IV. EXISTING CONDITIONS IN THE SONORAN DESERT

Current conditions in the Sonoran Desert ecoregion are introduced in this chapter with an overview of ecoregion character, terrestrial resources of concern, coarse filter vegetation communities, and aquatic resources (Section 4.1). The regional landscape intactness results for terrestrial and aquatic ecosystems and status for each of the core conservation elements appear in Section 4.2; the major change agents that affect the conservation elements are covered in Section 4.3. Two Case Study Inserts on a key conservation element, the desert tortoise, and the invasive riparian shrub tamarisk (or saltcedar) provide a more detailed discussion of two important regional issues. Since the huge volume of REA results can only be summarized in the body of the report, Appendices A–E (referenced periodically) provide additional information on methods and models and specific results for all conservation elements and change agents.

4.1. Sonoran Desert Resources of Concern

4.1.1 Ecoregion Character

Photo: Waterman Mountain view with transitional East Sonoran Basin (81l on ecoregion map) to Arizona Upland East Sonoran Mountains (81k) vegetation community. M.A. Dimmitt, Arizona-Sonora Desert Museum, Tucson, Arizona

The Sonoran Desert is considered a subtropical desert, somewhat warmer than the adjacent temperate warm deserts—the Mojave and Chihuahuan—that experience more seasonal variability in temperature (Turner and Brown 1994). Topographically, the Sonoran Desert is divided into a lower, drier western section, that includes the Salton Sea basin and the lower Colorado Desert (regions marked 81a, 81b, 81f, 81i, and 81j in Level IV ecoregion map in Figure 4-1) and a higher eastern section, the Arizona Upland, that is somewhat cooler and relatively moist by desert standards (ecoregions 81k, 81l, and 81n).

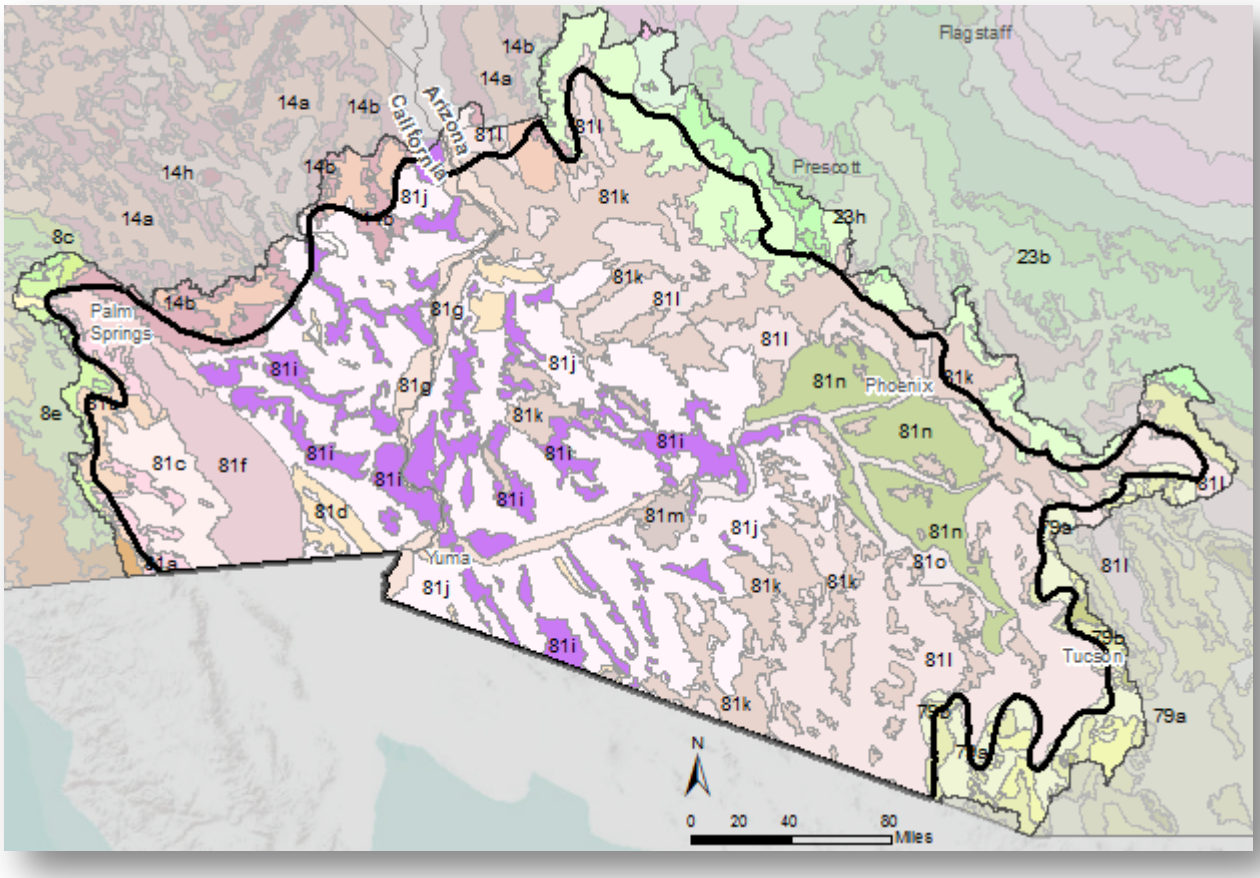


Figure 4-1. Level IV ecoregions of the Sonoran Desert, Griffith et al. (In Preparation a and b).

Across this elevational gradient, from the Salton Sea, at an elevation of 60 m (227 feet) below sea level, to the eastern boundary of the ecoregion at about 900 m (2950 ft.) on the western slope of the Mogollon Rim, precipitation ranges from 75–255 mm (3 to 10 inches). In the desert, a small difference in the amount or seasonality of precipitation can make a dramatic difference in vegetative cover; in the eastern Sonoran Desert a bimodal precipitation pattern supports a more diverse flora than that in other North American deserts (Dimmitt 2000a, Turner and Brown 1994).

Winter rainfall originates from the Pacific Ocean and decreases from west to east, depositing the greater proportion of rainfall in the northwest portion. During the summer monsoon, a shift of wind brings rain from the south beginning in July through September, mostly as localized storm cells (Turner and Brown 1994). Summer rainfall occurs in the opposite pattern, decreasing east to west, with most falling in the southeast portion (providing 30–60% Arizona Upland annual precipitation). Episodic summer storm events send pulses of flood water overland and down ephemeral and intermittent stream channels, prompting the growth of opportunistic summer annuals. The portion of Sonoran desert flora with subtropical origins has evolved with heat and aridity and this summer precipitation pattern, relying on summer rain for germination. Adequate winter precipitation, on the other hand, is necessary to sustain the region's winter annual plants (with a Mojave origin) that germinate in the winter and bloom in early spring (Turner and Brown 1994, Dimmitt 2000b, Van Devender 2000). The desert vegetation that characterizes the Sonoran Desert today has evolved fairly recently during the 9000 years since the end of the Pleistocene, with the northward movement of desert scrub and saguaro into the region followed by foothills palo verde and ironwood (Van Devender 2000).

The Colorado Desert covers the Salton Sea and Lower Colorado River basins eastward to the transition with the Arizona Upland. It is the hottest and driest of the two subregions with annual precipitation levels as low as 0–76 mm (3 in.). The western boundary of the region extends partly up the lower slopes of the California coastal mountains to where winter precipitation increases enough to support coastal chaparral (81b-8e boundary on ecoregion map). The northern boundary with the Mojave Desert follows the southern slopes of the mountain ranges within Joshua Tree National Park. The Colorado Desert is characterized by broad basins and playas punctuated by extremely dry and barren mountain ranges. Creosotebush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) cover an estimated 42% of lower elevations (Prior-Magee et al. 2007). The plants grow regularly spaced in fine-textured soils—their distance apart regulated by water availability and soil water-holding capacity (Dimmitt 2000b, Turner and Brown 1994). Saltbush (*Atriplex* spp.) is a secondary Colorado Desert vegetation community that was historically more widespread in the Gila Valley, Arizona and Coachella Valley, California until it was largely cleared for agriculture (Turner and Brown 1994).

Parts of the region that do not drain directly to the Salton Sea or to the Colorado River are internally drained with a network of anastomosing rills and washes that typically end with water absorbed into a basin or playa floor. The few tree species in the region (such as honey mesquite [*Prosopis glandulosa*], ironwood [*Olneya tesota*], blue palo verde [*Parkinsonia florida*], smoke tree [*Dalea spinosa*] and desert willow [*Chilopsis linearis*]) grow along these drainages or wherever ground water is forced nearer the surface. For example, honey mesquite forms groves or bosques at the scalloped edges of dune fields or where ground water is within reach (Jaeger 1957, Turner and Brown 1994, Barbour et al. 2007).

