminous United States, as originally defined by Omernik and others (1987) and later modified by the U.S. Environmental Protection Agency (1999), in addition to the ecoregions that are contained in the Western United States, Great Plains, Midwest–South Central United States, and Eastern United States regions. Also shown are the land-use/land-cover classes from the 2001 National Land-Cover Database (Homer and others, 2004).

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Ecoregion Abbreviations Used on Map

[Map is on following pages]

ACPB	Atlantic Coastal Pine Barrens Ecoregion
ANMM	Arizona/New Mexico Mountains Ecoregion
CR	Coast Range Ecoregion
CRK	Canadian Rockies Ecoregion
EGLHL	Eastern Great Lakes and Hudson Lowlands Ecoregion
HELP	Huron/Erie Lake Plains Ecoregion
LPH	Laurentian Plains and Hills Ecoregion
MACP	Middle Atlantic Coastal Plain Ecoregion
MRK	Middle Rockies Ecoregion
MVFP	Montana Valley and Foothill Prairies Ecoregion
MVLP	Mississippi Valley Loess Plains Ecoregion
NAPU	Northern Appalachian Plateau and Uplands Ecoregion
NCA	North Central Appalachians Ecoregion
NCHF	North Central Hardwood Forests Ecoregion
NECZ	Northeastern Coastal Zone Ecoregion
NEH	Northeastern Highlands Ecoregion
NLF	Northern Lakes and Forests Ecoregion
NMW	Northern Minnesota Wetlands Ecoregion
PL	Puget Lowland Ecoregion
SCCCOW	Southern and Central California Chaparral and Oak Woodlands Ecoregion
SCM	Southern California Mountains Ecoregion
SEWTP	Southeastern Wisconsin Till Plains Ecoregion
SFCP	Southern Florida Coastal Plain Ecoregion
TBP	Texas Blackland Prairies Ecoregion
WUM	Wasatch and Uinta Mountains Ecoregion
WV	Willamette Valley Ecoregion

Figure 1.1. Map of ecoregions in conterminous United States.


90°
80°
50°
40°
70°
30°
CANADA
Lake Agassiz Plain
NMW
Northern Lakes and Forests
Northern Glaciated Plains
NCHF
NLF
Driftless Area
SEWTP
HELP
Southern Michigan/ Northern Indiana Drift Plains
Western Corn Belt Plains
HELP
EGLHL
Erie Drift Plains
PLAINS
Central Corn Belt Plains
Eastern Corn Belt Plains
Western Allegheny Plateau
Central Irregular Plains
Flint Hills
Plains
Interior River Lowland
MIDWEST–SOUTH CENTRAL UNITED STATES
Interior Plateau
Central Appalachians
Ozark Highlands
Boston Mountains
Arkansas Valley
Ouachita Mountains
Mississippi Alluvial Plain
Ridge and Valley
Blue Ridge Mountains
Southwestern Appalachians
Piedmont
Northeastern Highlands
NEH
NEH
NEH
NECZ
NAPU
NCA
NCA
LPH
Northern Piedmont
ACPB
MACP
MACP
Middle Atlantic Coastal Plain
Atlantic Ocean
TBP
South Central Plains
East Central Texas Plains
TBP
Western Gulf Coastal Plain
MVLP
EASTERN UNITED STATES
Southeastern Plains
Southern Coastal Plain
SFCP
Gulf of Mexico
EXPLANATION
Land-use/land-cover class
Water
Developed
Barren
Forest
Grassland/Shrubland
Agriculture
Wetland
Ice/Snow
Ecoregion boundary
Major ecoregion group boundary

