Western Mountain Ranges Ecoregions

Status and Trends of Land Change in the Western United States—1973 to 2000
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Chapter 11

Cascades Ecoregion

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Ecoregion Description

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

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

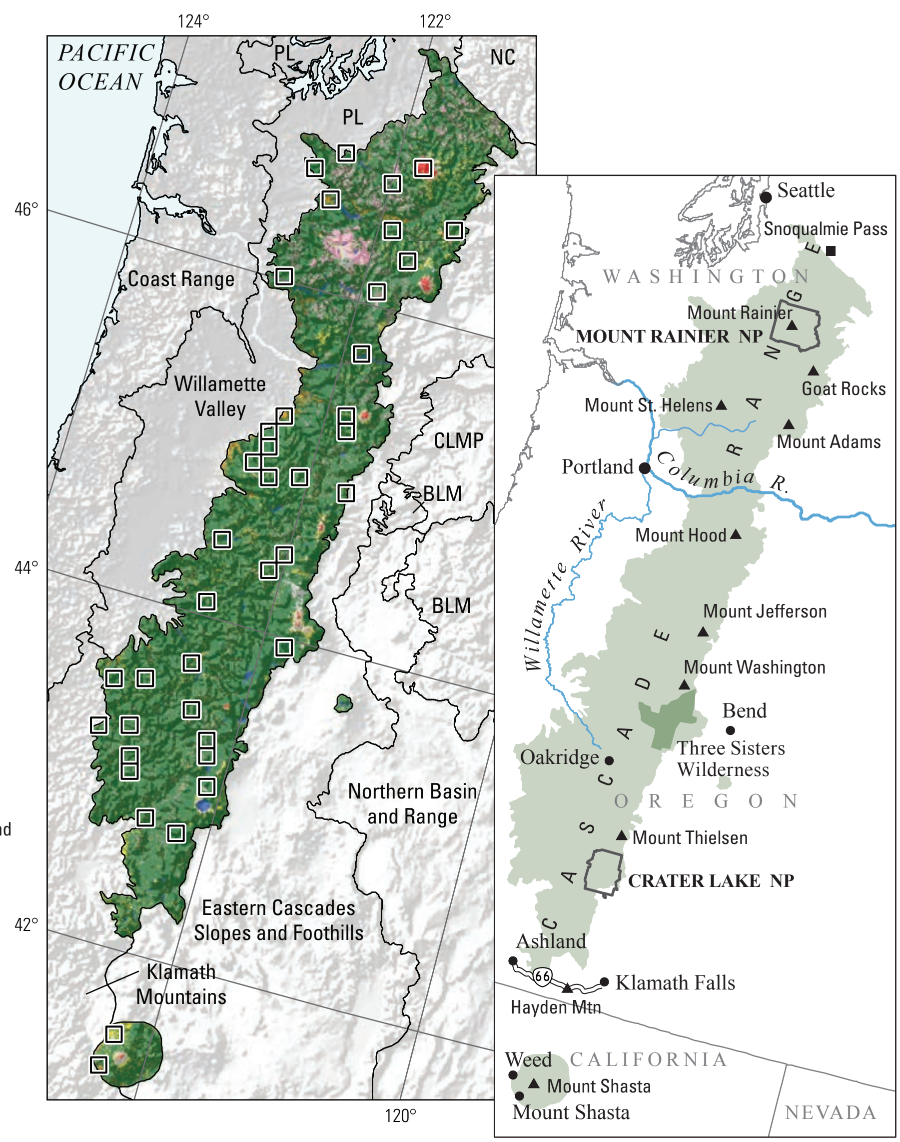
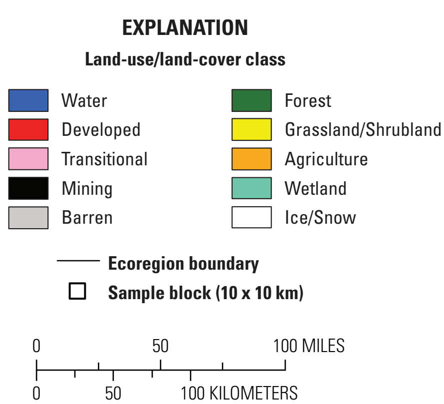


Figure 1. Map of Cascades Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and Trends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



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

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

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

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

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

Contemporary Land-Cover Change (1973 to 2000)

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

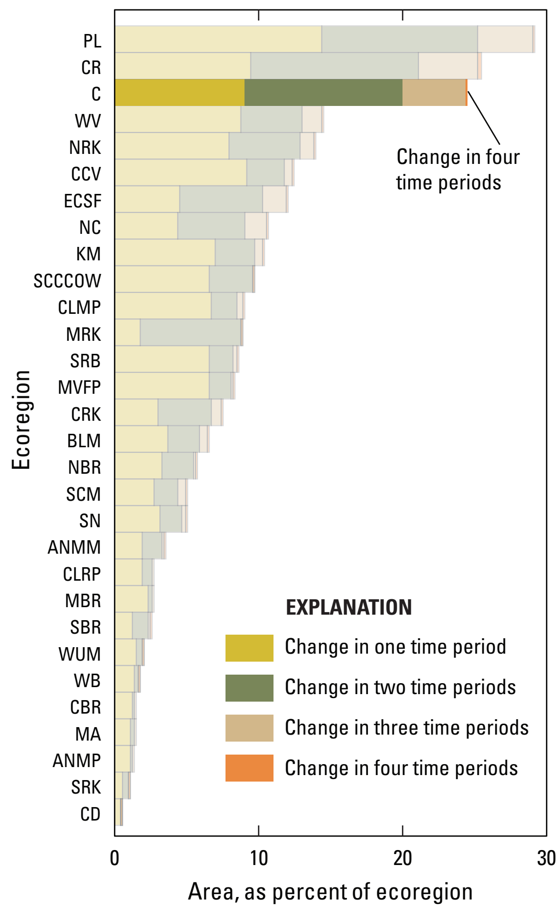


Figure 2. Overall spatial change in Cascades Ecoregion (C; darker bars) compared with that of all 30 all Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change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

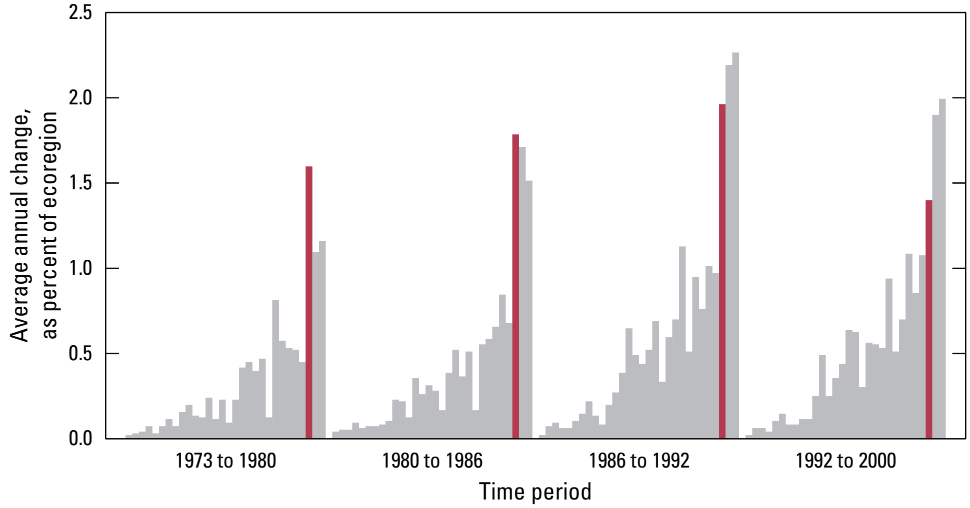


Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Cascades Ecoregion are represented by red bars in each time period.

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

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

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

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

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

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

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

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

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

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

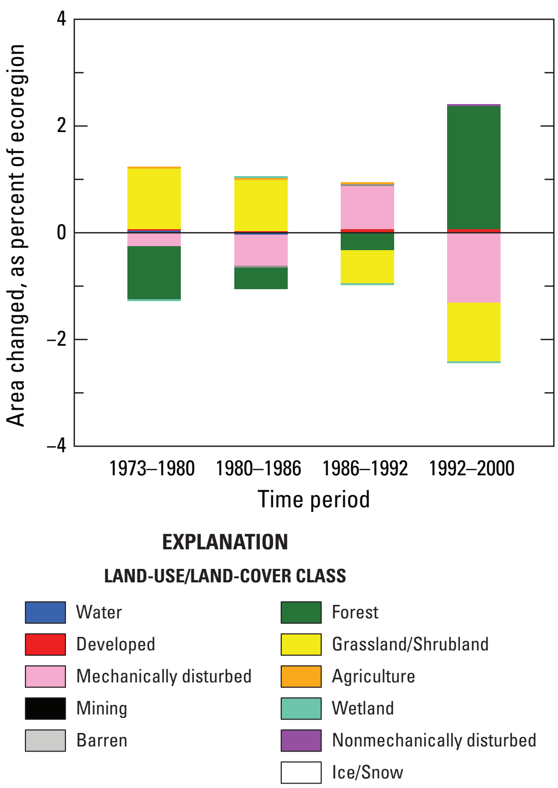


Figure 7. Normalized average net change in Cascades Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions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

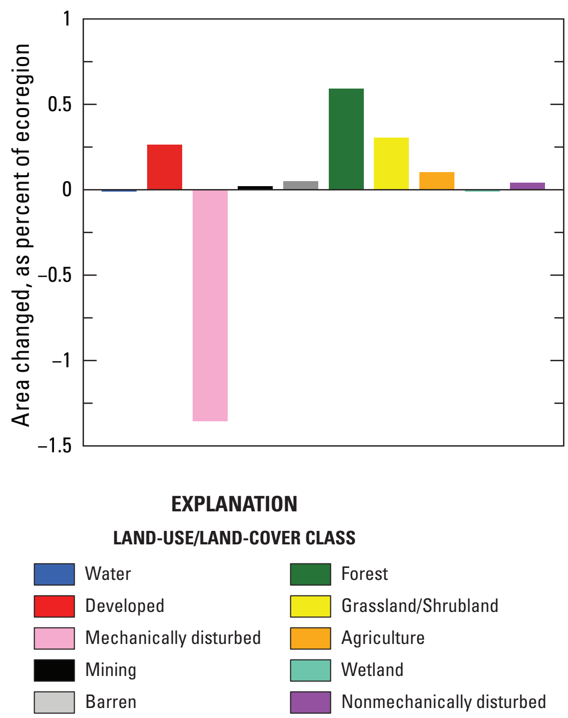


Figure 8. Estimated cumulative change in Cascades Ecoregion for each land-cover class between 1973 and 2000. Bars above zero axis represent overall gain, whereas bars below zero represent overall loss. Mechanically disturbed class experienced largest decrease, while grassland/shrubland and forest classes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

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

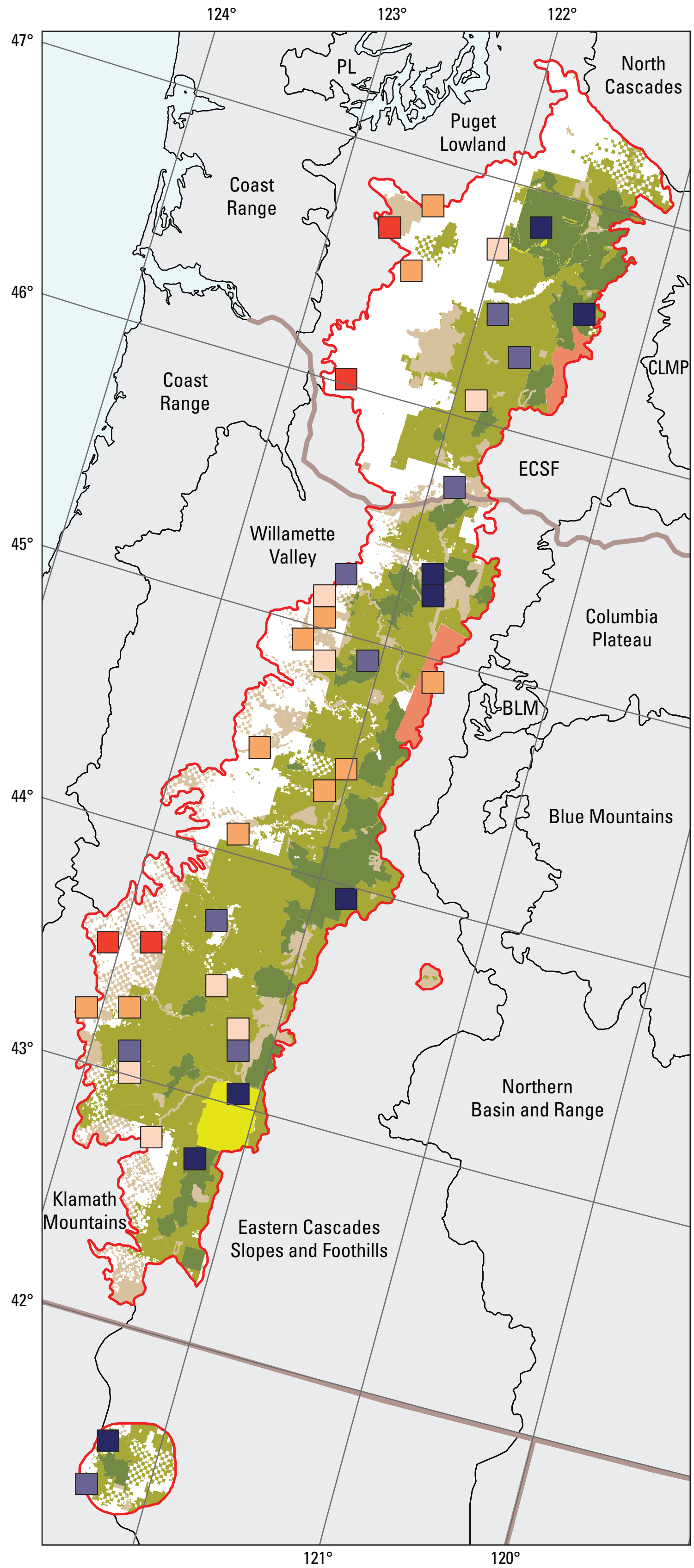


Figure 9. Federal land ownership and cumulative land-use/land-cover change (as percent of sample-block area) from 1973 to 2000 in Cascades Ecoregion. Sample blocks that fell on wilderness areas witnessed least amount of change. Most sample blocks that saw highest amount of change fell on privately held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

