Warm Deserts Ecoregions

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

Chapter 27

Chihuahuan Deserts Ecoregion

By Jana Ruhlman, Leila Gass, and Barry Middleton

Ecoregion Description

The Chihuahuan Desert is the largest of the North American deserts, extending from southern New Mexico and Texas deep into Mexico, with approximately 90 percent of its area falling south of the United States–Mexico border (Lowe, 1964, p. 24). The Chihuahuan Deserts Ecoregion covers approximately 174,472 km^2 (67,364 mi^2) within the United States, including much of west Texas, southern New Mexico, and a small portion of southeastern Arizona (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The ecoregion is generally oriented from northwest to southeast, with the Madrean Archipelago Ecoregion to the west; the Arizona/New Mexico Mountains, Arizona/New Mexico Plateau, Southwestern Tablelands, and Western High Plains Ecoregions to the north; and the Edwards Plateau and Southern Texas Plains Ecoregions to the east (fig. 1).

The Chihuahuan Desert is distinguished from other hot deserts in the Southwest by its higher elevation and summer-dominant rainfall. The terrain consists of broad basins and valleys bordered by sloping alluvial fans and terraces, along with isolated mesas and mountains. The alluvial fans and basins

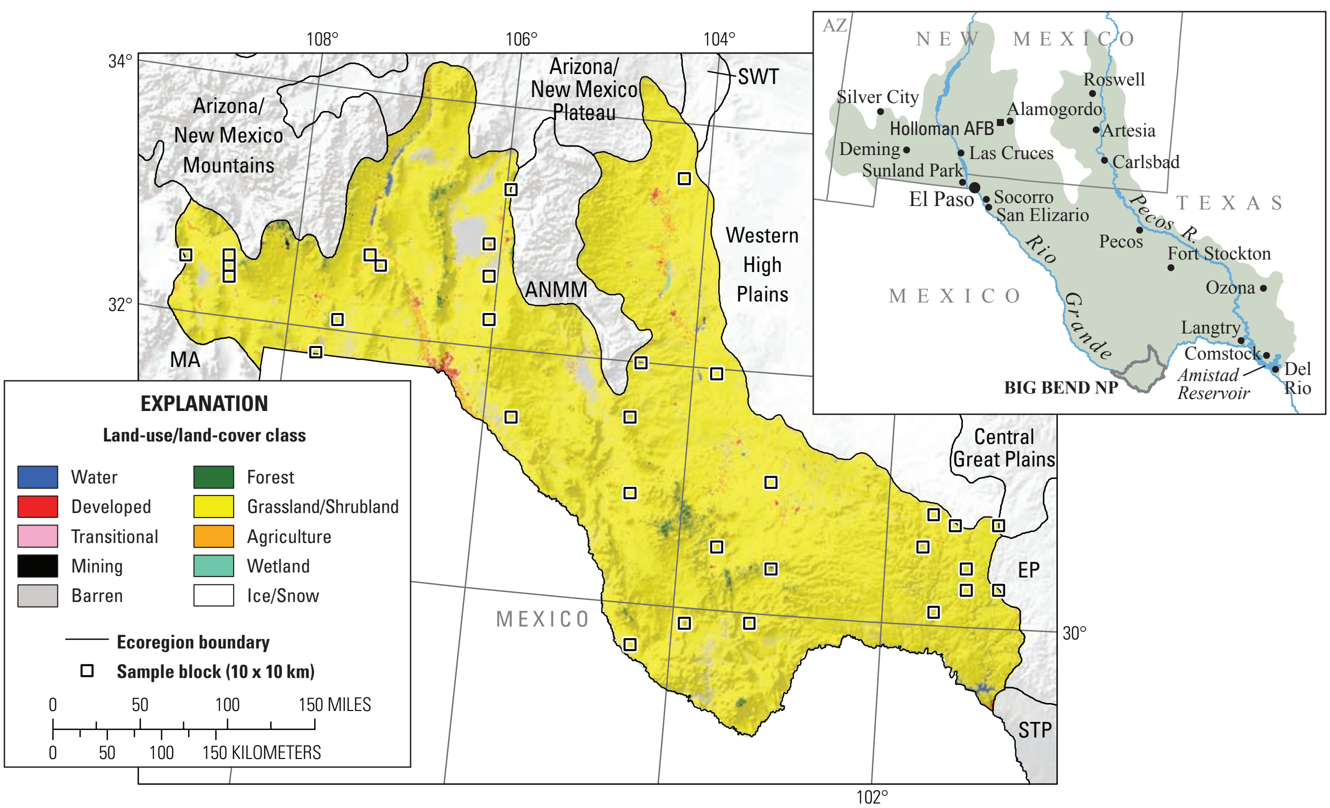


Figure 1. Map of Chihuahuan Deserts Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status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

play an important role in groundwater recharge of the alluvial-basin aquifer systems that supply water to human populations along the Texas–Mexico border.

In the northern Chihuahuan Desert, annual precipitation averages 245 to 265 mm, with most of the precipitation falling in the summer (Gucker, 2006; Schmidt, 1983). Annual mean temperatures range from less than 12°C to greater than 20°C throughout the part of the Chihuahuan Desert that is north of the border (Daly and others, 2002). January minimum temperatures reach near or below freezing except along parts of the Rio Grande in Texas, where July maximum temperature. exceed 36°C (National Park Service, 2007).

Unique in its diversity of yucca (*Yucca* spp.) and agave (*Agave* spp.) species (fig. 2), the Chihuahuan Desert replaces the large cacti, creosote bush (*Larrea tridentata*), and bursage (*Asteraceae* spp.) communities of the Sonoran Desert to the west with large yuccas amid a sea of sparse grass and shrubs. Much of the Chihuahuan Deserts Ecoregion was once covered by healthy semidesert grasslands, but heavy livestock grazing coupled with frequent droughts during the 20th century transformed thousands of acres to desert shrubland, a process that still continues (Hoyt, 2002). Extensive areas of Chihuahuan semidesert grasslands are now dominated by creosote bush (*Larrea tridentata*), tarbush (*Flourensia cernua*), and mesquite (*Prosopis* spp.) (Buffington and Herbel, 1964, p. 139). McClaran and Van Devender (1995, p. 250–251) stated that livestock grazing and range-management programs since the 1870s have "led to soil erosion, destruction of those plants most palatable to livestock, changes in grassland fire ecology, the spread of nonnative plants, and a steady increase in the density of woody shrubs and brush." However, some have challenged these prevailing interpretations of influences on environmental degradation, highlighting the significance of climate variability as a catalyst and the need for a more stakeholder-driven research approach when evaluating ecological stewardship (West and Vásquez-León, 2008).

Water in the ecoregion is limited, which makes its major rivers, the Rio Grande (fig. 3) and the Pecos River (fig. 4), precious resources. These river valleys create large riparian areas, and major pockets of development are located along their corridors (New Mexico State University, 2007). Most of the water in the Chihuahuan Deserts Ecoregion is associated with the Rio Grande and the Pecos River and their tributaries. Reservoirs on these rivers provide water for the ecoregion's limited irrigated agriculture, as well as supply water for its major cities, including Las Cruces and Roswell, New Mexico, and El Paso, Texas.

Livestock, oil and gas production, and tourism are all important to the economy of the Chihuahuan Deserts Ecoregion (Conservation History Association of Texas, 2009). The Natural Resources Conservation Service reported that, in the Chihuahuan Desert Resource Conservation and Development area of Texas, 89 percent of the area was rangeland, and beef cattle, dairy cattle, pecans, onions, and various other crops were the major agricultural products (U.S. Department of Agriculture, 2008). Wheat (mostly irrigated), hay, sorghum,

Figure 2. Soaptree yucca (*Yucca elata*) near Texas–New Mexico border, south of Carlsbad, New Mexico. This is one of many types of yuccas and agaves indigenous to Chihuahuan Deserts Ecoregion.

Figure 3. View of Rio Grande from scenic overlook in Big Bend National Park, looking southwest into Mexico at Santa Elena Mountains.

Figure 4. View looking north over Pecos River, between Langtry and Comstock, Texas. This part of river contains water impounded by Amistad Reservoir, located farther downstream.

cotton, and a variety of fruits, nuts, and vegetables, as well as livestock, are important to the economy of all New Mexico counties in the ecoregion (U.S. Department of Agriculture, 2007). Farmers in the ecoregion also grow many varieties of chili peppers in the fertile fields along the Rio Grande in both New Mexico and Texas.

Federal lands make up approximately 28 percent of the Chihuahuan Deserts Ecoregion, with the majority managed by the Bureau of Land Management and the Department of Defense (for example, White Sands Missile Range, Holloman Air Force Base, and Fort Bliss); these military installations are a vital part of the local economies (Las Cruces and Alamogordo, New Mexico, and El Paso, Texas, respectively). Approximately 4,460 km^2 are managed by the National Park Service within seven park units, and these represent the nation's most significant areas of preserved Chihuahuan Desert landscape (National Park Service, 2005). White Sands National Monument and Carlsbad Caverns National Park in New Mexico and Big Bend National Park in Texas are three of the more notable parks within the ecoregion.

Contemporary Land-Cover Change (1973 to 2000)

The Chihuahuan Deserts Ecoregion had very little land-cover change during the study period (fig. 5). An estimated 0.5 percent of the ecoregion (822 km^2) was converted to other land-cover types (table 1). The standard error of 0.2 percent is high in proportion to the overall change of 0.5 percent but is not unusual for an ecoregion with so little change. Compared to other western ecoregions, change in the Chihuahuan Deserts Ecoregion was the lowest (figs. 5,6). Low change is consistent with that of other ecoregions in the arid Southwest. The estimated change in land cover was 0.2 percent between 1980 and 1986 and between 1992 and 2000; it was 0.1 percent between 1973 and 1980 and between 1986 and 1992. When

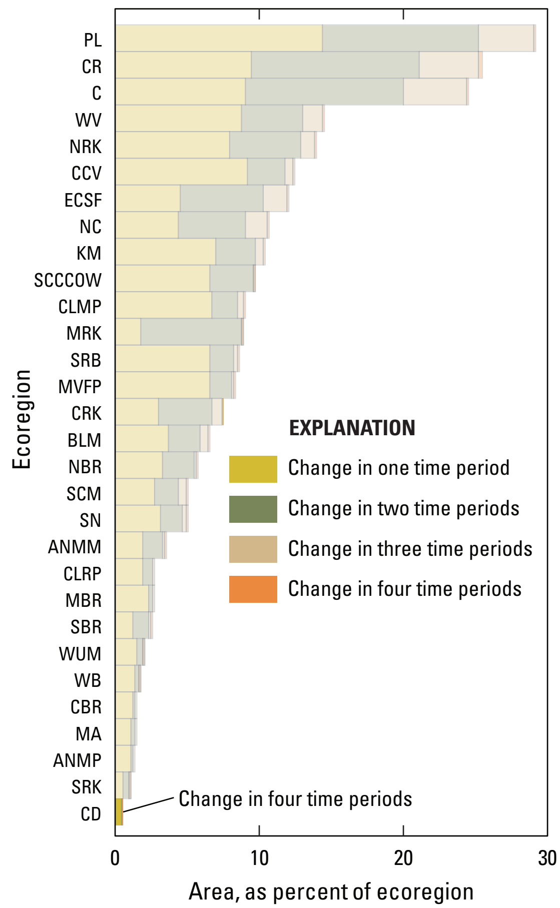


Figure 5. Overall spatial change in Chihuahuan Deserts Ecoregion (CD; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial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

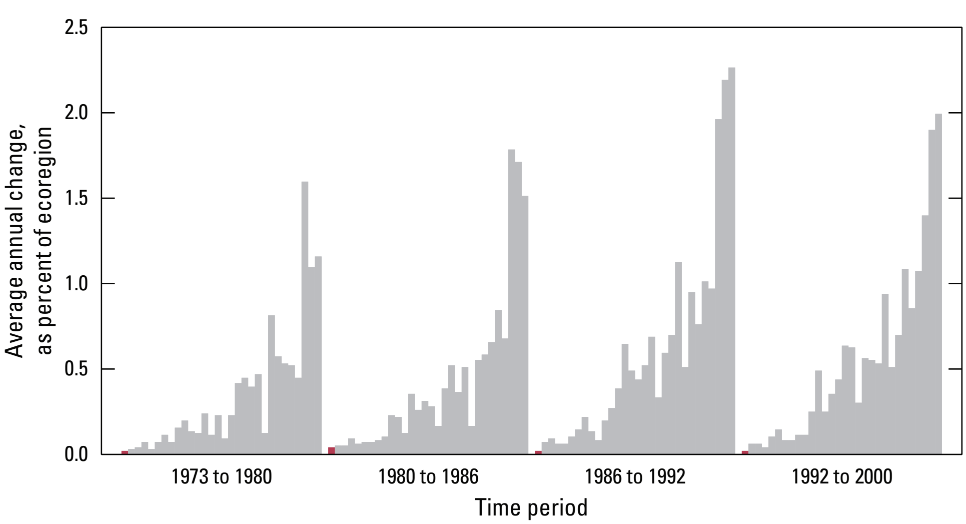


Figure 6. Estimates of land-cover change per time period normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Chihuahuan Deserts Ecoregion are represented by red bars in each time period.

the change estimates are normalized to account for the varying lengths of study periods, annual change ranged from 25 km^2 (1986–1992) to 57 km^2 (1980–1986) (table 2).

Grassland/shrubland was the predominant land cover, covering 95.6 percent of the Chihuahuan Deserts Ecoregion in 2000 (table 3; fig. 7). Forest (both riparian and higher elevation) was the second largest land cover in 2000 (2.4 percent), followed by developed lands at 1.0 percent. Water, mining, barren land, and agriculture contributed to the remaining 1.0 percent of the ecoregion's land-cover types.

Four classes changed by at least 100 km^2 during the study period: developed, mining, grassland/shrubland, and agriculture (table 3). The other classes experienced almost no change. Statistically significant, increasing trends of 11.2 percent over the study period were observed for the developed class, and the mining class nearly quadrupled in size, whereas a statistically significant, decreasing trend of 0.1 percent occurred in the grassland/shrubland class (fig. 8). No trend was apparent for agriculture, which fluctuated in gains and losses throughout the study period and had a net loss of 11.2 percent (fig. 8).

The most common conversions were grassland/shrubland to mining (217 km^2), grassland/shrubland to developed (187 km^2), and agriculture to grassland/shrubland (158 km^2) (table 4). The conversion from grassland/shrubland to mining, which occurred in each time period, was attributable to increased oil and gas extraction in the eastern part of the ecoregion (fig. 9). This type of conversion was evident in nine of the Chihuahuan Deserts Ecoregion's study blocks, which are located near the eastern border of the ecoregion and which overlie the Permian Basin, a geological province located in several counties in southeastern New Mexico and western Texas (fig. 10). More than half of the oil and gas production from Texas comes from the Permian Basin, making it the most prolific oil-producing province in United States history (Bureau of Economic Geology, 2005).

Conversion from grassland/shrubland to developed also took place during each time period, and it was the leading

Figure 7. Chihuahuan Desert grasslands south of Fort Stockton, Texas.

