

Chapter 28

Madrean Archipelago Ecoregion

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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 km² (15,651 mi²) 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

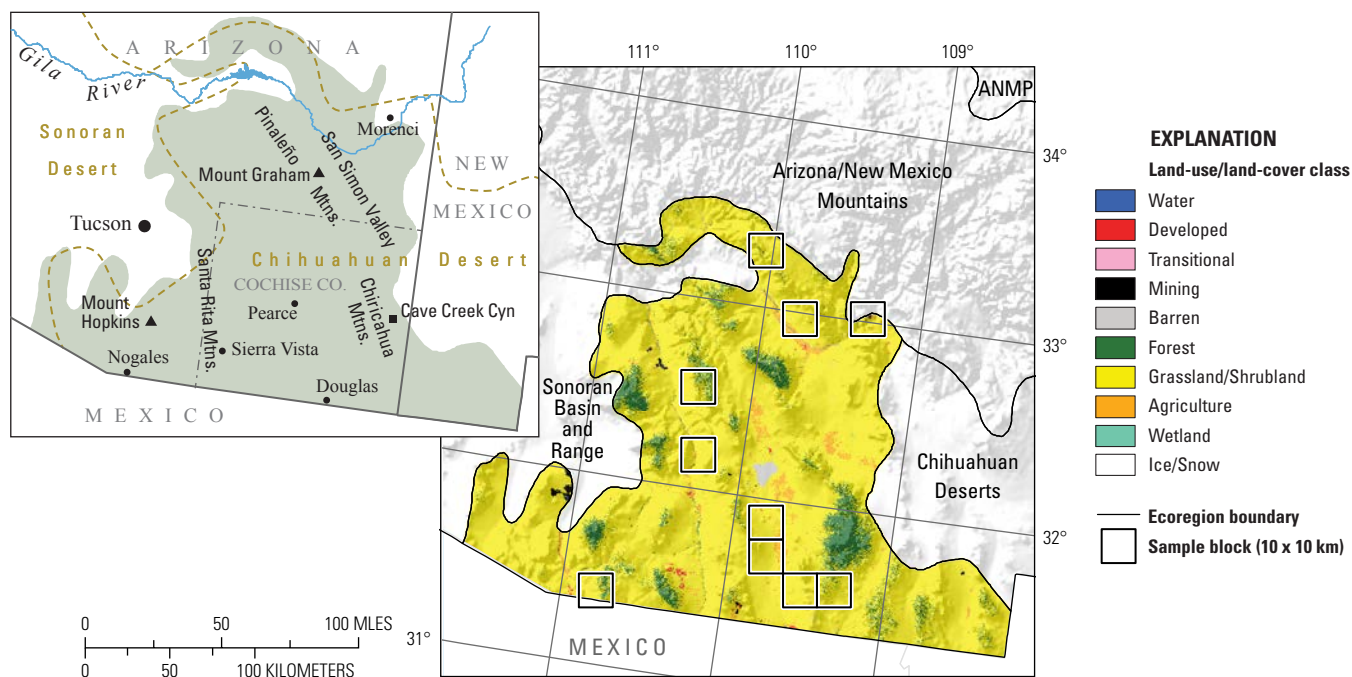


Figure 1. Map of Madrean Archipelago Ecoregion and surrounding ecoregions, showing land-use/land-cover classes from 1992 National Land Cover Dataset (Vogelmann and others, 2001); note that not all land-use/land-cover classes shown in explanation may be depicted on map; note also that, for this “Status 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 Pinaleno 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 7.9°C and 25.7°C, respectively (Western Regional Climate Center, 2009). Lowe (1964) described decreases in temperature of 2.2°C 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 km²) 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 km²) during the study period (table 3). Analysis of this