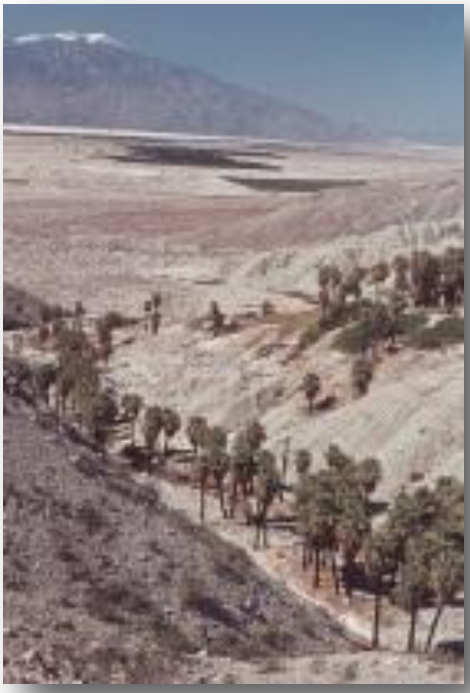


Photo: Fan palms (*Washingtonia filifera*), Indio Hills, California. M.A. Dimmitt, Arizona-Sonora Desert Museum Digital Library, Tucson, Arizona

Sand dunes and palm oases represent important fine filter communities of the Colorado Desert. Areas of sand dunes, such as the Algodones, Mohawk Valley, and Copper Basin Dunes (81d, ecoregion map), occur southeast of the Salton Sea and along the Colorado River. Forrest Shreve estimated that about 14% of the Sonoran Desert (in the US and Mexico) was in sand plain or dunes (F. Shreve in Jaeger 1957). Fan palm (*Washingtonia filifera*) oases occur in canyons and desert washes north and east of the Salton Sea (e.g. Palm Springs area) and in canyons on the eastern slopes of the San Jacinto and Santa Rosa Mountains (photo left, mountain ranges north and west of 81c on ecoregion map). Both of these ecosystems serve as refugia for a number of endemic and threatened and endangered species.

The transition between the Colorado Desert and the Arizona Upland occurs east of the Colorado River at about 300 m (984 ft.) where elevation and summer rainfall increase and winter temperatures fall (Turner and Brown 1994, Dimmitt 2000b, Griffith et al. In Preparation a). Although the landscape of the Arizona Upland does contain a number of broad valleys, the character of this portion of the ecoregion is defined more by its mountain ranges and bajadas (coalesced alluvial fans). A transitional Colorado Desert community occurs on the toeslopes of alluvial fans and lower bajadas, becoming more characteristic of the Arizona Upland higher upslope where desert trees and cacti become more abundant. At upper elevations of about 900 m (2952 feet), the ecoregion meets characteristic transitional vegetation (grassland or interior chaparral) of cooler and wetter ecoregions to the north and east (Arizona/New Mexico Mountains and Madrean Archipelago, Level III ecoregions 23 and 79, respectively, on ecoregion map).

4.1.2 Ecoregion Conceptual Model

The expression of known relationships in conceptual models forms the basis for the development of management questions and the selection of associated data layers and analyses. The ecoregion conceptual model gives a broad scale overview of the region, denoting important natural drivers and anthropogenic change agents (Figure 4-2). Later in the REA process, more detailed conceptual models were delineated to relate individual conservation elements to topical information gleaned through literature review and to identify what portion of that information was quantifiable and accessible as spatial data. In the ecoregion conceptual model, regional climatic conditions represent the dominant natural change agent. Secondary natural change agents include cyclical drought and the natural fire regime (a minor factor in the Sonoran Desert in presettlement times, but included here to help illustrate recently increasing incidence of fire). Human activities, or anthropogenic change agents, include land and resource use, which covers urban and industrial development, surface and groundwater extraction, recreation, agriculture, grazing, and the introduction of invasive plants.

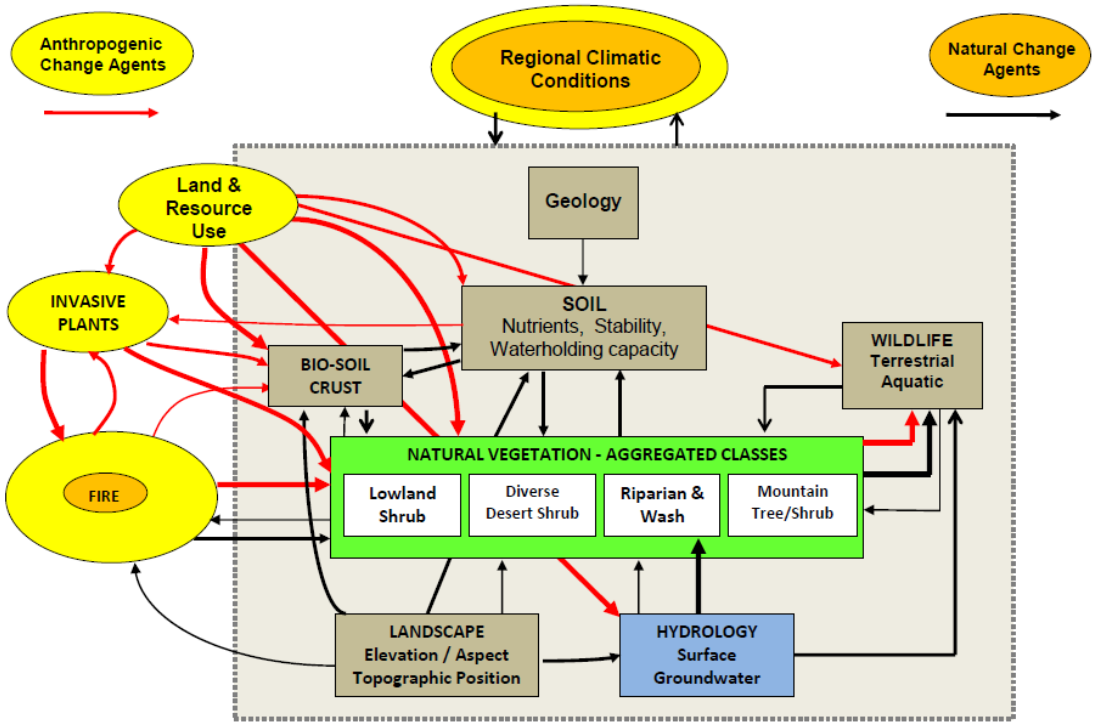


Figure 4-2. Basic ecoregion conceptual model for the Sonoran Desert ecoregion, with both natural and anthropogenic change agents shown. Boxes represent ecosystem components and conservation elements, ovals represent classes of change agents (natural and anthropogenic), and arrows represent the direct and indirect effects of change agents on conservation elements.

The orange and yellow concentric ovals surrounding the change agent *fire* symbolize the change in fire regime in the Sonoran desert in recent decades; historically, fire was not a major influence in the Sonoran desert, but the introduction of invasive annuals such as red brome (*Bromus madritensis L. ssp. rubens*) has been one factor implicated in the increasing incidence of fire (D'Antonio and Vitousek 1997, Esque et al. 2006). Similarly, a yellow concentric oval surrounds regional climate to indicate ongoing human-induced climate change in the region. Across the ecoregion, variability in geology, physiography, elevation, aspect, ground and surface water availability, and soil (texture, depth, and water-holding capacity) is reflected in patterns of vegetation.

Wildlife occurrence and abundance is dependent on interactions with all these abiotic factors (most importantly in the Sonoran ecoregion, temperature regulation and water availability) and the vegetation classes (or major habitats).

Four major natural vegetation (coarse filter) classes are centrally located in the model. The vegetation classes are depicted according to elevational and moisture differences; they represent aggregations of the Southwest Regional Gap Analysis (SW ReGAP) Ecological Systems classes covering more than 1 or 2% of the ecoregion area (Prior-Magee et al. 2007). The *Mountain Tree/Shrub* category is drawn from the Forest and Woodland and upper Shrub/Scrub vegetation classes—represented by small patches of chaparral, broadleaf evergreen, or conifer species in the transition to neighboring ecoregions or at the tops of Sonoran mountain ranges. The box marked *Diverse Desert Shrub* represents the upland Sonoran Paloverde-Mixed Cacti Desert Scrub (that includes saguaro) and the Mojave Mid-Elevation Mixed Desert Scrub (including the Joshua tree anomaly). *Lowland Shrub* corresponds to the Sonora-Mojave Creosotebush-White Bursage Desert Scrub, Sonora-Mojave Mixed Salt Desert Scrub, and the Sonoran Mid-Elevation Desert Scrub classes common to the Colorado Desert in the central and western Sonoran Desert. The box marked *Riparian and Wash Communities* represents the vegetation classes Woody Wetland and Riparian Communities and Emergent Herbaceous Wetlands. Xeroriparian desert wash communities—the North American Warm Desert Riparian Mesquite Bosque and the North American Warm Desert Wash—are also included in this class.

Although biological (cryptogamic) soil crusts might logically fall into several of the coarse-filter vegetation classes, soil crust is pictured separately in the ecoregion conceptual model to highlight its importance. Soil crusts serve as intermediaries between soil and vegetation, with important soil stabilization and nitrogen-fixing roles to play (Belnap and Gillette 1998, Belnap 2002, Housman et al. 2006). Biological soil crusts, composed of algae, lichens, and cyanobacteria, are important to hold the soil surface and to slow the spread of invasive annuals in a region with sparse vegetation. Biological soil crust is easily destroyed by vegetation disturbance of all kinds—clearing, trampling, and OHV traffic—opening the soil to exotic species invasion. Invasive species cover may be 4 times as high on damaged soil as on intact soil with biological soil crust (Wilson et al. 2002).

Photo: Biological soil crust, Saguaro National Park, Rincon Mountains, National Park Service.