Appendix 2. Abbreviations for Western United States Ecoregions

ANMM	Arizona/New Mexico Mountains Ecoregion
ANMP	Arizona/New Mexico Plateau Ecoregion
BLM	Blue Mountains Ecoregion
C	Cascades Ecoregion
CBR	Central Basin and Range Ecoregion
CCV	Central California Valley Ecoregion
CD	Chihuahuan Deserts Ecoregion
CLMP	Columbia Plateau Ecoregion
CLRP	Colorado Plateaus Ecoregion
CR	Coast Range Ecoregion
CRK	Canadian Rockies Ecoregion
ECSF	Eastern Cascades Slopes and Foothills Ecoregion
KM	Klamath Mountains Ecoregion
MA	Madrean Archipelago Ecoregion
MBR	Mojave Basin and Range Ecoregion
MRK	Middle Rockies Ecoregion
MVFP	Montana Valley and Foothill Prairies Ecoregion
NBR	Northern Basin and Range Ecoregion
NC	North Cascades Ecoregion
NRK	Northern Rockies Ecoregion
PL	Puget Lowland Ecoregion
SBR	Sonoran Basin and Range Ecoregion
SCCCOW	Southern and Central California Chaparral and Oak Woodlands Ecoregion
SCM	Southern California Mountains Ecoregion
SN	Sierra Nevada Ecoregion
SRB	Snake River Basin Ecoregion
SRK	Southern Rockies Ecoregion
WB	Wyoming Basin Ecoregion
WUM	Wasatch and Uinta Mountains Ecoregion
WV	Willamette Valley Ecoregion

Appendix 3. Land-Cover Classification System Used in "Status and Trends of Land Change" Study

This analysis of land-use/land-cover change during the 1973–2000 study period is based on land-cover classifications mapped for five study dates—1973, 1980, 1986, 1992, and 2000. The use of moderate-resolution imagery—Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus—necessitated a land-cover classification system that was fairly general in order to achieve high levels of accuracy and consistency in the interpretations. The classification system also needed to contain classes that could be used as an appropriate surrogate for land use. This classification, which is based on the Anderson Level I classes (Anderson and others, 1976), was used because the classes have been designed as use surrogates, but this system has been further modified by adding two transitional disturbance categories, mechanically disturbed (human induced) and nonmechanically disturbed (natural).

The classification system used consists of the following 11 general land-cover classes: water, developed, mechanically disturbed, mining, barren, forest, grassland/shrubland, agriculture, wetland, nonmechanically disturbed, and ice/snow. Classes are defined as follows:

Water—Areas that are persistently covered with water, such as perennial streams, canals, rivers, lakes, reservoirs, bays, and oceans.

Developed—Areas of intensive use, in which much of the land is covered with structures or other anthropogenically induced, impermeable surfaces (for example, high-density residential, commercial, and industrial areas, as well as roads, highways, and other transportation corridors), or less intensive use, in which the land-cover matrix includes both vegetation and structures (for example, low-density residential areas, recreational facilities, cemeteries, parking lots, and utility corridors). Land that is functionally related to urban or built-up environments (for example, parks and golf courses) is also included.

Mechanically disturbed—Land in an altered and often unvegetated state owing to disturbance by mechanical (that is, human) means. Mechanically disturbed land is in transition from one land-cover class to another. Processes leading to mechanical disturbance include forest clearcutting, earthmoving, scraping, chaining, reservoir drawdown, and other types of anthropogenically induced changes.

Mining—Areas of extractive mining activities that have significant surface expression, including mining buildings and apparatus, quarry pits, evaporation and leach ponds, tailings and overburden piles, and other components related to mining, to the extent that these features can be detected.

Barren—Areas of bare soil, sand, or rock, in which less than 10 percent of the area is vegetated. Barren lands generally are naturally occurring.

Forest—Tree-covered land where the tree-cover density is greater than 10 percent. Cleared forest land is mapped (according to land cover at the time of the imagery) as either mechanically disturbed or grassland/shrubland.

Grassland/Shrubland—Land that is predominately covered with grasses, forbs, or shrubs. Vegetated cover must make up at least 10 percent of the area.

Agriculture—Land, in either a vegetated or an unvegetated state, used for the production of food or fiber. This includes cultivated and uncultivated croplands, hay lands, pasture, orchards, vineyards, and confined-livestock operations. However, forest plantations always are classified as forest, regardless of how the wood products are used.

Wetland—Land where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities. Wetlands usually contain both water and vegetated cover.

Nonmechanically disturbed—Land in an altered and often unvegetated state owing to disturbance by nonmechanical (that is, natural) means. Nonmechanically disturbed land is in transition from one land-cover class to another. Causes of nonmechanical disturbance include fire, wind, floods, animals, and other similar phenomena.