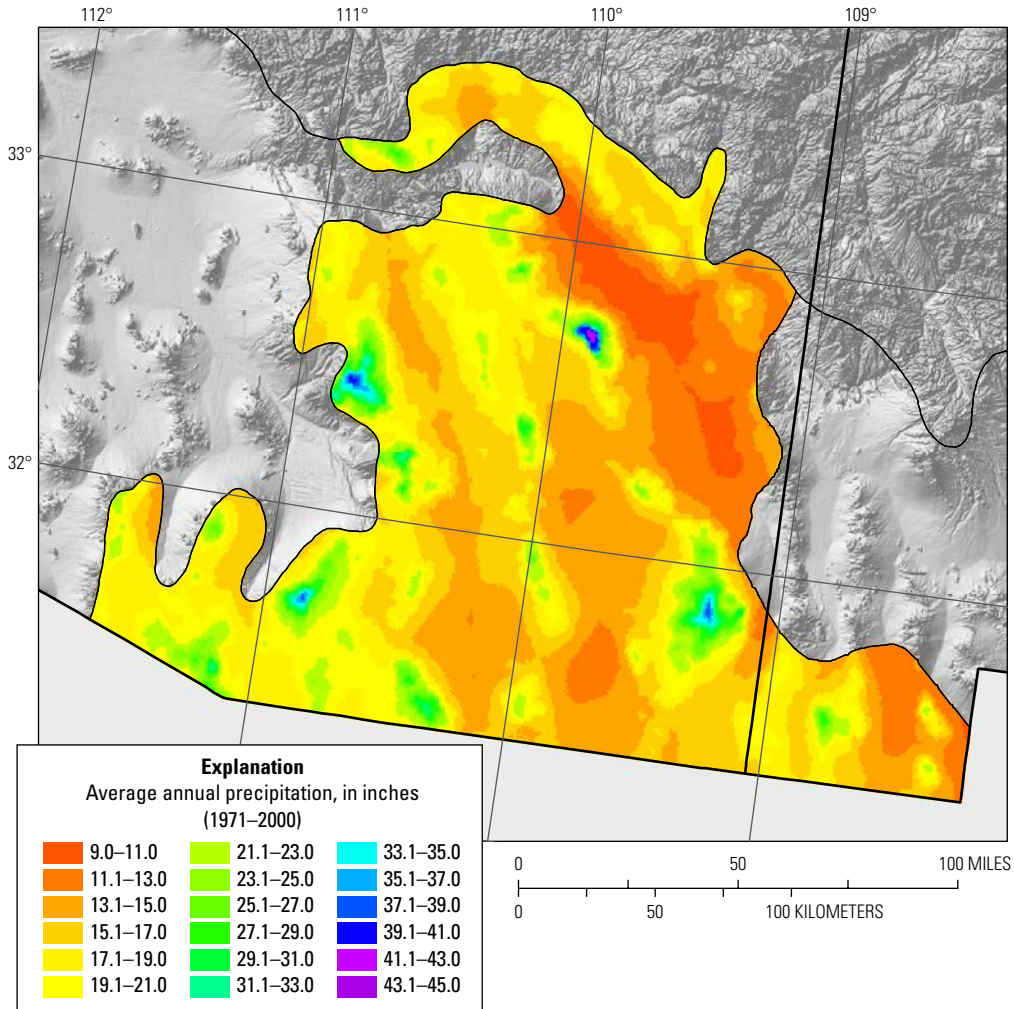


Figure 5. Estimated average annual precipitation in Madrean Archipelago Ecoregion between 1971 and 2000. Highest precipitation rates (shades of green, blue, purple) on mountaintops sustain evergreen woodlands and montane forests, whereas more arid lowland areas are covered in grassland and desert vegetation.



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

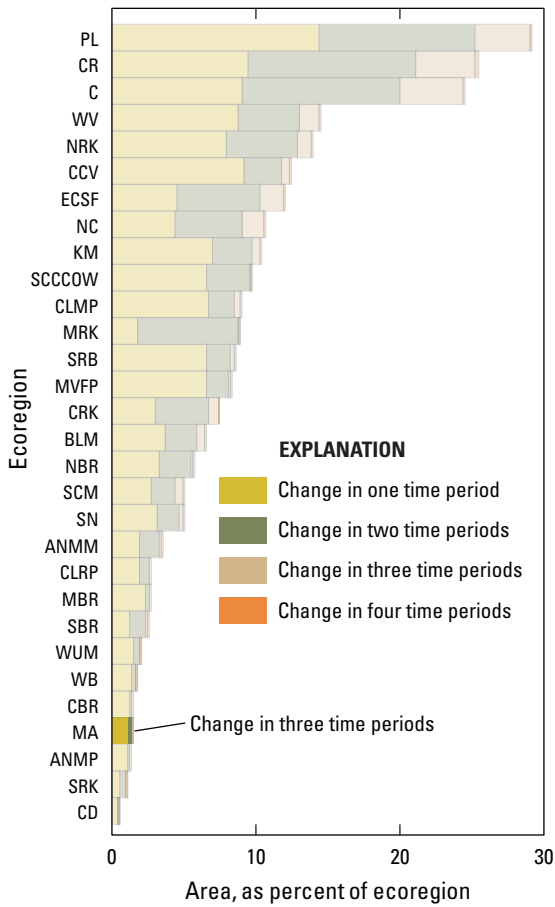


Figure 7. Overall spatial change in Madrean Archipelago Ecoregion (MA; darker bars) compared with that of all 30 Western United States ecoregions (lighter bars). Each horizontal set of bars shows proportions of ecoregion that changed during one, two, three, or four time periods; highest level of spatial 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.