In the Sonoran Desert, under hotter and drier conditions, soil crust does not develop as much of a pronounced visible corrugated micro-topography as it does farther north in the colder Central Basin and Range or Colorado Plateau ecoregions where frost heaving is common. In the Sonoran Desert where freezing occurs less often, crusts have a flatter appearance particularly where only cyanobacteria are present (Belnap et al. 2001). Where summer monsoons are consistent, cyanobacteria show greater species diversity and lichen abundance is reduced (fall, winter, spring moisture is optimal for lichen). However, even a thinner soil crust layer fixes nitrogen and binds soil particles together. Although REA participants recognized the importance of soil crust in the Sonoran Desert and initially selected it as a core conservation element, it was deleted as a conservation element during the pre-assessment phase when it became apparent that spatial data were lacking and modeling without adequate occurrence data would not be feasible.

4.1.3 Terrestrial Resources of Concern

4.1.3.1 Soil Stability

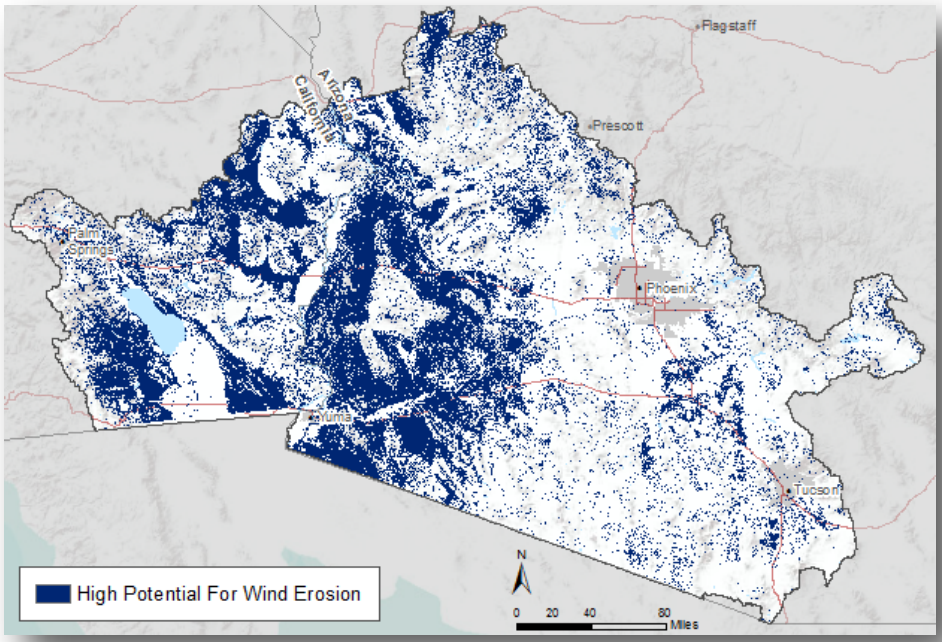
Soils Management Questions

1. Where are soils susceptible to wind and water erosion?
2. Where are sensitive soils (including saline, sodic, gypsiferous, shallow, low water holding capacity)?

Soil stability was selected as a terrestrial function of high ecological value for the Sonoran Desert REA. Sonoran Desert soils contain a high level of soluble salts and low humus content. Aridisol and Entisol soil orders are dominant with thermic and hyperthermic soil temperatures and aridic soil moisture regimes (McAuliffe 1994). Calcium carbonate commonly precipitates out in the soil to produce a *caliche* layer that restricts the downward movement of water (McAuliffe 2000). Sonoran Desert soils are sensitive with sparse vegetative cover and exposed to erosion by a number of natural and anthropogenic change agents. Soils on bajada slopes vary from rocky, colluvial material near the top to finer materials at the base. Finer silts and clays are carried to the basins by wind and water erosion where they have accumulated to 1000s of feet deep (McAuliffe 2000). Persistent wind and wind erosion of soil is a natural phenomenon in desert ecosystems, but human activities including energy and urban development, utility corridors, agriculture, recreation, and grazing all disturb the soil surface, exposing it to erosion. Wind erosion removes nutrients and growing medium from shallow desert soils and semi-arid agricultural areas. Airborne soil particles affect air quality and visibility, nutrient balance, and spring snowmelt in mountainous areas downwind, and blowing dust creates a health and safety hazard for the region's residents (Neff et al. 2008). Evidence suggests that accelerated wind erosion has occurred since Euro-American settlement and may increase in the future with increasing drought predicted under future climate change (Neff et al. 2008).

Photo: Dust storm approaching Phoenix, Arizona, 2003.

REA component maps produced using STATSGO and higher resolution SSURGO data, where available, depict classes of sensitive soils, wind erodibility, and a composite map of sensitive soils in the region (Figure 4-3, See Appendix A for modeling approach, data sources, and component maps).



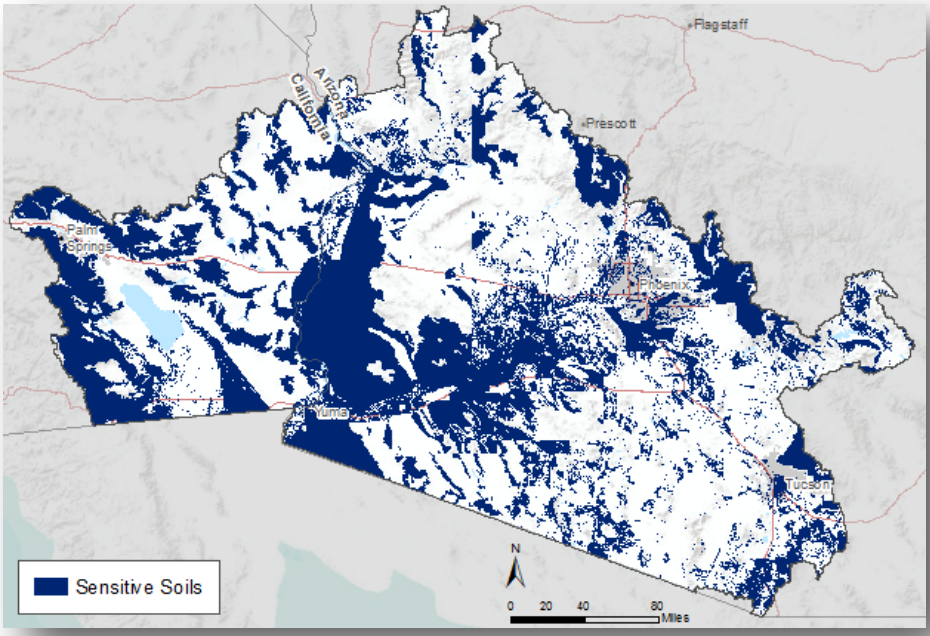


Figure 4-3. Top: Map depicting soils with high risk of wind erodibility in the Sonoran Desert ecoregion. Fine-textured soils susceptible to wind erosion are located mainly in the western and central portion of the Sonoran Desert in the basins of the Colorado Desert. Bottom: Map showing all classes of sensitive soils, including droughty, shallow, hydric, gypsiferous, saline, sodic, and calcareous.

The data for the soil maps were drawn from the 1:24,000 Soil Survey Geographic database (SSURGO) soil surveys and, where SSURGO data were lacking, from the coarser 1:250,000 State Soil Geographic database (STATSGO). The Natural Resources Conservation Service (NRCS) classifies soils into wind erodibility groups; the wind erodibility map depicts the most highly erodible classes 1 and 2 composed of fine-textured soils in the basins of the western and central Sonoran Desert. The second map, sensitive soils, combines soils that are sensitive to erosion or disturbance or that are physically or chemically challenging to vegetative growth. Eight soil classes are represented in the sensitive soils map:

- wind erodible group 1 or 2
- hydric; soils that are sufficiently wet in the upper part to develop anaerobic conditions during the growing season; define wetland conditions, though saturation may be seasonal
- droughty; Available Water Capacity is <0.05 in the top 40 inches of the soil
- calcareous; the $CaCO_3$ content is above 16%
- sodic; with Sodium Adsorption Ratio above 13
- gypsiferous; the gypsum content is above 10%
- shallow; the Rooting Depth is <10 in, or
- highly alkaline, with pH > 9
- saline (chloride)

Sensitive soils have characteristics that make them extremely susceptible to impacts and difficult to restore or reclaim. The classes listed above can serve as thresholds for local soil properties and be used to manage within acceptable ranges to protect vulnerable sites from accelerated erosion, compaction, or invasion by nonnative annual grasses or noxious weeds. Managers have the option to avoid locating disturbances in areas with high-risk sensitive soils and to incorporate best management practices to mitigate negative impacts in areas of low to moderate risk. Awareness of soil types and sensitivity thresholds is also useful for restoration efforts, such as soil crust restoration. Restoration of soil crust in highly disturbed areas is known to be extremely slow, taking as long as 100s of years for recovery (Belnap et al. 2001). Soil crust must go through a succession process with cyanobacteria establishing first and cyanolichens arriving years later after the slow development of the microtopography favorable to lichen recruitment (Belnap et al. 2001). Soil crust species richness is higher in gypsiferous soils, non-calcareous sandy soils, and limestone-derived soils, meaning that restoration efforts are more likely to be successful in those soil types.