Ice/Snow—Land where the accumulation of snow and ice does not completely melt during the summer period (for example, alpine glaciers and perennial snowfields).

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Appendix 4. Methodology Used in "Status and Trends of Land Change" Study

This appendix describes the methodology used to determine the temporal and spatial rates, trends, and types of change documented in this "Status and Trends of Land Change" study. The methodology is based on a statistical sampling approach, manual classification of land use and land cover, and postclassification comparisons of land cover over five different study dates (Loveland and others, 2002). U.S. Environmental Protection Agency's (1999) Level III ecoregions provided the geographic framework for regional land-cover change estimates, and land-use/land-cover change was estimated on an ecoregion-by-ecoregion basis using a probability sample of randomly selected blocks within each of 84 ecoregions across the conterminous United States. For each sample block, five dates of Landsat imagery were interpreted in order to map land use and land cover, using a classification system that consists of 11 general land-cover classes (see appendix 3, entitled "Land-Cover Classification System Used in 'Status and Trends of Land Change' Study"). The resulting land-cover data for each sample block were used to determine change for four time periods, and sample-block data were used to calculate change estimates for each ecoregion.

Sampling Strategy

In this study, a sampling strategy was used as a cost-efficient method for characterizing land-cover change in an area as large as the conterminous United States. The study used a stratified random sample of 2,688 square blocks (fig. 4.1); a random sample of these blocks was independently selected for each ecoregion analyzed. Because the study used a probability sample, the estimates of land-use/land-cover change that are derived can be considered as categorically representative of the population (Kish, 1987).

The size of each sample block in this study, as well as the sampling density (that is, the number of sample blocks analyzed per ecoregion), was based on a compromise between two conflicting objectives: (1) estimating change in land-cover area, and (2) estimating change in landscape pattern. Larger numbers of smaller sample blocks would result in more precise estimates of change in land-cover area, whereas smaller numbers of larger sample blocks would be more desirable for characterizing landscape pattern.

Size of Samples

In the initial study design, a 20 × 20 km (400 km^2) sample-block size was used, and nine ecoregions were analyzed, each analysis consisting of 9 to 11 sample blocks. On the basis of results from these initial ecoregion analyses, a decision was made to use a higher density of smaller (10 × 10 km; 100 km^2) sample blocks for the remainder of the ecoregion analyses in order to maximize the precision of the land-cover change estimates.

Sampling Density

The sampling density was determined by both the project requirements for precision in the change estimates and the expected characteristics of change within the ecoregion being studied. As precision requirements increase, so must the sampling density. Similarly, a greater sampling density is required when areas of change are expected to be less evenly distributed throughout an ecoregion.

In this study, the target precision level was to map gross overall change to within a ±1% margin of error at an 85% confidence level for each ecoregion. On the basis of this target precision level and the expected characteristics of change within all 84 ecoregions in the conterminous United States, it was determined that between 25 and 48 of the 10 × 10 km sample blocks per ecoregion would likely be needed to adequately characterize overall change in each ecoregion.

Implementation of the Sampling Strategy

The sampling strategy outlined above was fairly straightforward to implement. A regular grid of 10 × 10 km (or, in a few cases, 20 × 20 km) sample blocks was overlain on an ecoregion map of the conterminous United States. Blocks whose centers fell within the boundaries of an ecoregion were highlighted as potentially valid sample blocks for that ecoregion and then were assigned a unique numerical value from 1 to N. A random number generator was then used to select sample blocks, one at a time, until the desired number was reached. Thus, each sample block within an ecoregion had an equal probability of being included in the final sample analysis.

Although the number of sample blocks selected and analyzed was based on both the target precision level and the expected characteristics of change within the ecoregion, unexpected heterogeneity in the distribution of change could still result in the estimates of change having levels of precision that are lower than desired. Should this occur, the sampling strategy allowed for the selection and interpretation of additional sample blocks. The inclusion of these reserve blocks allowed the analysis to achieve change estimates that have acceptable levels of precision.

