Rocky Mountains Ecoregions

Status and Trends of Land Change in the Western United States—1973 to 2000
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Chapter 4
Canadian Rockies Ecoregion

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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

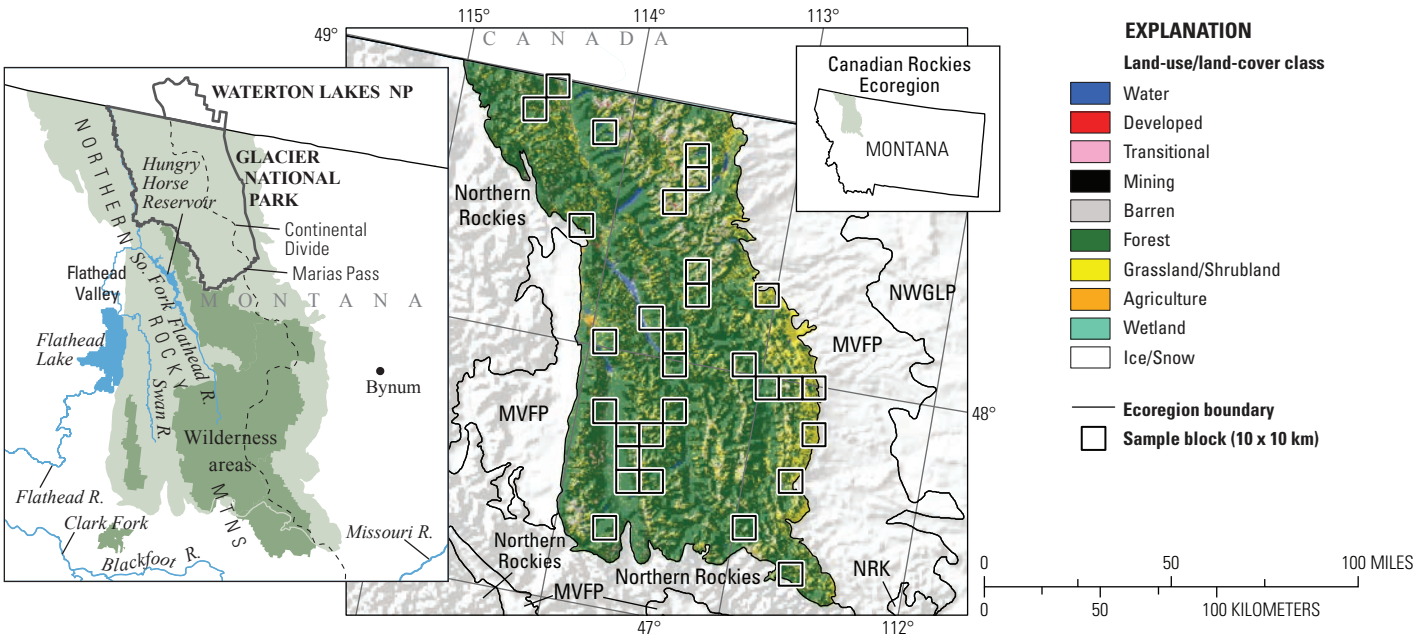

Figure 1. Map of Canadian Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and 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

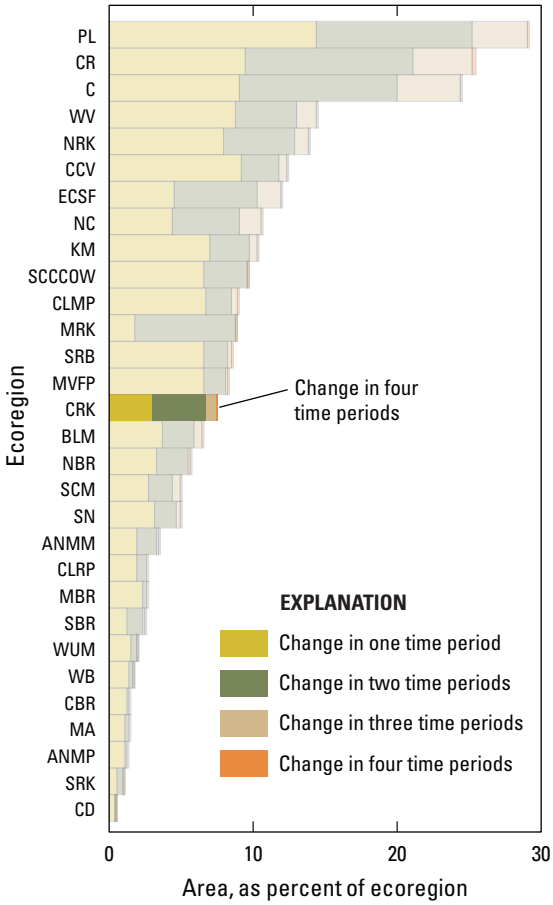

Figure 5. Overall spatial change in Canadian Rockies Ecoregion (CRK; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that change during one, two, three, or four time periods; highest level of spatial 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

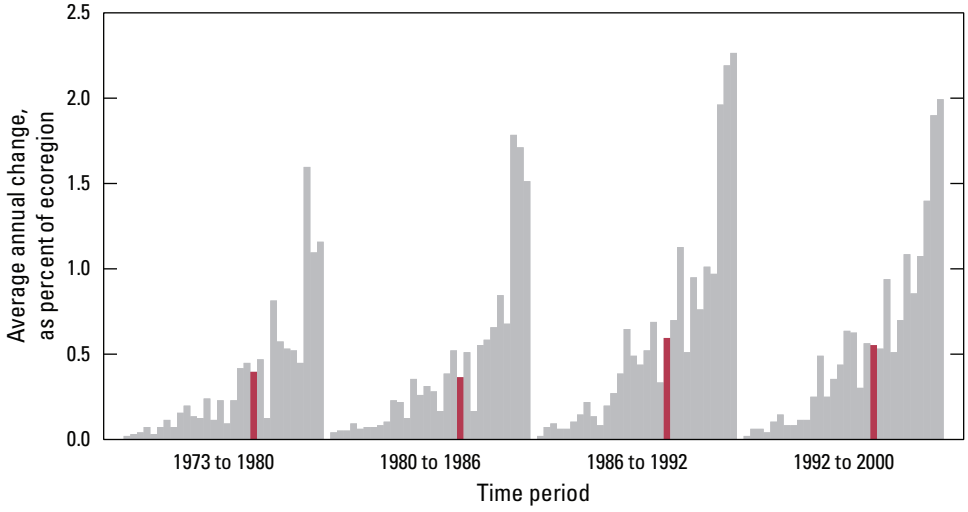

Figure 6. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Canadian Rockies Ecoregion are represented by red bars in each time period.

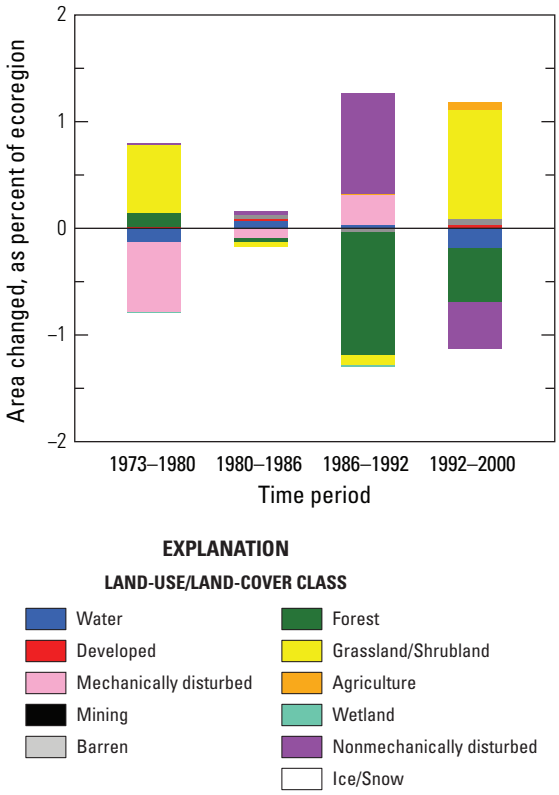

Figure 7. Normalized average net change in Canadian Rockies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for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