4.1.3.2 Coarse Filter Vegetation Communities

Vegetation Management Questions

1. Where are existing vegetative communities?

2. What change agents have affected existing vegetation communities?

The two major vegetation communities selected as coarse filter conservation elements for the Sonoran Desert REA were the Sonoran-Mojave Creosotebush-White Bursage Desert Scrub and the Sonoran Palo Verde-Mixed Cacti Desert Scrub (Prior-Magee et al. 2007). Together these vegetation classes cover 76% of the ecoregion. Mapped results for each vegetation community include 1) current distributions for both SW ReGAP and LANDFIRE existing vegetation, 2) recent disturbances based on disturbance agents drawn from LANDFIRE for 1999–2008, and 3) historic change experienced by each community (agriculture, development, invasive species, and vegetation change) based on a comparison of existing vegetation with a modeled presettlement reference condition (LANDFIRE Biophysical Settings [BpS] dataset [www.landfire.gov]). The creosotebush-white bursage community was

introduced in Chapter 3, Section 3.2.1, Conceptual models; a brief introduction to the palo verde-mixed cacti community follows below:

Photo: Arizona Upland, Ragged Top, Ironwood Forest National Monument. M.A. Dimmitt, Arizona-Sonora Desert Museum, Tucson, Arizona

The Palo Verde-Mixed Cacti community is characterized by leguminous trees, such as foothills palo verde (*Parkinsonia microphylla)*, blue palo verde (*P. florida*), and ironwood (*Olneya tesota*), thorn shrubs, succulents and an abundance of cacti: many cholla (*Cylindropuntia* spp.), barrel (*Ferocactus* spp.), and pricklypear (O*puntia* spp.) species. Some of the same woodland species that could grow only in the drainages of the Colorado Desert grow here on the open slopes of coalesced alluvial fans (bajadas) and give this region its subtropical thornscrub character (Turner and Brown 1994). Various associations of these species create a landscape of saguaro cacti (*Carnegia gigantea*) standing in and above a sparse to moderately dense canopy of woodland and shrub species, depending on site conditions, aspect, and elevation (Prior-Magee et al. 2007). Saguaro is the only columnar cactus to be cold hardy enough to survive the winter frosts that regularly occur in the region (Dimmitt 2000b). Two other species of columnar cacti, organ pipe cactus (*Stenocereus thurberi*) and senita (*Pachycereus schottii*), are not as frost hardy and occur in the U.S. only near the Mexican border in Organ Pipe Cactus National Monument and north to Ajo, Arizona. Creosotebush is a generalist and it occurs as a minor element even at higher elevations in the Arizona Upland.

Major threats to ecosystems in the Sonoran region include direct conversion of desert habitats to energy, agricultural, urban, and suburban development, overallocation of water for human consumption, and changes in species diversity and ecosystem character from the increasing incidence of fire and the invasion of exotic annual species. Besides mapping the distribution and status of the selected vegetation communities, REA analyses included both historic and recent changes to the two selected vegetation communities. Historic, cumulative change since presettlement times was expressed spatially for the Palo Verde-Mixed Cacti community by mapping areas of the community that have been converted to a land cover different from that modeled for that community's reference condition (LANDFIRE BpS). Four major change agents—energy and urban development, agriculture, invasive species predictions in burned areas, and uncharacteristic vegetation composition (derived from the LANDFIRE succession class dataset)—were included in the analysis.

Results for recent disturbances to the Palo Verde-Mixed Cacti community, drawn from LANDFIRE Disturbance datasets for 1999–2008, have been mapped using disturbance agents from four different disturbance categories—fire, mechanical treatment of vegetation communities, insects and disease, and other (herbicide, chemical treatment, or unknown). Fire is the predominant recent disturbance mapped in the Sonoran Desert. Results for historic change and recent disturbances to the two major vegetation communities selected as conservation elements are presented in Section 4.2.

4.1.4 Aquatic Resources of Concern

Surface and Groundwater Management Questions (MQ B1–B7, J3–J4)

1. Where are lotic and lentic surface waterbodies and livestock, wildlife watering tanks and artificial water bodies?
2. Where are perennial streams and stream reaches?
3. Where are the alluvial aquifers and their recharge areas (if known)?
4. Where are aquatic systems listed on (303d) for water quality or having low macroinvertebrate diversity?
5. Where are surface water flows likely to increase or decrease in the near-term, 2025 (development), and long-term, 2060 (climate change)?
6. What is the location/distribution of aquatic biodiversity sites?
7. What are seasonal maxima and minima discharges for the Colorado River and major tributaries at gaging stations?
8. Where are aquatic/riparian areas with potential to change from climate change?
9. Where areas of potential surface water flow change?

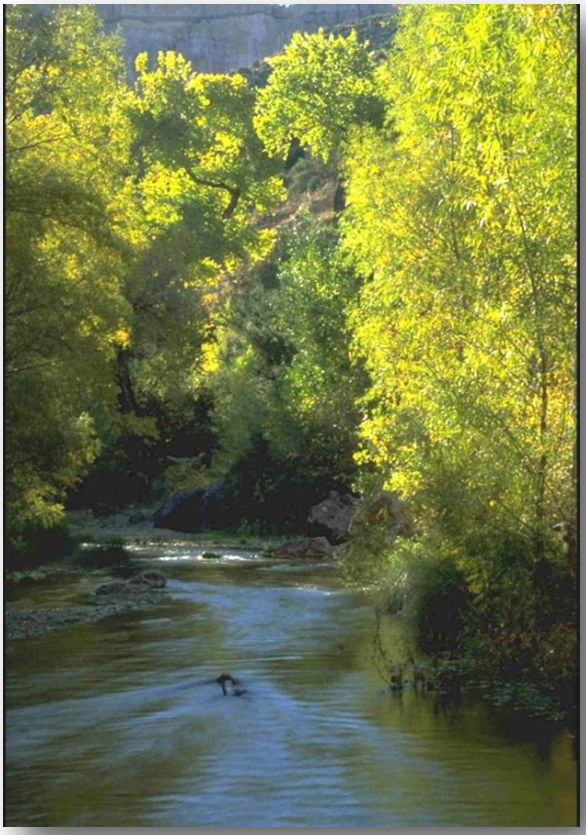


Photo: Aravaipa Creek, Arizona. Arizona BLM

The value of water resources to desert dwellers is obvious and inestimable. The importance of water resources to the Sonoran Desert REA process is reflected in the number of water-related management questions. Management questions 2 and 7 are answered in the body of the text; the rest may be found in Appendix A. Aquatic resources were also represented in REA data and results as aquatic sites of conservation concern, represented by The Nature Conservancy portfolio sites, and ecosystem functions and services—springs and seeps, lakes and artificial waterbodies, wetlands, and riparian areas. Natural lake habitats are limited in the region, but presently, 400 dams and reservoirs on the Colorado River and its tributaries (from headwaters to delta) have created permanent standing water habitat (Pool et al. 2010).

In arid and semi-arid regions, streams experience extreme variations in water flow, permanence, and sediment transport that produce braided, meandering, or anastomosing channels (Hughes et al. 2011). Stream flows range from perennial (mountain source or spring-fed) to spatially intermittent (flowing only where local hydrogeologic conditions raise the water table above the streambed), temporally intermittent (where the water table seasonally supports streamflow), and ephemeral (flowing in response to storms or derived from storm-related bank-storage events). Because of the cumulative impacts of factors such as human water consumption and channel dewatering, climate change, or simple mapping error, >70% of stream length in arid and semi-arid regions in the western U.S. that was historically mapped as permanent is now intermittent or ephemeral (Stoddard et al. 2005b, Figure 4-4, management question B2). Statewide, 66% of California streams and 94% of Arizona streams are intermittent or ephemeral (Levick et al. 2008). Carlisle

et al. (2011) also reported, in an assessment of streamflow alteration (1980–2007), that >50% of the stream length in arid U.S. regions experienced reduced base and flood flows. Diminished flow was the primary predictor of biological integrity for aquatic species with the likelihood of impairment increasing as flows diminished. In an assessment of stream resources in 12 western states, Stoddard et al. (2005a) estimated that 50% and 48% of the region's streams had highly disturbed vertebrate and macroinvertebrate biotic condition, respectively. Climate change is projected to result in mean air temperature increases, increased drought conditions, earlier and smaller spring peak flows, and lower summer flows (Cayan et al. 2001, Seager et al. 2007). Although fluctuating flows, high turbidity, and periodic flooding and drought are important natural processes in streams draining arid regions, the increasing amplitude and variability of these processes created by climate change and continued human pressures threaten to reduce and fragment aquatic habitats even further, stressing native species beyond their ability to adapt.