Geographic Framework

A central premise of the study design was the use of a geographic framework to provide regional land-cover change estimates. Geographers have long used regional frameworks because they capture the essence and potential of the landscape without masking the roles of environmental, social, and economic forces (Turner and Meyer, 1991). This "Status and Trends of Land Change" study chose to use ecoregions, as originally defined by Omernik (1987) and later modified by the U.S. Environmental Protection Agency (1999), as the framework from which to tell the regional story of change.

Ecoregions were chosen as the unit of analysis because (1) they provide a means to localize estimates of the rates and driving forces of change, (2) they were developed by synthesizing information on a wide variety of factors (for example, climate, geology, physiography, soils, vegetation, hydrology, and human influences) and, therefore, should reflect both current land-use and land-cover types and future change trajectories, and (3) they provide a framework that can be extended globally.

Landsat Data

Landsat satellite imagery was the primary source of data used for detecting land-cover change in this study. Data from the Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) instruments were acquired from the Landsat data archive: Landsat MSS datasets are available from late-1972 through late-1992; Landsat TM data are available from 1982 to the present; and Landsat ETM+ data are available from 1999 to the present. Each of these products provided a consistent, synoptic, multispectral view of the land surface from which land cover could be interpreted for the period between 1973 and 2000. To analyze trends in land-use/land-cover change throughout this period, five target study dates spaced at semiregular intervals (1973, 1980, 1986, 1992, and 2000) were selected. Landsat imagery corresponding to each 10 × 10 km (or 20 × 20 km) sample block was extracted from full Landsat scenes, resulting in five dates of satellite imagery for each sample block.

To reduce expenses, the initial data-acquisition strategy was to use existing geoprocessed Landsat datasets as the primary input data source. Four of the five dates of Landsat MSS, TM, and ETM+ data were available in a geocoded format as a result of processing done for two previous projects: (1) the North American Landscape Characterization (NALC) project produced 1973, 1986, and 1992 geocoded Landsat MSS datasets for the conterminous United States and Mexico (Lunetta and others, 1998), and (2) the 1992 TM and 2000 ETM+ data came from the Multiresolution Landscape Characterization initiative (Loveland and Shaw, 1996). New 1980 Landsat MSS acquisitions were obtained in order to maintain the six- to eight-year interval between the five target dates.

The Landsat MSS, TM, and ETM+ scenes obtained were previously georeferenced to root-mean-square error of 1 pixel or less but to differing map projections. For this study, all scenes were translated to a common Albers equal-area projection. Most of the NALC MSS data had also been terrain-corrected, but approximately one-third of the NALC data (path and rows) had been processed before the implementation of terrain-correction techniques. However, this was not considered a problem because the early NALC scenes were located primarily in areas with negligible terrain variability.

Ancillary Data

Additional ancillary data were acquired to aid interpreters in delineating land use and land cover from the Landsat data. For example, aerial photography was acquired for each sample block to provide a high-resolution data source to help with difficult interpretations. The National Aerial Photography Program (NAPP) generally provided one or two dates of color-infrared (CIR) and (or) black-and-white aerial photographs from 1987 to the present. The National High Altitude Photograph (NHAP) Program generally provided one date of CIR and (or) black-and-white aerial photographs between 1980 and 1986. Aerial photographs were not consistently available for dates prior to 1980 but were acquired when available. Although the Landsat imagery was always used as the source material for delineating land use and land cover, these higher resolution aerial photographs were invaluable for assisting in the interpretation of the imagery. Topographic maps, census data, other electronic sources of aerial photographs (for example, Google Earth), and digital raster graphics were among the other sources of information that interpreters found useful when processing the data.

Land-Cover Classification Scheme

The analysis of land use and land cover change during the 1973 to 2000 study period was based on classifications of land cover for the five target dates mentioned previously. The classification system used consists of the following 11 general land-cover classes: water, developed, mechanically disturbed, mining, barren, forest, grassland/shrubland, agriculture, wetland, nonmechanically disturbed, and ice/snow. See appendix 3, entitled “Land-Cover Classification System Used in ‘Status and Trends of Land Change’ Study,” for definitions of these 11 classifications.

