Status and Trends of Land Change in the Western United States—1973 to 2000
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Chapter 2
Puget Lowland Ecoregion

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Ecoregion Description

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

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

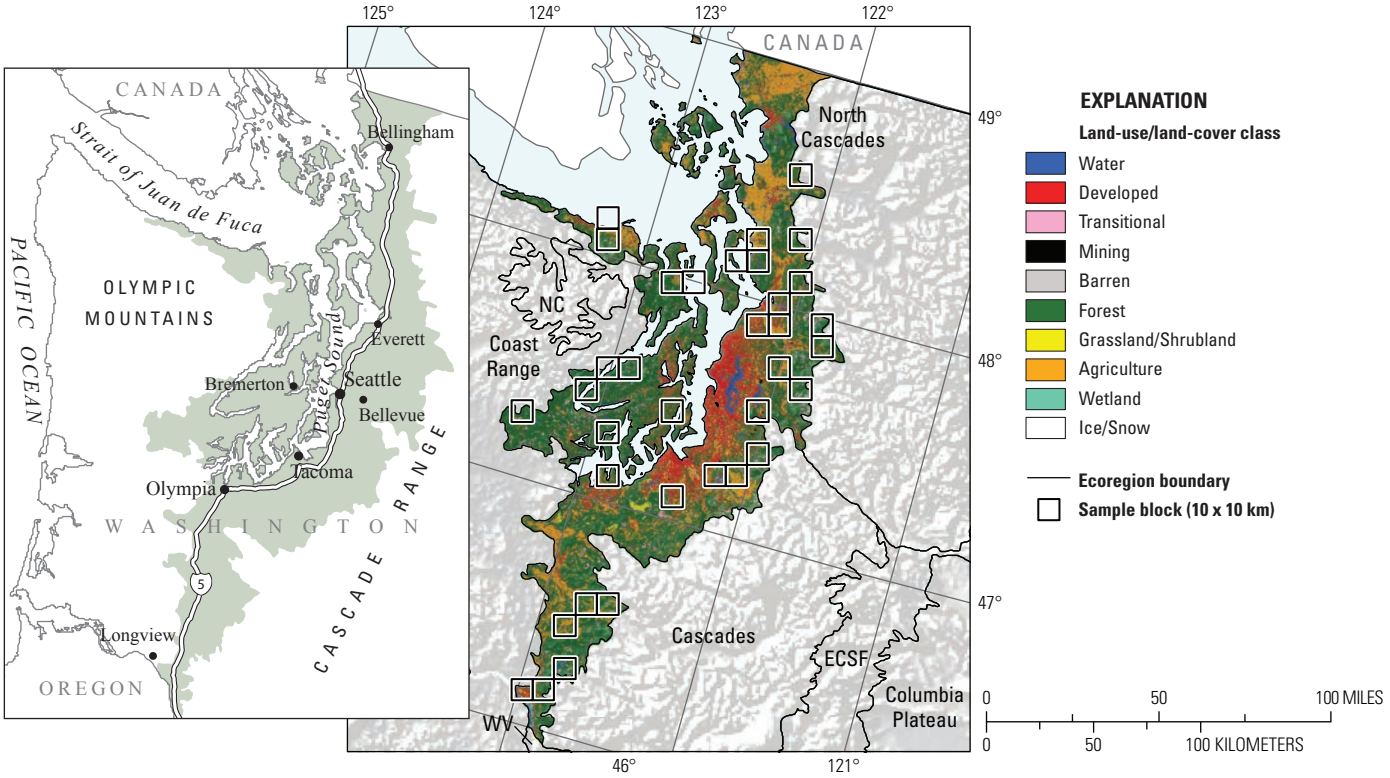

Figure 1. Map of Puget Lowland Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status and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

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

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

Contemporary Land-Cover Change (1973 to 2000)

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

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

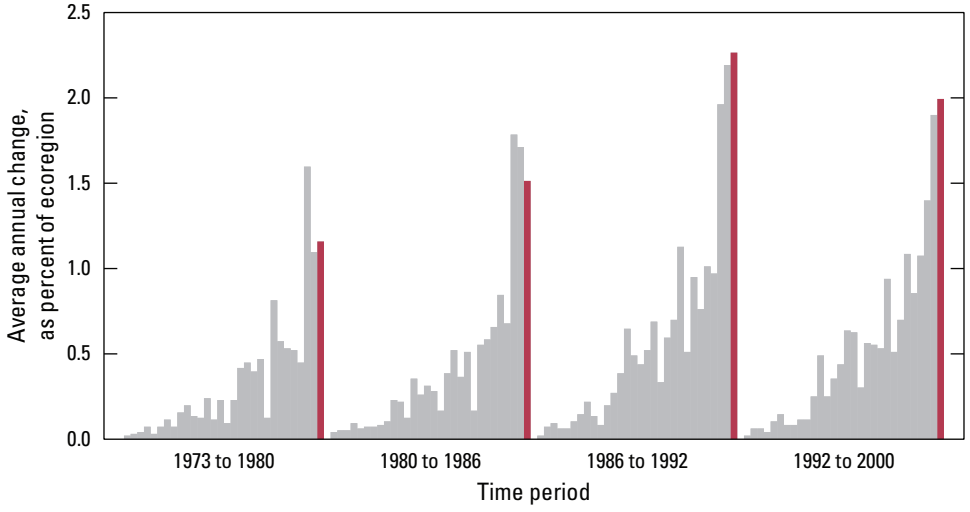

Figure 2. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Puget Lowland Ecoregion are represented by red bars in each time period.