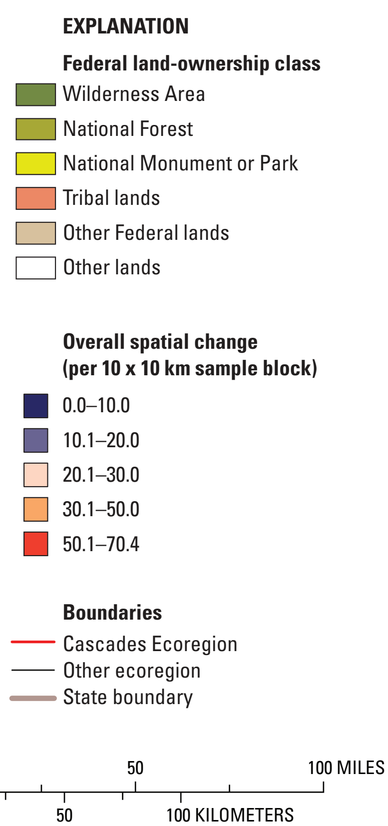


Table 1. Percentage of Cascades Ecoregion land cover that changed at least one time during study period (1973–2000) and associated statistical error.

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

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

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

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

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

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

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

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

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

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	2,134	486	331	4.6	40.7
	Mechanically disturbed	Grassland/Shrubland	1,412	389	265	3.0	26.9
	Mechanically disturbed	Forest	975	263	179	2.1	18.6
	Grassland/Shrubland	Forest	710	196	134	1.5	13.5
	Forest	Agriculture	20	11	8	0.0	0.4
	Other	Other	−9	n/a	n/a	0.0	−0.2
		Totals	5,242			11.2	100.0
1980–1986	Forest	Mechanically disturbed	1,830	337	230	3.9	36.6
	Mechanically disturbed	Grassland/Shrubland	1,418	363	247	3.0	28.4
	Grassland/Shrubland	Forest	954	217	148	2.0	19.1
	Mechanically disturbed	Forest	716	205	139	1.5	14.3
	Water	Mechanically disturbed	19	24	16	0.0	0.4
	Other	Other	60	n/a	n/a	0.1	1.2
		Totals	4,998			10.7	100.0
1986–1992	Forest	Mechanically disturbed	2,209	380	259	4.7	40.1
	Grassland/Shrubland	Forest	1,379	332	226	2.9	25.0
	Mechanically disturbed	Grassland/Shrubland	1,078	214	146	2.3	19.6
	Mechanically disturbed	Forest	745	189	129	1.6	13.5
	Forest	Developed	36	17	12	0.1	0.7
	Other	Other	68	n/a	n/a	0.1	1.2
		Totals	5,515			11.8	100.0
1992–2000	Forest	Mechanically disturbed	1,613	592	403	3.4	30.9
	Mechanically disturbed	Forest	1,434	348	237	3.1	27.5
	Grassland/Shrubland	Forest	1,315	263	179	2.8	25.2
	Mechanically disturbed	Grassland/Shrubland	777	135	92	1.7	14.9
	Forest	Developed	29	14	10	0.1	0.6
	Other	Other	46	n/a	n/a	0.1	0.9
		Totals	5,214			11.1	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	7,786	1,344	915	16.6	37.1
	Mechanically disturbed	Grassland/Shrubland	4,686	869	592	10.0	22.3
	Grassland/Shrubland	Forest	4,358	775	528	9.3	20.8
	Mechanically disturbed	Forest	3,870	820	559	8.3	18.5
	Forest	Developed	98	45	30	0.2	0.5
	Other	Other	172	n/a	n/a	0.4	0.8
		Totals	20,969			44.8	100.0

References Cited

Agee, J.K., 1993, Fire ecology of Pacific Northwest forests: Washington, D.C., Island Press, p. 229.

Alig, Ralph J., Zheng, Daolan, Spies, Thomas A., and Butler, Brett J., 2000, Forest cover dynamics in the Pacific Northwest west side—Regional trends and projections: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Research Paper PNW-RP-522, 22 p. (Available at http://www.treesearch.fs.fed.us/pubs/2935.)

Daniels, J.M., 2005, The rise and fall of the Pacific Northwest log export market: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-624.

Espy, M., and Babbitt, B., 1994, Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl: U.S. Department of Agriculture and U.S. Department of the Interior Northwest Forest Plan, 74 p. (Available at http://www.blm.gov/or/plans/nwfpnepa/FSEIS-1994/NWFPTitl.htm.)

Jacklet, Ben, 2009, Trouble in Timber Town—Decades after an industry downfall, towns still grapple with what's next: Oregon Business. (Available at http://www.oregonbusiness.com/articles/72-november-2009/2478-trouble-in-timber-town.)

McNab, W. Henry, and Avers, Peter E., 1994, Cascade mixed forest – Coniferous forest – Alpine meadow, *in* Ecological subregions of the United States: U.S. Department of Agriculture, Forest Service, WO-WSA-5, chap. 25. (Available at http://www.fs.fed.us/land/pubs/ecoregions/ch25.html.)

National Atlas of the United States, 2006, Federal Lands of the United States: National Atlas of the United States database, accessed February 19, 2006, at http://nationalatlas.gov.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, p. 118–125.

Perez-Garcia, John, and Barr, J. Kent, 2005, Forest products export trends update for the Pacific Northwest region: Seattle, University of Washington, College of Forest Resources, Northwest Environmental Forum. (Available at http://www.nwenvironmentalforum.org/science/papers.html.)

Risser, Paul G., 2000, Cascade Mountains Ecoregion, *in* Oregon State of the Environment Report 2000—Statewide Summary: State of the Environment Report Science Panel, Oregon Progress Board, chap. 4.3, accessed June 28, 2011, at http://www.oregon.gov/DAS/OPB/docs/SOER2000/Ch4.3.pdf.

Sugihara, Neil G., van Wagtendonk, Jan W., Shaffer, Kevin E., Fites-Kaufman, JoAnn, and Thode, Andrea E., eds., 2006, Fire in California's ecosystems: Berkeley, University of California Press, p. 215.

U.S. Census Bureau, 2000, U.S. Census, 2000: U.S. Census Bureau database, accessed September 28, 2009, at http://factfinder.census.gov.

U.S. Environmental Protection Agency, 1997, Descriptions of level III ecological regions for the CEC report on ecological regions of North America: U.S. Environmental Protection Agency database, accessed April 12, 2006, at http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Downloads.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and van Driel, N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering & Remote Sensing, v. 67, p. 650–662.

Wallin, D.O., Swanson, F.J., Marks, B., Cissel, J.H., and Kertis, J., 1996, Comparison of managed and pre-settlement landscape dynamics in forests of the Pacific Northwest, U.S.A.: Forest Ecology and Management, v. 85, p. 291–310.

Washington State Department of Natural Resources, 2001, Reforestation: Washington State Department of Natural Resources, Title 222 WAC - Forest practices rules, chap. 222-34 WAC, p. 34-2.

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Chapter 12

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By Daniel G. Sorenson

Ecoregion Description

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

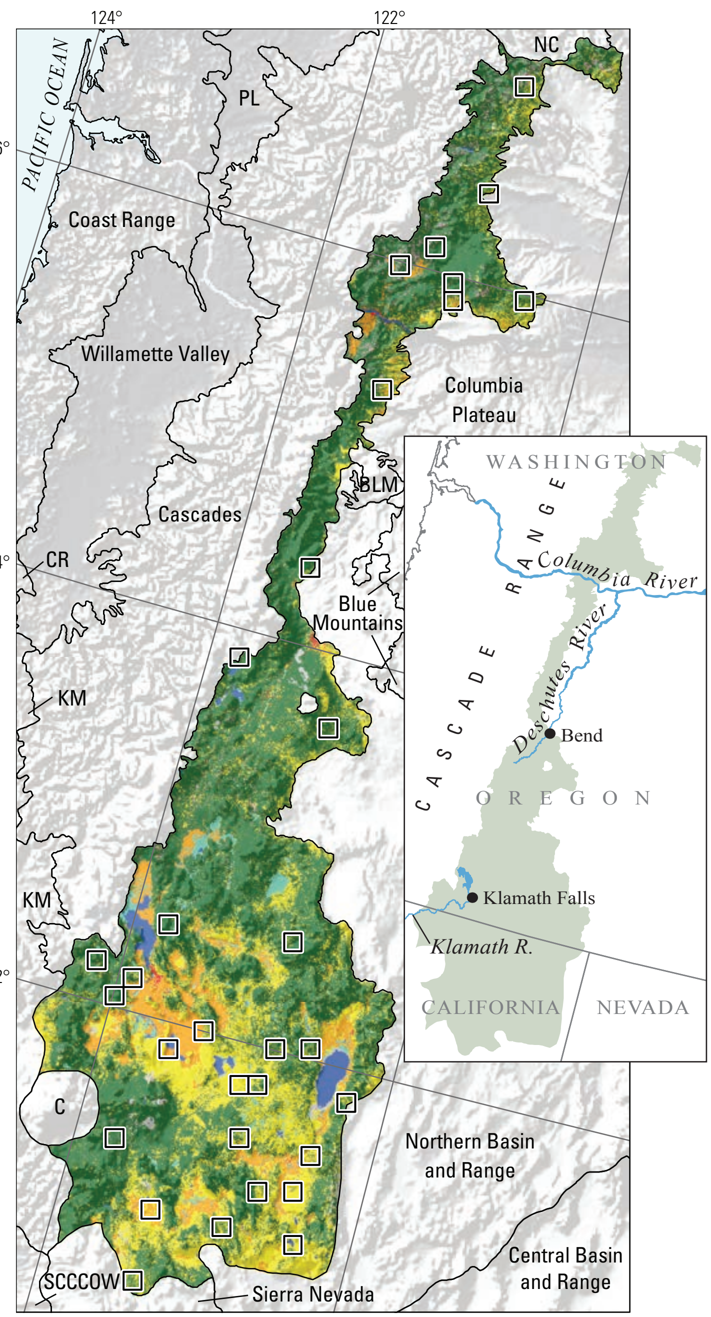

Figure 1. Map of Eastern Cascades Slopes and Foothills Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that,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

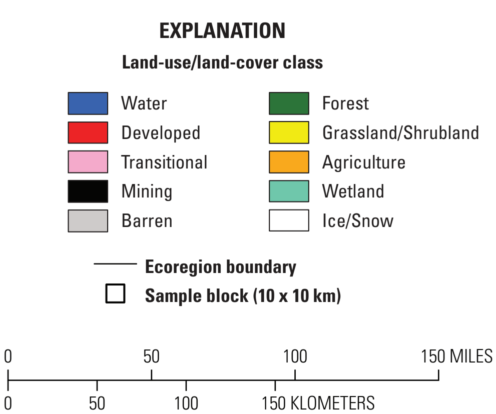

Figure 2. Grassy meadow and forested hillsides in Eastern Cascades Slopes and Foothills Ecoregion. Dominant land-cover class in Eastern Cascades Slopes and Foothills Ecoregion is forest, although grassland/shrubland makes up about one-third of ecoregion. Forests tend to be at higher elevations, in areas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