Two primary factors affected the design of the classification system. The first factor was recognizing that the use of moderate-resolution Landsat imagery would necessitate a land-cover classification system that was fairly general in order to achieve high interpretation accuracy and consistency. The ability to identify and map land cover would be limited both by the technical specifications of the Landsat MSS, TM, and ETM sensors and by the local and regional landscape characteristics that affect the form and contrast visible in satellite imagery. This would be especially true when interpreting Landsat MSS data.

The second factor involved choosing land-cover classes that captured the land-cover changes of interest. Because the project’s interest was in land-use change, with land cover serving as a surrogate for land use, the decision was to use the Anderson Level I classes (Anderson and others, 1976) because they were designed as use surrogates. However, the Anderson system was selectively modified by adding two disturbance categories, mechanically disturbed (human induced) and nonmechanically disturbed (natural).

Manual Land-Cover Delineation

Land-cover delineation for each sample block began with the creation of a baseline reference land-cover dataset. The 1992 date usually was the starting point owing to the availability of the 30-m-resolution 1992 National Land Cover Data (NLCD) dataset (Vogelmann and others, 2001). The NLCD dataset provided a starting template after the more detailed NLCD classes were aggregated to match the general land-cover classification described above.

The NLCD data first were manually edited on the computer screen, using on-screen interpretation methods, while using the 1992 Landsat TM data and the NAPP aerial photographs as interpretation aids. This cleanup procedure to improve the NLCD classification accuracy was carried out because the NLCD data were created using automated image-processing procedures, and they were not meant for use in local- or ecoregional-scale assessments. A minimum mapping unit of 60 m^2 was used for this study. Thus, features having ground footprints less than 60 m wide generally were not mapped, resulting in the exclusion of high-contrast features such as roads, which have a distinct spectral signature but have ground dimensions of less than 60 m.

To carry out the NLCD editing for a particular sample block, the analyst displayed the NLCD data alongside the 1992 Landsat TM data on the computer screen. These data sources, along with hard-copy prints of NAPP aerial photography roughly corresponding to the 1992 date, were visually inspected by the analyst to determine if any corrections were needed in the sample block. The analyst manually delineated polygons that consisted of contiguous blocks of specific land-cover classes. Each of these polygons was then given a code value that corresponded to the land-cover classes outlined in the classification scheme in appendix 3. The process continued until the entire sample block was manually inspected, mapped, and coded by the analyst.

To analyze change, land-cover classes for the 1973, 1980, 1986, and 2000 study dates were backward- or forward-classified using the 1992 land-cover dataset as the template. For example, creation of the 2000 land-cover product began by making an exact copy of the 1992 land-cover product. This copy served as a baseline for the 2000 land-cover product, in which identified changes between 1992 and 2000 were manually edited into the copied image. This baseline 2000 land-cover product was displayed on screen, along with the 1992 Landsat imagery and the 2000 Landsat imagery, allowing the analyst to pan through the entire area of the sample block while examining the 1992 and 2000 Landsat imagery and any relevant aerial photography for valid land-cover changes between the two study dates. Any identified land-cover changes were manually digitized on screen, and the land cover was recoded on the 2000 land-cover product.

Upon completion of the 2000 land-cover product, the same procedures were used to create the 1986, 1980, and 1973 land-cover products. This manual process eliminated errors that may occur between independently created land-cover products that are compared in a subsequent change analysis. Because only manually identified, delineated, and coded land-cover changes were analyzed during this phase, classification errors were greatly reduced.

Statistical Analysis

The resulting land-cover data for each sample block was used in postclassification comparisons to determine change between study years (fig. 4.2). Sample blocks within each ecoregion were used to generate change statistics for all 84 ecoregions. These statistics were used to determine the predominant types of land-cover conversions occurring within each ecoregion, the estimated rates of change for these conversions, and whether these types and rates of change are constant or variable across time. The analysis of change also involved looking for spatial correlations between conversion types and selected socioeconomic and environmental factors, such as timber production, agricultural yields, precipitation amounts, population levels, proximity to urban development, and overall economic conditions, in order to improve the understanding of potential drivers of change.