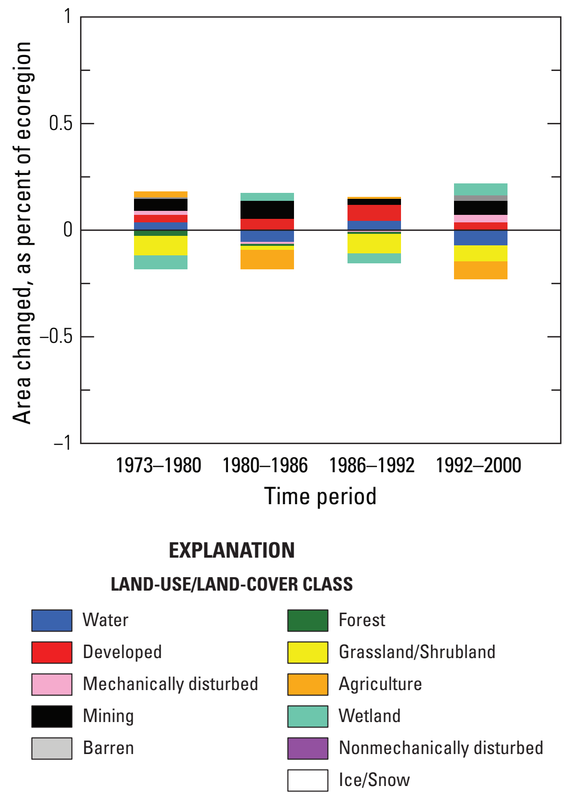


Figure 8. Normalized average net change in Chihuahuan Deserts Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3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

conversion between 1986 and 1992. The majority of mapped development increases, which were captured in three study blocks, took place in or near cities and near Holloman Air Force Base, New Mexico. Overall, developed land is estimated to have increased by 174 km^2 between 1973 and 2000.

Mining in the Chihuahuan Deserts Ecoregion is likely to continue to increase. In 2007, the U.S. Geological Survey estimated that 41 trillion ft^3 of undiscovered natural gas and 1.3 billion barrels of undiscovered oil are in the Permian Basin Province (Schenk and others, 2008). A decision in 2005 by the Bureau of Land Management allowed for oil and gas leasing and development on public lands in southern New Mexico's Sierra and Otero Counties. Publicized as one of the most restrictive plans ever developed for oil and gas leasing on federal lands, the plan provided for a variety of environmental protections and reclamation efforts for Chihuahuan Desert grasslands within the planning area (U.S. Bureau of Land Management, 2006).

Conversion of grassland/shrubland to developed is also likely to continue within the ecoregion. Areal interpolation of census-block data was used to obtain population totals for the Chihuahuan Deserts Ecoregion (U.S. Census Bureau, 2000). Using this technique, population in the ecoregion

Figure 9. Hydrocarbon-extraction facility southwest of Ozona, Texas.

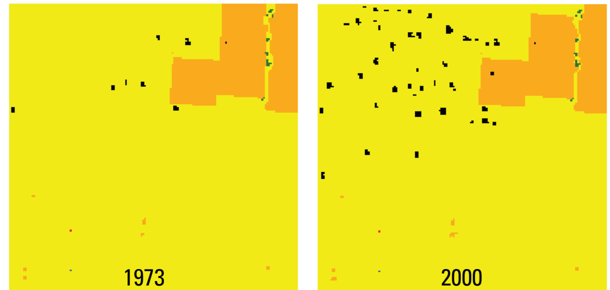


Figure 10. Sample block 24-1094, located between Pecos and Fort Stockton, Texas, showing land-use/land-cover data in 1973 (left) and 2000 (right). Between 1973 and 2000, oil and gas exploration and production increased in Permian Basin, part of Chihuahuan Deserts Ecoregion. Sample blocks show conversion between 1973 and 2000 of grassland/shrubland (yellow) to mining (black) associated with energy production; also shown are small areas of grassland/shrubland converting to agriculture (orange).

grew from 851,797 in 1980 to 1,178,626 in 2000, an increase of 38.4 percent. The population of the largest cities showed an overall increase of 67.1 percent between the 1970 and 2000 census (table 5).

A major concern in the Chihuahuan Deserts Ecoregion is the ongoing transformation of semidesert grassland into shrubland and a more desertlike ecosystem. The change in composition of the Chihuahuan grasslands has changed dramatically in the last century and continues to be observed (Brown, 1994, p. 169). Desert-scrub communities, which now make up nearly one half of the total vegetation in the Chihuahuan Desert, may have grown to their present extent through invasion of eroded grasslands (Chihuahuan Desert Research Institute, 2009). Scientists disagree, however, on the relative importance of factors such as livestock grazing, fire, and climate change as drivers of this transformation (McClaran and Van Devender, 1995, p. 265). (Note that the desertification of the Chihuahuan Desert grasslands is not reflected in the statistics of this report because capturing change within land-cover classes is not part of the Status and Trends of Land Change project design.)

Major land-cover classes changed very little in the Chihuahuan Deserts Ecoregion between 1973 and 2000. The small changes that did occur were due to increased oil and gas extraction and some urban growth, but these localized changes accounted for a small fraction of the overall ecoregion area. Except for its major cities, the ecoregion remains sparsely populated and consists mainly of large expanses of grassland and shrubland that are devoted to grazing. Little rainfall and a scarcity of both surface water and groundwater inhibit anthropogenic change in much of the ecoregion and will continue to be a challenge to future growth.

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

[Most sample pixels remained unchanged (99.5 percent), whereas 0.5 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	0.4	0.2	0.2	0.6	0.1	29.8
2	0.0	0.0	0.0	0.1	0.0	45.9
3	0.0	0.0	0.0	0.0	0.0	85.3
4	0.0	0.0	0.0	0.0	0.0	99.1
Overall spatial change	0.5	0.2	0.2	0.7	0.2	32.1

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

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

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.1	0.1	0.0	0.2	0.0	38.2	0.0
1980–1986	0.2	0.1	0.1	0.3	0.1	39.7	0.0
1986–1992	0.1	0.1	0.0	0.2	0.0	51.6	0.0
1992–2000	0.2	0.1	0.1	0.3	0.1	33.6	0.0
Estimate of change, in square kilometers							
1973–1980	198	112	87	310	76	38.2	28
1980–1986	341	200	141	541	135	39.7	57
1986–1992	151	115	36	266	78	51.6	25
1992–2000	299	148	151	447	100	33.6	37

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

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.1	0.1	0.9	1.0	0.0	0.0	0.0	0.0	0.2	0.1	2.4	1.3	95.8	2.3	0.6	0.6	0.0	0.1	0.0	0.0
1980	0.1	0.1	0.9	1.0	0.0	0.0	0.1	0.0	0.2	0.1	2.4	1.3	95.7	2.3	0.6	0.6	0.0	0.0	0.0	0.0
1986	0.1	0.1	0.9	1.0	0.0	0.0	0.1	0.1	0.2	0.1	2.4	1.3	95.7	2.3	0.6	0.5	0.0	0.0	0.0	0.0
1992	0.1	0.1	1.0	1.0	0.0	0.0	0.1	0.1	0.2	0.1	2.4	1.3	95.7	2.3	0.6	0.5	0.0	0.0	0.0	0.0
2000	0.1	0.0	1.0	1.0	0.0	0.0	0.2	0.1	0.2	0.1	2.4	1.3	95.6	2.3	0.6	0.5	0.0	0.0	0.0	0.0
Net change	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	−0.1	0.1	−0.1	0.1	0.0	0.0	0.0	0.0
Gross change	0.1	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Area, in square kilometers																				
1973	123	122	1,553	1,659	5	7	73	38	266	205	4,159	2,316	167,127	4,034	1,084	961	81	105	0	0
1980	160	175	1,581	1,675	22	26	124	65	271	205	4,139	2,298	167,043	4,050	1,107	969	25	26	0	0
1986	114	109	1,627	1,709	11	8	201	99	271	205	4,138	2,299	167,024	4,005	1,029	925	57	70	0	0
1992	153	163	1,692	1,746	5	7	227	104	271	205	4,131	2,299	166,941	4,022	1,032	926	18	19	0	0
2000	93	79	1,727	1,752	35	29	283	124	300	210	4,127	2,297	166,879	4,014	963	909	66	83	0	0
Net change	−30	46	174	116	30	28	210	98	34	49	−33	30	−249	151	−122	110	−15	22	0	0
Gross change	189	264	174	116	77	61	218	102	34	49	36	31	512	168	188	155	175	256	0	0

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

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

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Mining	51	34	23	0.0	25.8
	Wetland	Water	37	54	36	0.0	18.5
	Grassland/Shrubland	Developed	28	24	16	0.0	14.1
	Grassland/Shrubland	Agriculture	23	27	18	0.0	11.9
	Wetland	Grassland/Shrubland	20	29	20	0.0	10.0
	Other	Other	39	n/a	n/a	0.0	19.7
		Totals	198			0.1	100.0
1980–1986	Grassland/Shrubland	Mining	85	47	32	0.0	24.9
	Agriculture	Grassland/Shrubland	85	89	61	0.0	24.8
	Grassland/Shrubland	Developed	63	61	42	0.0	18.4
	Water	Wetland	32	47	32	0.0	9.4
	Developed	Grassland/Shrubland	19	28	19	0.0	5.6
	Other	Other	57	n/a	n/a	0.0	16.8
		Totals	341			0.2	100.0
1986–1992	Grassland/Shrubland	Developed	62	44	30	0.0	41.1
	Wetland	Water	41	59	40	0.0	27.0
	Grassland/Shrubland	Mining	27	18	12	0.0	18.1
	Forest	Grassland/Shrubland	7	11	7	0.0	4.8
	Mechanically disturbed	Developed	3	5	3	0.0	2.1
	Other	Other	10	n/a	n/a	0.0	6.9
		Totals	151			0.1	100.0
1992–2000	Agriculture	Grassland/Shrubland	71	67	46	0.0	23.8
	Grassland/Shrubland	Mining	53	33	23	0.0	17.8
	Water	Wetland	48	70	48	0.0	16.1
	Grassland/Shrubland	Developed	34	23	16	0.0	11.3
	Grassland/Shrubland	Mechanically disturbed	29	28	19	0.0	9.8
	Other	Other	63	n/a	n/a	0.0	21.2
		Totals	299			0.2	100.0
1973–2000 (overall)	Grassland/Shrubland	Mining	217	101	68	0.1	21.9
	Grassland/Shrubland	Developed	187	134	91	0.1	18.9
	Agriculture	Grassland/Shrubland	158	133	90	0.1	15.9
	Water	Wetland	82	120	81	0.0	8.3
	Wetland	Water	77	113	77	0.0	7.8
	Other	Other	269	n/a	n/a	0.2	27.2
		Totals	989	n/a	n/a	0.6	100.0

Table 5. Populations of largest cities in Chihuahuan Deserts Ecoregion that had both 1970 and 2000 census data. Cities of Socorro and San Elizario, Texas, and Sunland Park, New Mexico, had 2000 populations greater than 10,000, but no 1970 census data was available (U.S. Census Bureau, 2000).

City	State	1970 population	2000 population	County	Percent increase
El Paso	TX	322,261	563,662	El Paso	74.91
Las Cruces	NM	37,857	74,267	Dona Ana	96.18
Roswell	NM	33,908	45,293	Chaves	33.58
Alamogordo	NM	23,035	35,582	Otero	54.47
Del Rio	TX	21,330	33,867	Val Verde	58.78
Carlsbad	NM	21,297	25,625	Eddy	20.32
Deming	NM	8,343	14,116	Luna	69.20
Artesia	NM	10,315	10,692	Eddy	3.65
Silver City	NM	8,557	10,545	Grant	23.23
	Total	486,903	813,649		
	Total increase:		67.11%	Average increase:	48.26%

References Cited

Brown, D.E., 1994, Biotic communities—Southwestern United States and northwestern Mexico: Salt Lake City, University of Utah Press, 342 p.

Buffington, L., and Herbel, C., 1964, Vegetational changes on a semidesert grassland range from 1858 to 1963: U.S. Department of Agriculture, Jornada Experimental Range, accessed June 8, 2009, at http://usda-ars.nmsu.edu/biblio/pdf/091.pdf.

Bureau of Economic Geology, 2005, Oil and gas production in Texas: Bureau of Economic Geology, The University of Texas at Austin, accessed April 3, 2009, at http://www.beg.utexas.edu/UTopia/images/pagesizemaps/oilgas.pdf.

Chihuahuan Desert Research Institute, 2009, The Chihuahuan Desert—Major plant communities: Chihuahuan Desert Research Institute, accessed October 30, 2006, at http://cdri.org/desert-explorer/the-chihuahuan-desert-2/major-plant-communities/.

Conservation History Association of Texas, 2009, The Texas Legacy Project—An archive and documentary series: Conservation History Association of Texas, accessed March 30, 2009, at http://www.texaslegacy.org/bb/regions/transpecos.html.

Daly, C., Gibson, W., and Taylor, G., 2002, Development of a 103-year high-resolution climate data set for the conterminous United States: Corvallis, Oregon State University, The PRISM Climate Group, accessed April, 4, 2009, at http://www.prism.oregonstate.edu.

Gucker, C.L., 2006, Agave lechuguilla, *in* Fire effects information system: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory database, accessed March 24, 2009, at http://www.fs.fed.us/database/feis/plants/shrub/agalec/all.html#INTRODUCTORY.

Hoyt, C.A., 2002, The Chihuahuan Desert: Diversity at Risk: Endangered Species Bulletin, v. XXVII, no. 2, accessed November 2, 2006, at http://www.fws.gov/Endangered/bulletin/2002/03-06/16-17.pdf.

Lowe, C.H., 1964, The vertebrates of Arizona: Tucson, The University of Arizona Press.

McClaran, M.P., and Van Devender, T.R., 1995, The desert grassland: Tucson, The University of Arizona Press.

National Park Service, 2005, Inventory & Monitoring Program, Chihuahuan Desert Network: National Park Service database, accessed March 26, 2009, at http://science.nature.nps.gov/im/units/chdn/CHDN.cfm.

National Park Service, 2007, Weather and climate inventory, National Park Service, Chihuahuan Desert Network: National Park Service, Natural Resource Technical Report NPS/CHDN/NRTR—2007/034, WRCC Report 2007-09, accessed April 3, 2009, at http://www.wrcc.dri.edu/nps/reports/2007_04_24_chdninventory_final.pdf.

New Mexico State University, 2007, The Chihuahuan Desert: New Mexico State University database, accessed March 20, 2009, at http://ddl.nmsu.edu/chihuahua.html.

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

Schenk, C.J., Pollastro, R.M., Cook, T.A., Pawlewicz, M.J., Klett, T.R., Charpentier, R.R., and Cook, H.E., 2008, Assessment of undiscovered oil and gas resources of the Permian Basin Province of west Texas and southeast New Mexico, 2007: U.S. Geological Survey Fact Sheet 2007–3115, 4 p., accessed April 3, 2009, at http://pubs.usgs.gov/fs/2007/3115/.

Schmidt, R.H., Jr., 1983, Chihuahuan climate, *in* Second symposium on resources of the Chihuahuan Desert region, United States and Mexico, 20-21 October 1983: Alpine, Tex., Chihuahuan Desert Research Institute.

U.S. Bureau of Land Management, 2006, Record of decision and resource management plan amendment for McGregor Range in Otero County, New Mexico: accessed April 3, 2009, at http://www.blm.gov/pgdata/etc/medialib/blm/nm/field_offices/las_cruces/las_cruces_planning/mcgregor_range.Par.2140.File.dat/Final_ROD_RMPA.pdf.