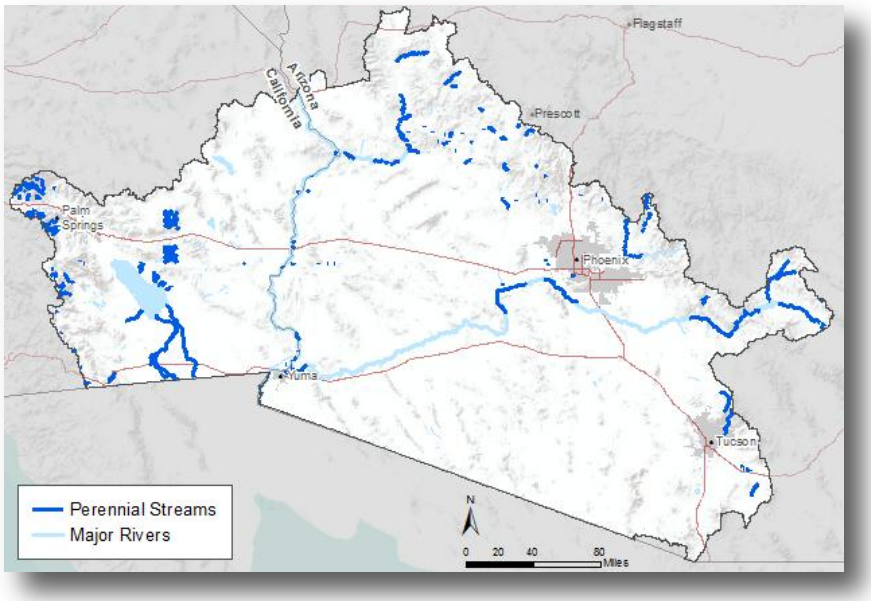


Figure 4-4. Map shows Sonoran Desert perennial streams (management question MQ B2). Mainstem Colorado and Gila rivers are in light blue. Data from the National Hydrography Dataset typically over-represent perennial streams because of mapping error or loss of perennial flow over time (water consumption, climate change).

Because of the region's aridity and high demand for water, most lotic and lentic ecosystems in the Sonoran Desert have been degraded by humans to some degree. About 90% of the region is drained by the Colorado River, one of the most-altered drainages in North America (Ohmart et al. 1988, Hughes et al. 2005). Thirty million people in the upper and lower Colorado River Basin depend on the Colorado River and its tributaries for their water supply; fluctuations in water yield occur from variability in precipitation, runoff, snow pack, and spring snow melt (Table 4-1, management question B3). The river and its tributaries are highly regulated and the water over-allocated. As early as midway into the 20th century, human water demands in the region were three times the amount available from surface waters, resulting in the mining of groundwater for human consumption, mining, industry, and agriculture (Harshbarger 1959). Two thirds of Arizona's available water supply is allocated to irrigated agriculture; this figure is somewhat reduced from that of the mid-20th century (90%) because of losses of agricultural land to urban development and more recent water conservation measures, including a non-expansion rule for groundwater pumping and best management practices for land preparation and water delivery to row crops (Figure 4-5, Bureau of Reclamation, and ADWR 2011). Irrigation tail-water is often reused and any water that is returned to the stream channel is laden with leached salts and agricultural chemicals. In a study examining the effects of agriculture on fish in the western U.S., Moore et al. (1996) reported that the number of fish species listed under the Endangered Species Act per county was positively correlated with the level of irrigated agriculture in that county.

Table 4-1 shows average seasonal maxima and minima for gaging stations on the lower Colorado River and major tributaries recording 12–100 years of records from various gaging stations through 9-30-2010 (Source: http://waterdata.usgs.gov/nwis). Figures in cubic feet/second rounded to the nearest cfs. Table answers management question MQ B3: *What are seasonal maximum and minimum discharges for the Colorado River and major tributaries at gaging stations?*

Gaging Station Location	SPMN	SPMX	SUMN	SUMX	FMN	FMX	WMN	WMX
COLORADO RIVER PARKER DAM, AZ-CA	7145	29691	7243	38777	2440	33405	2502	30791
WHITEWATER RIVER AT INDIO CA	0	4	0	53	0	28	0	500
COLORADO RIVER PALO VERDE DAM, AZ	6149	17167	5763	13332	2978	13119	2562	18403
SALT CREEK NEAR MECCA	2	21	1	50	1	53	3	90
ALAMO RIVER NEAR NILAND CA	683	1290	599	1274	540	1201	389	1133
NEW RIVER NEAR WESTMORLAND CA	469	918	416	1049	414	973	392	932
AGUA FRIA RIVER AT EL MIRAGE, AZ	0	43	0	19	0	15	0	101
VERDE RIVER NEAR SCOTTSDALE, AZ	0	3950	16	1883	6	2473	6	17144
SALT RIVER STEWART MT DAM, AZ	48	7707	147	2638	1	4672	0	19554
GILA BEND CANAL AT GILLESPIE DAM, AZ.	36	170	23	130	1	105	2	171
SANTA CRUZ RIVER NEAR LAVEEN, AZ.	0	56	0	843	0	1081	0	1017
COLORADO RIVER AT NIB	1567	19814	1644	30509	662	28100	920	24144
GILA RIVER NEAR DOME, AZ.	0	13257	0	3344	0	6667	0	15691
SAN CARLOS RIVER NEAR PERIDOT, AZ.	0	477	0	747	0	1276	2	4655
GILA RIVER AT KELVIN, AZ.	7	3034	3	5540	1	5405	14	16062
GILA RIVER AT CALVA, AZ.	1	3039	0	3101	0	9044	15	13905
COLORADO RIVER NEAR SAN LUIS, AZ.	0	15359	0	25060	0	24945	0	20648

SPMN=spring minimum; SPMX=spring maximum; SUMN=summer minimum; SUMX=summer maximum; FMN=fall minimum; FMX=fall maximum; WMN=winter minimum; WMX=winter maximum.

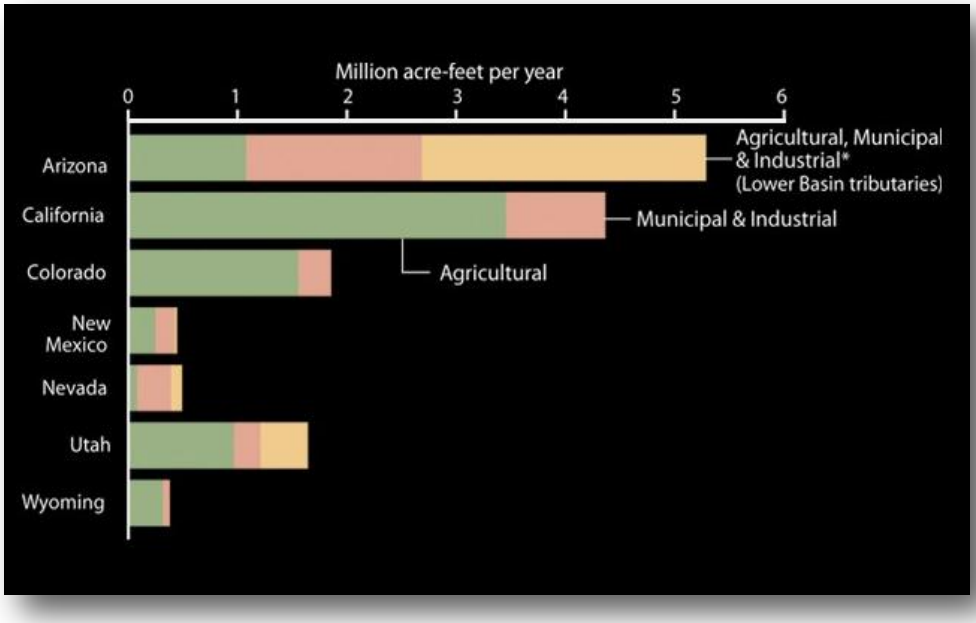
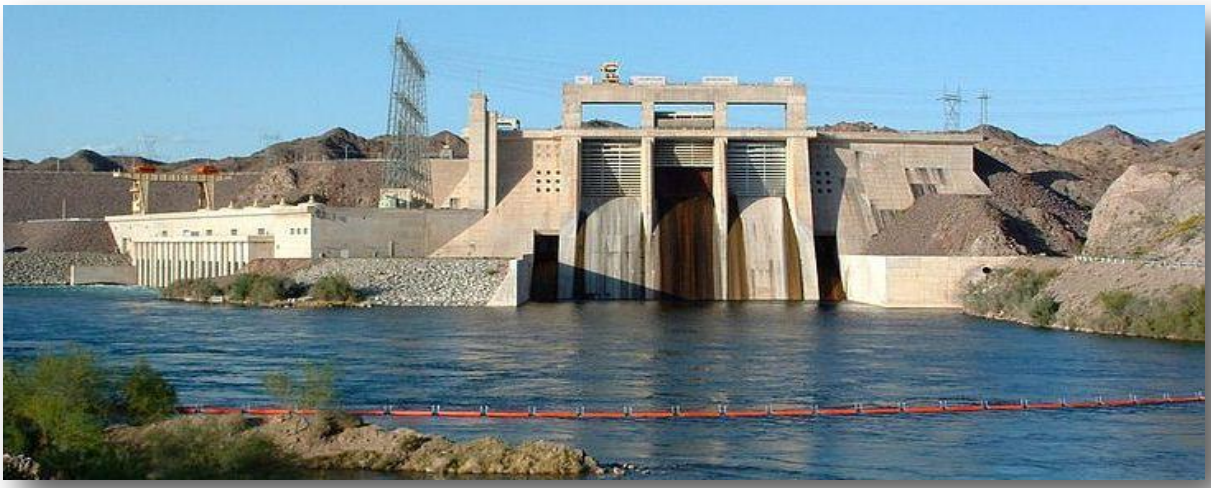


Figure 4-5. Water consumption of states of the upper and lower Colorado River basin for agriculture (green), municipal and industrial use (pink), and all usage from Colorado River tributaries (yellow, data not recorded by usage class). Data from Bureau of Reclamation (National Geographic website http://www.savethecolorado.org/map.php)



Davis Dam, pictured above, together with Hoover and Parker Dams, control the water allotment for the lower Colorado River Basin., Photo: K. Kolb, Wikimedia Commons

Metal mining occurs over relatively small areas of the Sonoran Desert compared to irrigated agriculture; however, mining also requires large quantities of water. Mining increases sediment loads to streams, alters channel structure and flow regimes, and frequently delivers highly toxic effluent to surface waters (Martin and Platts 1981, Woody et al. 2010). Mine effluent, spills, and runoff from exposed tailings may comprise the only flow in naturally temporary streams and the metal concentrations of those flows may exceed criteria for livestock and human consumption.