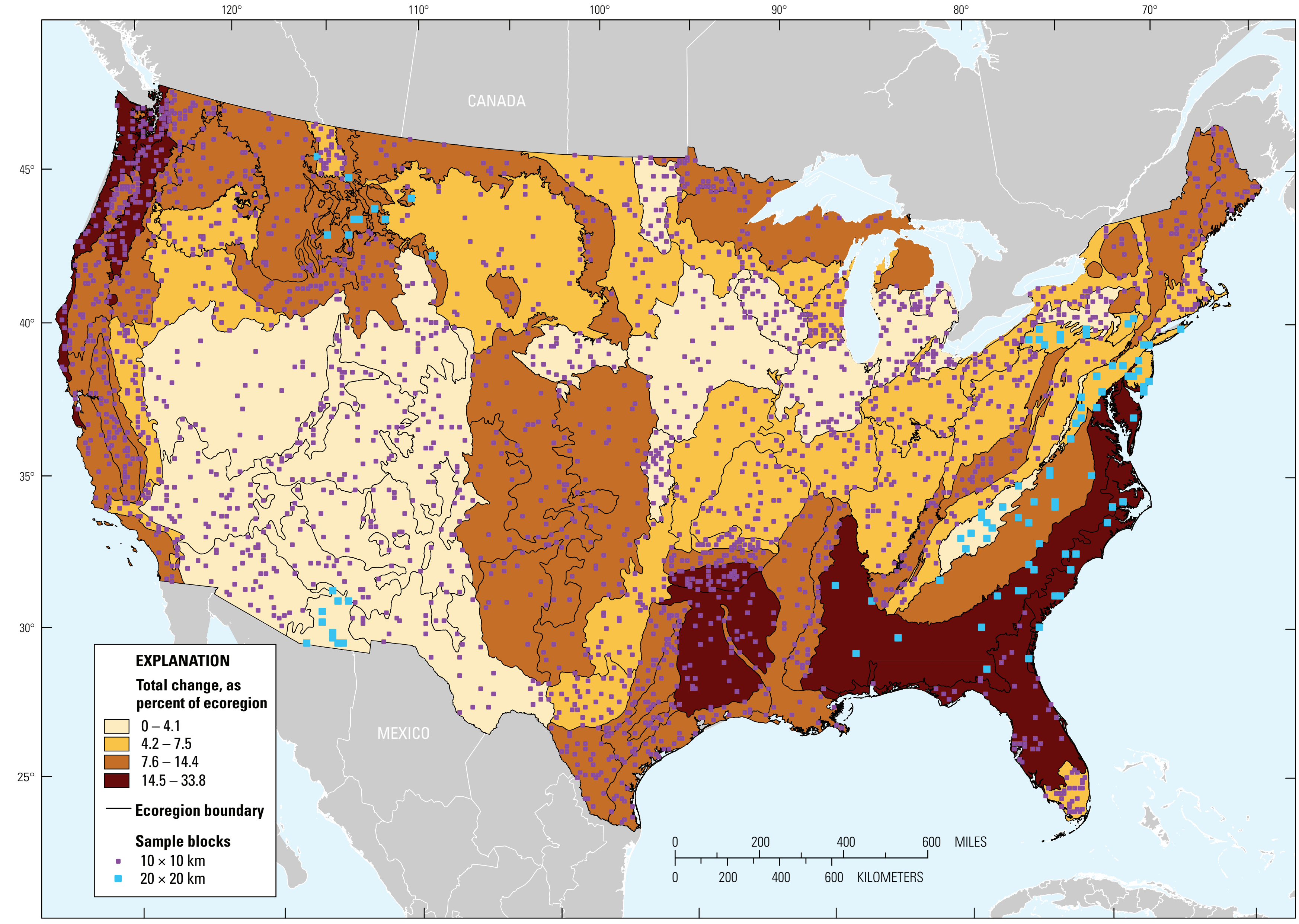

Figure 4.1. Map of ecoregions in conterminous United States, showing locations of 2,688 sample blocks that were used in "Status and Trends of Land Change" study (purple and blue squares indicate locations of 10 × 10 km and 20 × 20 km sample blocks, respectively). Also shown are amounts of total change in each ecoregion between 1973 and 2000, as percent of ecoregion.