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

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

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

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

Contemporary Land-Cover Change (1973 to 2000)

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

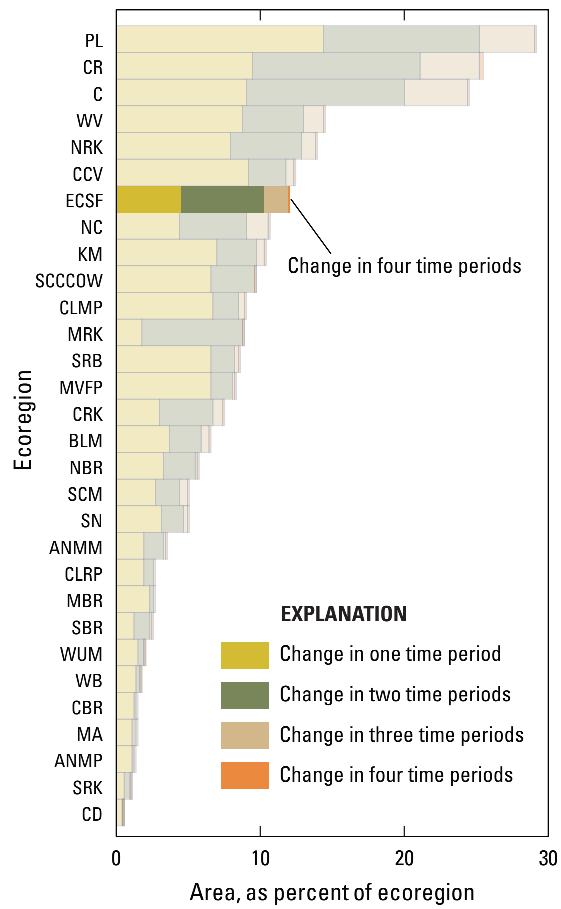

Figure 3. Overall spatial change in Eastern Cascades Slopes and Foothills Ecoregion (ECSF; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest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

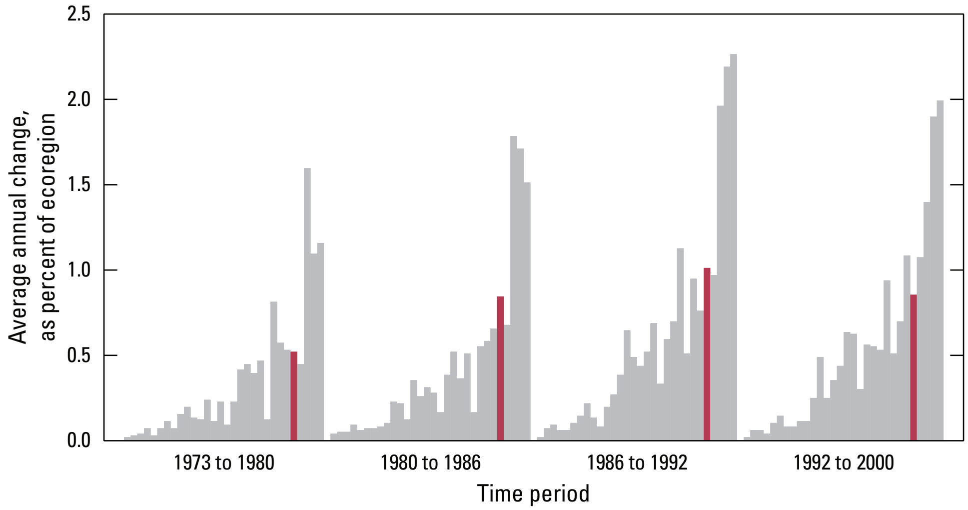

Figure 4. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Eastern Cascades Slopes and Foothills Ecoregion are represented by red bars in each time period.

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

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

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

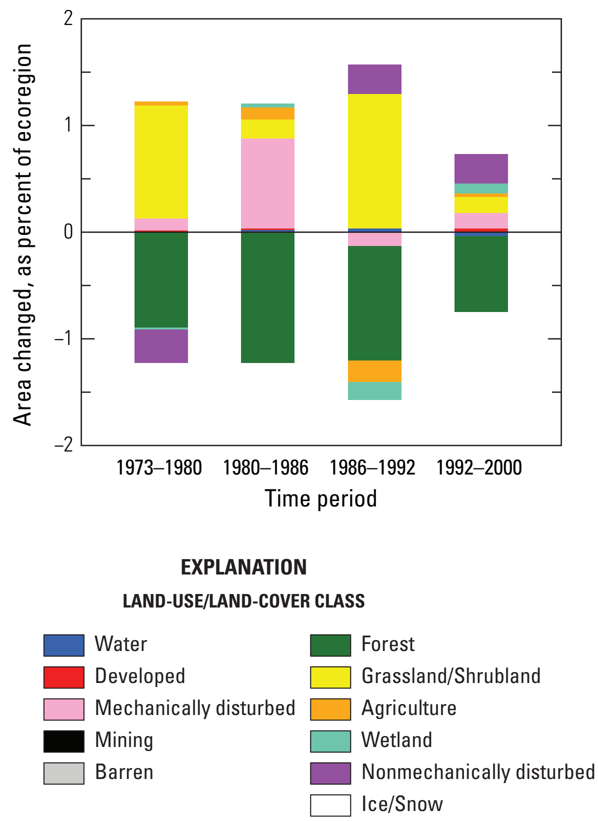

Figure 5. Normalized average net change in Eastern Cascades Slopes and Foothills Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure.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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

References Cited

Daniels, J.M., 2005, The rise and fall of the Pacific Northwest log export market: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-624, 80 p.

Lotan, James E., and Critchfield, William B., 1990, Silvics of North America: 1 Conifers, Lodgepole Pine: U.S. Department of Agriculture, Forest Service, Agriculture Handbook 654, v. 1, accessed June 23, 2009, at http://www.na.fs.fed.us/spfo/pubs/silvics_manual/Volume_1/pinus/contorta.htm.

McNab, W. Henry, and Avers, Peter E., 1994, Ecological subregions of the United States: U.S. Department of Agriculture, Forest Service, WO-WSA-5, chap. 25.

Oliver, William W., and Ryker, Russell A., 1990, Silvics of North America: 1 Conifers, Ponderosa Pine: U.S. Department of Agriculture, Forest Service, Agriculture Handbook 654, v. 1, accessed June 23, 2009, at http://www.na.fs.fed.us/spfo/pubs/silvics_manual/Volume_1/pinus/ponderosa.htm.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, p. 118–125.

Risser, P.G., 2000, East Cascades Slope and Foothills Ecoregion, *in* Oregon State of the Environment Report 2000—Statewide Summary: State of the Environment Report Science Panel, Oregon Progress Board, chap. 4.4, accessed June 23, 2009, at http://oregon.gov/DAS/OPB/docs/SOER2000/Ch4_4.pdf.

U.S. Census Bureau, 2000, U.S. Census, 2000, accessed April 1, 2009, at http://www.census.gov/prod/www/abs/decennial/index.htm.

U.S. Environmental Protection Agency, 1997, Descriptions of level III ecological regions for the CEC report on ecological regions of North America: U.S. Environmental Protection Agency database, accessed April 12, 2006, at http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Downloads.

U.S. Environmental Protection Agency, 2010, Primary distinguishing characteristics of Level III ecoregions of the continental United States: U.S. Environmental Protection Agency database, available at ftp://ftp.epa.gov/wed/ecoregions/us/Eco_Level_III_descriptions.doc.

Vogelmann, J.E., Howard, S.M., Yang L., Larson, C.R., Wylie B.K., and van Driel N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering & Remote Sensing, v. 67, p. 650–662.

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Chapter 13

Klamath Mountains Ecoregion

By Benjamin M. Sleeter and James P. Calzia

Ecoregion Description

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

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

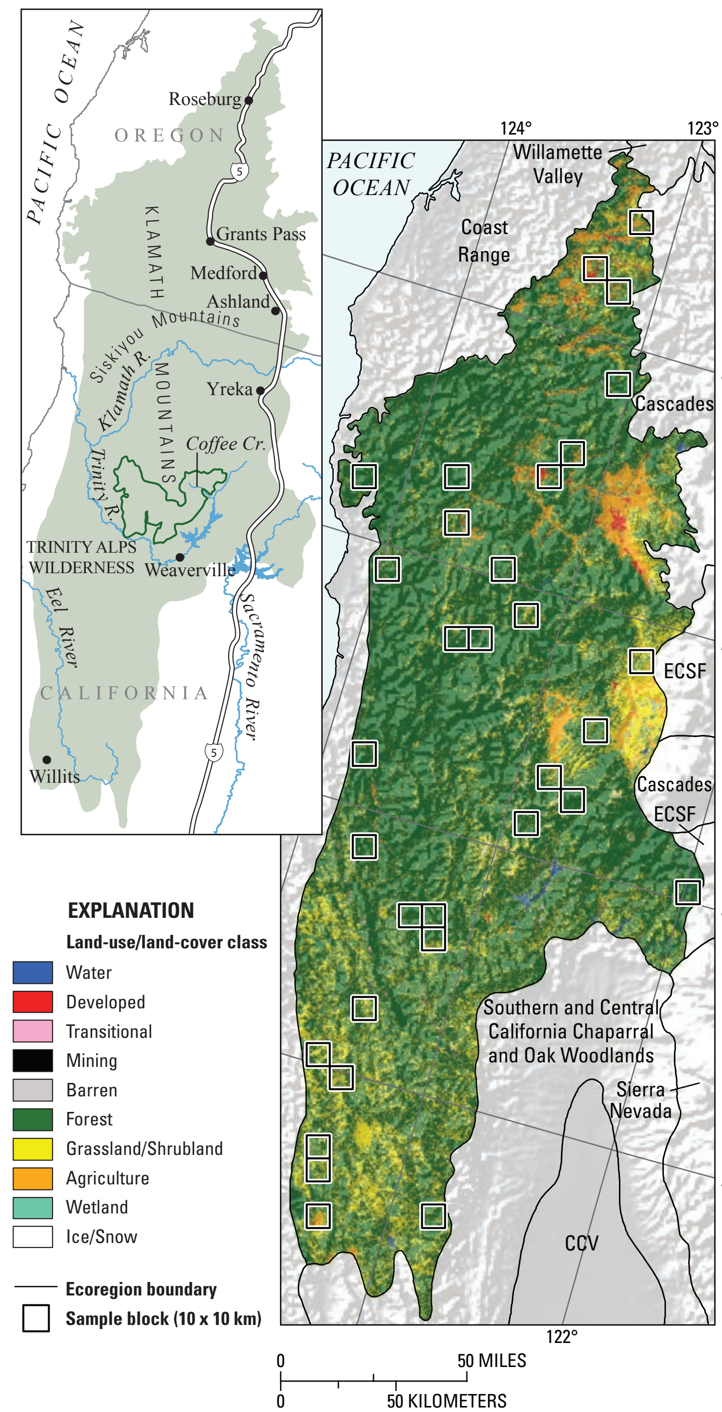
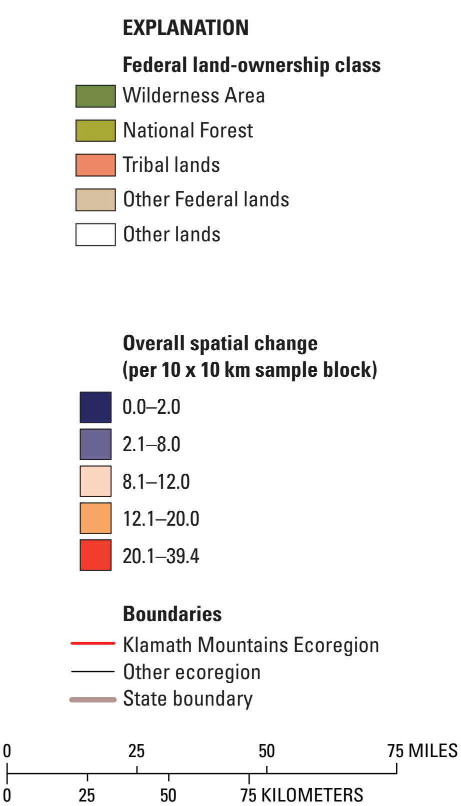


Figure 1. Map of Klamath Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status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