U.S. Census Bureau, 2000, U.S. Census, 2000, accessed April 3, 2009, at http://www.census.gov/prod/www/abs/decennial/index.htm.

U.S. Department of Agriculture, 2007, Census of Agriculture—State Level Data, New Mexico: U.S. Department of Agriculture, v. 1, chap. 1, at http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/New_Mexico/index.asp.

U.S. Department of Agriculture, 2008, Chihuahuan Desert RC&D area: U.S. Department of Agriculture, Natural Resources Conservation Service database, accessed March 26, 2009, at http://www.tx.nrcs.usda.gov/Programs/rcd/Chihuahuan_Desert.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.

West, C.T., and Vásquez-León, M., 2008, Misreading the Arizona landscape: Reframing analyses of environmental degradation in southeastern Arizona: Human Organization, v. 67, no. 4.

Chapter 28

Madrean Archipelago Ecoregion

By Jana Ruhlman, Leila Gass, and Barry Middleton

Ecoregion Description

The Madrean Archipelago Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997), also known as the “Madrean Sky Islands” or “Sky Islands,” covers an area of approximately 40,536 km^2 (15,651 mi^2) in southeastern Arizona and southwestern New Mexico (fig. 1). The ecoregion is bounded on the west by the Sonoran Basin and Range Ecoregion, on the east by the Chihuahuan Deserts Ecoregion, and on the north by the Arizona/New Mexico Mountains Ecoregion. This area of basin-and-range topography is one of the most biologically diverse in the world (Koprowski, 2005; Skroch, 2008). Although the mountains in the ecoregion bridge the Rocky Mountains to the north and the Sierra Madre Occidental in Mexico to the south (U.S. Environmental Protection Agency, 1997), the lower elevations act as a barrier to species dispersal. Nevertheless, the geographic convergence of these two major continental mountain ranges, as well as of the Chihuahuan Desert to the east and the Sonoran Desert to the west, forms the foundation for ecological interactions found nowhere else on Earth (Skroch, 2008).

A rise in elevation, from approximately 600 m in the lowlands to over 3,000 m in the mountains (Mount Graham summit, 3,267 m), is accompanied by dramatic gradients in temperature and precipitation, coinciding with at least eight distinct life zones (Skroch, 2008). Lower, hot and dry plains support desert and semiarid grasslands vegetation. Woodlands of oak (*Quercus* spp.) and juniper (*Juniperus* spp.) grow on lower slopes. Colder and wetter climates at higher elevations support ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and Engelmann spruce (*Picea engelmannii*) (figs. 2–4).

Climate summaries for 10 urban areas in the lowlands indicate that they average annual minimum and maximum

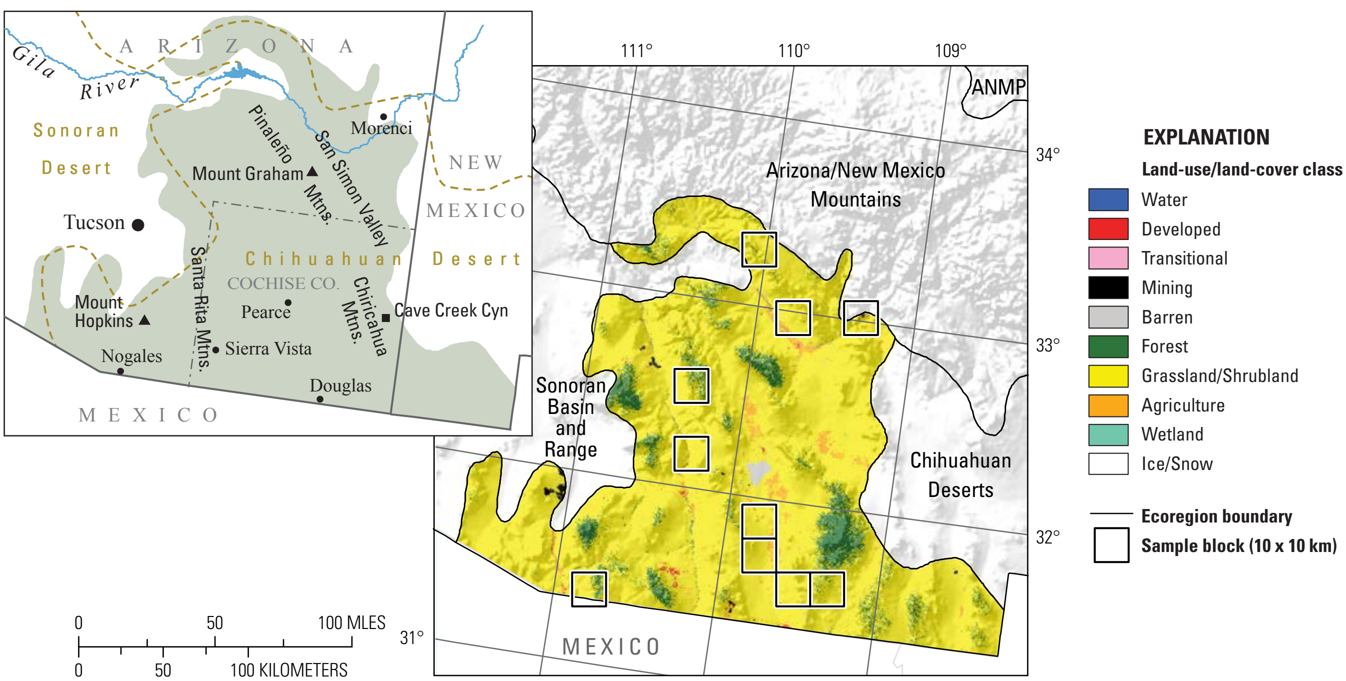


Figure 1. Map of Madrean Archipelago Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status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

Figure 2. View southeast toward San Simon Valley from Mount Graham, in Pinaleño Mountains in Arizona, showing diverse topography of Madrean Archipelago Ecoregion.

Figure 3. Whipple Observatory (elevation 2,623 m) on Mount Hopkins, in Santa Rita Mountains, south of Tucson, Arizona. Land cover includes grassland, oak woodland, and montane forest.

Figure 4. Grassland park near Cave Creek Canyon, in Chiricahua Mountains, Arizona.

temperatures of 7.9ºC and 25.7ºC, respectively (Western Regional Climate Center, 2009). Lowe (1964) described decreases in temperature of 2.2ºC and increases in precipitation of 100 to 125 mm for every 305 m gain in elevation. Estimates from the Parameter-elevation Regressions on Independent Slopes Model (Daly and others, 2002) indicate that as much as 1,118 mm of annual precipitation is received on mountaintops (fig. 5). The ecoregion receives a biseasonal rainfall regime, with frontal precipitation in winter and convective thunderstorms in summer. The large elevation and precipitation gradients caused by topography, coupled with the north-south convergence of multiple floral and faunal realms, are both important geographic factors that contribute to the high biodiversity in the Madrean Archipelago Ecoregion (Coblentz and Riitters, 2005).

The Madrean Archipelago Ecoregion is sparsely populated. Sierra Vista, Arizona, is the largest city in the ecoregion, having a 2000 census population of 37,775. Nogales and Douglas, Arizona, are the next largest cities, having populations of 20,878 and 14,312, respectively (U.S. Census Bureau, 2000). Farming and ranching are the principal industries of the ecoregion (fig. 6). Primary irrigated crops are corn, wheat, grain, alfalfa hay, and cotton (U.S. Department of Agriculture, 2004).

Contemporary Land-Cover Change (1973 to 2000)

As measured by the project methodology, the Madrean Archipelago Ecoregion experienced little land-cover change during the study period. An estimated 1.4 percent (575 km^2) of the ecoregion converted to other land-cover classes during the study period (table 1). The relative error is high at 33.7 percent, which is not unusual for an ecoregion with very little change. Compared to other western United States ecoregions, change in the Madrean Archipelago Ecoregion was low (figs. 7,8). However, change in this ecoregion is consistent with that of other ecoregions in the southwestern United States.

Total estimated change in land cover per time period varied from a high of 0.5 percent between 1973 and 1980 and between 1980 and 1986 to a low of 0.3 percent between 1992 and 2000 (table 2). When the total change estimates were normalized to account for the varying lengths of the time periods between satellite imagery dates, the period between 1992 and 2000 had a near 0 percent rate of change per year, while the other three time periods had 0.1 percent change per year (table 2).

A closer look at the net-change estimates reveals that each time period experienced a net increase for the mining and developed classes, although the size of the gains varied between time periods (fig. 9). Grassland/shrubland was the predominant land cover of the ecoregion (estimated at 87.9 percent in 2000), and this class experienced the greatest absolute amount of net change, with a net loss of 0.7 percent (271 km^2) during the study period (table 3). Analysis of this

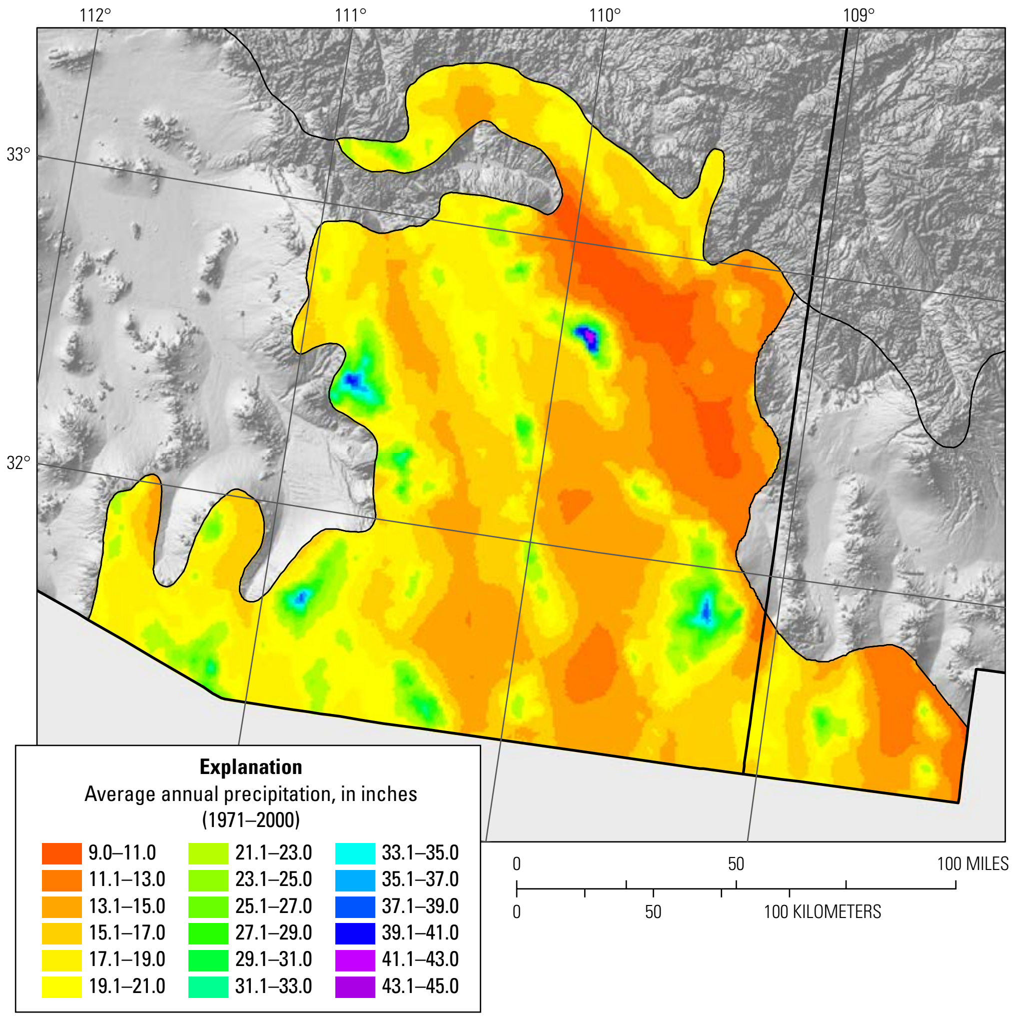


Figure 5. Estimated average annual precipitation in Madrean Archipelago Ecoregion between 1971 and 2000. Highest precipitation rates (shades of green, blue, purple) on mountaintops sustain evergreen woodlands and montane forests, whereas more arid lowland areas are covered in grassland and desert vegetation.

Figure 6. Harvested cotton field in Gila River valley, Arizona.

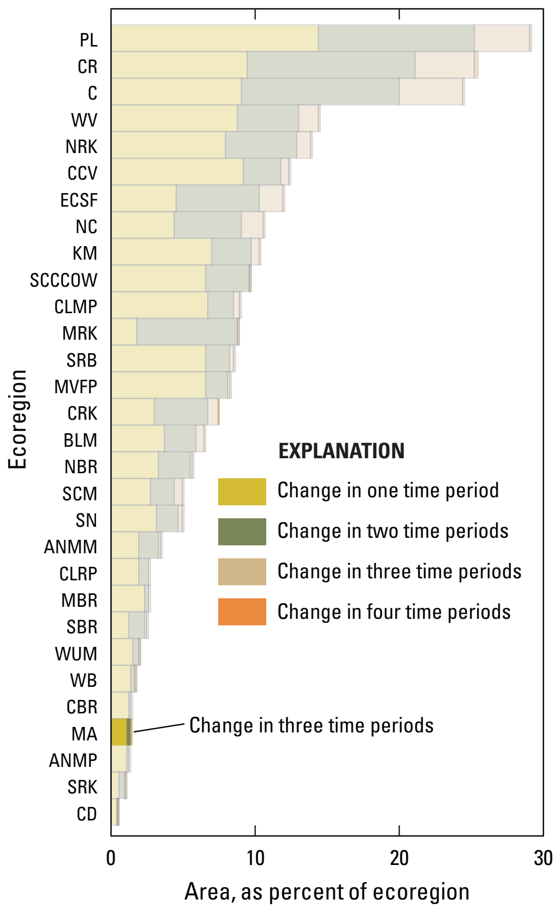


Figure 7. Overall spatial change in Madrean Archipelago Ecoregion (MA; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial change in Madrean Archipelago Ecoregion (three time periods) labeled for clarity. See table 2 for years covered by each time period. See appendix 2 for key to ecoregion abbreviations.