Besides diminished instream flow in streams, altered flow regimes created by dams, channelization, canal systems, and water withdrawals are associated with increased homogenization of fish assemblages through extirpations of native fishes coupled with increased dominance by non-native fishes (Williams et al. 1985, Stanford 1994, Hughes et al. 2005, Olden et al. 2006, Poff et al. 2007). Native fish species in the region have declined in range and abundance since the early 20th century; during that time, 25 of 31 native fish species in the lower Colorado River Basin have been federally listed as threatened or endangered (Pool et al. 2010). In a study using fish data from 159 watersheds in the lower Colorado River Basin, Pool et al. (2010) found that altered watersheds with high dam densities had higher non-native fish functional diversity, while watersheds with upstream land protection, lower dam densities, and variability in spring and summer precipitation supported an increased number of native fish species. They considered natural flow variability and overland flow from storm events to be vital for sustaining native species diversity.

Nonnative invasive species have been ranked as the second or third most important threat to the biodiversity of native fishes (Miller et al. 1989, Hughes et al. 2005, Reed and Czech 2005). Over twice as many nonnative fish species as native fish species reside in Arizona waters (Rinne 1995). Lomnicky et al. (2007) estimated that nonnative aquatic vertebrates occurred in 83 $\pm$ 10% of Arizona streams, and westwide, in 83 $\pm$ 6% of large rivers. Nonnatives alter native fish assemblages through competition (Dudley and Matter 2000) and predation (Li and Moyle 1981, Meffee 1984, Dunham et al. 2004). Nonnative predators may entirely eliminate a native fish assemblage in a particular catchment—even in an otherwise unmodified watershed—if the native fish are stressed or experiencing low recruitment, as during a drought (Probst et al. 2008). Nonnative invasive aquatic macroinvertebrates can be problematic as well. Stoddard et al. (2005a) estimated that nonnative crayfish occurred in 7 $\pm$ 3% and Asian clam occurred in 6 $\pm$ 3% of the stream length in xeric regions of the western U.S. Although their occurrence probabilities were low, when present, the crayfish and clam were associated west-wide with a doubling or tripling of the risk of having poor vertebrate and macroinvertebrate biological integrity scores (Stoddard et al. 2005a).

Thus, while the retention or mimicking of natural hydrologic regimes is essential for maintaining native fish assemblages (Poff et al. 1997), a reduction in competition from nonnative species is just as important (Eby et al. 2003, Mueller 2005, Propst et al. 2008). A natural flow regime allows connectivity and genetic diversity, but it also allows nonnative fish easy access to native refugia (Propst et al. 2008). Recovery activities for native aquatic species includes managing water releases from dams to benefit native species life cycles, acquisition of bottomlands and easements, breaching of levees, stocking hatchery-raised threatened and endangered species, managing nonnative species introductions, and conducting targeted nonnative species control (Mueller 2005).

The only (semi-)aquatic species examined for this REA was the Lowland Leopard Frog (*Lithobates yavapaiensis*); the species was extirpated in California because of habitat loss and degradation and it has declined in the Arizona portion of its range. No fish species were selected as conservation elements for the Sonoran Desert REA. Fish are highly managed (meaning many threatened species are reared in captivity and introduced into appropriate habitats), and threatened species' locational data are considered sensitive. The endangered fish species in the Colorado River are managed by the Bureau of Reclamation, Fish and Wildlife Service, and State fish and wildlife agencies in the Lower Colorado River Multispecies Conservation Plan (LCRMSCP 2004). Desert pupfish are not ecoregionally distributed and they are managed at the local scale.

Instead, without aquatic species, the riparian zone became an REA focus for examining several conservation elements and related change agents, since it is also a critical desert ecosystem and the interface between Sonoran Desert terrestrial and water resources. Markedly altered flow regimes may eliminate native riparian vegetation (Rood and Mahoney 1990, Lytle and Merritt 2004), change riparian community composition (Busch and Smith 1995, Merritt and Wohl 2006, Stromberg et al. 2007, Merritt & Poff 2010, Mortenson and Weisberg 2010), species richness (Nilsson et al. 1991), and productivity (Stromberg and Patten 1990, Molles et al. 1998). Although historically riparian habitats composed about 1% of the land area of the western states, ground water pumping and a broad range of human disturbances have resulted in the loss of >90% of the region's wetlands and native riparian woodlands (Krueper 1996, Cline and Zarate 2010) and 80% of Colorado River delta wetlands (Hinojosa-Huerta et al. 2005). As much as 80% of all vertebrates use the remaining riparian habitats for cover and foraging, and over 50% of southwestern bird species use riparian woodland and shrubland for nesting (Knopf et al. 1988, Krueper 1996). Lucy's warbler and Bell's vireo are two riparian bird species conservation elements discussed in Appendix C. Xeroriparian habitats are just as important in arid ecosystems; in the lower Colorado River Basin, dry washes occupy <5% of the area, but support 90% of its bird species (Dimmitt 2000a, Levick et al. 2008). For more on birds and xeroriparian habitats, see the discussion of Le Conte's thrasher in Appendix C.

Photo: Xeroriparian habitat with velvet mesquite (*Prosopis velutina*), Ironwood Forest National Monument, M.A. Dimmitt, Arizona-Sonora Desert Museum, Tucson, Arizona.

Just as was done for terrestrial landscape intactness (in Chapter 3, Section 3.2.3), a companion fuzzy logic model for aquatic intactness was developed and organized by 5th level HUC (Figure 4-6). It is used later in the report to assess status for aquatic conservation elements (Section 4.2.1). The model includes 10 primary inputs with three major contributors to high aquatic intactness—low hydrologic alteration, high land and water quality, and low road impacts, represented as intermediate results in purple boxes below (Figure 4-6).

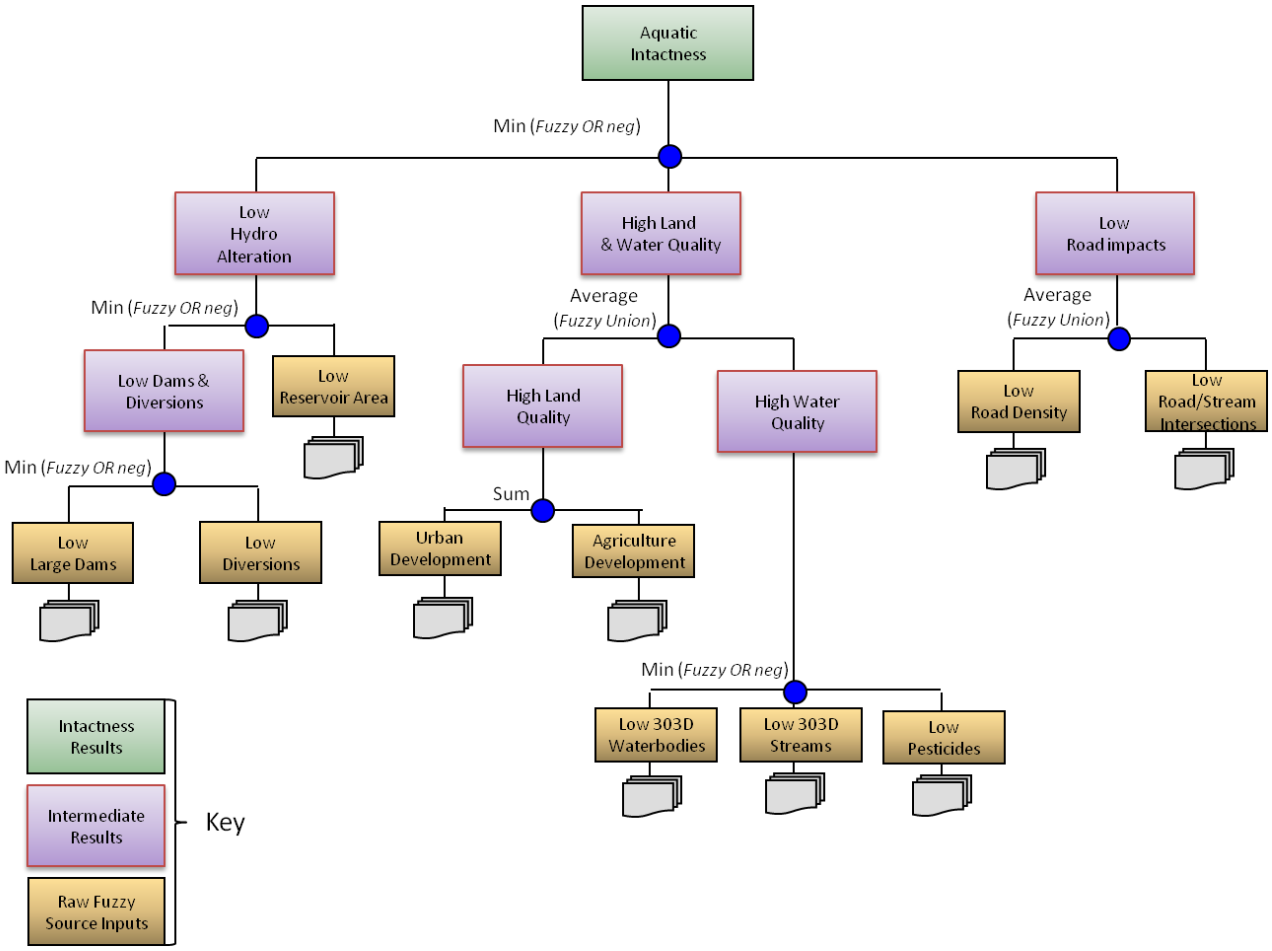
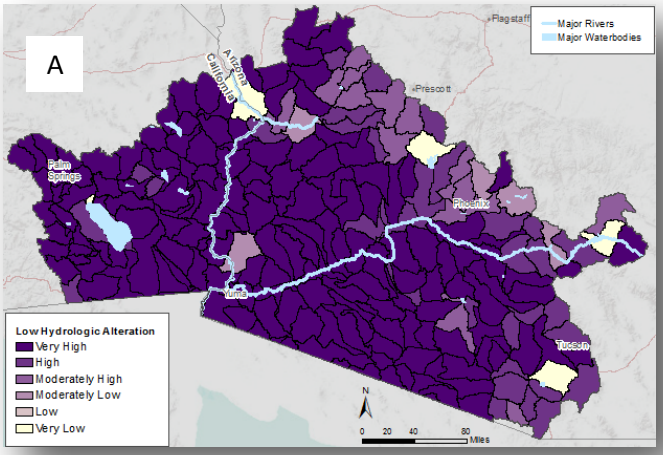
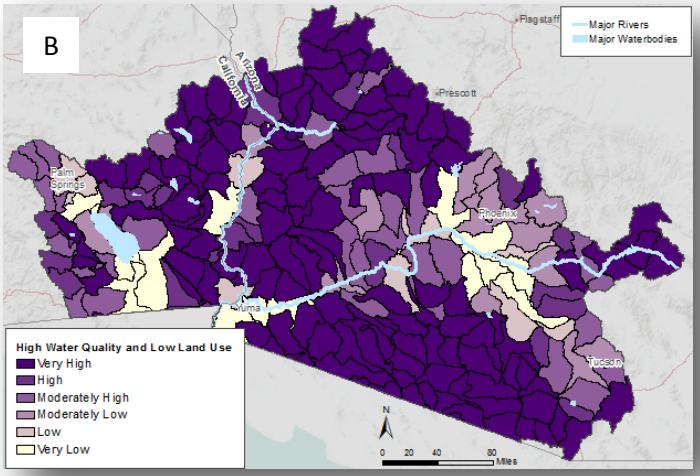