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

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



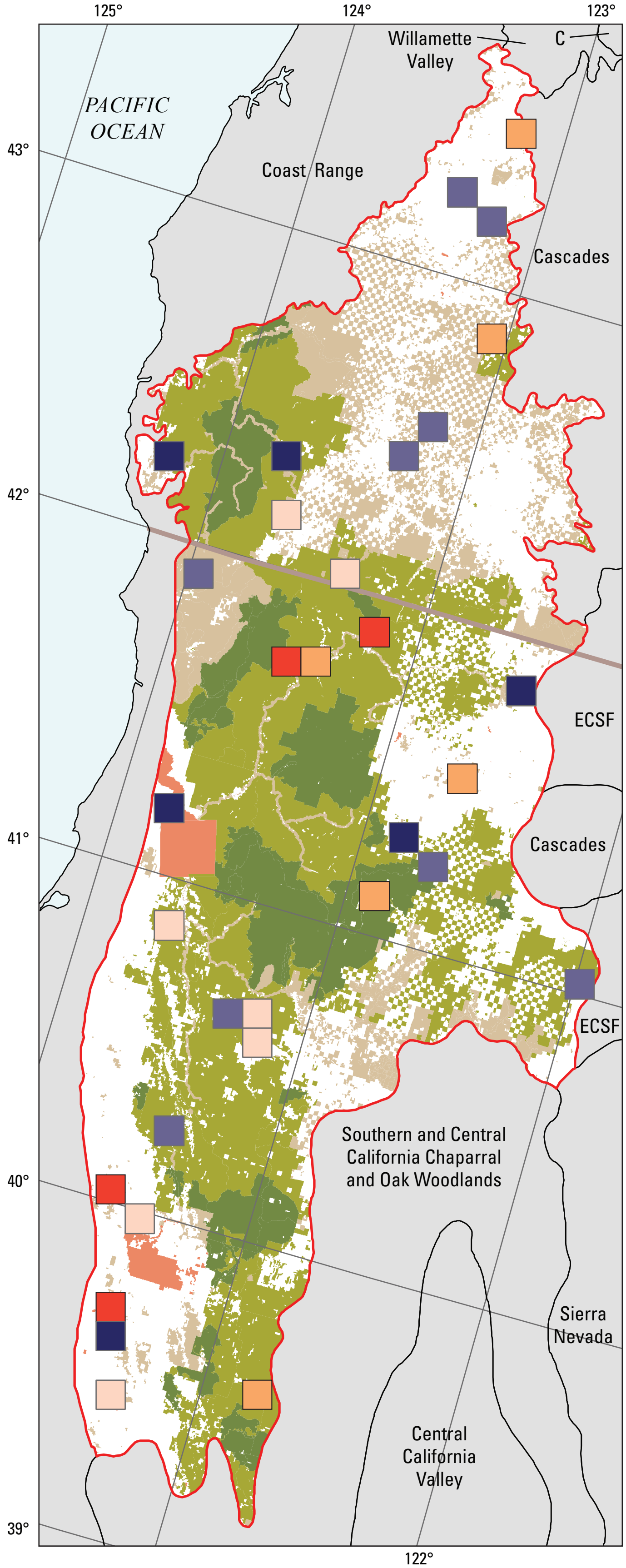


Figure 2. Federal land ownership and cumulative land-use/land-cover change (as percent of sample-block area) from 1973 to 2000 in Klamath Mountains Ecoregion. Land-ownership data from National Atlas of the United States (2006). See appendix 2 for abbreviations for Western United States ecoregions.

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

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

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

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

Contemporary Land-Cover Change (1973 to 2000)

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

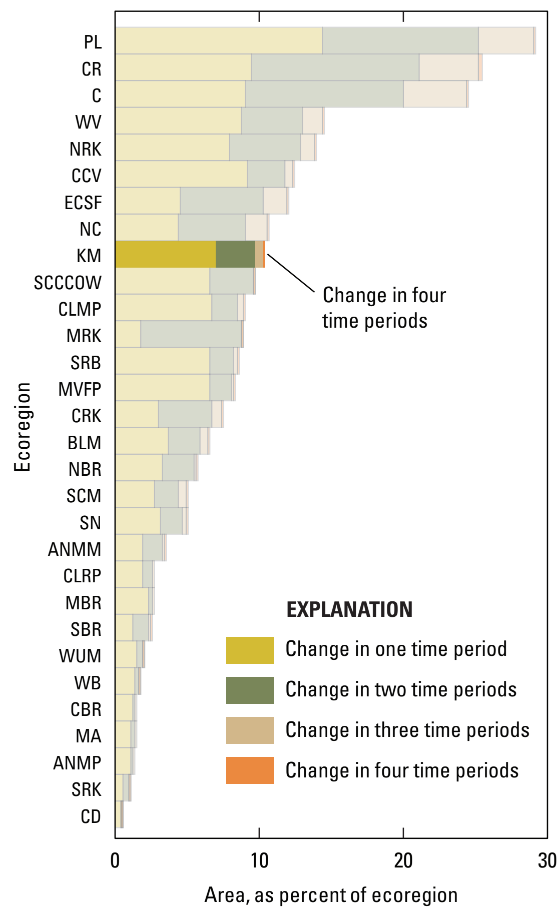


Figure 4. Overall spatial change in Klamath Mountains Ecoregion (KM; darker bars) compared with that of all Western United States Ecoregions (lighter bars). Each horizontal set of bars shows proportion of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change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

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

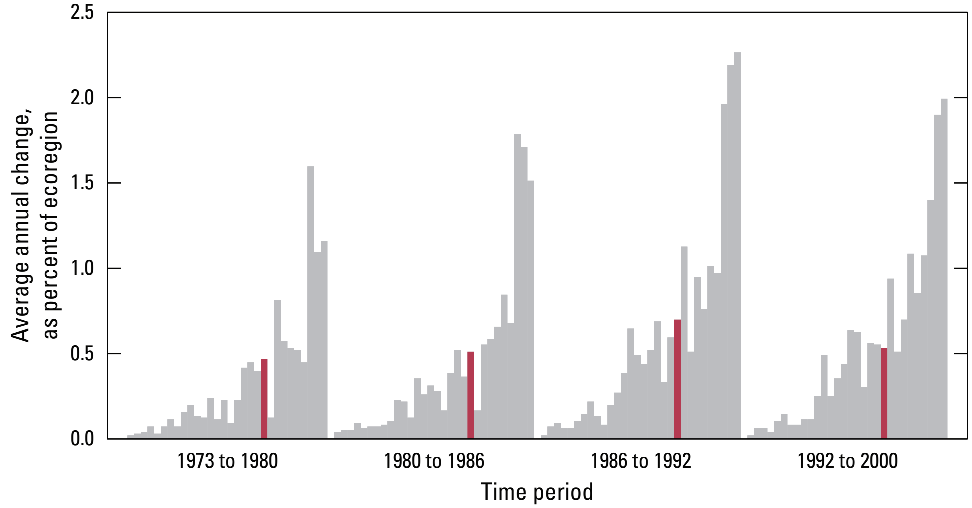


Figure 5. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Klamath Mountains Ecoregion are represented by red bars in each time period.

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

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

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

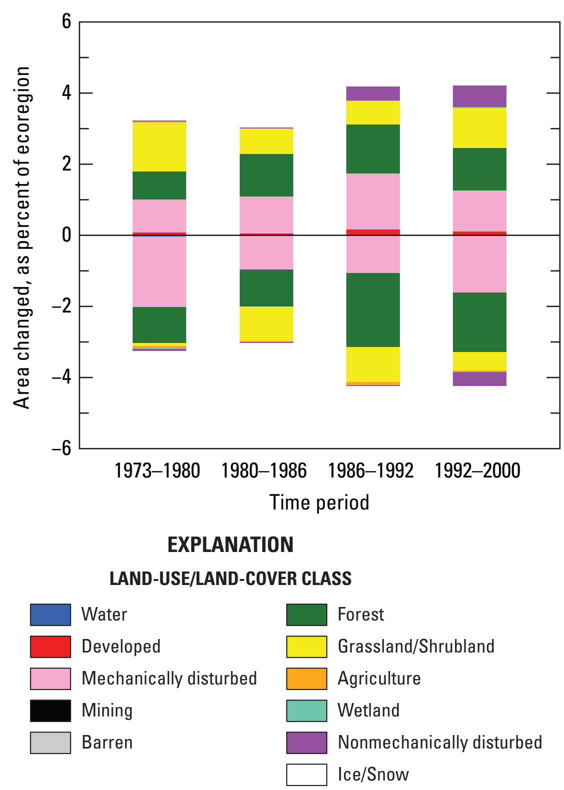


Figure 7. Gross change (area gained and lost) in Klamath Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix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

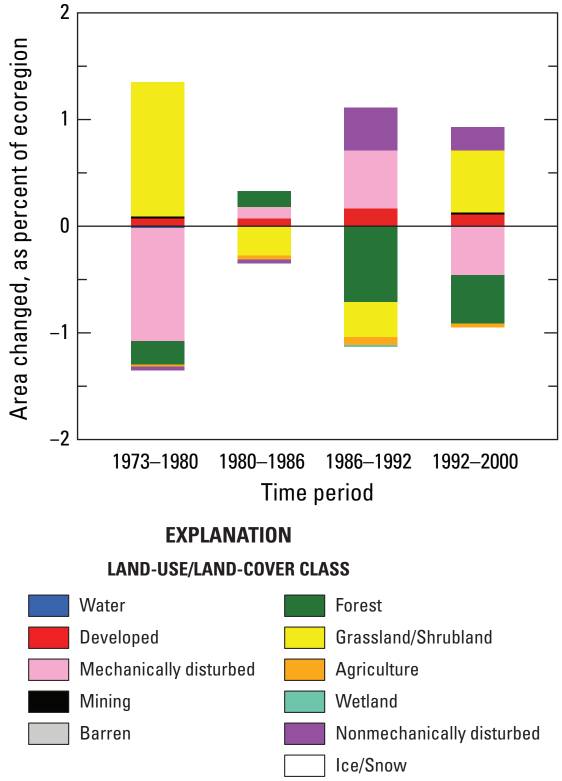


Figure 8. Normalized average net change in Klamath Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3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

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

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

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

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

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

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

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

Figure 11. Lumber mill in Roseburg, Oregon.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

References Cited

Cohen, W.B., Spies, T.A., Alig, R.J., Oetter, D.R., Maiersperger, T.K., and Fiorella, M., 2002, Characterizing 23 years (1972-95) of stand replacement disturbance in Western Oregon forests with Landsat imagery: Ecosystems, v. 5, p. 122–137.

Coleman, R.G., and Kruckeberg, A.R., 1999, Geology and plant life of the Klamath-Siskiyou Mountain region: Natural Areas Journal, v. 19, no. 4, p. 320–340.

Conservation Biology Institute, 2003, Protected areas GIS data layer: Corvallis, Oregon, Conservation Biology Institute, accessed September, 2008, at http://consbio.org.

Daniels, J.M., 2005, The rise and fall of the Pacific Northwest log export market: U.S. Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-624, 88 p.

DellaSala, D.A., Reid, S.B., Frest, T.J., Strittholt, J.R., and Olson, D.M., 1999, A global perspective on the biodiversity of the Klamath-Siskiyou ecoregion: Natural Areas Journal, v. 19, no. 4, p. 300–319.

DellaSala, D.A., Staus, N.L., Strittholt, J.R., Hackman, A., and Iacobelli, A., 2001, An updated protected areas database for the United States and Canada: Natural Areas Journal, v. 21, no. 2, p. 124–135.

Espy, M., and Babbitt, B., 1994, Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl: U.S. Department of Agriculture and U.S. Department of the Interior Northwest Forest Plan, 74 p. (Available at http://www.blm.gov/or/plans/nwfpnepa/FSEIS-1994/NWFPTitl.htm.)

Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDriel, J.N., and Wickham, J., 2007, Completion of the 2001 National Land Cover Database for the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 73, no. 4, p. 337–341.

Irwin, Porter, 1966, Geology of the Klamath Mountains province, *in* Bailey, E.H., ed., Geology of Northern California: California Division Mines and Geology Bulletin 190, p. 19–39.

Kruckeberg, A.R., 1984, California serpentines—Flora, vegetation, geology, soils and management problems: Berkeley, University of California Press, 180 p.

National Atlas of the United States, 2006, Federal lands of the United States: National Atlas of the United States database, accessed February 19, 2006, at http://nationalatlas.gov.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118–125.

Sawyer, J.O., 1996, Northern California, *in* Kirk, R., ed., The enduring forests: Northern California, Oregon, Washington, British Columbia and Southwest Alaska: Seattle, Wash., The Mountaineers Press, p. 22–41.

Sawyer, J.O., 2007, Why are the Klamath Mountains and adjacent north coast floristically diverse?: Fremontia, v. 35, no. 3, p. 3–11.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Caicco, S., Groves, G., Ulliman, J., Anderson, H., and Wright, R.G., 1993, Gap analysis: a geographic approach to protection of biological diversity: Wildlife Monographs, v. 123, p. 1–41.