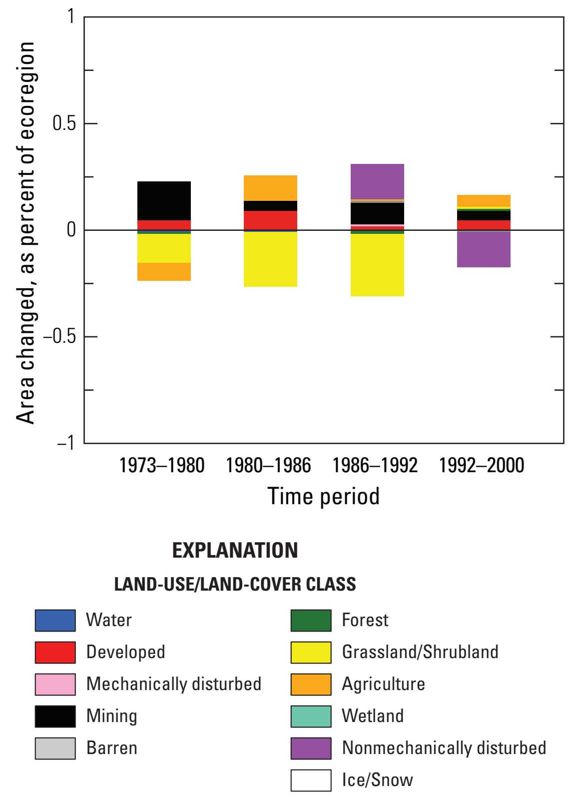
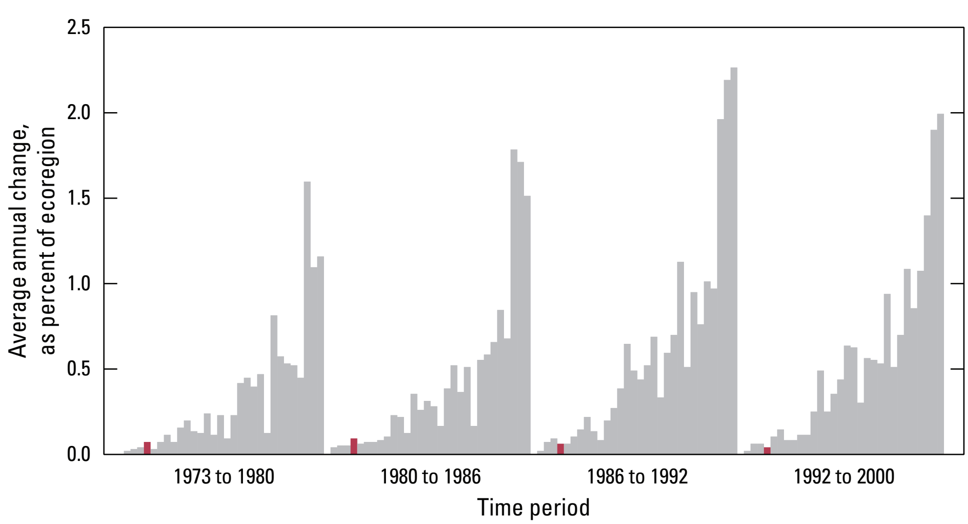


Figure 9. Normalized average net change in Madrean Archipelago Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 3 for definitions of land-use/land-cover classifications.

Figure 8. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Madrean Archipelago Ecoregion are represented by red bars in each time period.



class per time period shows net losses for the first three time periods but a slight gain between 1992 and 2000 (fig. 9).

The second and third most common land-cover types in 2000 were forest (5.3 percent) and agriculture (3.9 percent), followed by mining (1.1 percent). Although developed land was estimated at just 1.0 percent in 2000, it expanded 34 percent (98 km^2) over the course of the study; its increases were associated with small declines in grassland/shrubland. Overall, no statistically significant trends were observed during the study period.

The two most common conversions from 1973 to 2000 were grassland/shrubland to mining and grassland/shrubland to agriculture (table 4). Grassland/shrubland to developed land was the third most common conversion in all time periods except between1986 and 1992, when it ranked fourth. The conversion of 65 km^2 from grassland/shrubland to nonmechanically disturbed between 1986 and 1992 and its reversion back to grassland in the following period (1992–2000) was probably due to a fire event, followed by quick revegetation of the area.

This study's analysis clearly indicates that the Madrean Archipelago Ecoregion experienced very little land-cover change between 1973 and 2000. Reasons for this stability are diverse, but the principal factor is probably the sparse population of the region. Other possible contributing factors include the high percentage of federal land in the ecoregion (approximately 48 percent), the scarcity of water, and the mountainous terrain, all of which inhibit large amounts of anthropogenic change. The lack of statistically significant trends and the high levels of uncertainty prohibit drawing clear-cut conclusions, but each time period experienced an increase in the developed and mining land-cover classes. The increase in developed land between 1973 and 2000 is shown on fig. 10.

The steady increase in developed land may be correlated to increased population in the Madrean Archipelago Ecoregion. U.S. Census Bureau (2000) figures show that the population of the three Arizona counties that form most of the Madrean Archipelago Ecoregion grew an average of 122 percent between 1970 and 2000, an increase of 97,163 persons. Population growth is predicted to continue, both in the currently populated areas and in the rural parts of the ecoregion (Carreira, 2005). In rural Cochise County alone, the population increased 11.5 percent between 2000 and 2010, from 117,755 persons in 2000 to 131,346 persons in 2010 (U.S. Census Bureau, 2010), likely owing to its proximity to a major highway, railroads, and the United States–Mexico border, as well as its amenable climate, cultural history, growing golf-course communities, outdoor-recreation opportunities, and fertile agricultural lands (Cochise County, 2012).

The land-cover transformation from grassland/shrubland to mining in all four time periods was primarily attributable to the observed growth of the massive open-pit copper mine at Morenci, Arizona, one of five major copper mines located within the ecoregion (Arizona Department of Mines and Mineral Resources, 2008). The gains in the developed and mining classes all came at the expense of the grassland/shrubland class, but the total converted area totaled only 271 km^2 over entire the study period.

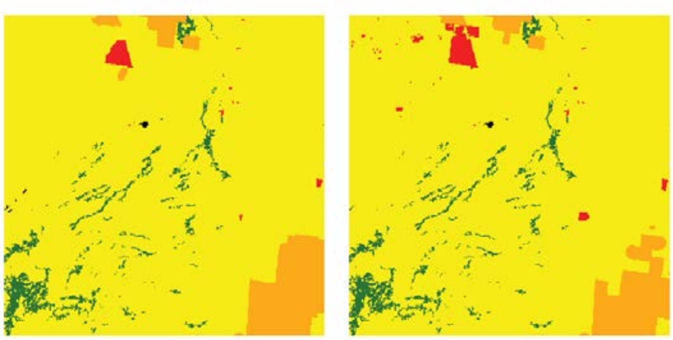


Figure 10. Sample block 79-6, centered over Pearce, Arizona, showing land-use/land-cover data in 1973 (left) and 2000 (right). Sample blocks show expansion of developed land (red) between 1973 and 2000, especially in Sunsites, Arizona, which is a growing, unincorporated retirement and golf community in northern part of sample block. Also shown are areas of agricultural land (orange) that reverted back to grassland/shrubland (yellow).

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

[Most sample pixels remained unchanged (98.6 percent), whereas 1.4 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.2	0.7	0.4	1.9	0.5	39.9
2	0.2	0.2	0.0	0.5	0.1	61.9
3	0.0	0.0	0.0	0.0	0.0	63.3
4	0.0	0.0	0.0	0.0	0.0	0.0
Overall spatial change	1.4	0.8	0.7	2.2	0.5	33.7

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

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

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.5	0.3	0.1	0.8	0.2	47.2	0.1
1980–1986	0.5	0.3	0.2	0.9	0.2	41.8	0.1
1986–1992	0.4	0.3	0.1	0.6	0.2	46.1	0.1
1992–2000	0.3	0.2	0.1	0.6	0.1	45.4	0.0
Estimate of change, in square kilometers							
1973–1980	185	137	47	322	87	47.2	26
1980–1986	210	138	72	348	88	41.8	35
1986–1992	145	105	40	251	67	46.1	24
1992–2000	132	95	38	227	60	45.4	17

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

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.1	0.1	0.7	0.4	0.0	0.0	0.7	1.0	0.6	0.4	5.3	2.5	88.5	4.3	3.8	2.5	0.2	0.3	0.0	0.0
1980	0.1	0.1	0.8	0.4	0.0	0.0	0.9	1.3	0.6	0.4	5.3	2.5	88.4	4.4	3.7	2.5	0.2	0.3	0.0	0.0
1986	0.1	0.1	0.9	0.4	0.0	0.0	0.9	1.4	0.6	0.4	5.3	2.5	88.2	4.5	3.8	2.7	0.2	0.3	0.0	0.0
1992	0.1	0.1	0.9	0.4	0.0	0.0	1.0	1.5	0.6	0.4	5.3	2.5	87.9	4.4	3.8	2.7	0.2	0.3	0.2	0.2
2000	0.1	0.1	1.0	0.4	0.0	0.0	1.1	1.6	0.6	0.4	5.3	2.5	87.9	4.5	3.9	2.8	0.2	0.3	0.0	0.0
Net change	0.0	0.0	0.2	0.1	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.0	−0.7	0.7	0.1	0.4	0.0	0.0	0.0	0.0
Gross change	0.0	0.0	0.2	0.1	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.0	1.3	0.8	0.6	0.5	0.0	0.0	0.3	0.5
Area, in square kilometers																				
1973	41	41	298	155	6	9	289	417	259	178	2,154	1,015	35,891	1,744	1,528	1,033	70	104	0	0
1980	40	41	319	165	6	9	364	527	255	176	2,151	1,016	35,838	1,775	1,493	1,006	70	104	0	0
1986	38	41	357	164	6	9	381	554	258	177	2,151	1,016	35,735	1,814	1,541	1,098	70	104	0	0
1992	40	41	366	164	6	9	424	616	260	177	2,144	1,018	35,615	1,791	1,546	1,099	70	104	65	97
2000	40	41	387	169	6	9	443	644	256	176	2,146	1,018	35,620	1,837	1,569	1,121	70	104	0	0
Net change	−1	3	89	59	0	0	153	227	−2	6	−8	15	−271	269	41	157	0	0	0	0
Gross change	6	6	90	60	1	1	158	226	19	16	18	13	538	309	230	198	0	0	129	194

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

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

Period	From class	To class	Area changed (km^2)	Margin of error (+/– km^2)	Standard error (km^2)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Mining	73	108	69	0.2	39.6
	Agriculture	Grassland/Shrubland	59	59	38	0.1	32.0
	Grassland/Shrubland	Developed	21	23	14	0.1	11.1
	Grassland/Shrubland	Agriculture	19	16	10	0.0	10.4
	Barren	Agriculture	4	7	4	0.0	2.4
	Other	Other	8	n/a	n/a	0.0	4.5
		Totals	185			0.5	100.0
1980–1986	Grassland/Shrubland	Agriculture	92	137	87	0.2	43.8
	Agriculture	Grassland/Shrubland	37	42	27	0.1	17.8
	Grassland/Shrubland	Developed	34	32	20	0.1	16.0
	Grassland/Shrubland	Mining	24	34	21	0.1	11.6
	Mining	Grassland/Shrubland	8	9	6	0.0	4.1
	Other	Other	14	n/a	n/a	0.0	6.8
		Totals	210			0.5	100.0
1986–1992	Grassland/Shrubland	Nonmechanically disturbed	65	97	61	0.2	44.6
	Grassland/Shrubland	Mining	39	56	36	0.1	27.1
	Grassland/Shrubland	Agriculture	10	10	6	0.0	6.9
	Grassland/Shrubland	Developed	6	7	4	0.0	4.4
	Grassland/Shrubland	Barren	5	7	4	0.0	3.1
	Other	Other	20	n/a	n/a	0.0	13.9
		Totals	145			0.4	100.0
1992–2000	Nonmechanically disturbed	Grassland/Shrubland	65	97	61	0.2	48.9
	Grassland/Shrubland	Agriculture	23	27	17	0.1	17.4
	Grassland/Shrubland	Developed	21	13	8	0.1	15.6
	Grassland/Shrubland	Mining	19	28	18	0.0	14.1
	Barren	Grassland/Shrubland	3	5	3	0.0	2.5
	Other	Other	2	n/a	n/a	0.0	1.5
		Totals	132			0.3	100.0
1973–2000 (overall)	Grassland/Shrubland	Mining	155	226	144	0.4	23.1
	Grassland/Shrubland	Agriculture	144	177	112	0.4	21.4
	Agriculture	Grassland/Shrubland	100	92	59	0.2	15.0
	Grassland/Shrubland	Developed	81	56	36	0.2	12.1
	Grassland/Shrubland	Nonmechanically disturbed	65	97	61	0.2	9.6
	Other	Other	126	n/a	n/a	0.3	18.8
		Totals	672			1.7	100.0

References Cited

Arizona Department of Mines and Mineral Resources, 2008, Arizona major mines: Arizona Department of Mines and Mineral Resources, accessed July 29, 2008, at http://mines.az.gov/Info/MajorMines08.pdf.

Carreira, R., 2005, Populations projected to 2015 for Cochise, Santa Cruz counties, *in* The Indicator: Cochise College, Center for Economic Research, v. 8, no. 2, accessed July 30, 2008, at http://www.cochise.edu/deptsdirs/organizations/cer/documents/indicator/IndicatorSpring05.pdf.

Coblentz, David, and Riitters, K.H., 2005, A quantitative topographic analysis of the Sky Islands—A closer examination of the topography-biodiversity relationship in the Madrean Archipelago, *in* Gottfried, G.J., and others, comps., Connecting mountain islands and desert seas—Biodiversity and management of the Madrean Archipelago II: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-36, p. 69–74, accessed July 29, 2008, at http://www.treesearch.fs.fed.us/pubs/23173.

Cochise County, 2012, Economic Development: Cochise County, Arizona, accessed March 22, 2012, at http://cochise.az.gov/cochise_economic_development.aspx?id=1584.

Daly, C., Gibson, W., and Taylor, G., 2002, Development of a 103-year high-resolution climate data set for the conterminous United States: Corvallis, Oregon State University, The PRISM Climate Group, accessed July, 22, 2008, at http://www.prism.oregonstate.edu.

Koprowski, J.L., Edelman, A.J., Pasch, B.S., and Buecher, D.C., 2005, A dearth of data on the mammals of the Madrean Archipelago—What we think we know and what we actually do know, *in* Gottfried, G.J., and others, comps., Connecting mountain islands and desert seas—Biodiversity and management of the Madrean Archipelago II: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-36, p. 412–415, available at http://www.treesearch.fs.fed.us/pubs/21519.

Lowe, C.H., 1964, Vertebrates of Arizona: Tucson, The University of Arizona Press, p. 10, 85.

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

Skroch, M., 2008, Sky Islands of North America—A globally unique and threatened inland archipelago: Terrain.org, A Journal of the Built & Natural Environments, Winter/Spring Issue, no. 21, Islands & Archipelagos, p. 147–152. (Available at http://www.terrain.org/articles/21/skroch.htm.)

U.S. Census Bureau, 2000, State & county quickfacts: U.S. Census Bureau database, accessed July 29, 2008, at http://quickfacts.census.gov/qfd/states/.

U.S. Census Bureau, 2010, State & county quickfacts: U.S. Census Bureau database, accessed March 22, 2012, at http://quickfacts.census.gov/qfd/states/04/04003.html.

U.S. Department of Agriculture, 2004, 2002 census of agriculture, Arizona state and county data: U.S. Department of Agriculture, National Agricultural Statistics Service, Geographic Area Series, v. 1, pt. 3, AC-02-A-3, p. 204–207, accessed July 22, 2008, at http://www.agcensus.usda.gov/Publications/2002/Volume_1,_Chapter_2_County_Level/Arizona/st04_2_001_001.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 & Remote Sensing, v. 67, p. 650–662.

Western Regional Climate Center, 2009, SOD USA climate archive: Desert Research Institute, Western Regional Climate Center, accessed July 22, 2008, at http://www.wrcc.dri.edu/summary/.