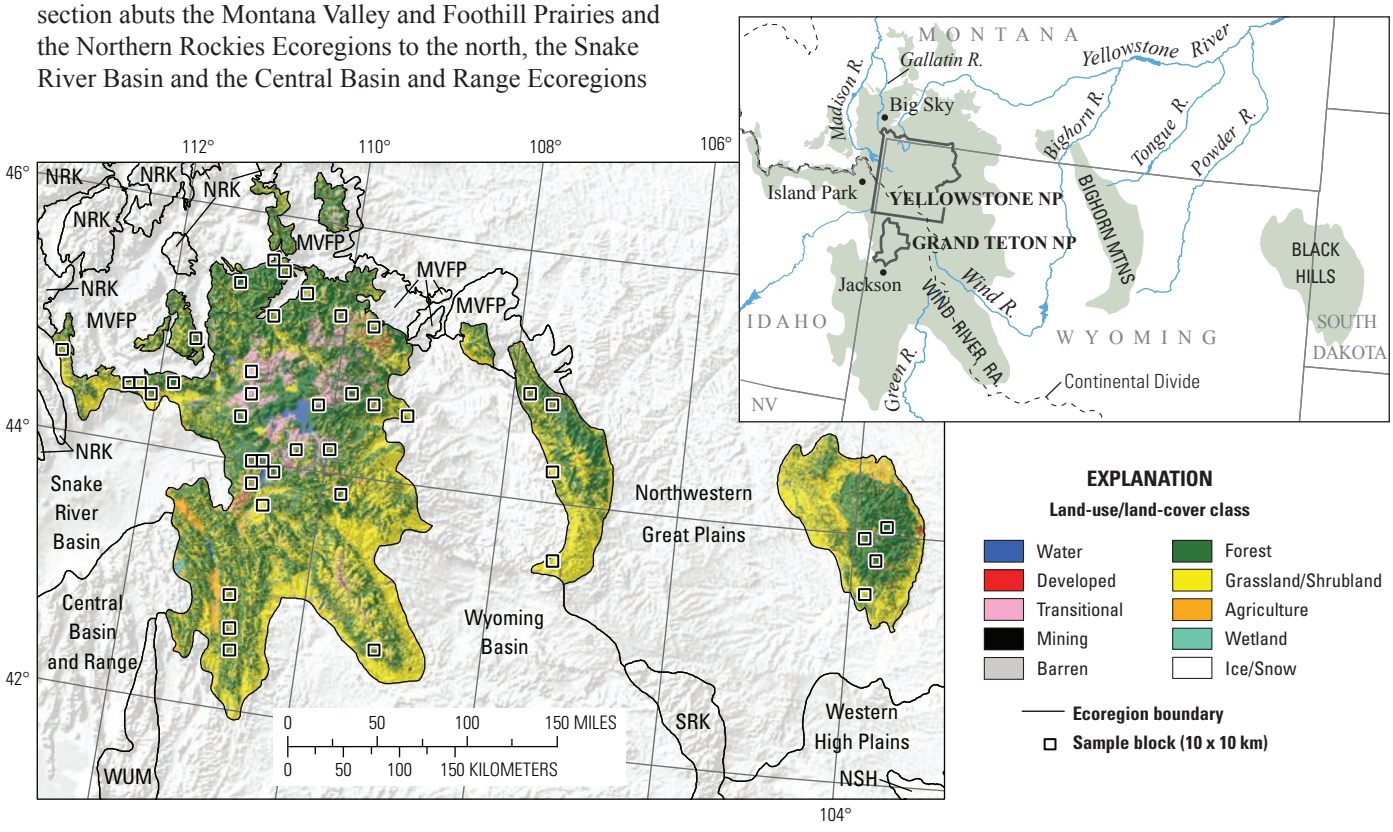

Figure 1. Map of Middle Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and 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.

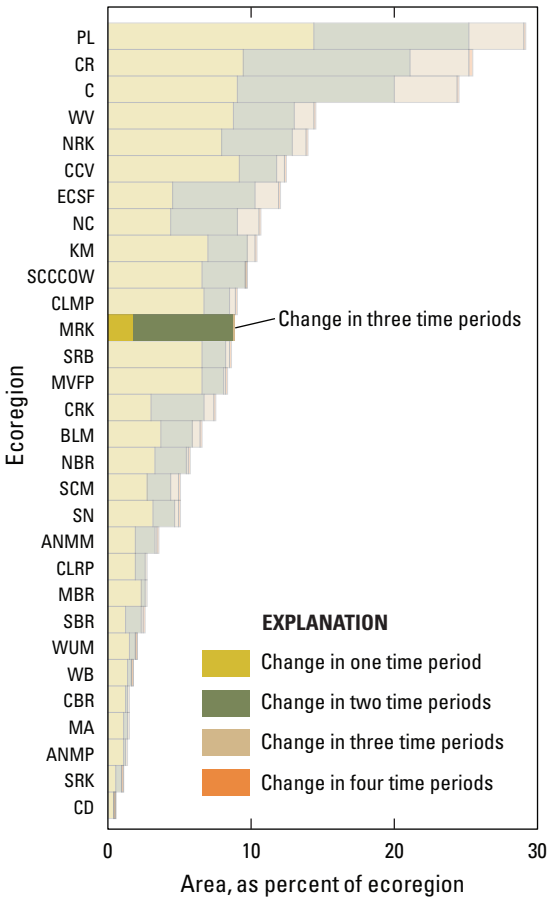

Figure 4. Overall spatial change in Middle Rockies Ecoregion (MRK; darker bars) compared with that of all 30 Western United States ecoregions. Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Middle 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 km²) (table 1). Of that total, 1.7 percent (1,533 km²) changed one time, and 7.1 percent (6,401 km²) 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 km²) between 1973 and 1980 to a high of 7.5 percent (6,740 km²) 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 km²) per year between 1973 and 1980 to a high of 1.1 percent (1,012 km²) per year between 1986 and 1992 (fig. 5).

In 1973, forest made up 50.4 percent (45,463 km²) of the ecoregion, grassland/shrubland made up 44.4 percent (40,061 km²), 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 km²), 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,

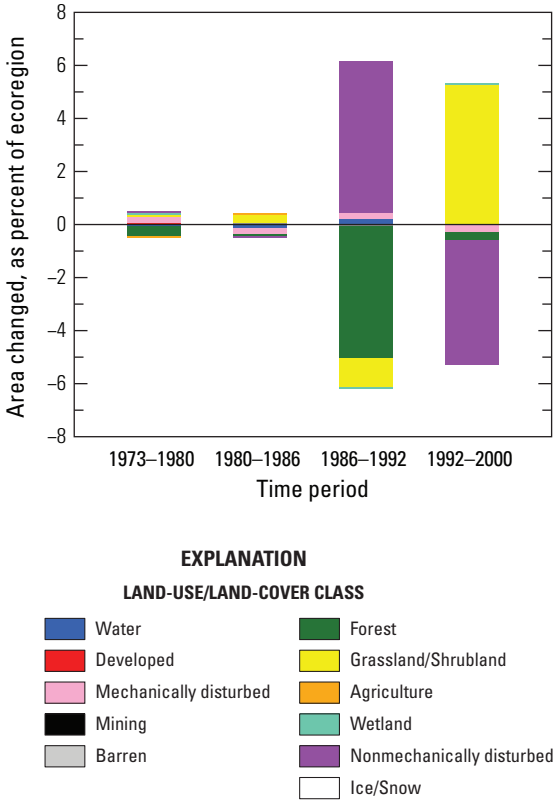

Figure 6. Normalized average net change in Middle Rockies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for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

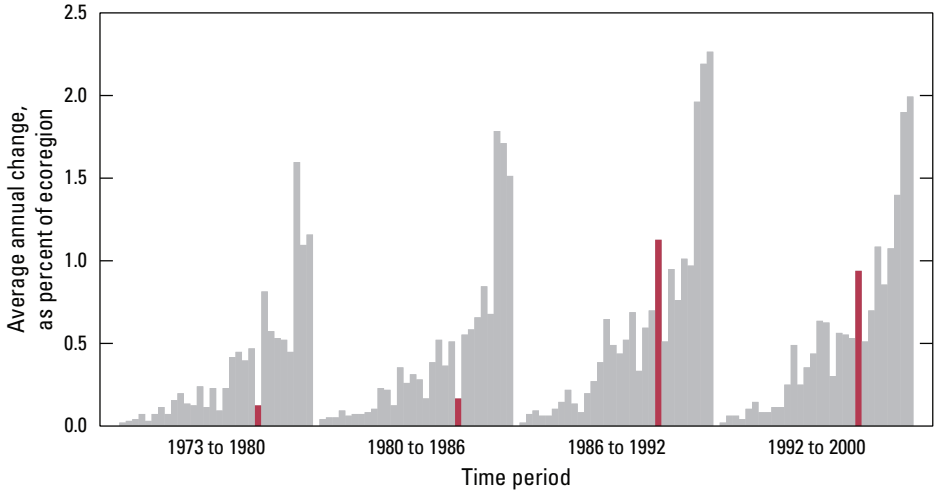

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Middle Rockies Ecoregion are represented by red bars in each time period.