Snoke, A.W., and Barnes, C.G., eds., 2006, Geological studies in the Klamath Mountains province, California and Oregon: Geological Society of America Special Paper 410, 505 p.

Staus, N.L., Strittholt, J.R., DellaSala, D.A., and Robinson, R., 2002, Rate and pattern of forest disturbance in the Klamath-Siskiyou ecoregion, USA between 1972 and 1992: Landscape Ecology, v. 17, p. 455–470.

U.S. Census Bureau, 2008, State and County Quickfacts—Oregon: U.S. Census Bureau database, accessed February 28, 2008, at http://quickfacts.census.gov/qfd/states/41000.html.

U.S. Environmental Protection Agency, 1997, Descriptions of level III ecological regions for the CEC report on ecological regions of North America: U.S. Environmental Protection Agency database, accessed April 12, 2006, at http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Downloads.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and van Driel, N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering & Remote Sensing, v. 67, p. 650–662.

Wagner, D.H., 1997, Klamath-Siskiyou region, California and Oregon, USA, *in* Davis, S.D., Heywood, V.H., Herrera-MacBryde, O., Villa-Lobos, J., and Hamilton, A.C., eds., Centres of Plant Diversity, a guide and strategy for their conservation—Vol. 3, the Americas: New York, New York, USA, World Wildlife Fund for Nature and IUCN (World Conservation Union), p. 74–76. (Available at http://botany.si.edu/projects/cpd/na/na16c.htm.)

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., and Swetnam, T.W., 2006, Warming and earlier spring increase Western U.S. forest wildfire activity: Science, v. 313, p. 940–943.

Whittaker, R.H., 1960, Vegetation of the Siskiyou Mountains, Oregon and California: Ecological Monographs, v. 30, p. 279–338.

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Chapter 14

North Cascades Ecoregion

By Tamara S. Wilson

Ecoregion Description

The North Cascades Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 30,421 km² (11,746 mi²) of predominantly steep, mountainous terrain, home to peaks rising more than 3,000 m, which are carved by valleys that drop below 150 m elevation (fig. 1). The unique topography in this geographically isolated ecoregion has been shaped by glacial processes, and its deep drainage canyons have been further incised by subsequent runoff. Beautiful alpine scenery is a major feature of the ecoregion, which includes several national forests, parks, and wilderness areas such as the North Cascades National Park, the Mount Baker–Snoqualmie National Forest, the Okanogan National Forest, and the Wenatchee National Forest, as well as the Pasayten Wilderness, the Glacier Peak Wilderness, the Alpine Lakes Wilderness, and the Henry M. Jackson Wilderness.

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

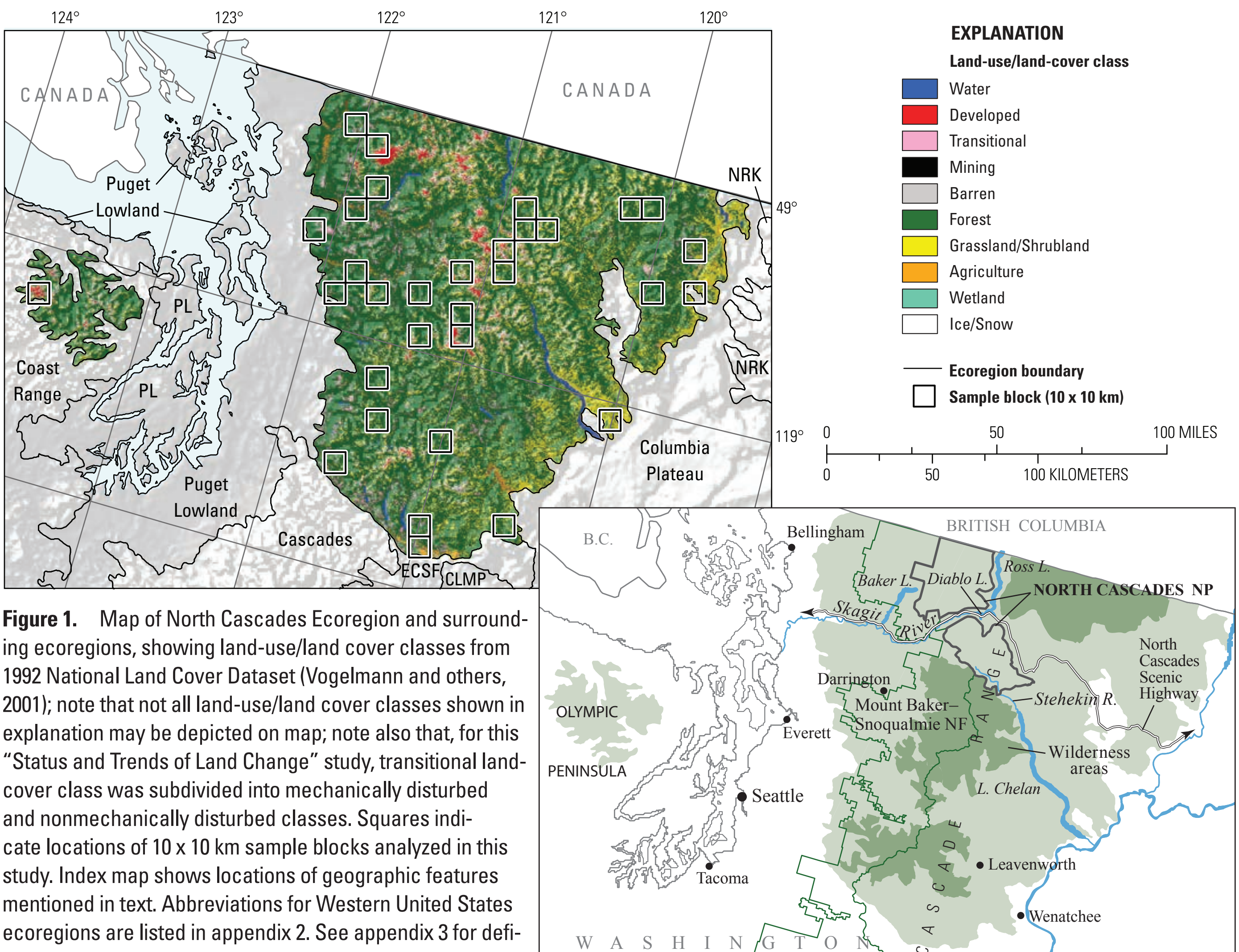

Figure 1. Map of North Cascades Ecoregion and surrounding ecoregions, showing land-use/land cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land cover classes shown in explanation may be depicted on map; note also that, for this "Status and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

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

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

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

The North Cascades Ecoregion supports a diverse range of forests, including some of the oldest and richest tracts remaining in the conterminous United States. At lower elevations and along the west flank of the Cascade Range, these forests are composed of western red cedar (*Thuja plicata*),

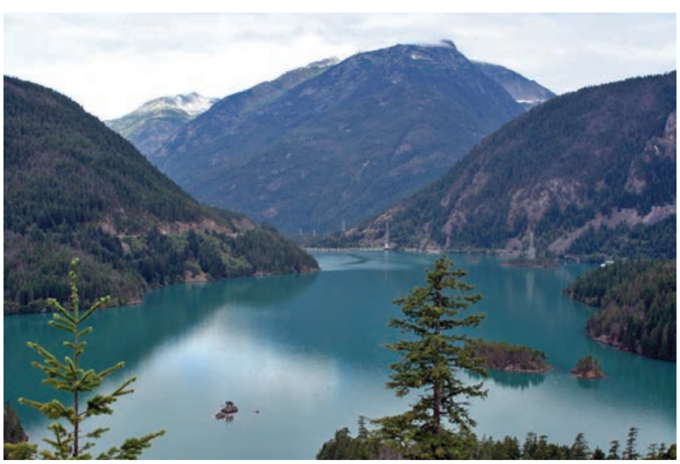

Figure 2. Diablo Lake, man-made reservoir along North Cascades Highway in North Cascades National Park, Washington.

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

Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllum*) (fig. 3). Upslope, lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), Pacific silver fir (*Abies amabilis*), Engelmann spruce (*Picea engelmannii*), western larch (*Larix occidentalis*), and whitebark pine (*Pinus albicaulis*) are more common (Uhler, 2007; Washington Department of Fish and Wildlife, 2005).

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

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

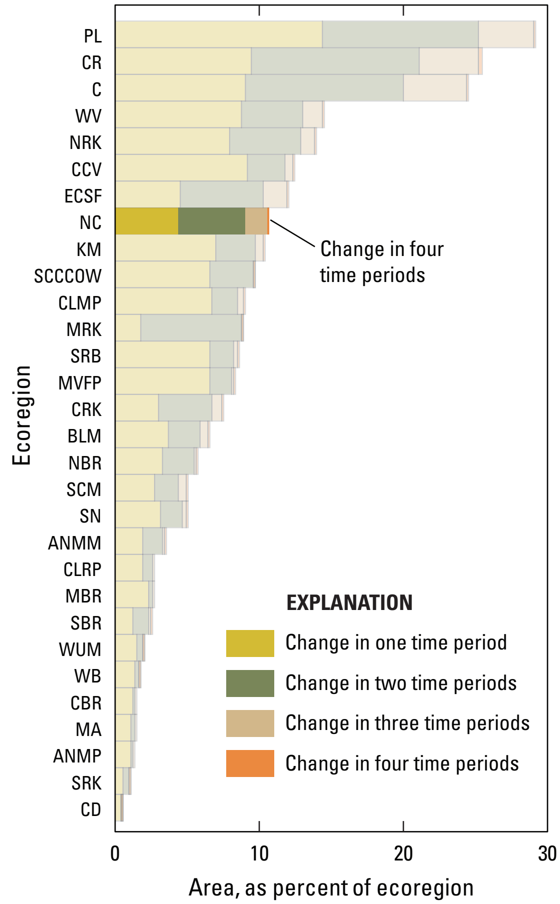

Figure 5. Overall spatial change in North Cascades Ecoregion (NC; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during time periods 1, 2, 3, or 4; highest level of spatial change in North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

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

Contemporary Land-Cover Change (1973 to 2000)

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

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

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

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

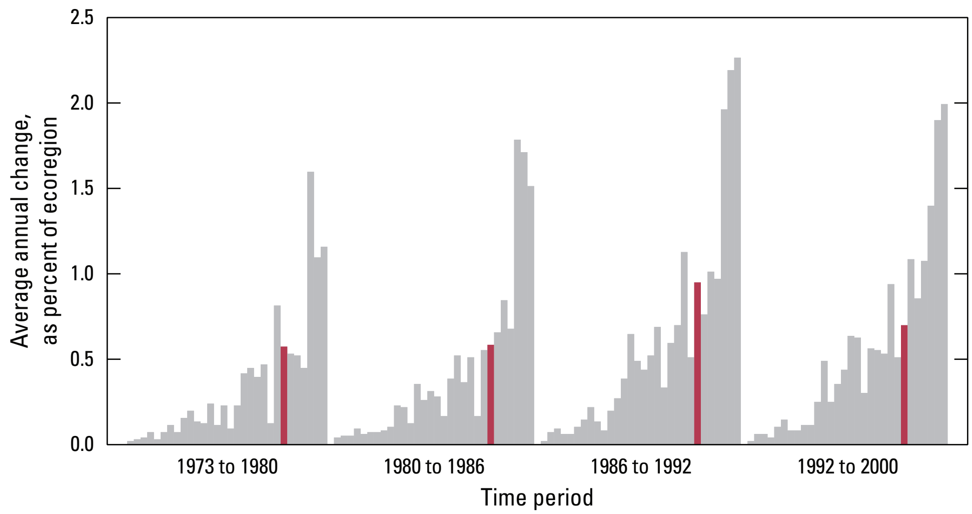

Figure 6. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for North Cascades Ecoregion are represented by red bars in each time period.

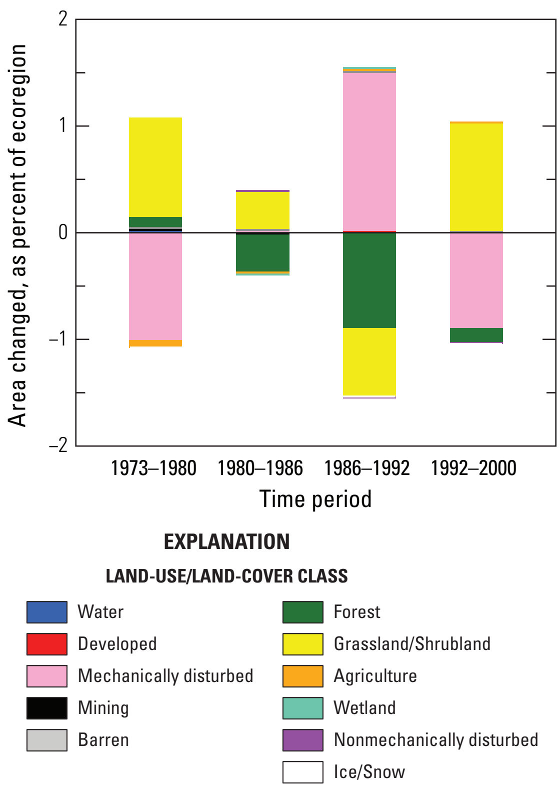

Figure 7. Normalized average net change in North Cascades Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

References Cited

Arthur, B., Uniack, T., and Owen, J., 2009, The gift of wilderness for the people of Washington: The Seattle Times, accessed July 2, 2009, at http://seattletimes.nwsource.com/html/opinion/2009413013_guests03owen.html.