Chapter 29

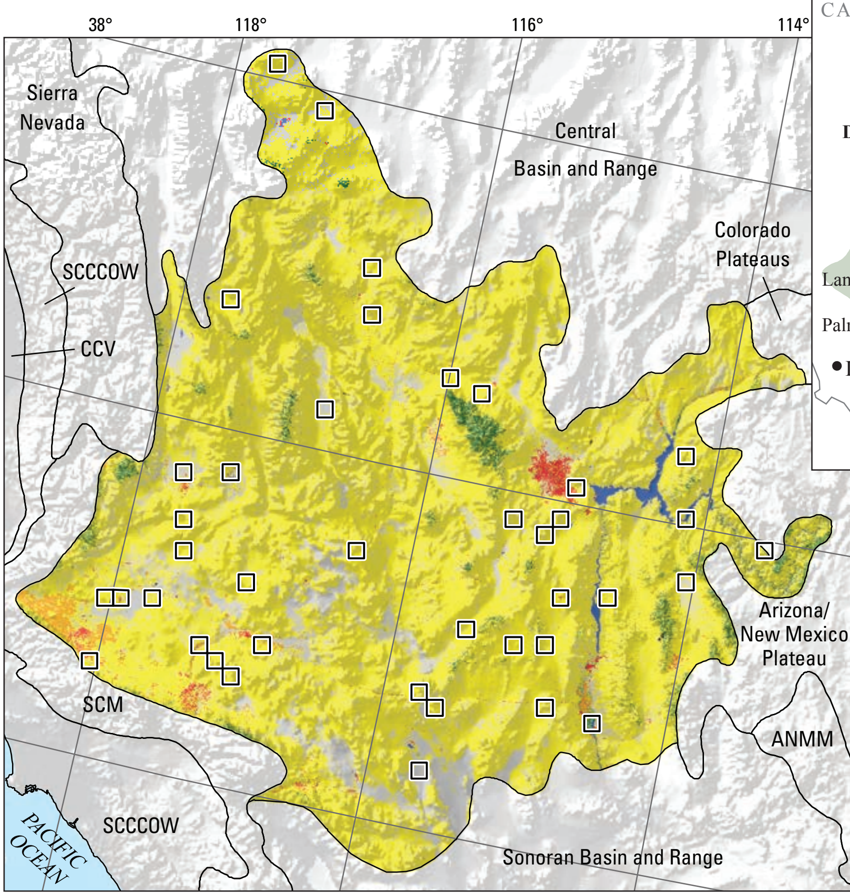
Mojave Basin and Range Ecoregion

By Benjamin M. Sleeter and Christian G. Raumann

This chapter has been modified from original material published in Sleeter and Raumann (2006), entitled “Land-cover trends in the Mojave Basin and Range Ecoregion” (U.S. Geological Survey Scientific Investigations Report 2006–5098).

Ecoregion Description

The Mojave Basin and Range Ecoregion (Omernik, 1987; U.S. Environmental Protection Agency, 1997) covers approximately 130,922 km^2 (50,549 mi^2) in the southwestern United States. The ecoregion, which encompasses parts of four states, includes the Mojave Desert and much of the other desert areas in southeastern California, as well as a large part of the southern Nevada desert (fig. 1). The ecoregion is bounded on the north by the Central Basin and Range Ecoregion, on the east by the Colorado Plateaus and the Arizona/New Mexico Plateau Ecoregions, on the south by the Sonoran Basin and Range Ecoregion, and on the west by the Southern California Mountains and the Sierra Nevada Ecoregions.



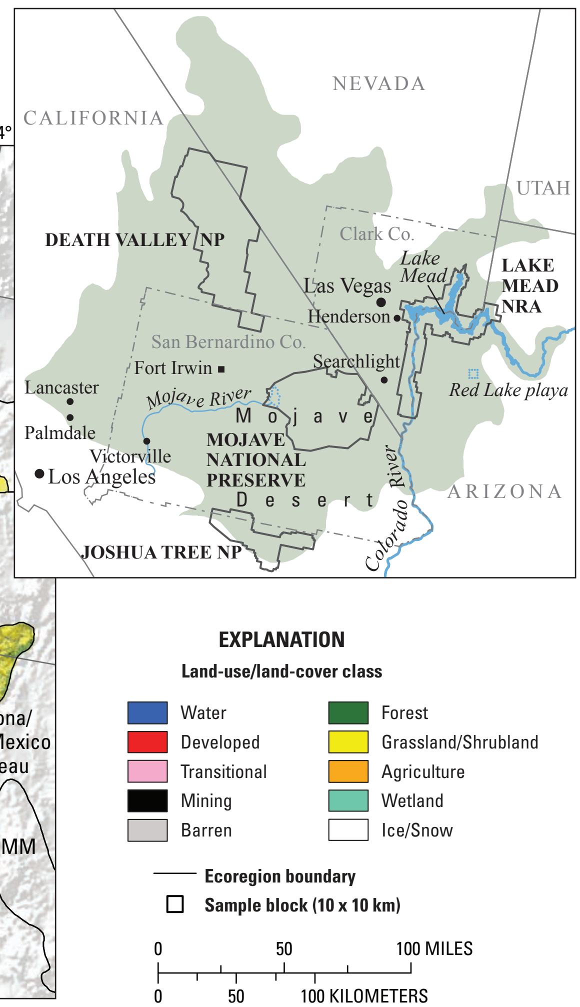


Figure 1. Map of Mojave Basin and Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status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

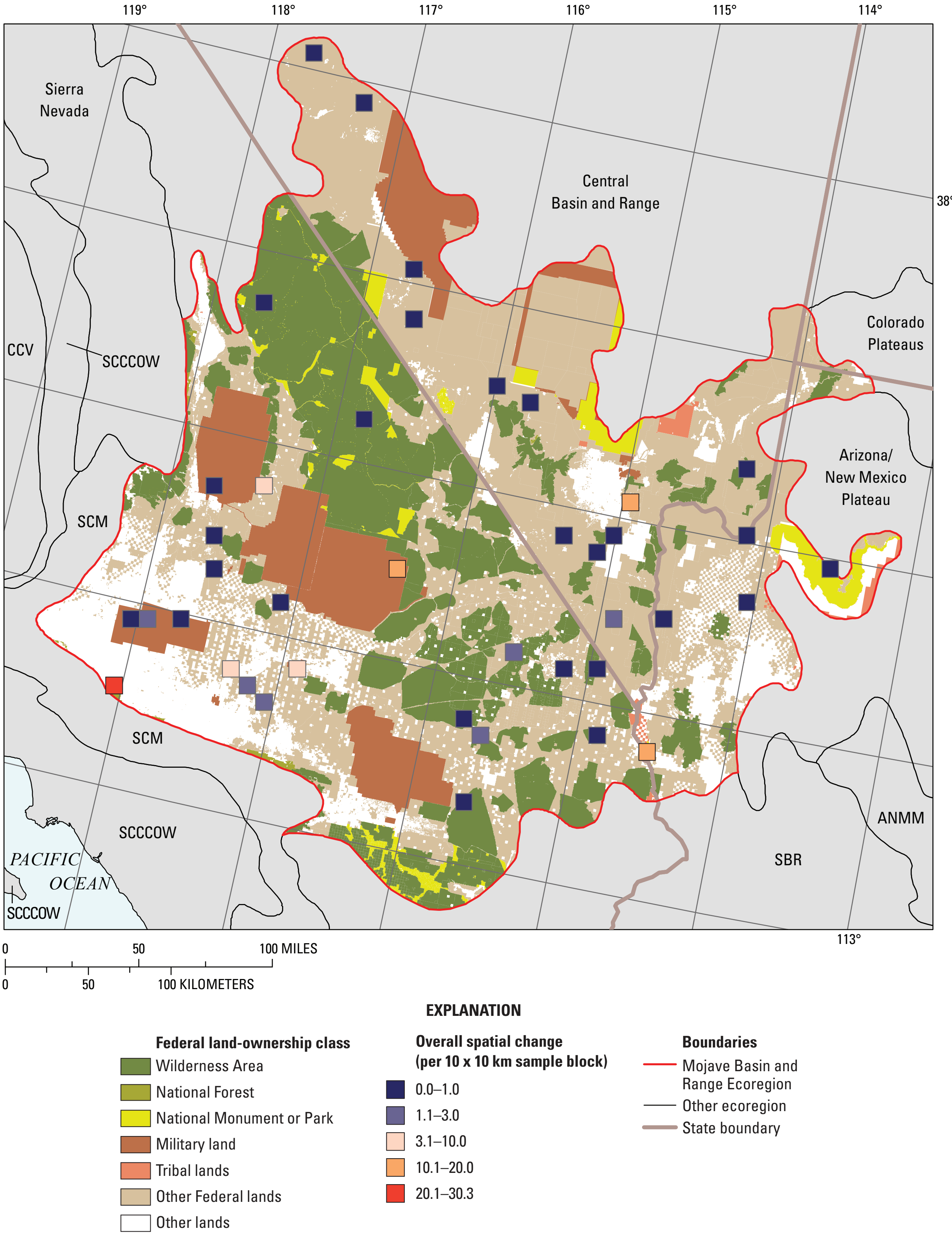


Figure 2. Federal land ownership and cumulative land-use/land-cover change (as percent of sample-block area) from 1973 to 2000 in Mojave Basin and Range Ecoregion. Land-ownership data from National Atlas of the United States (2006). See appendix 2 for abbreviations for Western United States ecoregions.

Figure 3. Construction of new hotel, resort, and lake (Lake Las Vegas) outside of Henderson, Nevada.

Figure 4. Abandoned mine shaft outside Searchlight, Nevada.

Figure 5. Staging and camping area for off-highway-vehicle users near Red Lake playa, Arizona, located about 30 km southeast of Lake Mead.

The Mojave Basin and Range Ecoregion is characterized by distinct fault-bounded mountain ranges that typically run northeast to southwest. The ecoregion receives very little annual precipitation (50–250 mm in the valleys), which, when combined with high temperatures during summer months, results in an ecoregion slow to recover from anthropogenic disturbances (Hunter and others, 2003). Federal lands constitute approximately 81 percent of the total land area (fig. 2), with major holdings under the jurisdiction of the Bureau of Land Management, National Park Service, and Department of Defense. Grasslands and shrublands dominate the ecoregion, whereas developed land accounts for only 1.5 percent of total land area (Vogelmann and others, 2001). Although developed land is limited, the two major urban areas found in the ecoregion are among the fastest growing locales in the western United States. Las Vegas, Nevada, is the major urban center within the ecoregion (fig. 3), although the cities of Palmdale and Lancaster, California, also had significant growth between 1973 and 2000.

The Mojave Basin and Range Ecoregion has long supported human activities such as livestock grazing, mining, military training, and recreation, all of which have had some effect on the desert landscape (Lovich and Bainbridge, 1999). Agriculture, although not extensive, takes place along the Colorado and Mojave Rivers. Mining, which historically has been an important land-use activity, is found throughout the ecoregion wherever mineral resources are available (fig. 4). Recreation activities have become increasingly important in the ecoregion, with millions of people each year visiting Death Valley National Park, Mojave National Preserve, and Lake Mead National Recreation Area, as well as numerous open-access Bureau of Land Management lands (fig. 5).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change (that is, the percentage of area that changed at least one time between 1973 and 2000) in the Mojave Basin and Range Ecoregion is estimated at 2.7 percent (3,474 km^2), which is low when compared to other western United States ecoregions (fig. 6). The ecoregion also showed low rates of change across all time periods when compared to other western United States ecoregions (fig. 7). The period between 1986 and 1992 had the highest estimated rate of change, at 1.3 percent. In addition, when change estimates are normalized to account for the varying lengths of the time periods, change remained highest between 1986 and 1992, at 0.2 percent per year, whereas the other three time periods (1973–1980, 1980–1986, and 1992–2000) are estimated at 0.07 to 0.08 percent per year (table 2).

The largest change in any one land-cover class was the estimated loss of 2,387 km^2 of grassland/shrubland, a 2.0

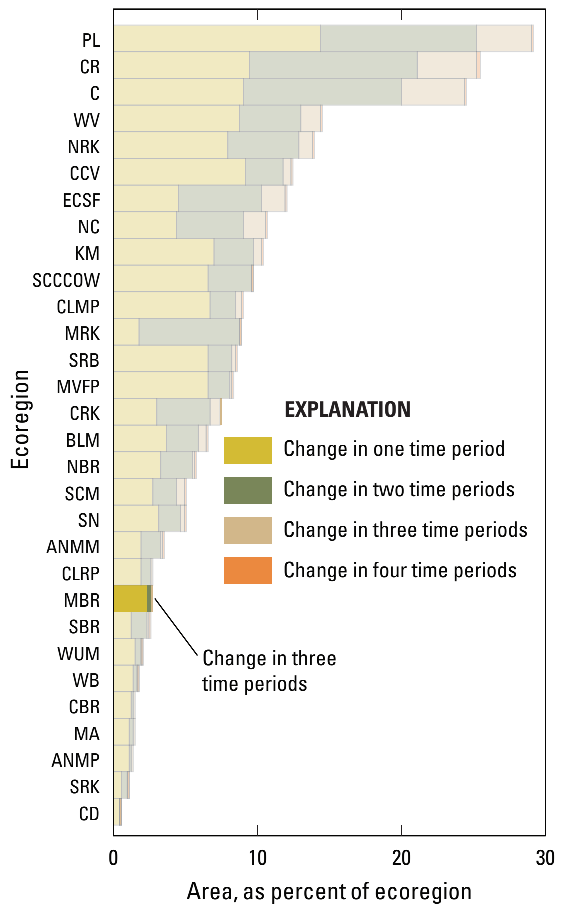


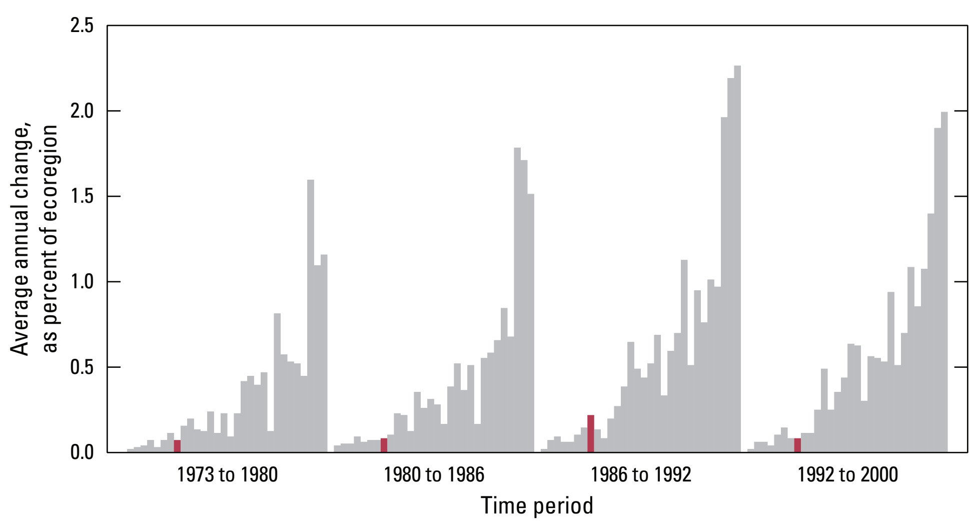
Figure 6. Overall spatial change in Mojave Basin and Range Ecoregion (MBR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of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

percent decline. In 1973, grassland/shrubland is estimated to account for 89.2 percent of the ecoregion. In 2000, grassland/shrubland accounted for 87.4 percent of the ecoregion. The second largest change was the addition of 1,673 km^2 of developed land, which increased from 1.5 percent of the ecoregion in 1973 to 2.8 percent of the ecoregion in 2000. Estimates of land-cover composition for all classes for each time period can be found in table 3. Normalized net change values for all classes for each time period can be found in figure 8.