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 (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	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

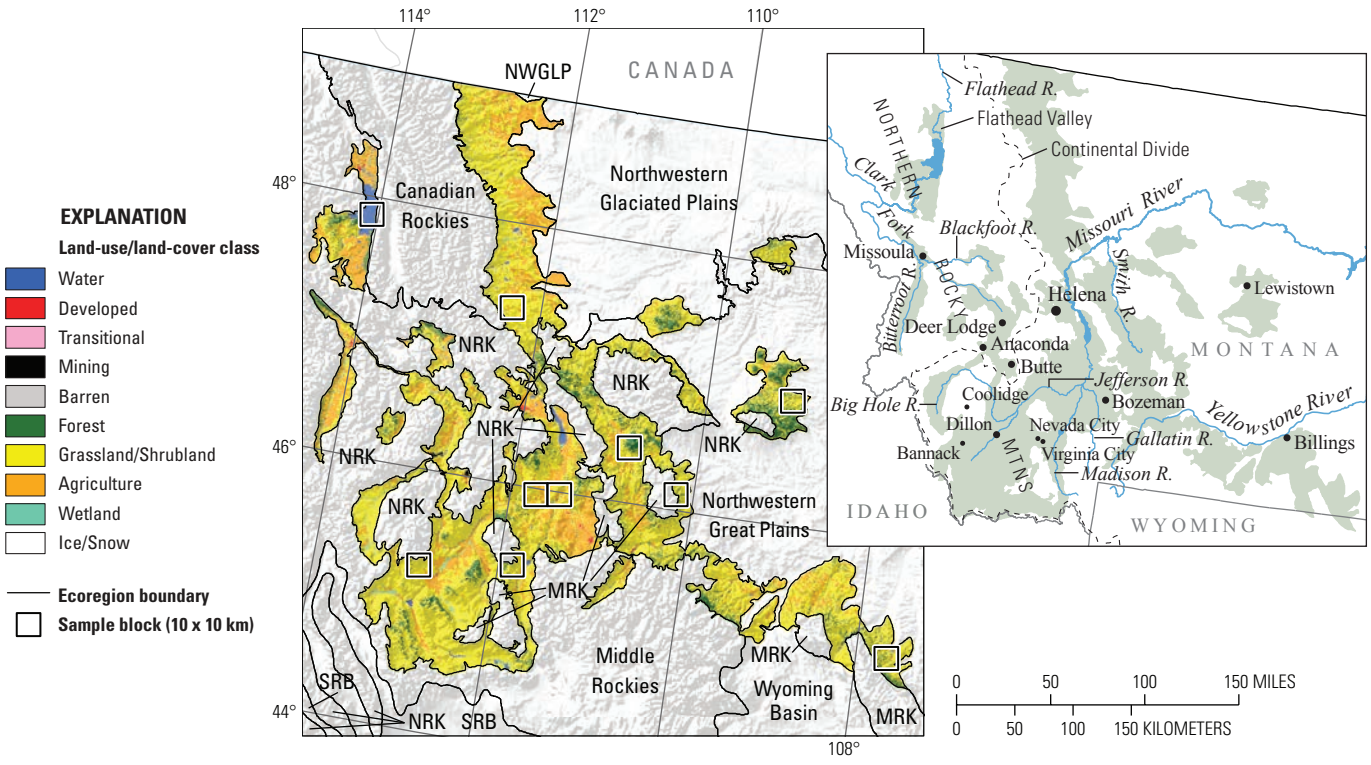

Figure 1. Map of Montana Valley and Foothill Prairies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, 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.

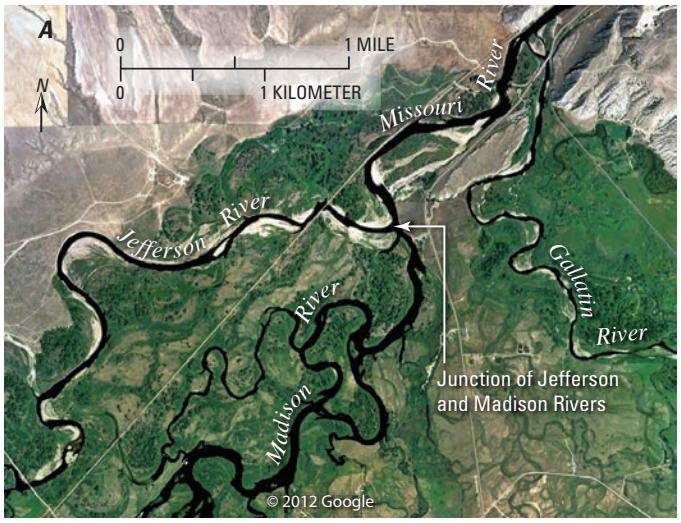

Figure 2. Headwaters of Missouri River in Montana Valley and Foothill Prairies Ecoregion. *A*, Satellite image showing Jefferson and Madison Rivers coming together to form Missouri River. Downstream from junction, note Gallatin River also joining Missouri River. *B*, View to west of junction of Jefferson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

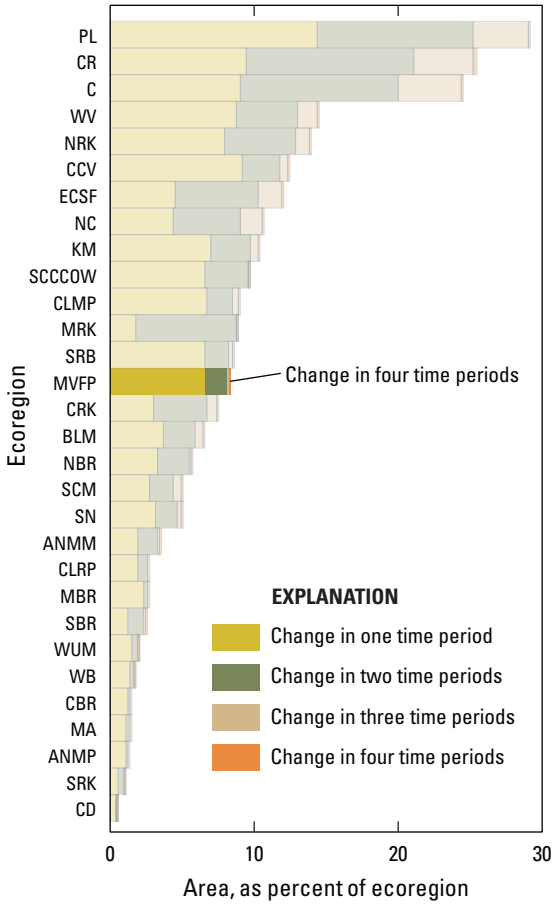

Figure 4. Overall spatial change in Montana Valley and Foothill Prairies Ecoregion (MVFP; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportion of ecoregion that changed during one, two, three, or four time periods; highest 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).

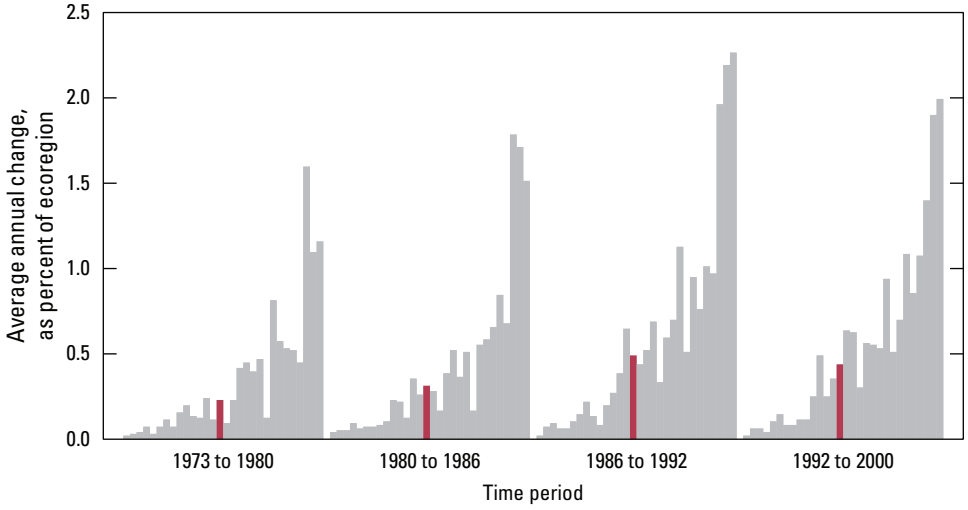

Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Montana Valley and Foothill Prairies Ecoregion are represented by red bars in each time period.