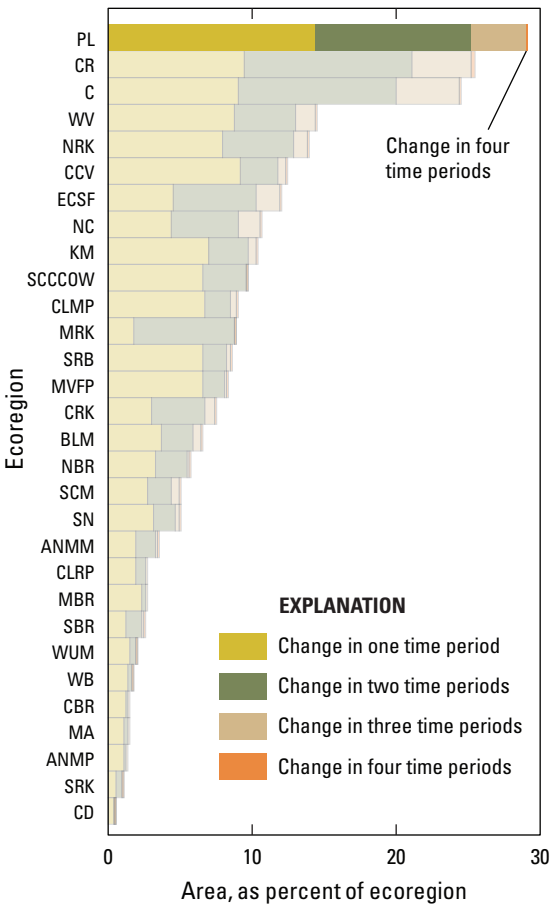

Figure 3. Overall spatial change in Puget Lowland Ecoregion (PL; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change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

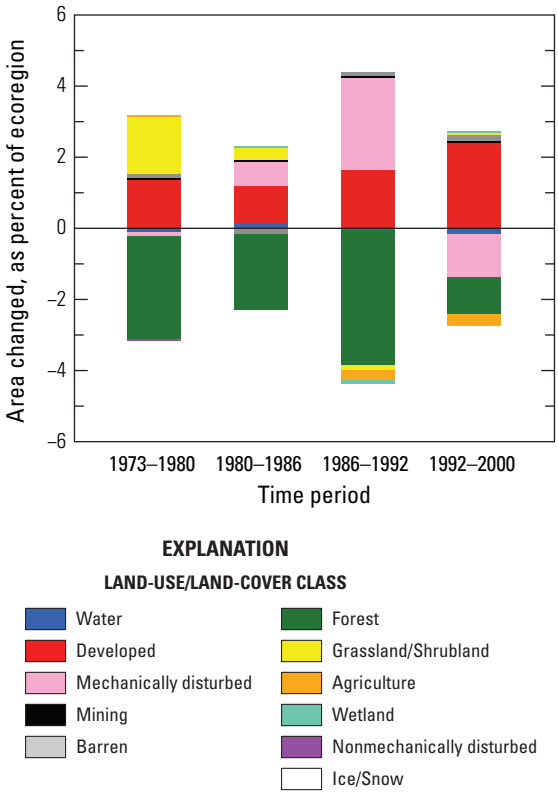

Figure 4. Normalized average net change in Puget Lowland Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for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

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

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

The 1990s also ushered in an era of federal forest protection in the Pacific Northwest. The Northwest Forest Plan was implemented to protect the old-growth forest habitat of the threatened Northern Spotted Owl (*Strix occidentalis caurina*). (Daniels, 2005). The Northern Spotted Owl prefers to roost, forage, and nest in old growth forests that have moderate to high canopy enclosure and many large trees (Tesky, 1992). Under the Northwest Forest Plan, timber harvest was banned on 10 million of the 17 million acres (40,000 of 69,000 km²) of national forest land in the Pacific Northwest. Before the Northwest Forest Plan, timber sales from these national forests were approximately 4 to 5 billion board feet per year. After

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

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

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

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

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

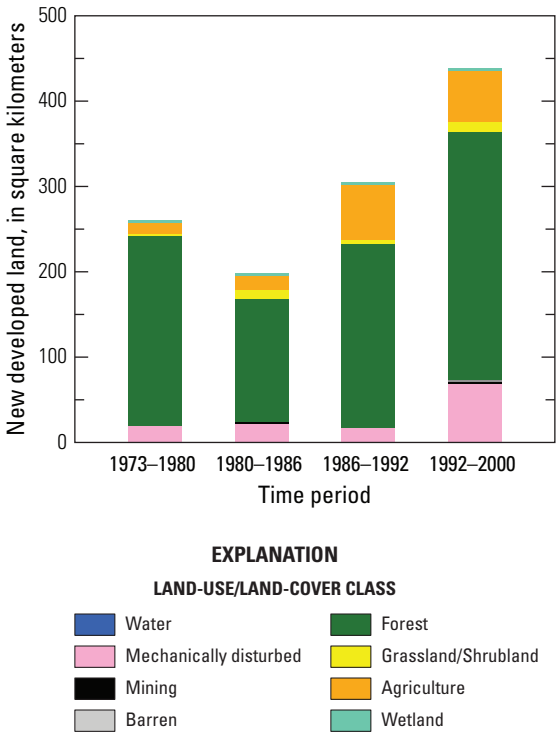

Figure 8. Gains in developed land-cover class in Puget Lowland Ecoregion. Values are areas in square kilometers that converted into developed land. Colors indicate which land-cover class converted to developed land.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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