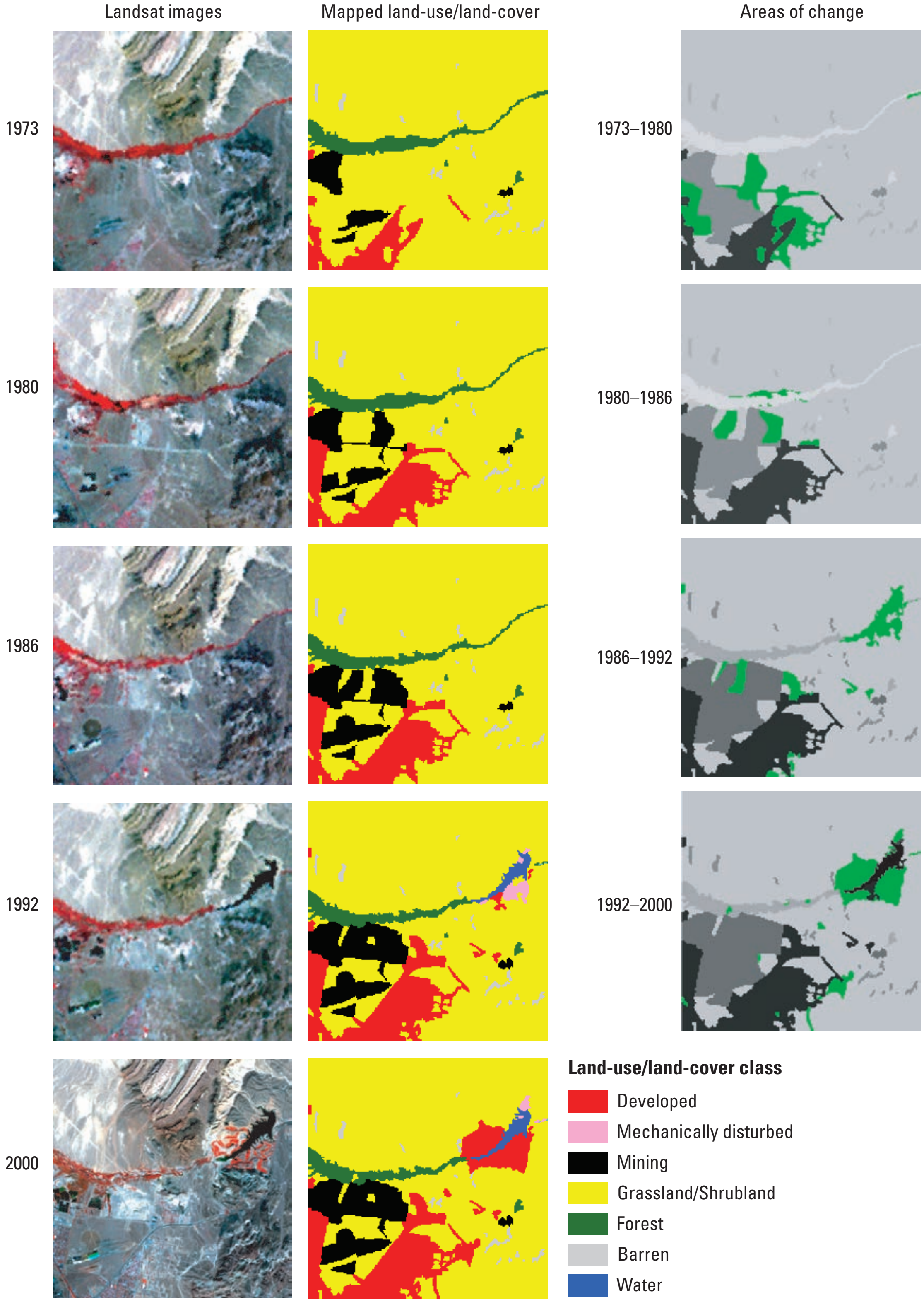

Figure 4.2. Example of data compiled for each sample block, showing sample block 14-0555 (located near Henderson, Nevada, in Mojave Basin and Range Ecoregion). Left column is satellite imagery collected for each of five years analyzed in study (imagery sources for study years: 1973, 1980, and 1986 are Landsat Multispectral Scanner (MSS) images; 1992 is Landsat Thematic Mapper (TM) image; 2000 is Landsat Enhanced Thematic Mapper (ETM) image). Center column is mapped land-use/land-cover data for each study year. Right column shows areas that changed (green areas) in each of four time periods between study years; light- and dark-gray-shaded areas show areas of previous change and represent overall land-change footprint throughout study period.