Daniels, J.M., 2005, The rise and fall of the Pacific Northwest log export market: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-624.

Espy, M., and Babbitt, B., 1994, Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl: U.S. Department of Agriculture and U.S. Department of the Interior Northwest Forest Plan, 74 p. (Available at http://www.blm.gov/or/plans/nwfpnepa/FSEIS-1994/NWFPTitl.htm.)

National Park Service, 1999, Loggers, *in* North Cascades National Park, Washington: National Park Service database, accessed March 27, 2012, at http://www.nps.gov/noca/historyculture/loggers.htm.

National Park Service, 2009, North Cascades National Park, Washington: National Park Service database, accessed March 27, 2012, at http://www.nps.gov/noca/index.htm.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p.118–125.

Uhler, J.W., 2007, North Cascades National Park information page: North Cascades National Park Information, accessed July 1, 2009, at http://www.north.cascades.national-park.com/info.htm#bio.

U.S. Census Bureau, 2009, Population estimates—Places in Washington listed alphabetically, *in* State and County QuickFacts—Washington QuickLinks: U.S. Census Bureau database, accessed at http://quickfacts.census.gov/qfd/states/53000lk.html.

U.S. Congress, 1984, Washington State Wilderness Act of 1984—An act to designate certain National Forest System lands in the State of Washington for inclusion in the National Wilderness Preservation System, and for other purposes: U.S. Congress, 98th, Public Law 98–339, 9 p. (Available at http://www.wilderness.net/NWPS/documents/publiclaws/PDF/98-339.pdf.)

U.S. Environmental Protection Agency, 1997, Descriptions of level III ecological regions for the CEC report on ecological regions of North America: U.S. Environmental Protection Agency database, accessed April 12, 2006, at http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Downloads.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and van Driel, N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering and Remote Sensing, v. 67, p. 650–662.

Warren, D.D., 1999, Production, prices, employment, and trade in Northwest forest industries, fourth quarter 1997: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Resource Bulletin PNW-RB-230, 130 p.

Washington Department of Fish and Wildlife, 2005, Ecoregions—Washington's Ecoregional Conservation Strategy, *chapter VI in* Washington's Comprehensive Wildlife Conservation Strategy: Washington Department of Fish and Wildlife report, vol. 1, p. 257–555, accessed at http://wdfw.wa.gov/conservation/cwcs/cwcs.html.

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Chapter 15

Sierra Nevada Ecoregion

By Christian G. Raumann and Christopher E. Soulard

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

Ecoregion Description

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

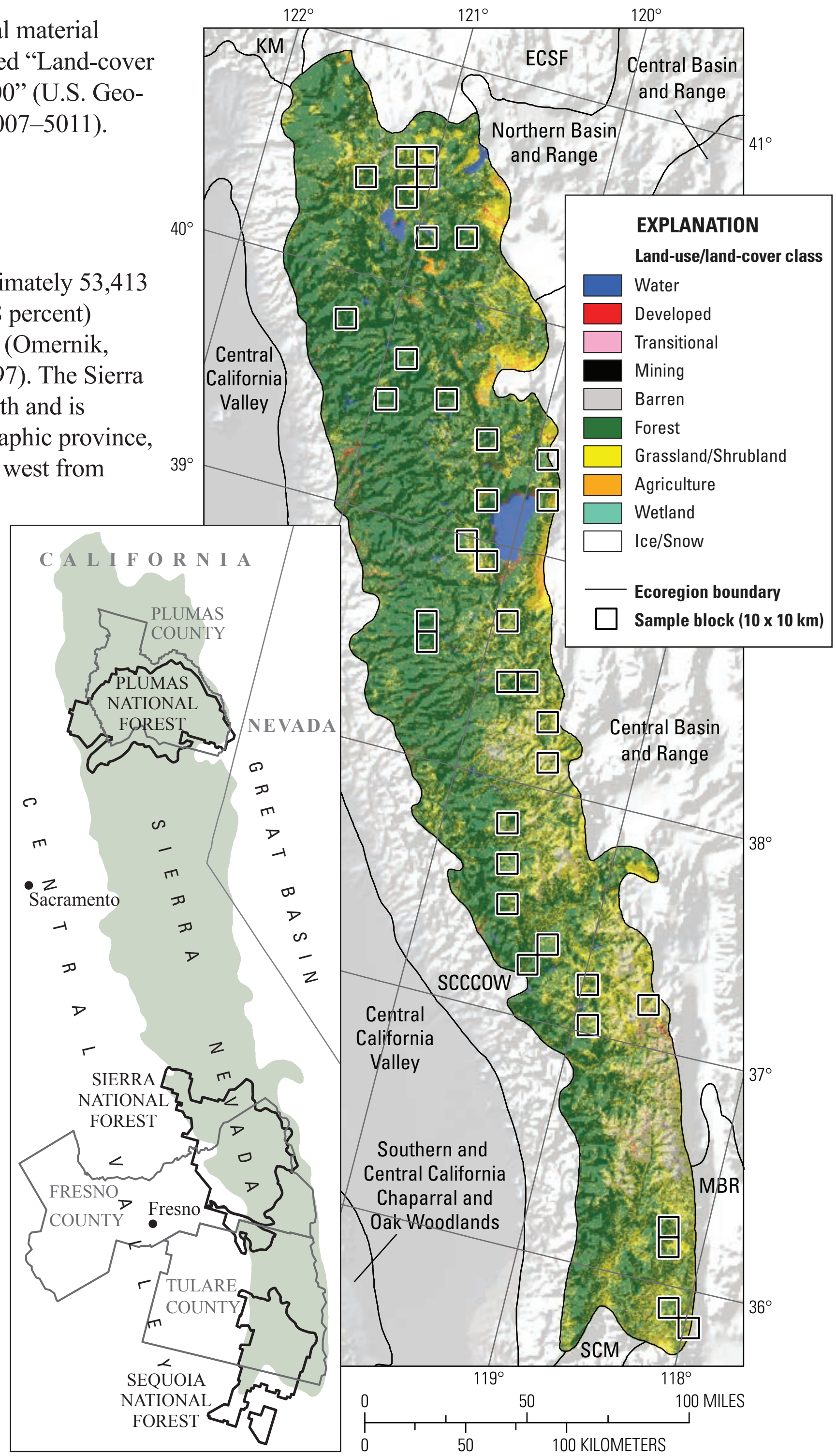

Figure 1. Map of Sierra Nevada Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status and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

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

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

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

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

Contemporary Land-Cover Change (1973 to 2000)

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

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

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

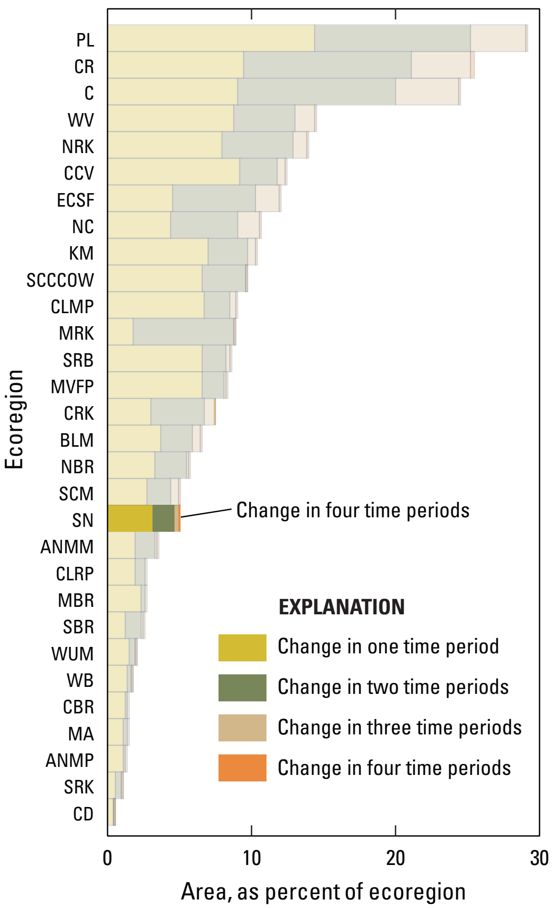

Figure 2. Overall spatial change in Sierra Nevada Ecoregion (SN; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change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

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

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

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

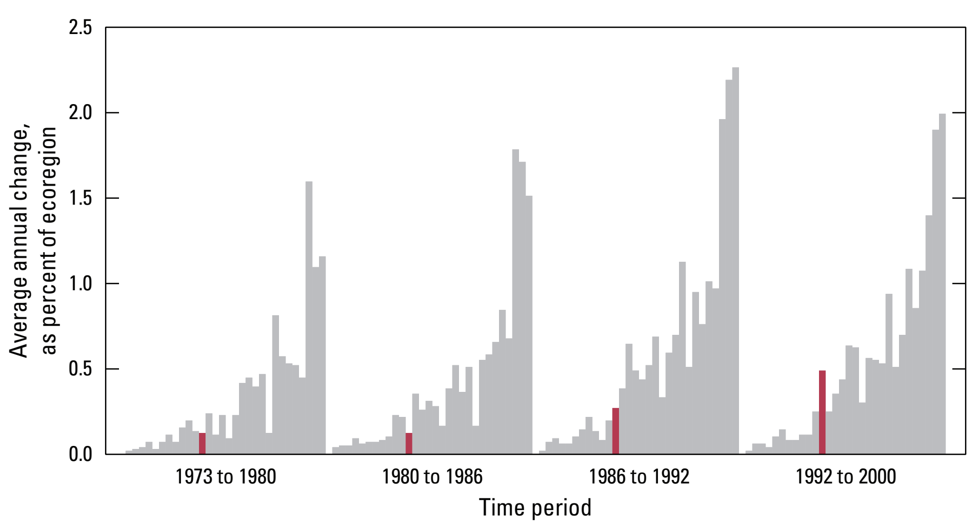

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Sierra Nevada Ecoregion are represented by red bars in each time period.

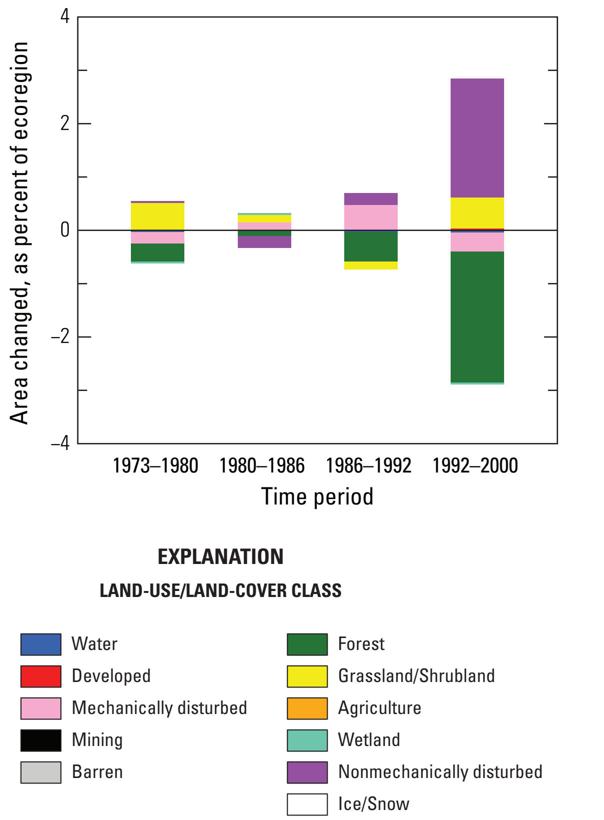

Figure 4. Normalized average net change in Sierra Nevada Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for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