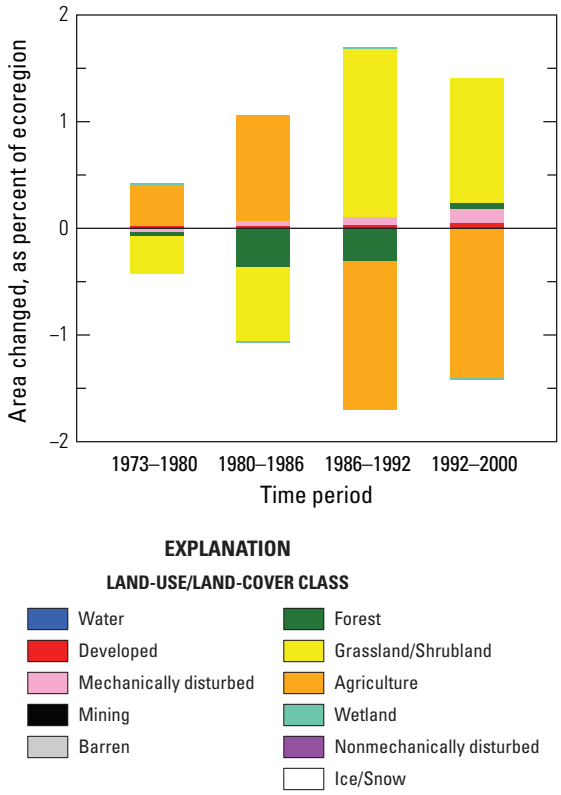

Figure 6. Normalized average net change in Montana Valley and Foothill Prairies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. 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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Status and Trends of Land Change in the Western United States—1973 to 2000
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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

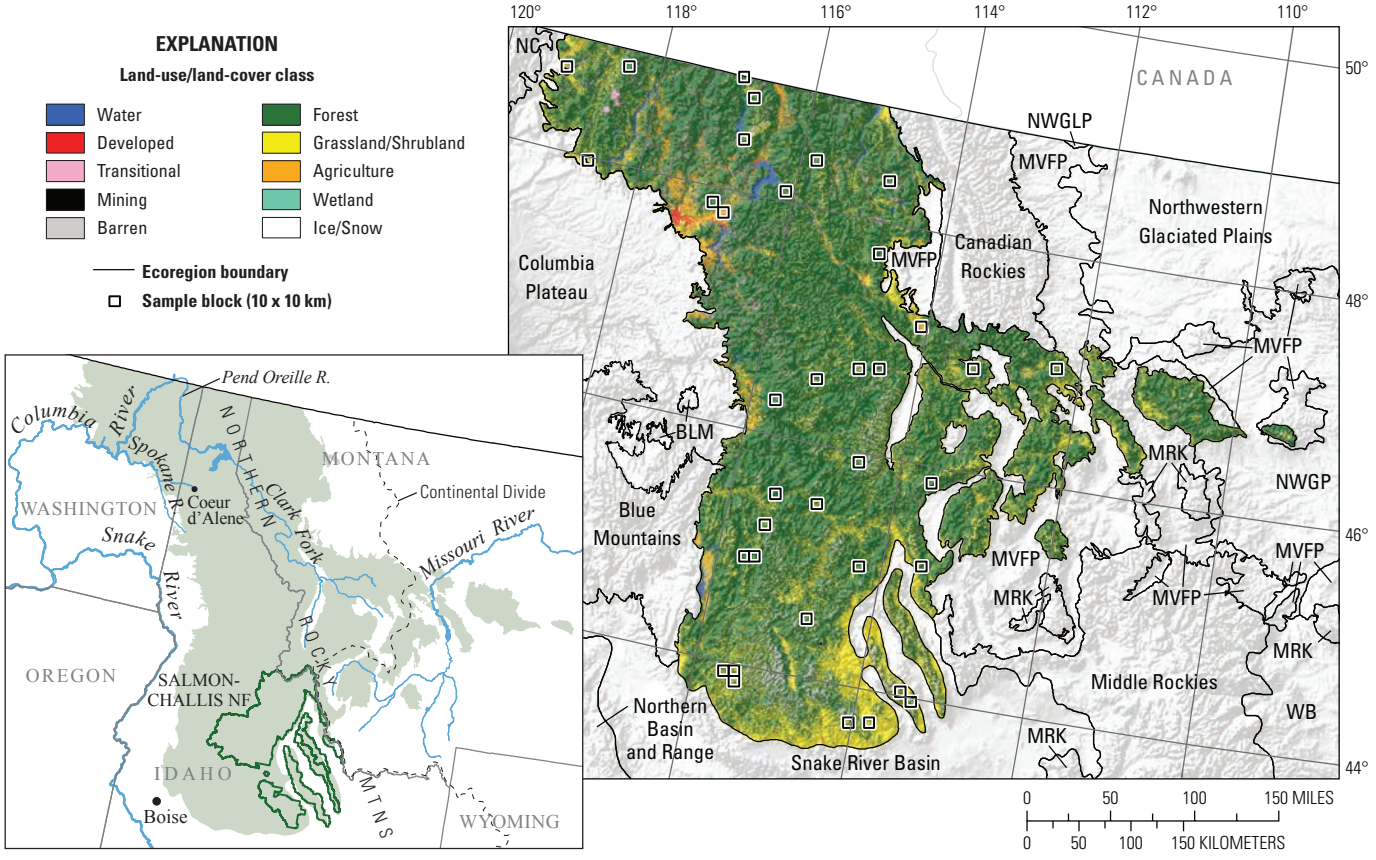

Figure 1. Map of Northern Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and 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 7. Salmon-Challis National Forest is just one of 15 national forests within Northern Rockies Ecoregion. 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 8. Flathead Reservation is just one of five reservations within Northern Rockies Ecoregion. 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.

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

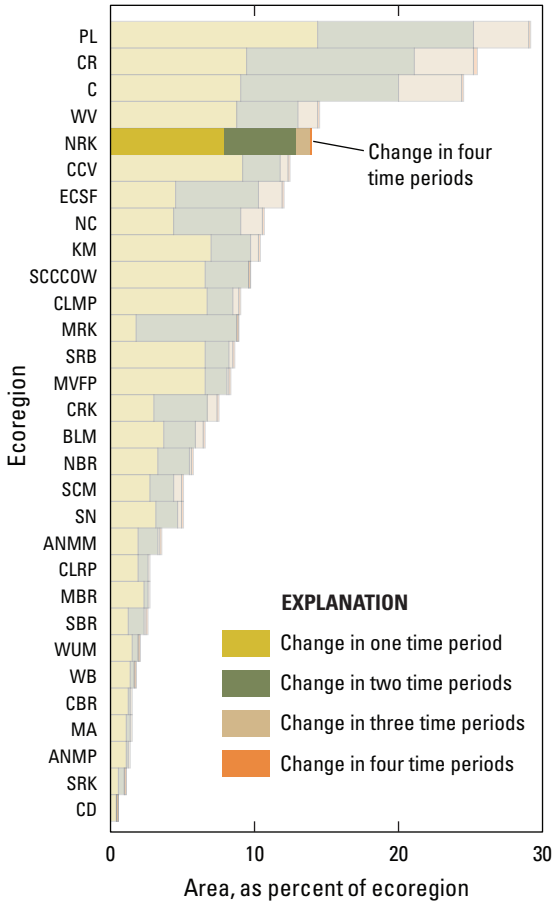

Figure 9. Overall spatial change in Northern Rockies Ecoregion (NRK; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that experienced change during one, two, three, or four time periods; highest level 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.