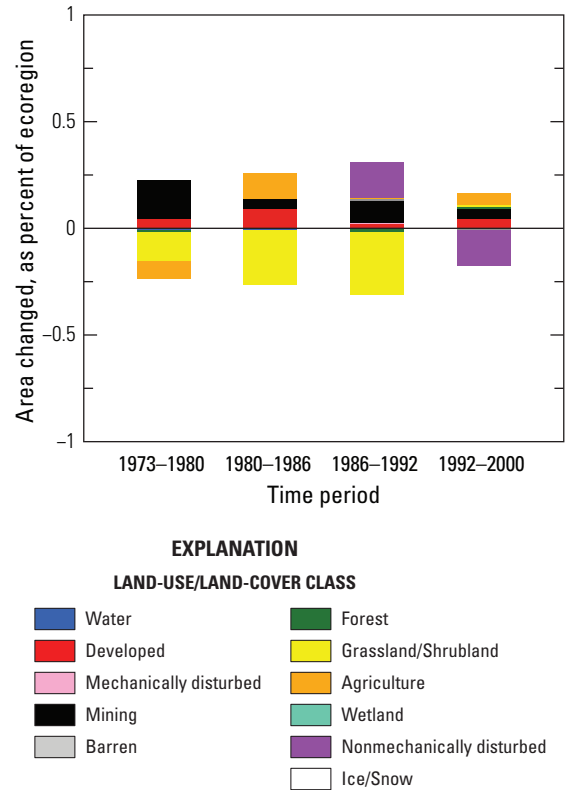
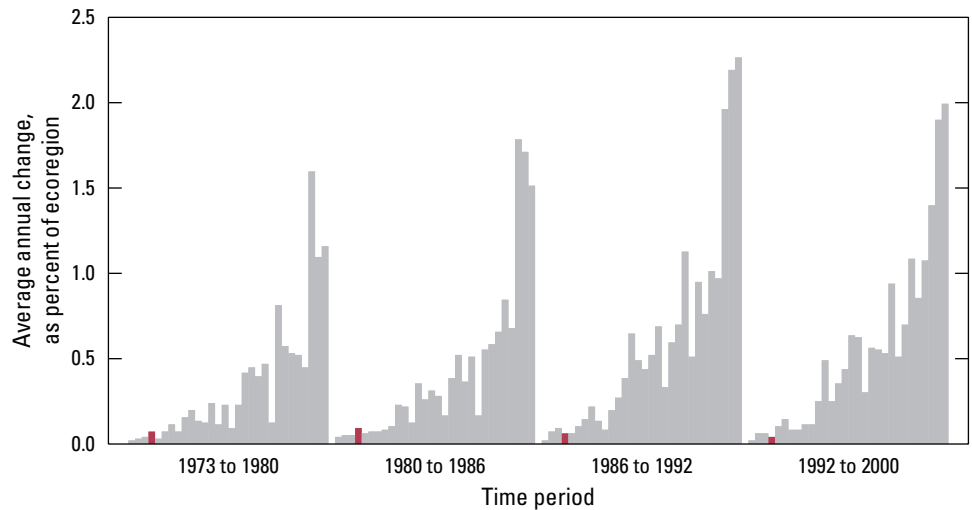


Figure 9. Normalized average net change in Madrean Archipelago Ecoregion by time period for each land-cover class. Bars above zero axis represent net gain, whereas bars below zero represent net loss. Note that not all land-cover classes shown in explanation may be represented in figure. See appendix 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 km²) 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 between 1986 and 1992, when it ranked fourth. The conversion of 65 km² 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 km² over entire the study period.

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

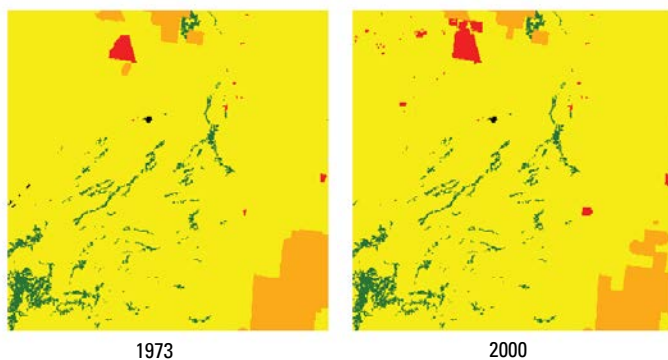


Figure 10. Sample block 79-6, centered over Pearce, Arizona, showing land-use/land-cover data in 1973 (left) and 2000 (right). Sample blocks show expansion of developed land (red) between 1973 and 2000, especially in Sunsites, Arizona, which is a growing, unincorporated retirement and golf community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

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

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

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

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

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