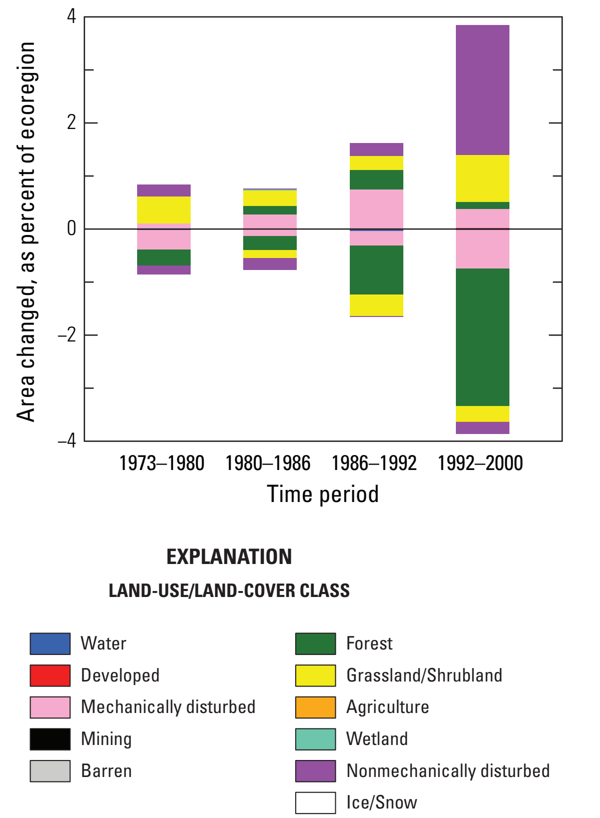

Figure 5. Gross change (area gained and lost) in Sierra Nevada Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix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

developed) and shows the direction of change. Table 4 shows the individual conversions ranked from greatest to least area converted. The most common individual conversions describe the disturbance of forest land by mechanical (that is, clearcuts) and nonmechanical (that is, fire) means. Overall, the most common conversion was that of 1,404 km² of forest to the nonmechanically disturbed class, which accounted for 37.1 percent of all conversions (fig. 6). The second most common conversion was that of 784 km² of forest to the mechanically disturbed class, accounting for 20.7 percent of all changes (fig. 7). Conversion of mechanically and nonmechanically disturbed land to the grassland/shrubland class (753 km² and 307 km², respectively) were the two next most common conversions and represented the process of vegetation regeneration after clearcutting or fire (fig. 8). Similarly, conversion of grassland/shrubland to forest (303 km²) represented the final stage of the regeneration cycle. A much less common but noteworthy conversion was that of water to mechanically disturbed (26 km²), which accounted for 0.7 percent of all individual conversions (fig. 9). This conversion indicates surface-level fluctuations of reservoirs in the ecoregion.

More insight can be provided by aggregating the conversions listed in table 4 to identify how a single land-use class was affected. Between 1973 and 2000, 1,540 km² of vegetation (forest, grassland/shrubland, and wetland) area was converted to the nonmechanically disturbed class. Fire caused all of these conversions, and almost all of this change (1,302 km²) took place between 1992 and 2000. Regeneration after disturbance was captured as the conversion of nonmechanically disturbed land to vegetation classes (forest and grassland/shrubland) and conversion of mechanically disturbed land to vegetation classes (forest and grassland/shrubland) for aggregated totals of 307 km² and 753 km², respectively.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Mechanically disturbed	Grassland/Shrubland	191	144	98	0.4	42.1
	Forest	Nonmechanically disturbed	112	152	103	0.2	24.6
	Nonmechanically disturbed	Grassland/Shrubland	84	109	74	0.2	18.6
	Forest	Mechanically disturbed	58	38	26	0.1	12.9
	Water	Mechanically disturbed	6	9	6	0.0	1.4
	Other	Other	2	n/a	n/a	0.0	0.5
		Totals	454			0.9	100.0
1980–1986	Forest	Mechanically disturbed	146	89	60	0.3	36.5
	Nonmechanically disturbed	Grassland/Shrubland	110	152	103	0.2	27.4
	Grassland/Shrubland	Forest	81	78	53	0.2	20.3
	Mechanically disturbed	Grassland/Shrubland	54	37	25	0.1	13.5
	Mechanically disturbed	Forest	4	6	4	0.0	1.0
	Other	Other	4	n/a	n/a	0.0	1.1
		Totals	400			0.7	100.0
1986–1992	Forest	Mechanically disturbed	391	154	105	0.7	45.1
	Grassland/Shrubland	Forest	190	171	116	0.4	21.9
	Mechanically disturbed	Grassland/Shrubland	146	89	60	0.3	16.8
	Forest	Nonmechanically disturbed	102	96	65	0.2	11.8
	Grassland/Shrubland	Nonmechanically disturbed	23	32	22	0.0	2.6
	Other	Other	16	n/a	n/a	0.0	1.8
		Totals	868			1.6	100.0
1992–2000	Forest	Nonmechanically disturbed	1,190	1,230	835	2.2	57.8
	Mechanically disturbed	Grassland/Shrubland	361	135	92	0.7	17.6
	Forest	Mechanically disturbed	188	104	71	0.4	9.1
	Nonmechanically disturbed	Grassland/Shrubland	112	119	81	0.2	5.4
	Grassland/Shrubland	Nonmechanically disturbed	112	116	79	0.2	5.4
	Other	Other	96	n/a	n/a	0.2	4.7
		Totals	2,059			3.9	100.0
1973–2000 (overall)	Forest	Nonmechanically disturbed	1,404	1,244	845	2.6	37.1
	Forest	Mechanically disturbed	784	299	203	1.5	20.7
	Mechanically disturbed	Grassland/Shrubland	753	323	219	1.4	19.9
	Nonmechanically disturbed	Grassland/Shrubland	307	214	145	0.6	8.1
	Grassland/Shrubland	Forest	303	195	132	0.6	8.0
	Other	Other	231	n/a	n/a	0.4	6.1
		Totals	3,782			7.1	100.0

References Cited

Manley, P.N., Fites-Kaufman, J.A., Barbour, M.G., Schlesinger, M.D., and Rizzo, D.M., 2000, Biological integrity, *in* Murphy, D.D., and Knopp, C.M., eds., Lake Tahoe watershed assessment: U.S. Forest Service Pacific Southwest Research Station, Albany, Calif., Gen. Tech. Rep. PSW-GTR-175, v. 1, chap. 5, p. 403–598.

McKelvey, K.S., Skinner, C.N., Chang, C., Erman, D.C., Husari, S.J., Parsons, D.J., van Wagtendonk, J.W., and Weatherspoon, C.P., 1996, An overview of fire in the Sierra Nevada, *in* Sierra Nevada Ecosystem Project final report to Congress, vol. II, Assessments and scientific basis for management options: Davis, University of California, Centers for Water and Wildlands Research, v. 2, chap. 37, p. 1,033–1,040.

Oliver, W.W., Ferrell, G.T., and Tappeiner, J.C., 1996, Density management of Sierra Forests, *in* Sierra Nevada Ecosystem Project final report to Congress, vol. III, Assessments, commissioned reports, and background information: Davis, University of California, Centers for Water and Wildlands Research, v. 3, chap. 11, p. 217–276.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118–125.

Raumann, C.G., and Soulard, C.E., 2007, Land-cover trends of the Sierra Nevada Ecoregion, 1973-2000: U.S. Geological Survey Scientific Investigations Report 2007–5011, available at http://pubs.usgs.gov/sir/2007/5011/.

Ruth, L., 1996, Conservation and controversy—national forest management, 1960-95, *in* Sierra Nevada Ecosystem Project final report to Congress, vol. II, Assessments and scientific basis for management options: Davis, University of California, Centers for Water and Wildlands Research, v. 2, chap. 7, p. 145–162.

Sierra Nevada Ecosystem Project Science Team and Special Consultants, 1996, People and resource use, *in* Sierra Nevada Ecosystem Project final report to Congress, vol. I, Assessment summaries and management strategies: Davis, University of California, Centers for Water and Wildlands Research, v. 1, chap. 2, p. 17–45.

Skinner, C.N., and Chang, C., 1996, Fire regimes, past and present, *in* Sierra Nevada Ecosystem Project final report to Congress, vol. II, Assessments and scientific basis for management options: Davis, University of California, Centers for Water and Wildlands Research, v. 2, chap. 38, p. 1,041–1,069.

Stine, S., 1996, Climate, 1650-1850, *in* Sierra Nevada Ecosystem Project final report to Congress, vol. II, Assessments and scientific basis for management options: Davis, University of California, Centers for Water and Wildlands Research, v. 2, chap. 2, p. 25–30.

U.S. Environmental Protection Agency, 1997, Descriptions of level III ecological regions for the CEC report on ecological regions of North America: U.S. Environmental Protection Agency database, accessed April 12, 2006, at http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Downloads.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and van Driel, N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering and Remote Sensing, v. 67, p. 650–662.

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Chapter 16

Blue Mountains Ecoregion

By Christopher E. Soulard

Ecoregion Description

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

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

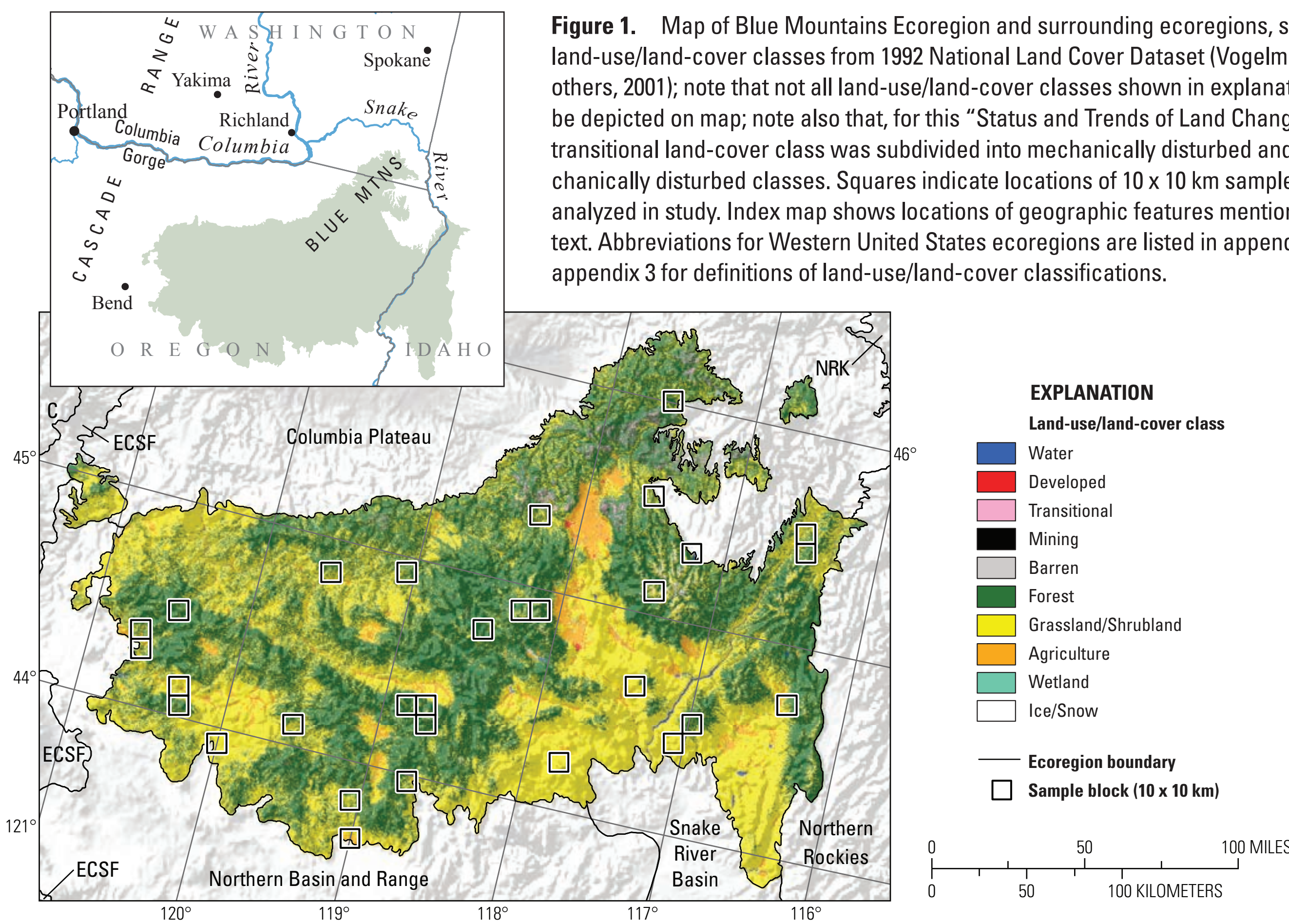

Figure 1. Map of Blue Mountains Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and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