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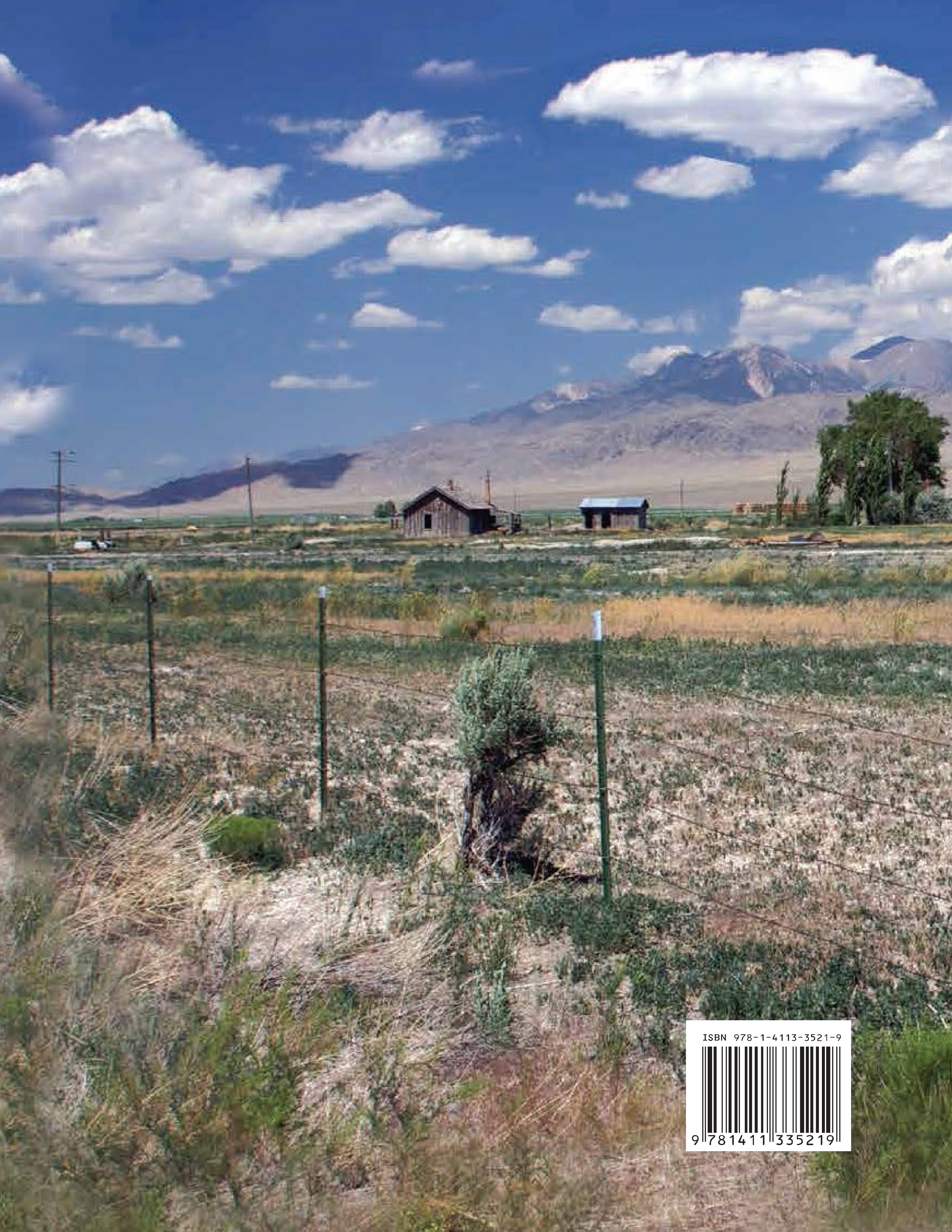

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