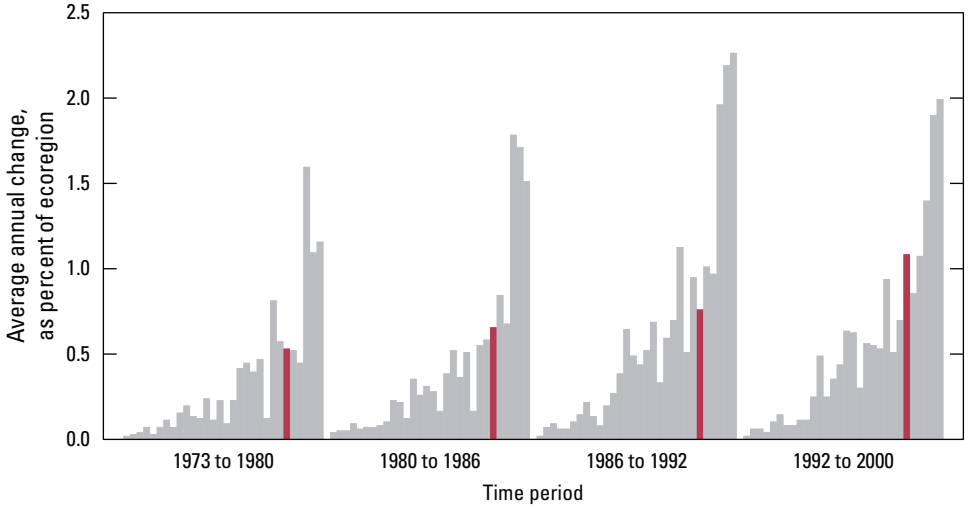

Figure 10. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Northern Rockies Ecoregion are represented by red bars in each time period.

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

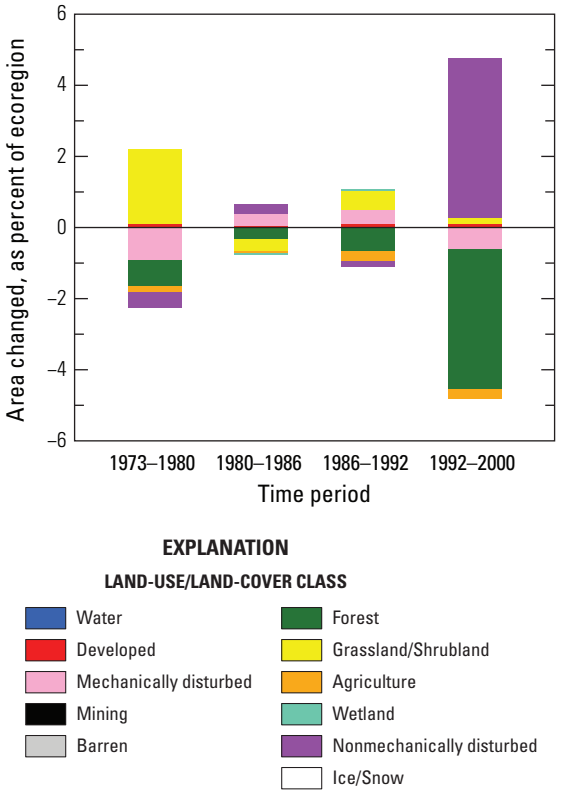

Figure 12. Normalized average net change in Northern Rockies Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 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	Margin of error	Standard error	Percent of ecoregion	Percent of all changes
			(km²)	(+/– km²)	(km²)		
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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Status and Trends of Land Change in the Western United States—1973 to 2000
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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 km^2 (53,612 mi^2), 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.

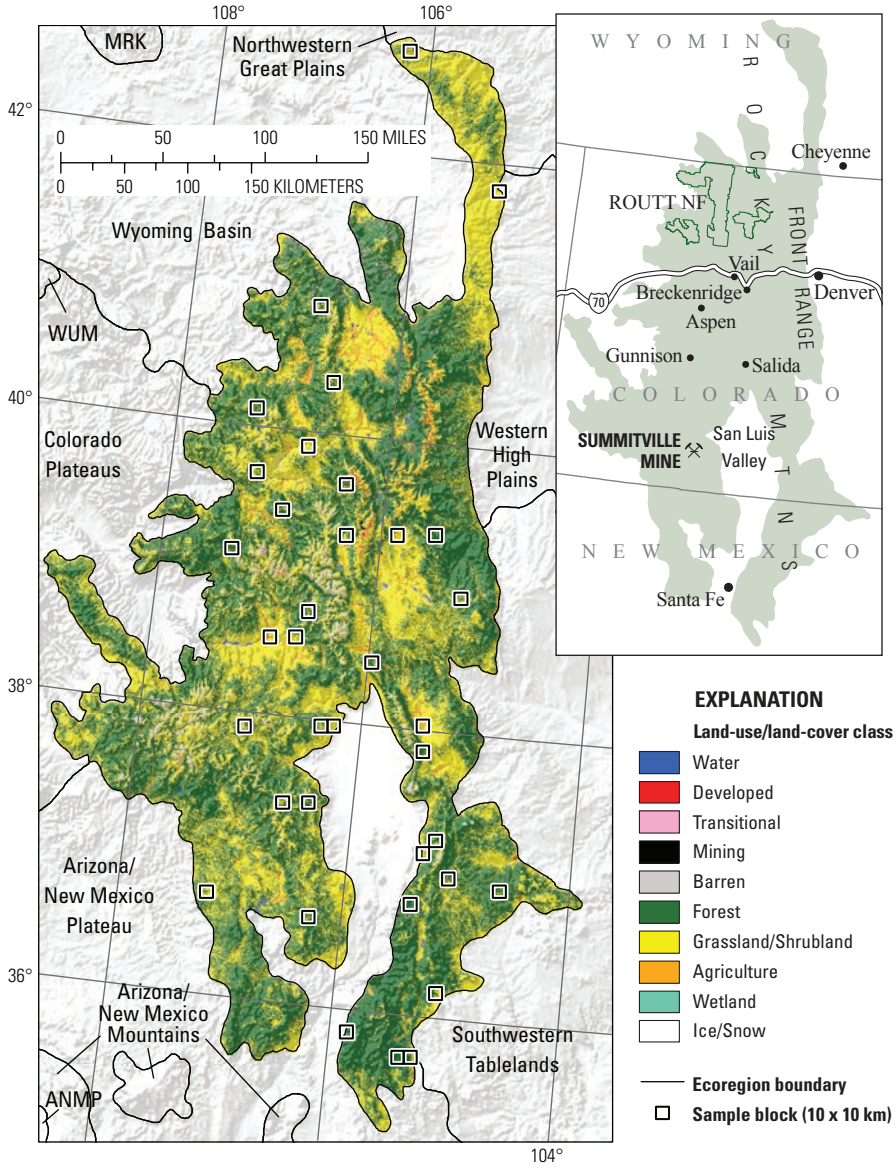

Figure 1. Map of Southern Rockies Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and 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.

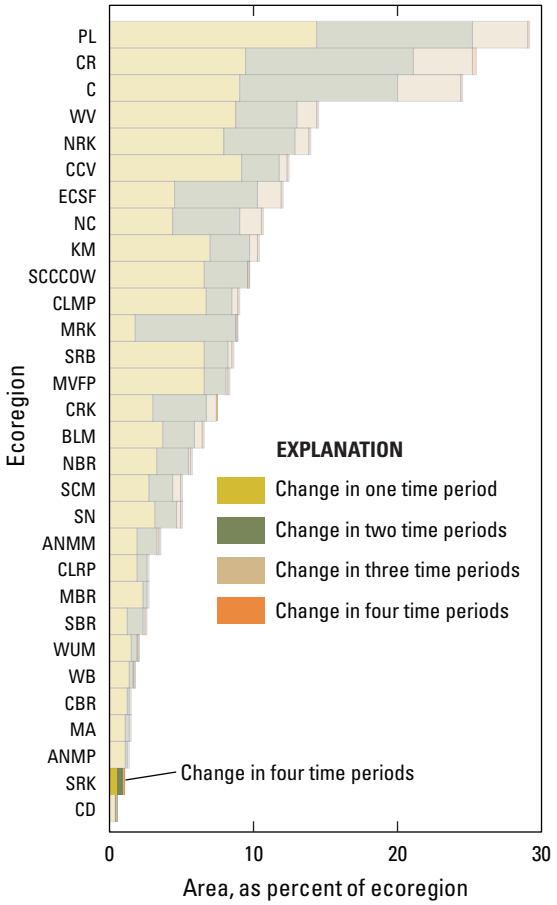

Figure 8. Overall spatial change in Southern Rockies Ecoregion (SRK; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial 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.