Figure 4-6. Fuzzy logic model for aquatic intactness in the Sonoran Desert ecoregion.

The intermediate results maps for the three major contributors represent aquatic degradation drivers and show widespread aquatic impacts throughout the ecoregion (Figure 4-7). Darker color is higher on a relative scale. For example, in Figure 4-7A and C there are few areas with either low hydrologic alteration or low road impacts. The map in Figure 4-7B shows areas in the Salton Sea basin and the Phoenix-Tucson corridor with high land use and low water quality as expected. Final aquatic intactness results are provided in Section 4.2.1. Appendix A contains specific results for each stated aquatic management question listed at the beginning of this section.





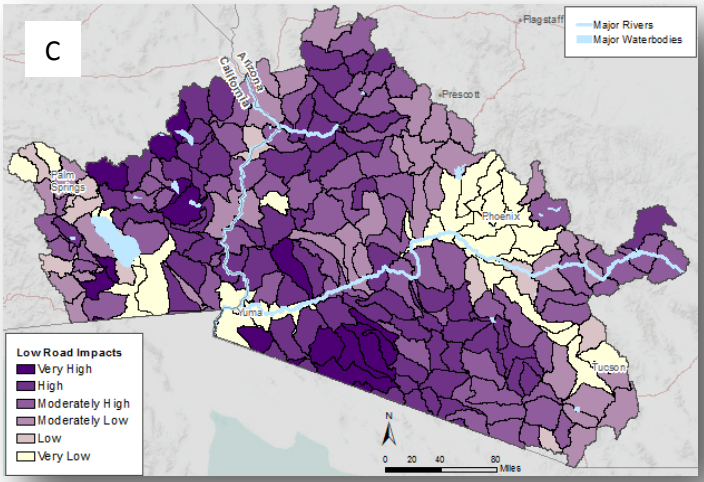


Figure 4-7. Intermediate results for aquatic intactness model including (A) Low Hydrologic Alteration, (B) High Land and Water Quality, and (C) Low Road Impacts. Darker color is high on a relative scale to map topic; i.e., dark purple area along southern border in map 4-6C means low road impacts (very low road density).

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Photo: Mesquite bosques at the margin of a dune field, Chuckwalla Valley. M.A. Dimmitt, Arizona-Sonora Desert Museum Digital Library.

4.2 Distribution and Status of Conservation Elements

Species Management Questions

1. What is the current distribution of available occupied habitat and CE status?
2. Where are potential areas to restore connectivity?
3. What is the location of terrestrial biodiversity sites?
4. Where are HMAs located?

Conservation elements were organized into three categories—wildlife species, ecological systems, and designated sites, and analyses were conducted on 11 wildlife species (3 mammals, 5 birds, 2 reptiles, and 1 amphibian, Table 4-2). Three ecological systems were assessed, including the two major coarse filter vegetation communities plus riparian vegetation (Table 4-3). Sites of ecological and management concern included designated sites, high biodiversity sites, and herd management areas (HMAs). In addition, Natural Heritage occurrence data were examined that were provided by NatureServe. Natural heritage data summaries included number of species, number of U.S. Fish and Wildlife Service threatened and endangered species, and number of globally critically imperiled, imperiled, and vulnerable species (G1 –G3, Master et al. 2000) organized by 5th level HUCs. The first three management questions listed are answered in the text (Section 4.2) for wildlife species, vegetation communities, and designated protected areas. All other management questions results and conservation elements not featured in the body of the text may be found in Appendices A, B, or C.

Table 4-2. List of species conservation elements (CEs) evaluated for the Sonoran Desert ecoregion.

Species CEs	
Bell's Vireo (Vireo bellii and Vireo bellii pusillus)	Lowland Leopard Frog (*Lithobates yavapaiensis*)
Desert Bighorn Sheep (Ovis canadensis nelsoni)	Lucy's Warbler (Oreothlypis luciae)
Mojave Desert tortoise (Gopherus agassizii)	Mountain Lion (Puma concolor)
Sonoran Desert tortoise (Gopherus morafkai)	Mule Deer (Odocoileus hemionus)
Golden Eagle (Aquila chrysaetos)	SW Willow Flycatcher (Empidonax traillii extimus)
Le Conte's Thrasher (Toxostoma lecontei)	

Table 4-3. List of ecological systems with highlighted dominant species and other site-related conservation elements (CEs) examined in the Sonoran Desert ecoregion.

Ecological Systems CEs
Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Creosotebush)
Sonoran Paloverde Mixed Cacti Desert Scrub (Saguaro Cacti)
Riparian Vegetation
Sites CEs
Designated Sites
Biodiversity Sites – Terrestrial and Aquatic
HMAs

4.2.1 Evaluating Wildlife Species Current Distribution and Status

Current distribution mapping for the species conservation elements were derived from state GAP, Southwest ReGAP, or compilations of state agency spatial data. Acquisition of state wildlife agency data was emphasized because it tended to be more conservative, although occasionally it was impossible to reconcile boundary issues between the different states. Original species distribution mapping of potential habitat was not possible due to a lack of detailed occurrence records necessary to conduct MaxEnt modeling. An existing MaxEnt model for Mojave desert tortoise (*G. agassizii*, Nussear et al. [2009]) was available for use in this REA. For the other Sonoran Desert species, species distribution models and maps were based on state-level data that tended to be more restrictive than the more generalized SW ReGAP data.

The total area examined in the ecoregion was 34.9 million acres (14 million hectares). Current distributions for the terrestrial species ranged from about 139,000 acres to almost 26,846,000 acres (Table 4-4).

Table 4-4. Total current distribution area (in 1000s of acres) for terrestrial species conservation elements for the Sonoran Desert ecoregion.

Species CEs	Total Distribution Area	Percent of Ecoregion
Bell's Vireo (*Vireo bellii and Vireo bellii* pusillus)	2,821	8.1%
Desert Bighorn Sheep (*Ovis canadensis nelsoni*)	7,863	22.5%
Mojave Desert tortoise (*G. agassizii*)	3,181	9.1%
Sonoran Desert tortoise (*G. morafkai*)	6,951	19.9%
Golden Eagle (*Aquila chrysaetos*)	17,257	49.4%
Le Conte's Thrasher (*Toxostoma lecontei*)	9,772	28%
Lowland Leopard Frog (*Lithobates yavapaiensis*)	678	1%
Lucy's Warbler (*Oreothlypis luciae*)	13,753	39.4%
Mountain Lion (*Puma concolor*)	13,893	39.8%
Mule Deer (*Odocoileus hemionus*)	26,846	76.9%
SW Willow Flycatcher (*Empidonax traillii extimus*)	139	0.4%

Species status was evaluated in two ways—1) a review of background information (discussed in individual species profiles in Appendix C) and 2) an examination of the overlay of current distribution with terrestrial and aquatic landscape intactness (at 4 km x 4 km resolution for terrestrial species and organized by 5th level HUC for the lowland leopard frog).