The dominant land-cover change that occurred in the Mojave Basin and Range Ecoregion was the conversion of grassland/shrubland to developed land. An estimated 1,426 km^2 of grassland/shrubland were converted to developed land between 1973 and 2000, with 52.7 percent (751 km^2) converting between 1986 and 1992. Grassland/shrubland converting to mechanically disturbed and mining, forest converting to mechanically disturbed, and mechanically disturbed converting to developed were the other top land-cover conversions between 1973 and 2000 (table 4). Combined, these conversions account for an estimated 78.5 percent of all changes in the ecoregion.

Population growth in the Mojave Basin and Range Ecoregion, much of it spillover from the Los Angeles, California, metropolitan area, was the primary driver of change in the ecoregion. In three of the four time periods (1973–1980, 1980–1986, and 1986–1992), grassland/shrubland converting directly to developed land was the most common conversion and, between 1992 and 2000, the second most common conversion. New developed land was added to the ecoregion at an average rate of 62 km^2 per year, an estimated total of 1,680 km^2 over the 27-year study period. Development was not dispersed evenly across the ecoregion. On the basis of field observations, increases in developed land appeared to be concentrated in two main regions, the Las Vegas, Nevada, metropolitan area and the cities of Victorville, Lancaster, and Palmdale, California, in the western

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



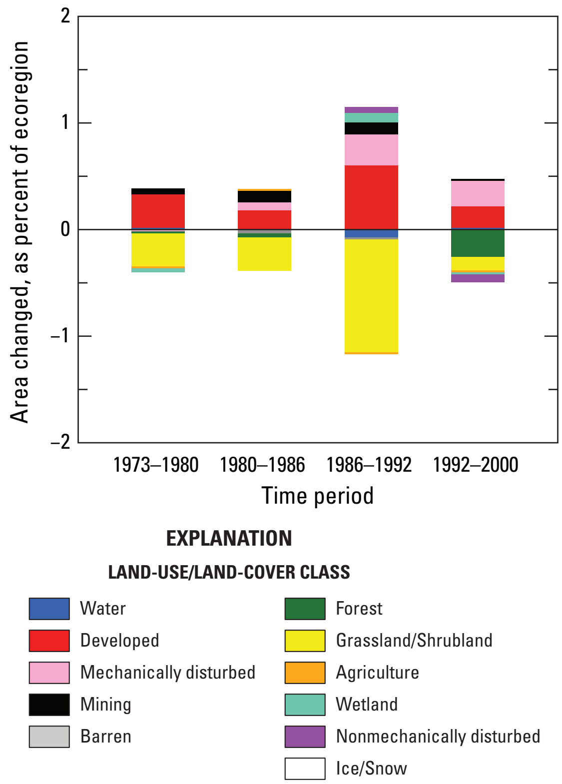


Figure 8. Normalized average net change in Mojave Basin and Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix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

Mojave Desert; Las Vegas is one of the fastest growing cities in the United States, whereas Palmdale and Lancaster both have populations larger than 100,000 (U.S. Census Bureau, 2001). Population statistics show that Clark County, Nevada, added more than 1.3 million residents between 1970 and 2000, whereas San Bernardino County, California, has added more than 1.175 million people during the same time period (fig. 9) (U.S. Census Bureau, 2001). Figure 10 shows land-use/land-cover data for a sample site near Palmdale, California, which has experienced rapid urbanization.

Land ownership is another driving force of land-cover change. As previously noted, the Federal Government owns a large percentage of land within the ecoregion, the largest landholder being the Bureau of Land Management, and each federal agency manages public lands to meet distinct goals and objectives. For instance, Bureau of Land Management lands are often open for public use and recreation such as off-highway-vehicle (OHV) activities (Lovich and Bainbridge, 1999). In most cases, OHV disturbances such as single vehicle tracks were not detected in image interpretations because of the coarse size of the minimum mapping unit (60 m) and are, therefore, not described by the change estimates. However, image interpretations did identify several OHV staging areas where relatively large areas of grassland/shrubland have been gradually stripped of vegetation. Continued use of these areas has resulted in soil compaction, which has prevented the reestablishment of vegetation. The growth of OHV activity in the ecoregion can be attributed largely to the open-access policy of the Bureau of Land Management lands, as well as the close proximity of these lands to major urban areas (Sheridan, 1979).

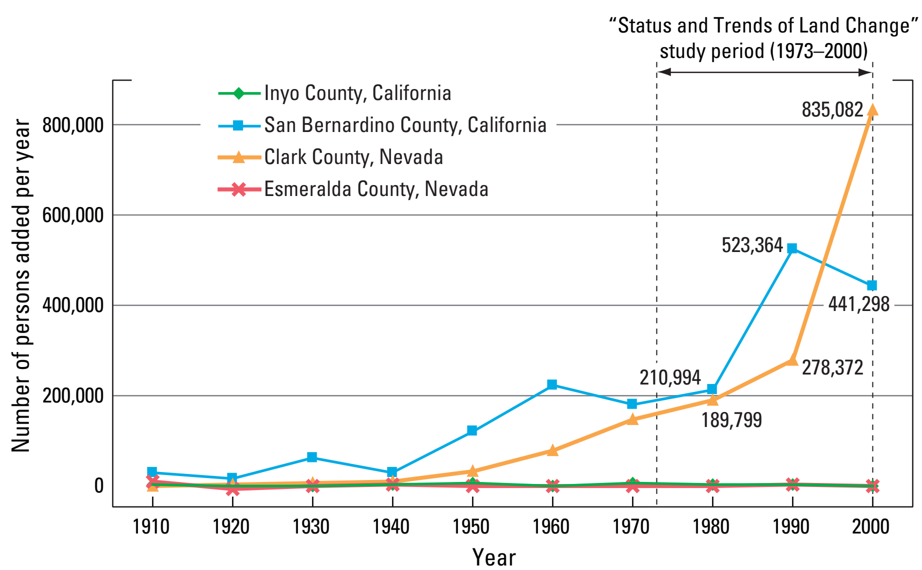


Figure 9. Population trends between 1910 and 2000 of selected counties in Mojave Basin and Range Ecoregion. Numbers of persons added to each county are from U.S. Census data at 10-year intervals (U.S. Census Bureau, 2001). San Bernardino County, California, and Clark County, Nevada, have experienced highest growth of any counties in ecoregion, each adding more than 175,000 persons in each decade since 1980.

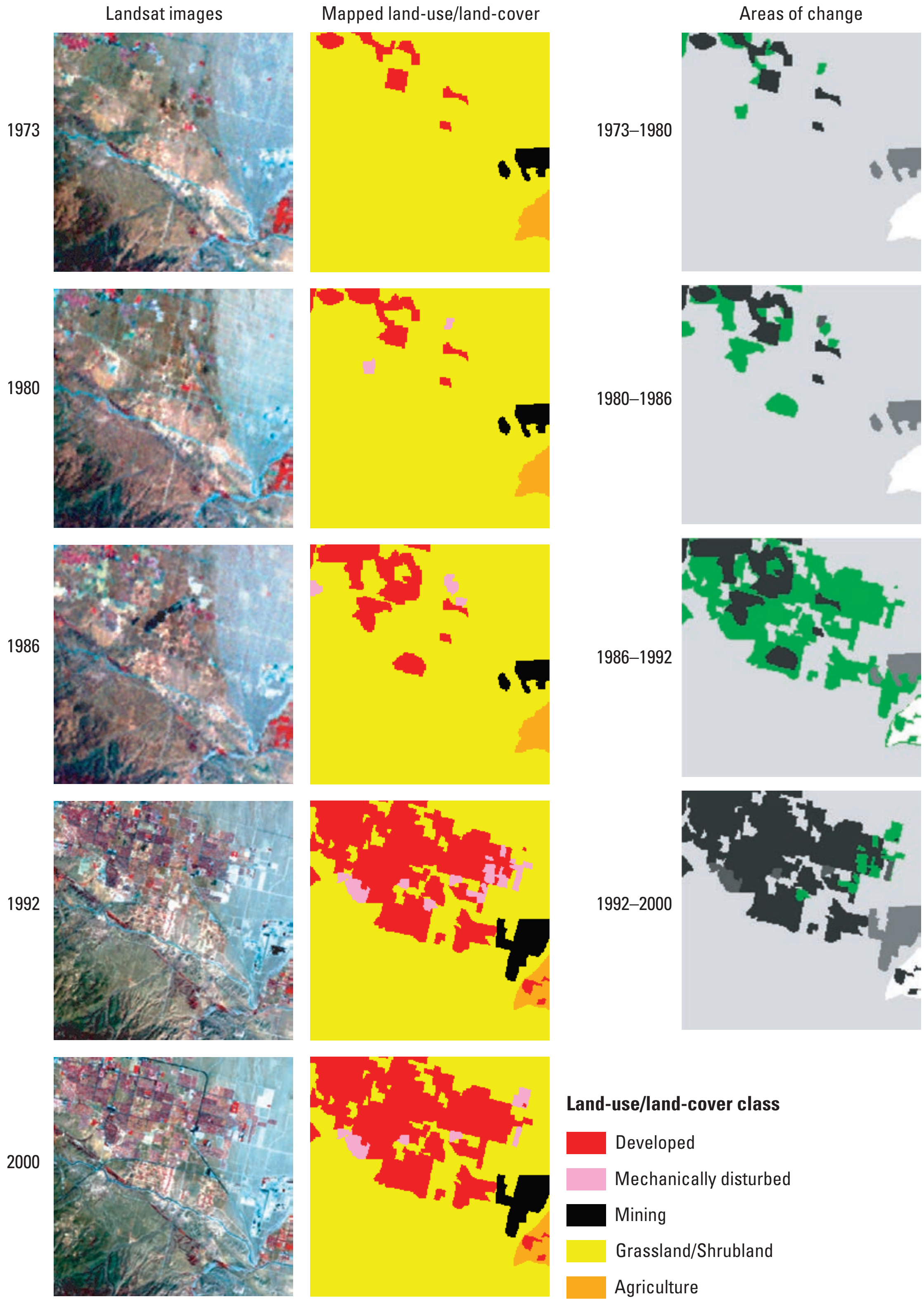


Figure 10. Data for sample block 14-1009, located near Palmdale, California, illustrating urbanization taking place in Mojave Basin and Range Ecoregion. Left column is satellite imagery collected for each of five years analyzed in study, used to map land-use/land-cover change in four time periods between study years (imagery sources for study years: 1973, 1980, and 1986 are Landsat Multispectral Scanner (MSS) images; 1992 is Landsat Thematic Mapper (TM) image; 2000 is Landsat Enhanced Thematic Mapper (ETM) image). Center column is mapped land-use/land-cover data for each study year. Right column shows areas that changed (green areas) in each of four time periods between study years; light- and dark-gray-shaded areas do not change between study years but, rather, represent overall land-use/land-cover footprint throughout study period.

Figure 11. Mechanical disturbance (vehicle tracks) observed at Fort Irwin National Training Center, California, site of intensive military training that includes live-fire exercises.

The Department of Defense has a substantially different mandate pertaining to its land ownership and management policies. The Department of Defense manages vast areas of the ecoregion (fig. 2) for conducting military training activities. The largest of the facilities that lie entirely within the ecoregion is Fort Irwin National Training Center, California (2,369 km^2), which is used for desert-warfare training that includes live-fire exercises. Tracked and wheeled vehicles, which operate throughout the facility, can have a major impact on the health and composition of desert flora and fauna (Prose and Wilshire, 2000). Recent studies have estimated that several hundred years will be needed for desert soils and vegetation to recover once exposed to these intensive land-use practices (Prose and Wilshire, 2000; Steiger and Webb, 2000). This phenomenon was observe. in the eastern part of Fort Irwin, which was heavily used for tracked- and wheeled-vehicle operations training (fig. 11). Evidence of this destruction includes compacted and rutted soils, low shrub density, and stunted growth of creosote bush (*Larrea tridentata*) and other vegetation.

Unlike the Bureau of Land Management and Department of Defense, the National Park Service attempts to preserve natural desert lands while promoting low-impact public recreation such as camping, hiking, and sightseeing. The largest holding of the National Park Service within the ecoregion is Death Valley National Park (12,759 km^2). Other National Park Service areas include Mojave National Preserve and Joshua Tree National Park. With the exception of small, tourism-supported development such as visitor centers, boardwalks, campgrounds, hiking trails, and unimproved roads, no land-cover changes were detected on National Park Service lands, further illustrating the significant role that land-ownership and -management goals play in regards to the spatial distribution of contemporary land-cover change.

Results show that change between land-cover classes in the Mojave Basin and Range Ecoregion is relatively rare and highly localized. Urbanization is the primary source of change, although other human-use activities such as military training and recreation are significant contributors to change within the ecoregion.

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

[Most sample pixels remained unchanged (97.3 percent), whereas 2.7 percent changed at least once throughout study period. Two dashes (--) indicate that, because zero pixels changed four times during study period, relative error is not calculable]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	2.4	1.3	1.1	3.8	0.9	37.0
2	0.2	0.1	0.1	0.3	0.1	45.9
3	0.0	0.0	0.0	0.0	0.0	98.5
4	0.0	0.0	0.0	0.0	0.0	--
Overall spatial change	2.7	1.4	1.2	4.1	1.0	36.5

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

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

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	0.5	0.3	0.2	0.8	0.2	37.0	0.1
1980–1986	0.5	0.2	0.2	0.7	0.2	36.4	0.1
1986–1992	1.3	0.9	0.3	2.2	0.6	50.6	0.2
1992–2000	0.6	0.5	0.2	1.1	0.3	50.5	0.1
Estimate of change, in square kilometers							
1973–1980	675	366	308	1,041	250	37.0	96
1980–1986	605	323	282	928	220	36.4	101
1986–1992	1,660	1,232	428	2,892	839	50.6	277
1992–2000	841	624	217	1,466	425	50.5	105

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

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.9	0.9	1.5	0.9	0.1	0.1	1.1	1.2	4.7	3.9	2.0	1.6	89.2	4.6	0.2	0.2	0.3	0.3	0.0	0.0
1980	0.9	0.9	1.8	1.0	0.1	0.1	1.1	1.2	4.7	3.9	2.0	1.6	88.9	4.6	0.2	0.2	0.2	0.3	0.0	0.0
1986	0.9	0.9	2.0	1.0	0.2	0.1	1.3	1.3	4.7	3.9	1.9	1.6	88.6	4.6	0.2	0.2	0.2	0.3	0.0	0.0
1992	0.8	0.9	2.6	1.4	0.5	0.4	1.4	1.4	4.7	3.9	1.9	1.6	87.5	4.7	0.2	0.2	0.3	0.4	0.1	0.1
2000	0.9	0.9	2.8	1.5	0.7	0.6	1.4	1.4	4.7	3.9	1.7	1.5	87.4	4.7	0.2	0.2	0.3	0.4	0.0	0.0
Net change	0.0	0.1	1.3	1.0	0.6	0.6	0.3	0.2	−0.1	0.1	−0.3	0.4	−1.8	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Gross change	0.2	0.2	1.3	1.0	0.8	0.6	0.3	0.2	0.1	0.1	0.3	0.4	2.0	1.3	0.1	0.1	0.1	0.2	0.1	0.2
Area, in square kilometers																				
1973	1,164	1,183	1,958	1,184	152	104	1,394	1,604	6,196	5,097	2,581	2,119	116,844	5,984	303	270	331	419	0	0
1980	1,198	1,209	2,349	1,263	124	96	1,482	1,627	6,196	5,096	2,570	2,113	116,430	6,001	277	243	296	370	0	0
1986	1,198	1,209	2,594	1,303	216	185	1,638	1,707	6,153	5,094	2,522	2,097	116,013	5,991	293	250	296	370	0	0
1992	1,108	1,123	3,386	1,784	609	587	1,776	1,777	6,123	5,093	2,520	2,106	114,622	6,096	287	250	408	530	82	118
2000	1,139	1,140	3,638	1,908	925	790	1,813	1,783	6,123	5,093	2,189	1,903	114,457	6,150	270	228	369	474	0	0
Net change	−25	106	1,680	1,329	773	745	418	281	−73	110	−392	493	−2,387	1,646	−33	50	38	55	0	0
Gross change	224	274	1,680	1,329	1,073	785	422	281	93	109	417	528	2,611	1,649	73	67	185	267	163	236