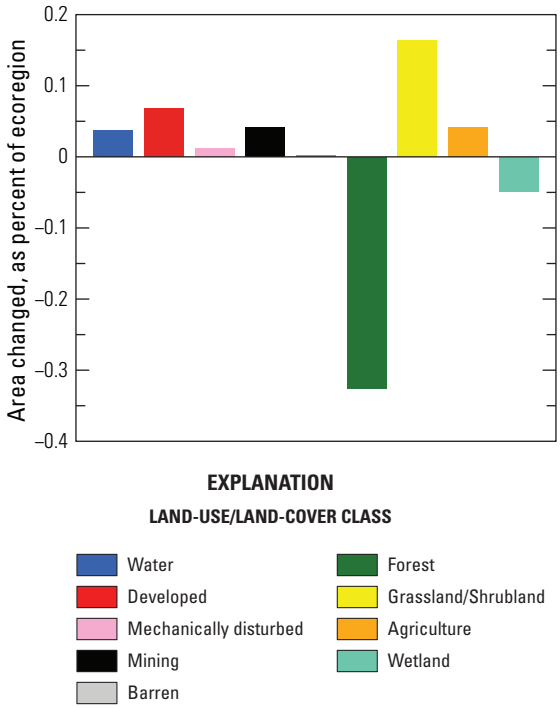

Figure 9. Estimates of net land-cover change in Southern Rockies Ecoregion for each land-cover class between 1973 and 2000. Bars above zero axis represent net gain, whereas bars below zero represent net loss. See appendix 3 for definitions of land-use/land-cover classifications.

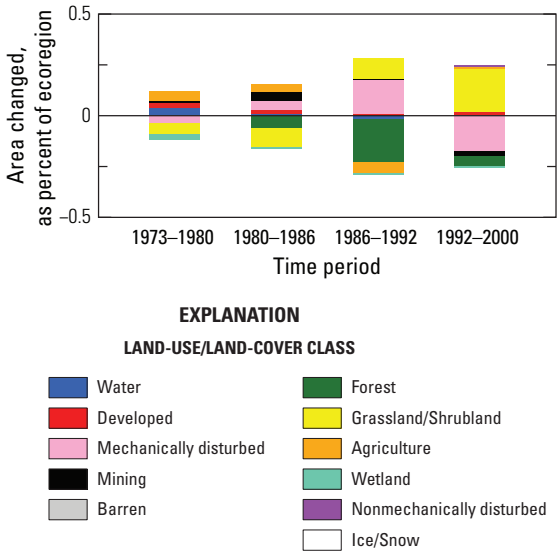

Figure 10. Normalized average net change in Southern Rockies Ecoregion by time period for each land cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3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

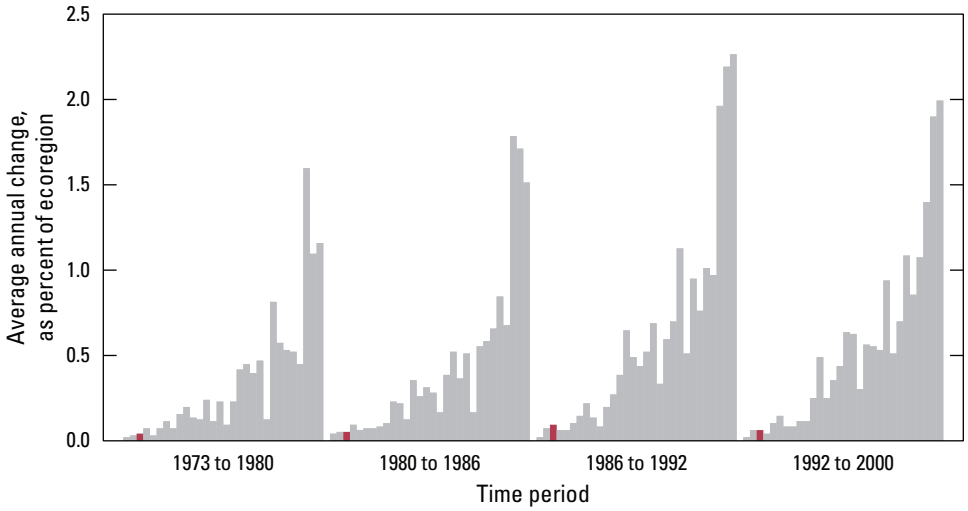

Figure 11. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Southern Rockies Ecoregion are represented by red bars in each time period.

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 (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	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

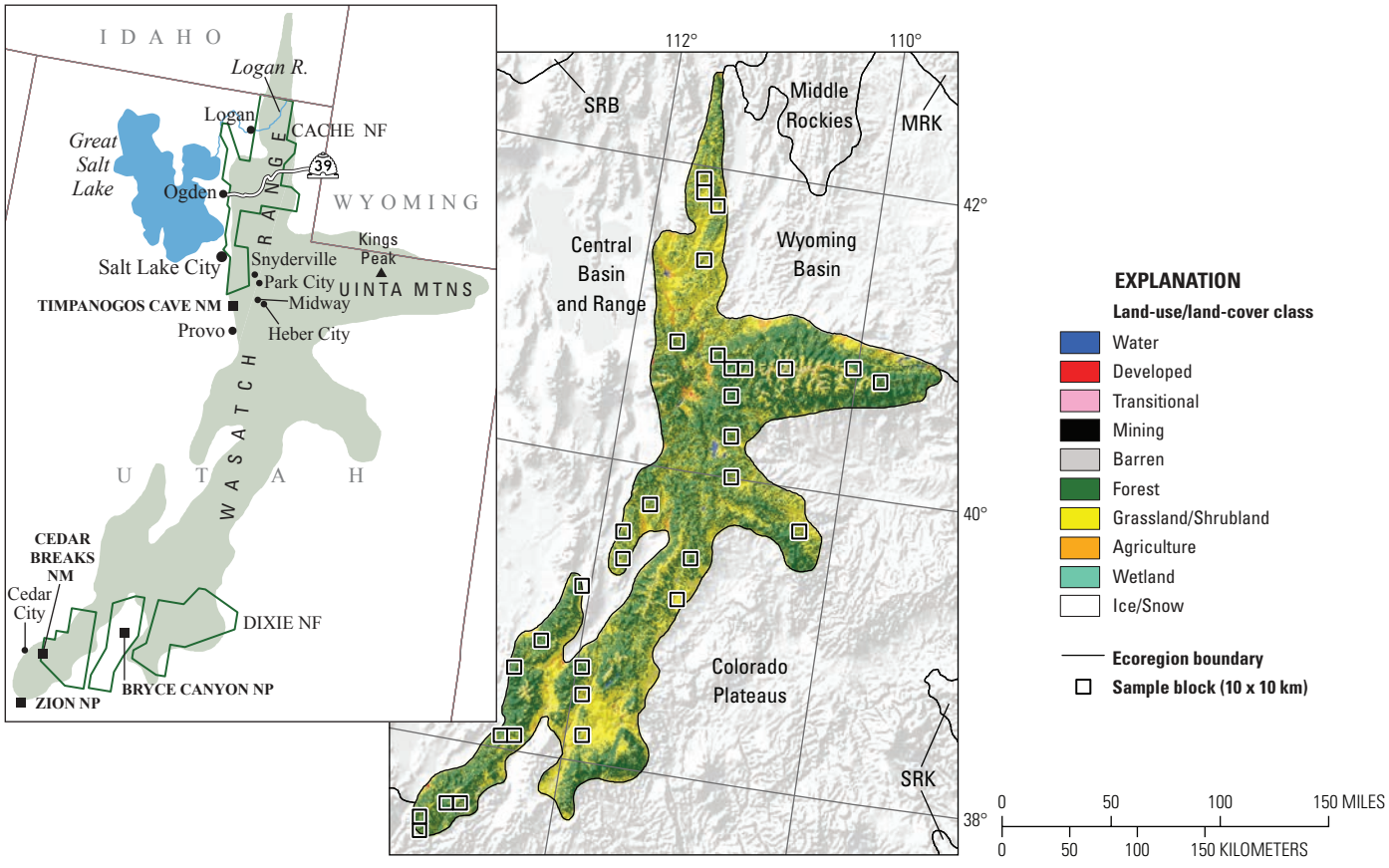

Figure 1. Map of Wasatch and Uinta Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "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