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

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

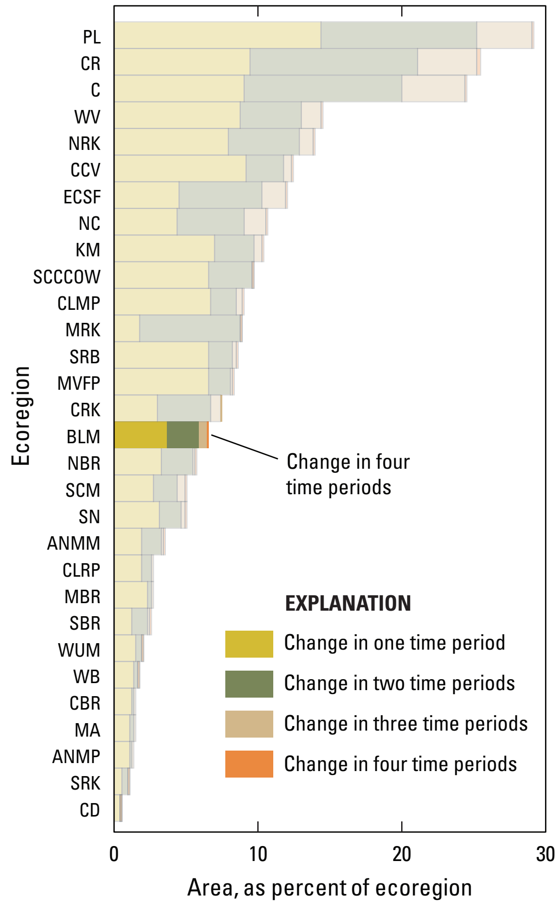

Figure 2. Overall spatial change in Blue Mountains Ecoregion (BLM; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial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

Contemporary Land-Cover Change (1973 to 2000)

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

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

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

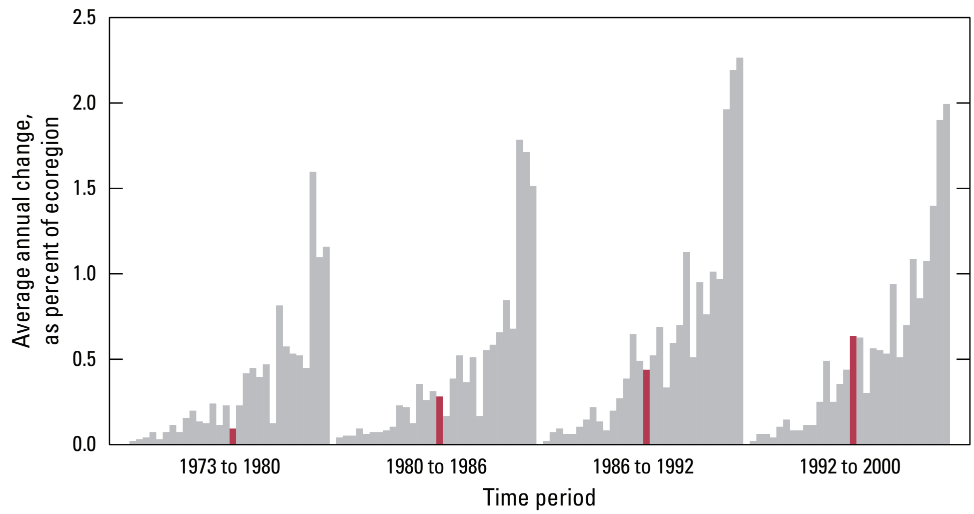

Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Blue Mountains Ecoregion are represented by red bars in each time period.

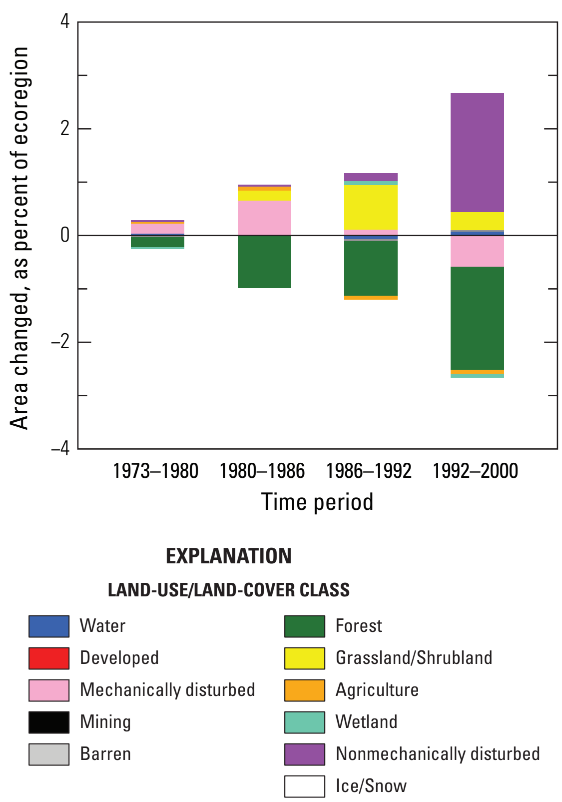

Figure 4. Normalized average net change in Blue Mountains Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for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

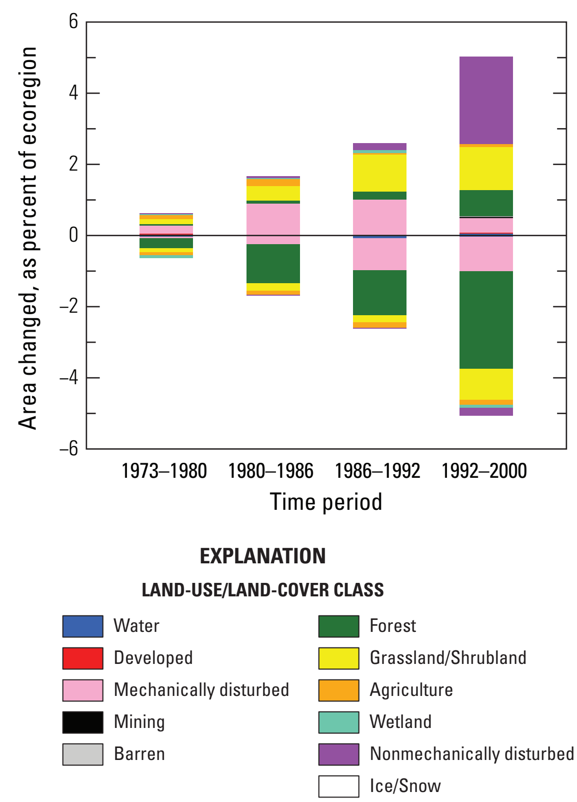

Figure 5. Gross change (as percent of ecoregion) in Blue Mountains Ecoregion by time period for each land-cover class. Diagram illustrates how net change can mask within-class fluctuations in each period and for entire 27-year study period. Bars above zero axis represent area gained, whereas bars below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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Forest	Mechanically disturbed	152	67	45	0.2	38.0
	Agriculture	Grassland/Shrubland	52	47	32	0.1	13.1
	Grassland/Shrubland	Agriculture	51	49	33	0.1	12.9
	Wetland	Water	31	32	22	0.0	7.7
	Mechanically disturbed	Grassland/Shrubland	30	18	12	0.0	7.4
	Other	Other	83	n/a	n/a	0.1	20.9
		Totals	399			0.6	100.0
1980–1986	Forest	Mechanically disturbed	579	404	273	0.9	52.9
	Mechanically disturbed	Grassland/Shrubland	118	53	36	0.2	10.8
	Grassland/Shrubland	Agriculture	91	64	43	0.1	8.4
	Forest	Grassland/Shrubland	75	107	72	0.1	6.9
	Agriculture	Grassland/Shrubland	63	56	38	0.1	5.8
	Other	Other	168	n/a	n/a	0.3	15.3
		Totals	1,094			1.7	100.0
1986–1992	Forest	Mechanically disturbed	653	340	230	1.0	38.1
	Mechanically disturbed	Grassland/Shrubland	527	363	246	0.8	30.7
	Forest	Nonmechanically disturbed	139	163	110	0.2	8.1
	Grassland/Shrubland	Forest	96	78	53	0.1	5.6
	Agriculture	Grassland/Shrubland	90	111	75	0.1	5.2
	Other	Other	210	n/a	n/a	0.3	12.3
		Totals	1,714			2.6	100.0
1992–2000	Forest	Nonmechanically disturbed	1,471	1,170	791	2.2	44.6
	Mechanically disturbed	Grassland/Shrubland	566	293	198	0.9	17.1
	Grassland/Shrubland	Forest	397	251	170	0.6	12.0
	Forest	Mechanically disturbed	279	137	93	0.4	8.5
	Grassland/Shrubland	Nonmechanically disturbed	125	114	77	0.2	3.8
	Other	Other	462	n/a	n/a	0.7	14.0
		Totals	3,300			5.0	100.0
1973–2000 (overall)	Forest	Mechanically disturbed	1,663	809	547	2.5	25.5
	Forest	Nonmechanically disturbed	1,632	1,178	797	2.5	25.1
	Mechanically disturbed	Grassland/Shrubland	1,240	630	426	1.9	19.0
	Grassland/Shrubland	Forest	554	293	198	0.8	8.5
	Agriculture	Grassland/Shrubland	273	247	167	0.4	4.2
	Other	Other	1,146	n/a	n/a	1.8	17.6
		Totals	6,508			9.9	100.0

References Cited

Brandt, J.P., Morgan, T.A., Dillon, T., Lettman, G.J., Keegan, C.E., and Azuma, D.L., 2006, Oregon's forest products industry and timber harvest, 2003: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-681. (Available at www.fs.fed.us/pnw/pubs/pnw_gtr681.pdf.)

Bryce, S.A., 2006, Development of a Bird Integrity Index; Measuring avian response to disturbance in the Blue Mountains of Oregon, USA: Environmental Management, v. 38, no. 3, p. 470–486.

Busacca, A.J., 1991, Loess deposits and soils of the Palouse and vicinity, *in* Baker, V.R., ed., Quaternary geology of the Columbia Plateau, *in* Morrison, R.B., ed., Quaternary nonglacial geology—conterminous U.S.: Geological Society of America, Decade of North American Geology, DNAG, v. K–2, p. 216–228.

Cochran, P.H., Geist, J.M., Clemens, D.L., Clausnitzer, R.R., and Powell, D.C., 1994, Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region Research Note PNW-RN-513. (Available at http://www.treesearch.fs.fed.us/pubs/25113.)

Heyerdahl, E.K., Brubaker, L.B., and Agee, J.K., 2001, Spatial controls of historical fire regimes; A multiscale example from the Interior West, USA: Ecology, v. 82, no. 3, p. 660–678.

McCullough, D.G., Werner, R.A., and Newmann, D., 1998, Fire and insects in northern and boreal forest ecosystems of North America: Annual Review of Entomology, v. 43, p. 107–127.

Mutch, R.W., Arno, S.F., Brown, J.K., Carlson, C.E., Ottmar, R.D., and Peterson, J.L., 1993, Forest health in the Blue Mountains; A management strategy for fire-adapted ecosystems: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region General Technical Report PNW-GTR-310. (Available at http://www.treesearch.fs.fed.us/pubs/9056.)

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118–125.

Parker, T.J., Clancy, K.M., and Mathiase, R.L., 2006, Interactions among fire, insects and pathogens in coniferous forests of the interior western United States and Canada: Agricultural and Forest Entomology, v. 8, p. 167–189.

Raumann, C.G., and Soulard, C.E., 2007, Land-cover trends of the Sierra Nevada Ecoregion, 1973–2000: U.S. Geological Survey Scientific Investigations Report 2007–5011, 29 p. (Available at http://pubs.usgs.gov/sir/2007/5011/.)

Thorson, T.D., Bryce, S.A., Lammers, D.A., Woods, A.J., Omernik, J.M., Kagan, J., Pater, D.E., and Comstock, J.A., 2003, Ecoregions of Oregon: U.S. Geological Survey Ecoregion Map Series, scale 1:1,500,000. (Available at http://www.epa.gov/wed/pages/ecoregions/or_eco.htm.)

U.S. Department of Agriculture, 1979, Wildlife habitats in managed areas; The Blue Mountains of Oregon and Washington: U.S. Department of Agriculture, Forest Service, Agriculture Handbook No. 553, 512 p.

U.S. Environmental Protection Agency, 1997, Descriptions of level III ecological regions for the CEC report on ecological regions of North America: U.S. Environmental Protection Agency database, accessed April 12, 2006, at http://www.epa.gov/wed/pages/ecoregions/na_eco.htm#Downloads.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and van Driel, N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources: Photogrammetric Engineering & Remote Sensing, v. 67, p. 650–662.

Wickman, B.E., 1992, Forest health in the Blue Mountains; The influence of insects and disease: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-295. (Available at http://www.treesearch.fs.fed.us/pubs/9032.)

Zarnowitz, J.E., and Manuwal, D.A., 1985, The effects of forest management on cavity-nesting birds in northwestern Washington: The Journal of Wildlife Management, v. 49, no. 1, p. 255–263.