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

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

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Developed	314	241	164	0.2	46.5
	Grassland/Shrubland	Mining	90	94	64	0.1	13.3
	Mechanically disturbed	Developed	52	56	38	0.0	7.7
	Wetland	Water	34	50	34	0.0	5.1
	Barren	Grassland/Shrubland	34	49	34	0.0	5.0
	Other	Other	151	n/a	n/a	0.1	22.4
		Totals	675			0.5	100.0
1980–1986	Grassland/Shrubland	Developed	202	192	131	0.2	33.3
	Grassland/Shrubland	Mechanically disturbed	115	132	90	0.1	19.0
	Grassland/Shrubland	Mining	110	103	70	0.1	18.1
	Barren	Mining	49	70	48	0.0	8.0
	Mechanically disturbed	Developed	38	35	24	0.0	6.2
	Other	Other	92	n/a	n/a	0.1	15.3
		Totals	605			0.5	100.0
1986–1992	Grassland/Shrubland	Developed	751	851	580	0.6	45.2
	Grassland/Shrubland	Mechanically disturbed	435	421	287	0.3	26.2
	Water	Wetland	125	180	123	0.1	7.5
	Grassland/Shrubland	Mining	110	97	66	0.1	6.6
	Grassland/Shrubland	Nonmechanically disturbed	82	118	80	0.1	4.9
	Other	Other	158	n/a	n/a	0.1	9.5
		Totals	1,660			1.3	100.0
1992–2000	Forest	Mechanically disturbed	324	467	318	0.2	38.5
	Grassland/Shrubland	Developed	160	183	124	0.1	19.1
	Mechanically disturbed	Developed	89	80	54	0.1	10.5
	Nonmechanically disturbed	Grassland/Shrubland	82	118	80	0.1	9.7
	Grassland/Shrubland	Mechanically disturbed	77	58	40	0.1	9.1
	Other	Other	110	n/a	n/a	0.1	13.1
		Totals	841			0.6	100.0
1973–2000 (overall)	Grassland/Shrubland	Developed	1,426	1,191	811	1.1	37.7
	Grassland/Shrubland	Mechanically disturbed	651	591	403	0.5	17.2
	Grassland/Shrubland	Mining	345	245	167	0.3	9.1
	Forest	Mechanically disturbed	340	488	332	0.3	9.0
	Mechanically disturbed	Developed	205	138	94	0.2	5.4
	Other	Other	814	n/a	n/a	0.6	21.5
		Totals	3,781			2.9	100.0

References Cited

Hunter, L.M., Gonzalez, M. de J., Stevenson, M., Karish, K.S., Toth, R., Edwards, T.C., Lilieholm, R.J., and Cablk, M., 2003, Population and land use change in the California Mojave; natural habitat implications of alternative futures: Population Research and Policy Review, v. 22, p. 373–379.

Lovich, J.E., and Bainbridge, D., 1999, Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration: Environmental Management, v. 24, p. 309–326.

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.

Prose, D.V., and Wilshire, H.G., 2000, The lasting effects of tank maneuvers on desert soils and intershrub flora: U.S. Geological Survey Open-File Report 00–512, 22 p., accessed at http://geopubs.wr.usgs.gov/open-file/of00-512/.

Sheridan, D., 1979, Off-road vehicles on public land: Council on Environmental Quality, 84 p.

Sleeter, B.M., and Raumann, C.G., 2006, Land-cover trends in the Mojave Basin and Range Ecoregion: U.S. Geological Survey Scientific Investigations Report 2006–5098, 18 p., accessed at http://pubs.usgs.gov/sir/2006/5098/.

Steiger, J.W., and Webb, R.H, 2000, Recovery of perennial vegetation in the military target sites in the eastern Mojave Desert, Arizona: U.S. Geological Survey Open-File Report 00–355, 28 p., accessed at http://geopubs.wr.usgs.gov/open-file/of00-355/.

U.S. Census Bureau, 2001, American Fact Finder: U.S. Census Bureau database, accessed May 1, 2005, at http://factfinder.census.gov/home/saff/main.html?_lang=en.

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.

Chapter 30

Sonoran Basin and Range Ecoregion

By James P. Calzia and Tamara S. Wilson

Ecoregion Description

The Sonoran Basin and Range Ecoregion covers approximately 116,364 km^2 (44,928 mi^2) of desert landscape in southeastern California and southwestern Arizona (fig. 1) (Omernik, 1987; U.S. Environmental Protection Agency, 1997). This ecoregion is bounded on the west by the Southern and Central California Chaparral and Oak Woodlands and the Southern California Mountains Ecoregions; on the north by the Mojave Basin and Range, the Arizona/New Mexico Plateaus, and the Arizona/New Mexico Mountains Ecoregions; and on the east by the Madrean Archipelago Ecoregion (fig.1). The Sonoran Basin and Range Ecoregion extends far southward into both mainland Mexico and northeastern Baja California peninsula; however, those international parts were not included in the present study. The largest concentrations of population in the ecoregion include the Palm Springs–Coachella Valley area (population 332,485 in 2000) in California's Riverside County, as well as the Phoenix and Tucson metropolitan areas (metropolitan populations of approximately 4.2 million and 1 million, respectively) in Arizona (U.S. Census Bureau, 2011).

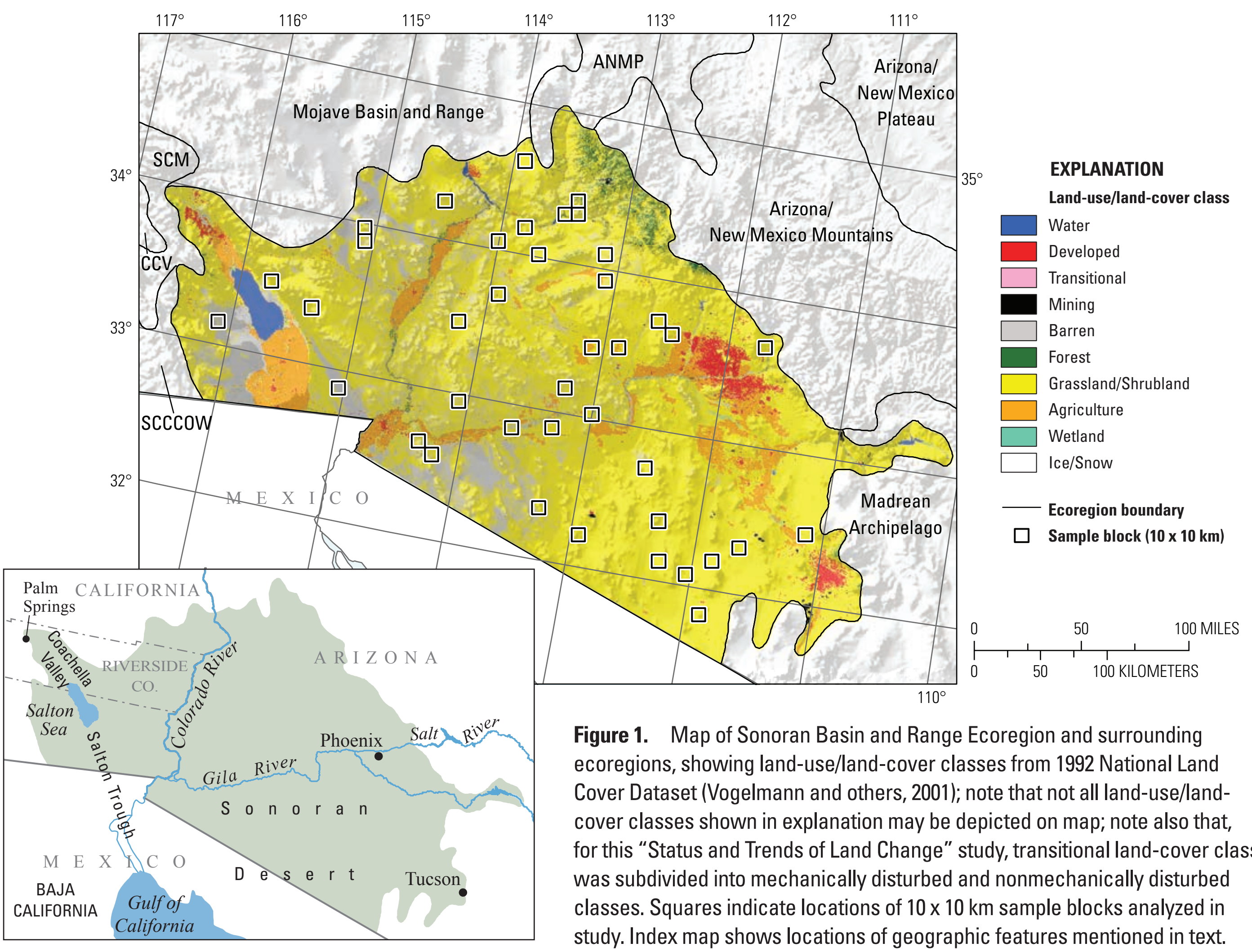


Figure 1. Map of Sonoran Basin and Range Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this "Status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

The geography of the Sonoran Basin and Range Ecoregion is characterized by discontinuous mountain ranges separated by wide alluvial plains. The mountains are composed of igneous, sedimentary, and metamorphic rocks that vary in age from Precambrian to Tertiary (Jennings, 1977; Arizona Geological Survey and Bureau of Land Management, 1993). Elevations range from 20 to 1,830 m. The largest rivers include the Colorado River along the boundary between California and Arizona, as well as the Gila and Salt Rivers in Arizona. The Salton Sea at the northern end of the Salton Trough is located near the ecoregion's western border.

The Sonoran Basin and Range Ecoregion is characterized by a warm, arid climate. During winter months, daytime temperatures can average 21°C, and overnight temperatures can drop to below freezing in some low-lying desert valleys (Climate Assessment for the Southwest, 2010). In summer months, temperatures often climb above 38°C during the day. Daily temperature variation can exceed 15°C (Climate Assessment for the Southwest, 2010). Annual precipitation varies from 7.5 to 43 cm, with slightly more rainfall at higher elevations (Arizona Fish and Game Department, 2006; McGinnies, 1976) and a gradient of increasing precipitation from west to east. The western Sonoran Desert receives most of its precipitation in winter, whereas summer precipitation totals farther east are greater because of the influence of monsoon rains fed by higher temperatures and moisture pumped in from the Gulf of California and the Gulf of Mexico (Comrie and Glenn, 1998).

The bimodal precipitation pattern contributes to the surprisingly diverse range of vegetation within the Sonoran Basin and Range Ecoregion. More than 2,500 species, including both annual and perennial trees and shrubs, as well as succulents and cacti (Turner and others, 1995), are found here. Vast expanses of cholla (*Opuntia* spp.) cactus in California are joined by the giant saguaro (*Carnegia gigantea*) cactus in Arizona. The saguaro is cold-intolerant and highly susceptible to winter freeze mortality; it cannot survive in the California part of the ecoregion (Steenbergh and Lowe, 1977). Creosote (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), ocotillo (*Fouquieria splendens*), and brittlebush (*Encelia farinosa*) shrubs dominate plant communities in the hottest, driest areas; palo verde (*Parkinsonia* spp.), mesquite (*Prosopis* spp.), and ironwood (*Olneya tesota*) trees are common on slopes and near the heads of alluvial fans.

Land ownership in the ecoregion is primarily Federal, managed by the Bureau of Land Management, Department of Defense, and National Park Service, and some of the remainder is occupied by tribal lands. Major land uses include urban and rural settlement, agriculture and livestock grazing, mining, and military training. Agriculture was established where water was available, but in recent years it has given way to urban growth. The dry climate makes this ecoregion a favored destination for relocation and retirement (Arizona Fish and Game, 2006).

Contemporary Land-Cover Change (1973 to 2000)

The overall spatial change of land cover in the Sonoran Basin and Range Ecoregion between 1973 and 2000 was estimated at 2.6 percent (table 1). Although the overall change is small when compared to other ecoregions in the western United States, the amount of change is high relative to the adjacent Chihuahuan Deserts (0.5 percent; CD, on fig. 2) and Madrean Archipelago (1.4 percent; MA, on fig. 2) Ecoregions. Our estimates indicate that between 1973 and 2000, 1.3 percent of the ecoregion changed at least once, and 1.1 percent changed at least two times (table 1).

The normalized annual rates of land-cover change, which account for varying lengths of time between imagery dates (table 2), show that the rate of land-cover change in the

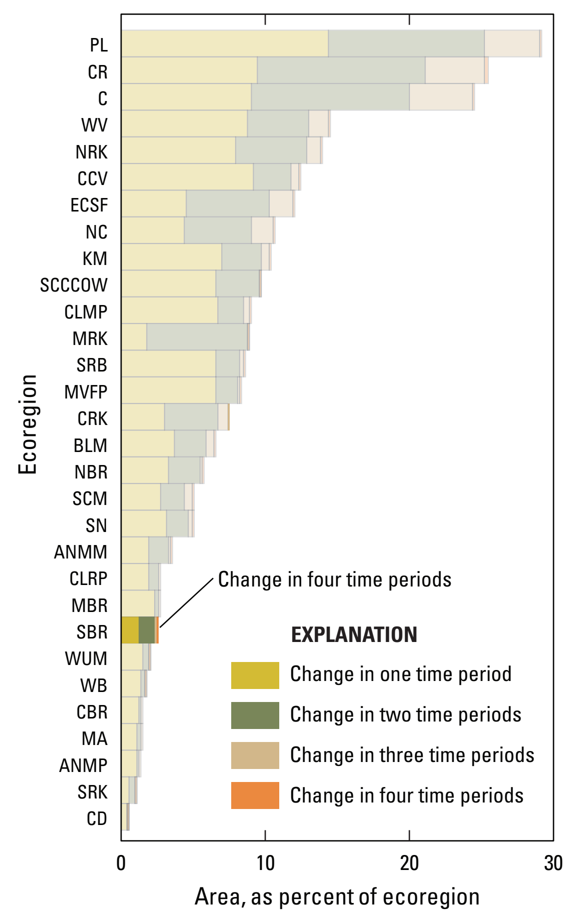


Figure 2. Overall spatial change in Sonoran Basin and Range Ecoregion (SBR; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of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

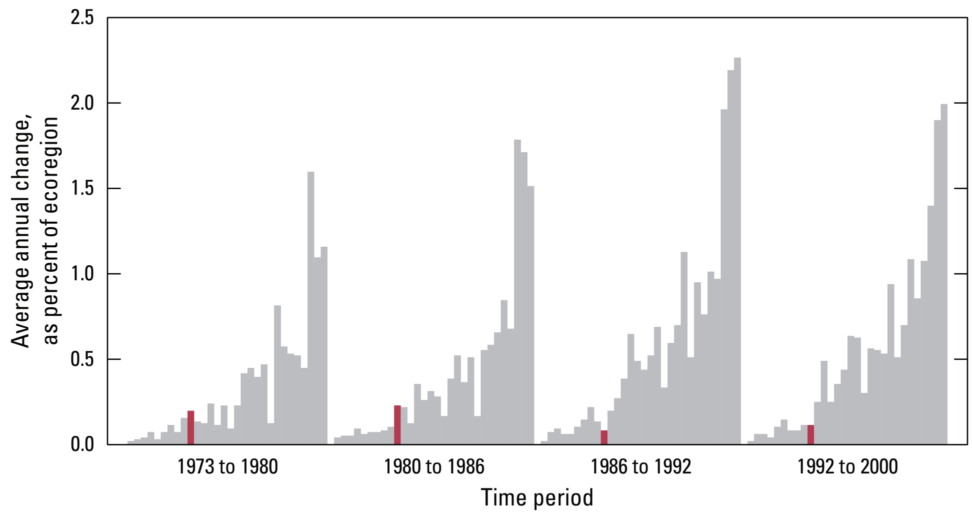


Figure 3. Estimates of land-cover change per time period, normalized to annual rates of change for all 30 Western United States ecoregions (gray bars). Estimates of change for Sonoran Basin and Range Ecoregion are represented by red bars in each time period.