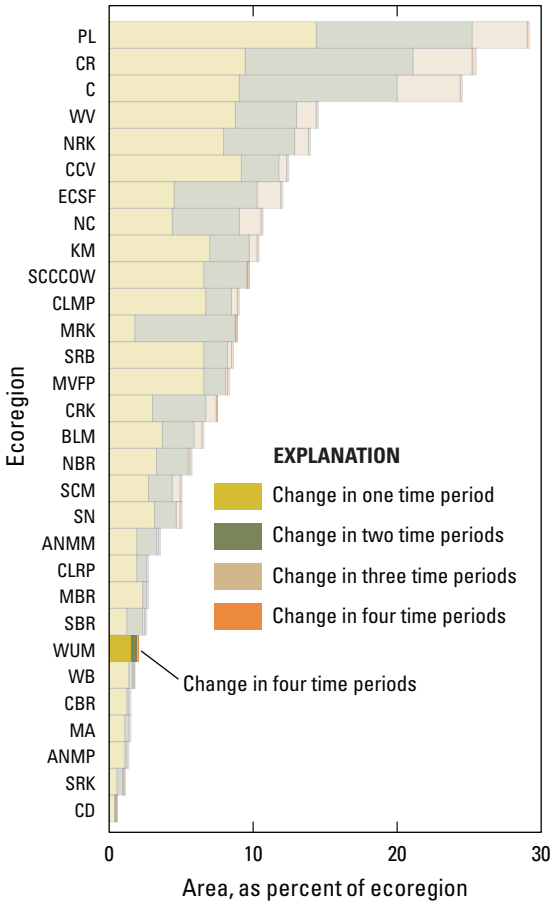

Figure 2. Overall spatial change in Wasatch and Uinta Mountains Ecoregion (WUM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level 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.

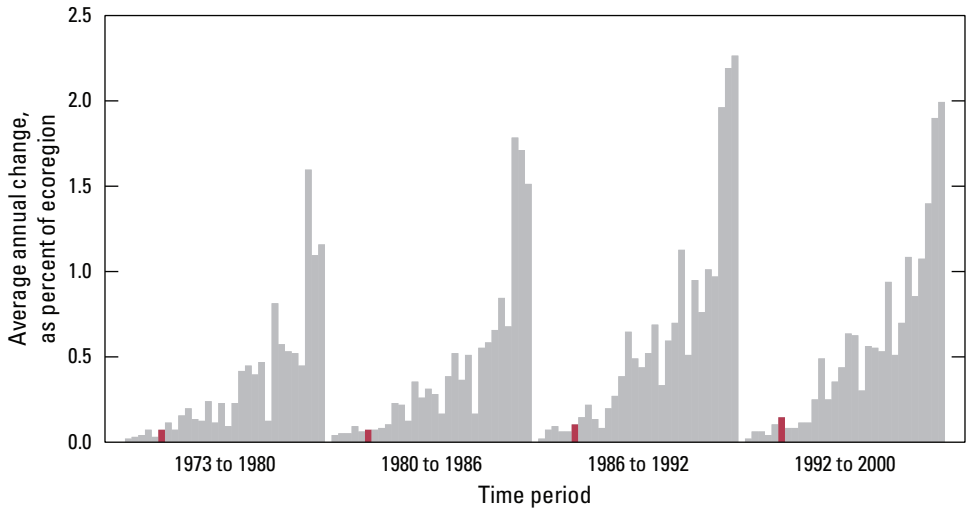

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Wasatch and Uinta Mountains Ecoregion are represented by red bars in each time period.

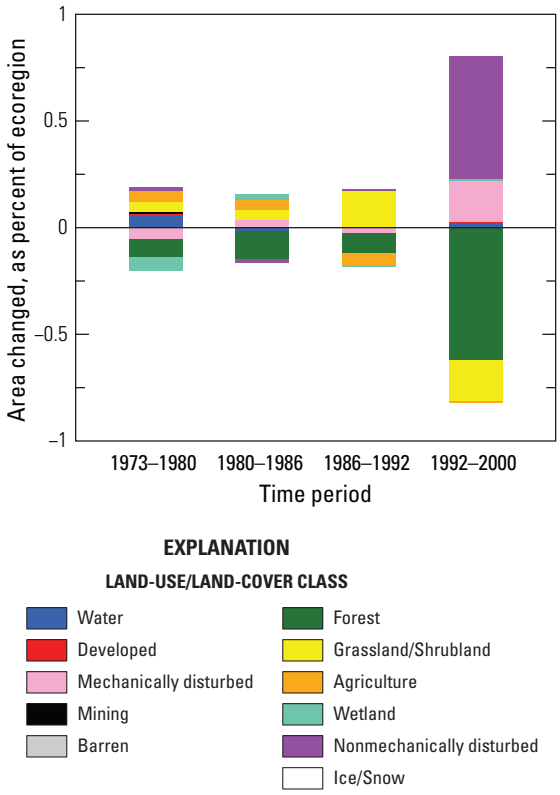

Figure 4. Normalized average net change in Wasatch and Uinta Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix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

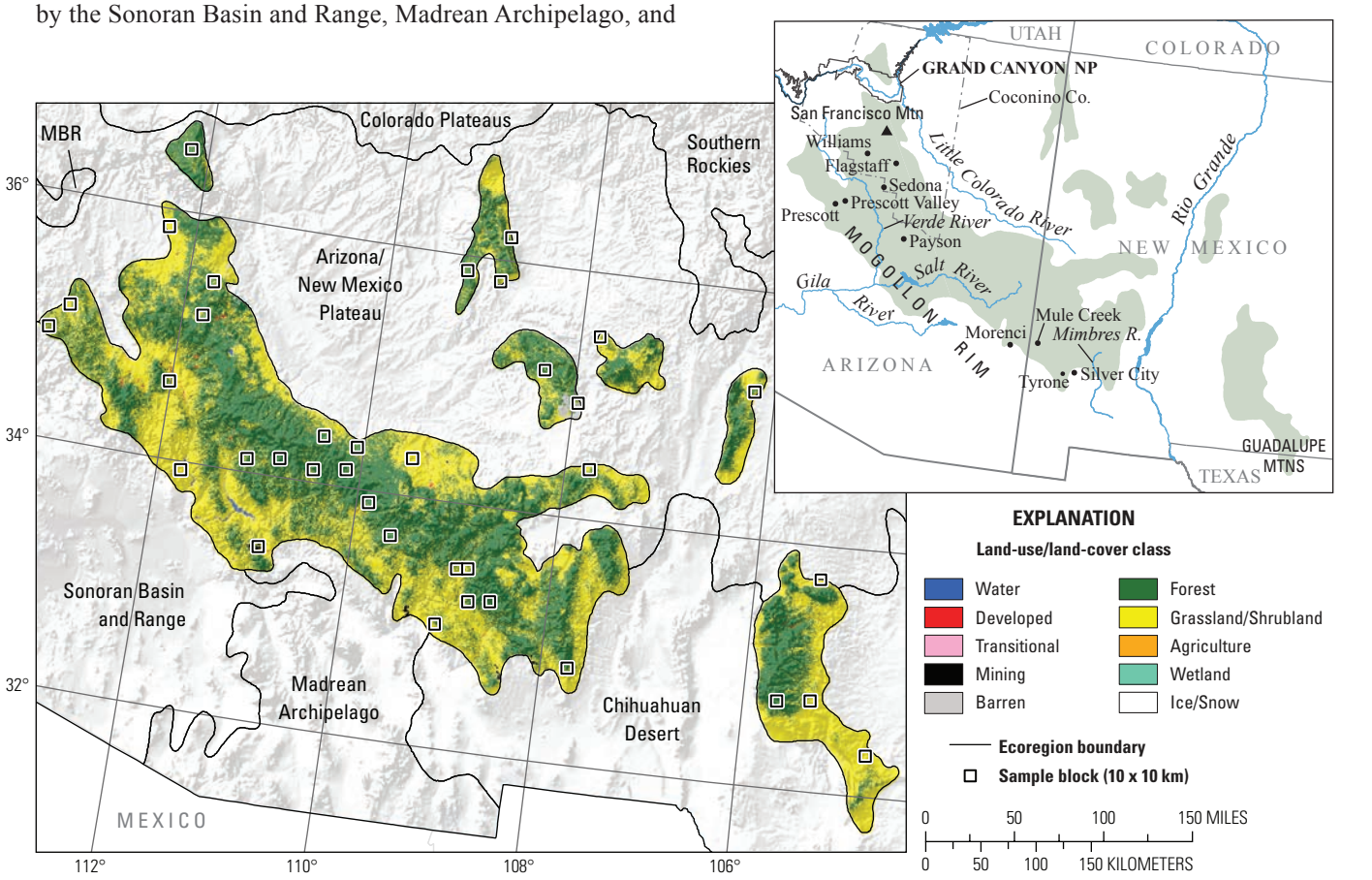

Figure 1. Map of Arizona/New Mexico Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "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.