Sonoran Basin and Range Ecoregion was very low compared to that in other ecoregions in the western United States (fig. 2). Within the Sonoran Basin and Range Ecoregion itself, the fastest rate of land-cover change occurred between 1980 and 1986, when approximately 264 km^2 changed land-cover classes per year, followed closely by 221 km^2 annually between 1973 and 1980. These rates were nearly twice as fast as between 1986 and 1992 and were approximately 50 percent faster than the rate of change between 1992 and 2000. It is worth noting that, because considerable error is associated with these rates, they may not be significantly different (table 2).

Net change in land-cover classes per time period is presented in figure 4. Between 1973 and 1980, a large net increase in water coupled with a large net decrease in grassland/shrubland was observed, whereas between 1980 and 1986 this trend reversed, with a large increase in grassland/shrubland and wetland coupled with a large decrease in water. These changes in land cover were in response to short-term climate fluctuations that resulted in widely varied reservoir levels. Grassland/shrubland changes were also influenced by an increase in developed land, which expanded by 173 percent over the study period, from 278 to 759 km^2.

Grassland/shrubland dominates the Sonoran Basin and Range Ecoregion, followed distantly by agriculture. In 2000 the grassland/shrubland class covered 92.9 percent (108,139 km^2) of the ecoregion, while agriculture covered 3.2 percent of the ecoregion (3,698 km^2) (table 3). Between 1973 and 1980, 617 km^2 of grassland/shrubland and 264 km^2 of wetland were converted to water, and another 257 km^2 of grassland/shrubland was converted to agriculture (table 4). Nearly the same area of water changed back to grassland/shrubland and wetland between 1980 and 1986. In addition, 147 km^2 of grassland/shrubland was converted to agriculture, and 96 km^2 was

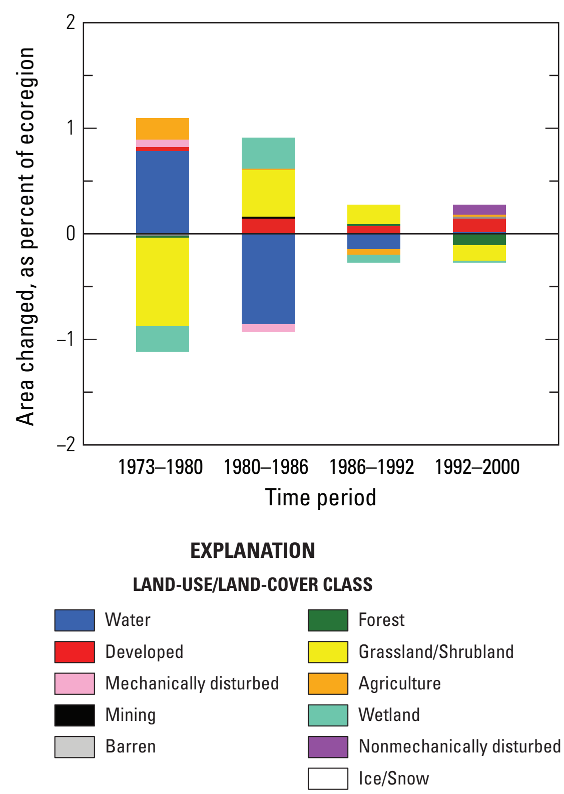


Figure 4. Normalized average net change in Sonoran Basin and Range Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix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

reclassified as developed. These changes continued between 1986 and 2000, during which time the Sonoran Basin and Range Ecoregion experienced net losses of 461 km^2 of grassland/shrubland and 245 km^2 of water, as well as net gains of 244 km^2 of agricultural land and 481 km^2 of developed land (fig. 4).

Estimates suggest that, between 1973 and 2000, land-cover change in the Sonoran Basin and Range Ecoregion was small, and it also occurred at a slow rate relative to other ecoregions in the western United States. However, as in the Mojave Basin and Range Ecoregion to the north, a seemingly small, yet significant change was occurring in developed land (fig. 5). Although development is sparse, all three major metropolitan regions in the Sonoran Basin and Range Ecoregion experienced unprecedented rates of population growth both during and since the study period. Between 1990 and 2000 alone, the population of the Coachella Valley grew at more than twice the rate of any other region in California. This growth has continued since the end of the study: between 2000 and 2005, the population of the Coachella Valley grew to 410,974 (an increase of 23.6 percent) (U.S. Census Bureau, 2011); by 2008, the Phoenix metropolitan area added nearly a million more people, a 31.7 percent increase since 2000. The greater Tucson region grew from 531,443 residents in 1980 to 666,880 in 1990 (a 25.5 percent increase) and to an estimated 843,746 people in 2000 (a 26.5 percent increase since 1990) (U.S. Census, 2011). In 1990, the Sonoran Basin and Range Ecoregion included 6.9 million residents; by 2020, the population is expected to reach 12 million (U.S. Census Bureau, 2011). Land-cover data suggest that urbanization of the Sonoran Basin and Range Ecoregion comes primarily at the expense of grassland/shrubland. As the population grows, water resources may become limited as human uses draw down regional water tables by groundwater pumping and also tax the Colorado River’s finite water resources and its long-distance water delivery systems (for example, the Central Arizona Project canal) (fig. 6).

Figure 5. Changing landscape of Sonoran Basin and Range Ecoregion. *A,* Typical grassland/shrubland land cover within ecoregion. *B*, Result of change from grassland/shrubland to developed land-cover classes.

Figure 6. Increased use of water (*A*), coupled with decreasing water supplies (*B*), has controlled, and will continue to control, rate of land-cover change in Sonoran Basin and Range Ecoregion.

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

[Most sample pixels remained unchanged (97.4 percent), whereas 2.6 percent changed at least once throughout study period]

Number of changes	Percent of ecoregion	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)
1	1.3	0.7	0.6	2.0	0.5	35.4
2	1.1	0.8	0.2	1.9	0.6	53.1
3	0.2	0.2	0.0	0.4	0.1	84.0
4	0.0	0.0	0.0	0.0	0.0	85.9
Overall spatial change	2.6	1.4	1.2	3.9	0.9	36.4

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

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

Period	Total change (% of ecoregion)	Margin of error (+/– %)	Lower bound (%)	Upper bound (%)	Standard error (%)	Relative error (%)	Average rate (% per year)
Estimate of change, in percent stratum							
1973–1980	1.3	0.9	0.4	2.2	0.6	45.4	0.2
1980–1986	1.4	1.1	0.3	2.5	0.7	55.0	0.2
1986–1992	0.5	0.4	0.1	0.8	0.2	50.2	0.1
1992–2000	0.8	0.5	0.4	1.3	0.3	38.8	0.1
Estimate of change, in square kilometers							
1973–1980	1,544	1,029	515	2,574	701	45.4	221
1980–1986	1,583	1,277	306	2,861	870	55.0	264
1986–1992	558	411	147	969	280	50.2	93
1992–2000	985	560	424	1,545	382	38.8	123

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

	Water		Developed		Mechanically disturbed		Mining		Barren		Forest		Grassland/ Shrubland		Agriculture		Wetland		Non-mechanically disturbed	
	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–	%	+/–
Area, in percent stratum																				
1973	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	2.1	2.9	0.8	0.4	93.3	3.4	3.0	2.0	0.2	0.3	0.0	0.0
1980	1.1	1.1	0.3	0.1	0.1	0.1	0.0	0.0	2.1	2.9	0.8	0.4	92.5	3.6	3.2	2.1	0.0	0.0	0.0	0.0
1986	0.2	0.2	0.4	0.2	0.0	0.0	0.0	0.0	2.1	2.9	0.8	0.4	92.9	3.5	3.2	2.1	0.3	0.4	0.0	0.0
1992	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.0	2.1	2.9	0.9	0.4	93.1	3.4	3.2	2.0	0.2	0.3	0.0	0.0
2000	0.1	0.0	0.7	0.4	0.0	0.0	0.0	0.0	2.1	2.9	0.8	0.3	92.9	3.5	3.2	2.1	0.2	0.3	0.1	0.1
Net change	−0.2	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	−0.1	0.1	−0.4	0.6	0.2	0.4	0.0	0.1	0.1	0.1
Gross change	1.9	1.9	0.4	0.3	0.1	0.2	0.0	0.0	0.0	0.0	0.2	0.2	2.3	1.4	0.8	0.5	0.7	0.9	0.1	0.1
Area, in square kilometers																				
1973	308	402	278	143	8	7	8	6	2,449	3,332	981	478	108,599	4,012	3,454	2,355	280	387	0	0
1980	1,224	1,321	328	172	88	90	9	6	2,428	3,326	962	489	107,615	4,175	3,696	2,398	14	13	0	0
1986	218	224	511	257	14	11	14	9	2,431	3,324	973	490	108,115	4,033	3,724	2,388	366	511	0	0
1992	43	42	604	313	15	13	14	10	2,435	3,323	995	495	108,315	4,010	3,674	2,381	269	368	0	0
2000	62	56	759	426	20	16	19	14	2,439	3,324	876	376	108,139	4,048	3,698	2,400	239	321	113	163
Net change	−245	396	481	310	12	11	11	13	−10	9	−104	130	−461	717	244	500	−42	67	113	163
Gross change	2,173	2,267	482	310	164	178	12	13	51	37	282	220	2,719	1,666	987	565	757	1,083	113	163

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

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

Period	From class	To class	Area changed (km²)	Margin of error (+/– km²)	Standard error (km²)	Percent of ecoregion	Percent of all changes
1973–1980	Grassland/Shrubland	Water	617	608	414	0.5	40.0
	Wetland	Water	264	381	260	0.2	17.1
	Grassland/Shrubland	Agriculture	257	188	128	0.2	16.6
	Grassland/Shrubland	Forest	90	120	82	0.1	5.8
	Grassland/Shrubland	Mechanically disturbed	80	90	61	0.1	5.2
	Other	Other	236	n/a	n/a	0.2	15.3
		Totals	1,544			1.3	100.0
1980–1986	Water	Grassland/Shrubland	657	738	503	0.6	41.5
	Water	Wetland	344	496	338	0.3	21.7
	Grassland/Shrubland	Agriculture	147	112	76	0.1	9.3
	Grassland/Shrubland	Developed	96	75	51	0.1	6.1
	Agriculture	Grassland/Shrubland	90	108	74	0.1	5.7
	Other	Other	249	n/a	n/a	0.2	15.7
		Totals	1,583			1.4	100.0
1986–1992	Wetland	Grassland/Shrubland	158	227	155	0.1	28.3
	Water	Grassland/Shrubland	147	160	109	0.1	26.4
	Grassland/Shrubland	Developed	91	63	43	0.1	16.3
	Agriculture	Grassland/Shrubland	49	44	30	0.0	8.7
	Grassland/Shrubland	Wetland	47	67	46	0.0	8.4
	Other	Other	67	n/a	n/a	0.1	12.0
		Totals	558			0.5	100.0
1992–2000	Grassland/Shrubland	Agriculture	245	264	180	0.2	24.9
	Agriculture	Grassland/Shrubland	207	161	110	0.2	21.0
	Grassland/Shrubland	Developed	135	99	68	0.1	13.7
	Forest	Nonmechanically disturbed	113	163	111	0.1	11.5
	Wetland	Grassland/Shrubland	89	128	87	0.1	9.0
	Other	Other	195	n/a	n/a	0.2	19.8
		Totals	985			0.8	100.0
1973–2000 (overall)	Water	Grassland/Shrubland	833	809	551	0.7	17.8
	Grassland/Shrubland	Water	682	620	422	0.6	14.6
	Grassland/Shrubland	Agriculture	651	427	291	0.6	13.9
	Agriculture	Grassland/Shrubland	360	241	164	0.3	7.7
	Water	Wetland	358	514	350	0.3	7.7
	Other	Other	1,786	n/a	n/a	1.5	38.2
		Totals	4,671			4.0	100.0

References Cited

Arizona Fish and Game Department, 2006, Section 10: Sonoran Desert, *in* Arizona's Comprehensive Wildlife Conservation Strategy: 2005-2015: Arizona Fish and Game Department. (Available at http://www.azgfd.gov/pdfs/w_c/cwcs/downloads/Section10Sonoran.pdf.)

Arizona Geologic Survey and Bureau of Land Management, 1993, Arizona geologic map: Arizona Geological Survey Map 26.

Climate Assessment for the Southwest, 2010, Temperature and precipitation: Tucson, University of Arizona, accessed June 24, 2011, at http://www.climas.arizona.edu/sw-climate/temp-precip.

Comrie, A.C., and Glenn, E.C., 1998, Principal components-based regionalization of precipitation regimes across the Southwest United States and Northern Mexico, with an application to monsoon precipitation variability: Climate Research, v. 10, p. 201–215.

Jennings, C.W., 1977, Geologic map of California: California Geological Survey Geologic Data Map No. 2, scale 1: 750,000.

McGinnies, W.G., 1976, An overview of the Sonoran Desert: An essay developed from a paper given at the opening session of the 2nd Annual Conference of the Consortium of Arid Lands Institutions (CALI), February 4, 1976, in Tucson, Arizona: Tucson, University of Arizona, Arid Lands Information Center. (Available at http://alic.arid.arizona.edu/sonoran/documents/mcginnies/McGinnies_overview.html.)

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

Steenbergh, W.F., and Lowe, C.H., 1977, Ecology of the saguaro, II—reproduction, germination, establishment, growth, and survival of the young plant: National Park Service, Scientific Monograph 8.

Turner, R.M., Bowers, J.E., and Burgess, T.L., 1995, Sonoran desert plants—an ecological atlas, (2d ed.): Tucson, University of Arizona Press, 501 p.

U.S. Census Bureau, 2011, New American Fact Finder: U.S. Census Bureau database, accessed June 23, 2011, at http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.

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.