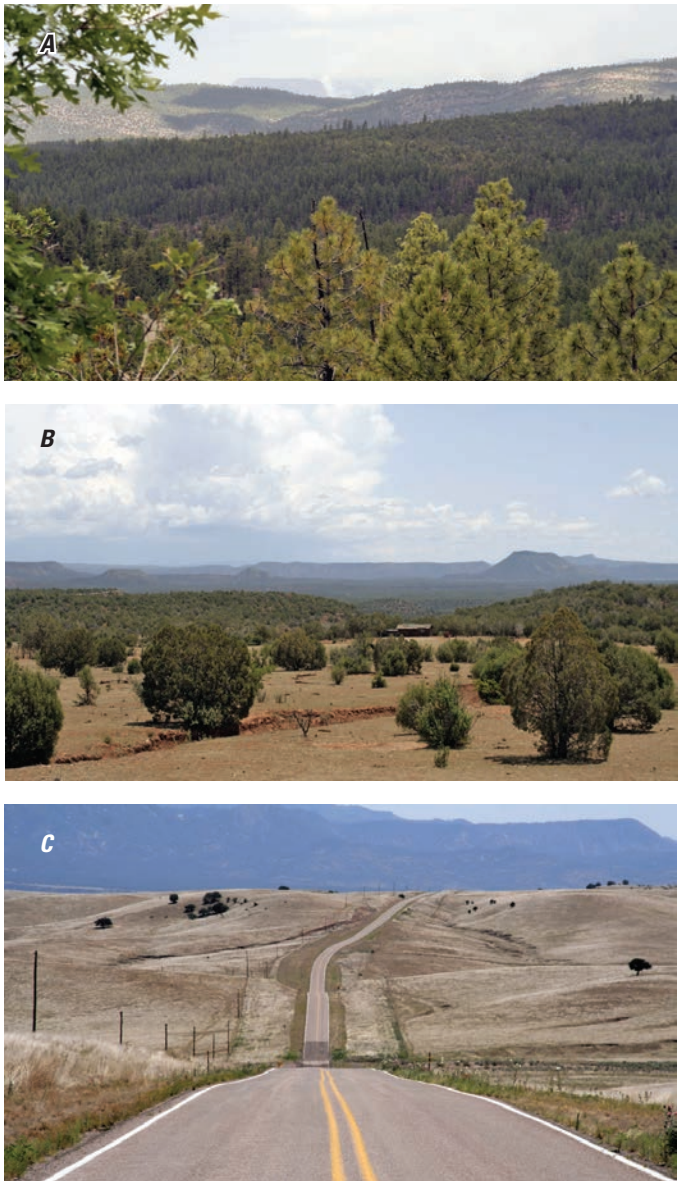

Figure 2. Various vegetation zones of Arizona/New Mexico Mountains Ecoregion. *A*, Ponderosa pine forest in Tonto National Forest, central Arizona. *B*, Pinyon-juniper woodland on Fort Apache Reservation, eastern Arizona. *C*, Grassland near Mule Creek, New Mexico.

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

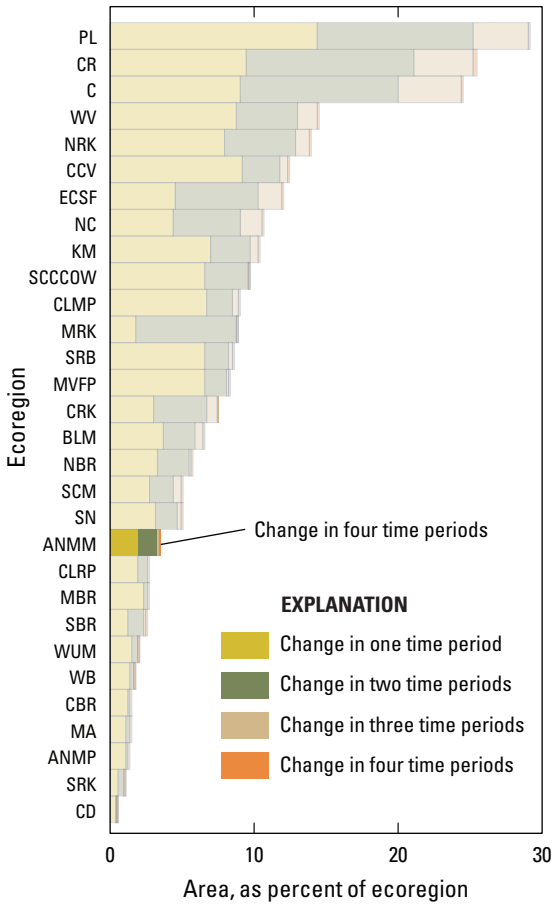

Figure 3. Overall spatial change in Arizona/New Mexico Mountains Ecoregion (ANMM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level 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

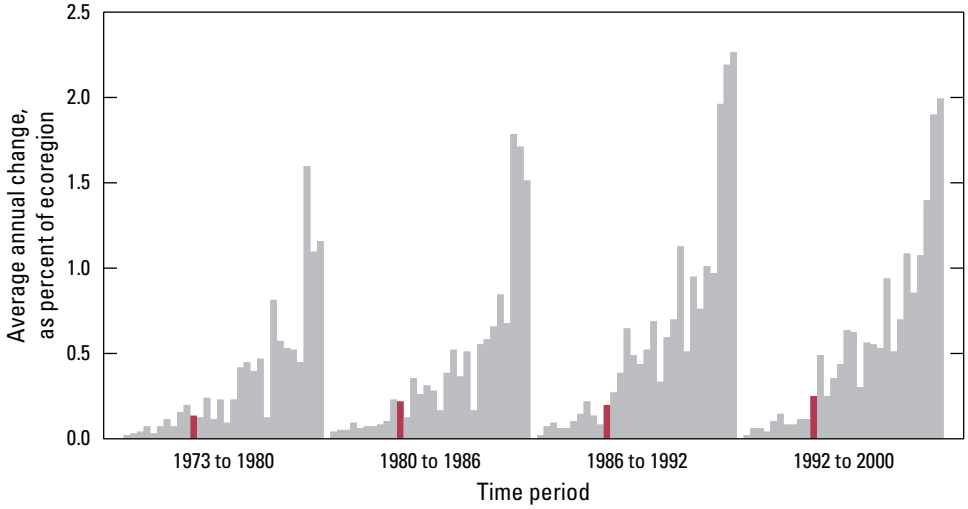

Figure 4. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Arizona/New Mexico Mountains Ecoregion are represented by red bars in each time period.

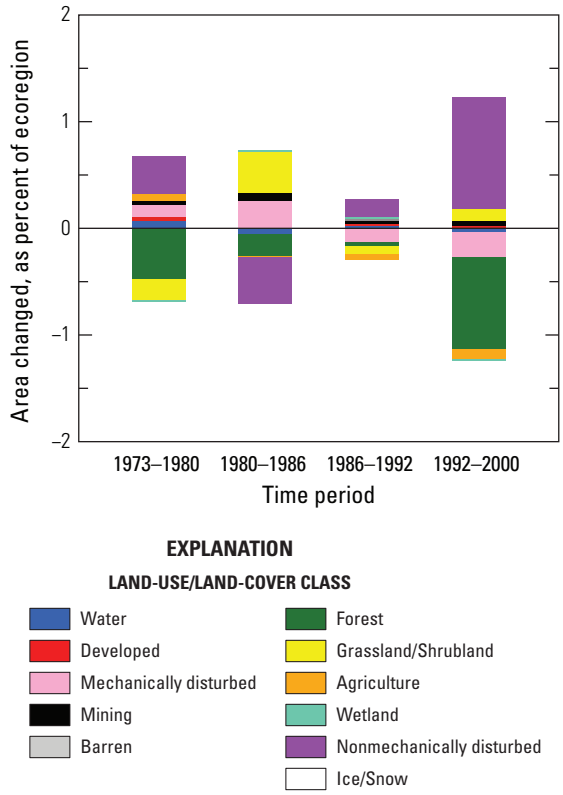

Figure 5. Normalized average net change in Arizona/New Mexico Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See 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 (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	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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