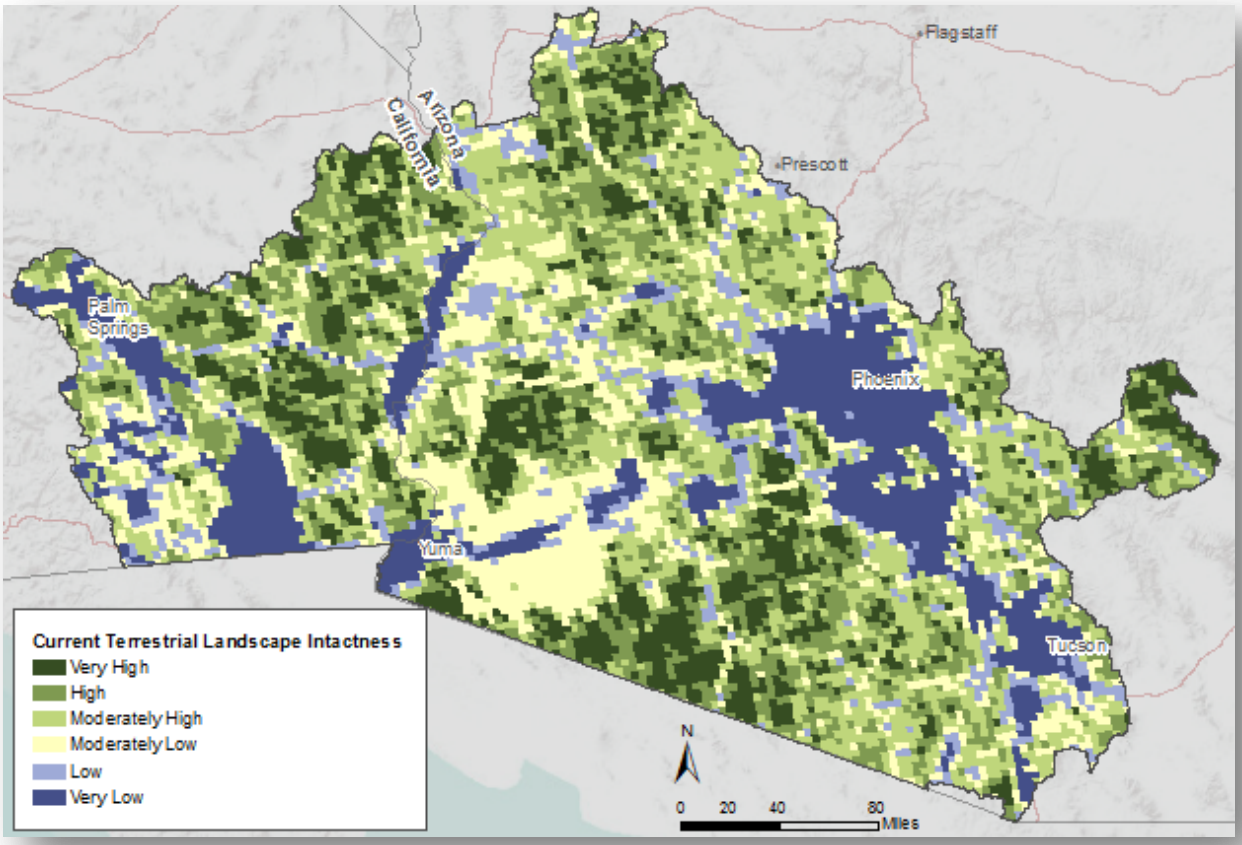
Terrestrial landscape intactness was mapped following the methods described in Chapter 3, Section 3.2.3 and 3.2.4. Intactness is an indicator of habitat quality based on available spatial data reported at a fairly coarse 4 km X 4 km scale; expectations of accuracy should match the scale of the reporting unit. Working at the ecoregion scale and at finer local scales will require calibration of intactness with finer scale map and field data. As a result, in this report, use of the term habitat quality is a relative term meaning potential quality. The intactness model is generalized, based on landscape characteristics, and typically not tied to individual species' requirements. However, for this model, numerous species-level attributes and indicators (Appendix D) were evaluated, paying particular attention to known change agents that provide the most important information related to changes in species status over time. Unfortunately, the scientific literature does not provide many quantifiable indicators, and when it does, spatial data are typically lacking. For example, golden eagle status is closely tied to prey density (especially jackrabbits). Prey density would be a strong indicator for this species, but prey density data are not available to create a spatial model. Even if data for this indicator could be generated, it would still be challenging to use because of its inherent dynamism—many prey species such as jackrabbits display boom and bust population cycles every 7 to 10 years (Gross et al. 1974).

This model of intactness is fundamental to assessing status for all conservation elements in the REA. Some of the more common status indicators for species pertain to one or more types of human development (including urban, agriculture, mining, recreation and roads); in other words, minimal human development generally indicates intact habitat conditions for a species and high levels of development indicate degraded conditions. For this reason, status was evaluated for each species against the overall intactness model as it provides the best regional perspective for vegetation condition and habitat quality, development profile, and natural habitat fragmentation patterns. Not all species demonstrate the same level of tolerance to the various model inputs, but an overall intactness model provides a standard baseline from which to explore specific species or regions where tolerances to various components may vary. Current terrestrial landscape intactness at 4 km x 4km resolution (Figure 4-8) and aquatic intactness organized by 5th level HUC (Figure 4-9) for the Sonoran Desert ecoregion show the full range of values from Very Low to Very High. In general, results for the terrestrial intactness model showed the greatest percent area (26%) in the Moderately High category followed by High with 21%. Very High and Very Low intactness showed similar amounts, 13.5% and 14.7% respectively. Aquatic intactness showed a similar pattern for the Moderately High and High categories, but it had a higher percentage of area in the Very Low class (19% vs. 14.7% for terrestrial intactness).

In cases where more quantifiable thresholds have been reported and can be tested, the logic model is easily modified. For example, Figure 4-10 shows two terrestrial intactness results for mountain lion. Map 4-10A shows the overall intactness model results overlaid by mountain lion distribution to provide a status profile and Map 4-10B shows the same mountain lion distribution over a customized version of the intactness model that includes a road density tolerance threshold of 0.60 km/km^2 reported by Van Dyke et al. (1986). One can easily see the difference a reported threshold can have on the results. The histograms show a significant decline of suitable potential mountain lion habitat when this threshold is enforced in the model. Map 4-10B clearly shows islands of high quality mountain lion habitat based on noted attributes and indicators for this species (Appendix D). A handful of these blocks are very large while others are small and somewhat isolated from one another. Mountain lions could occur over a good portion of the ecoregion according to the distribution data (nearly 40%), but in areas of low or very low intactness, mountain lions would be expected to come into regular contact with human activities often with negative consequences. Prey density (especially mule deer) is another important indicator of mountain lion habitat. While spatially explicit information for primary prey species density is not available, one can simply compare the status results using the reported road density threshold with current distribution of mule deer and bighorn sheep and observe the overlap.

The three mammal species conservation elements in the Sonoran Desert share a similar status profile (Figure 4-11). Desert bighorn sheep has more of its distribution in more intact habitats than mule deer and mountain lion. Of the three mammal species, the adaptable mule deer showed more of its current distribution in least intact habitats. Note that species distribution is indicated in blue on the distribution maps for each of the 11 species and intactness is represented in the histograms. Live maps may be viewed on the data portal for panning, zooming, or combining this information with other data layers (weblink in Section 2.2.3).

For the reptiles, the two desert tortoise species showed similar status profiles based on the terrestrial landscape intactness results (Figure 4-12). Most of the distribution for both species is located within the three higher intactness classes with *G. agassizii* more skewed to potentially higher quality habitat than *G. morafkai*. Such high results do not necessarily mean these two species are currently secure (for more details on both desert tortoise species, see Desert Tortoise Case Study Insert located after Section 4.2.1). As additional data becomes available specific to tortoise disturbance thresholds, the models can be further refined. The lowland leopard frog status results, based on the aquatic intactness model organized by 5th level HUCs, shows approximately 60% of its current distribution in the lower intactness categories, including 27% in the Very Low category. Some portion of this result may be due to the coarse scale of the 5th level HUC, but the results support reported declines of the frog in the ecoregion (Rorabaugh 2006).



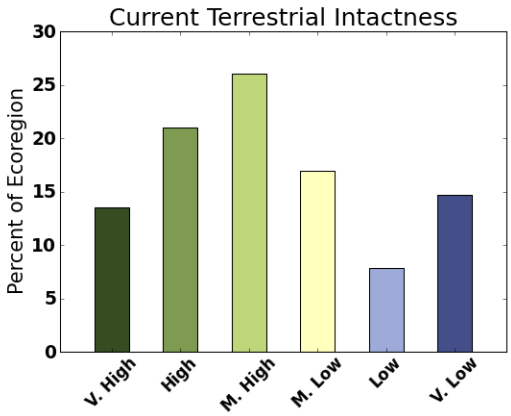
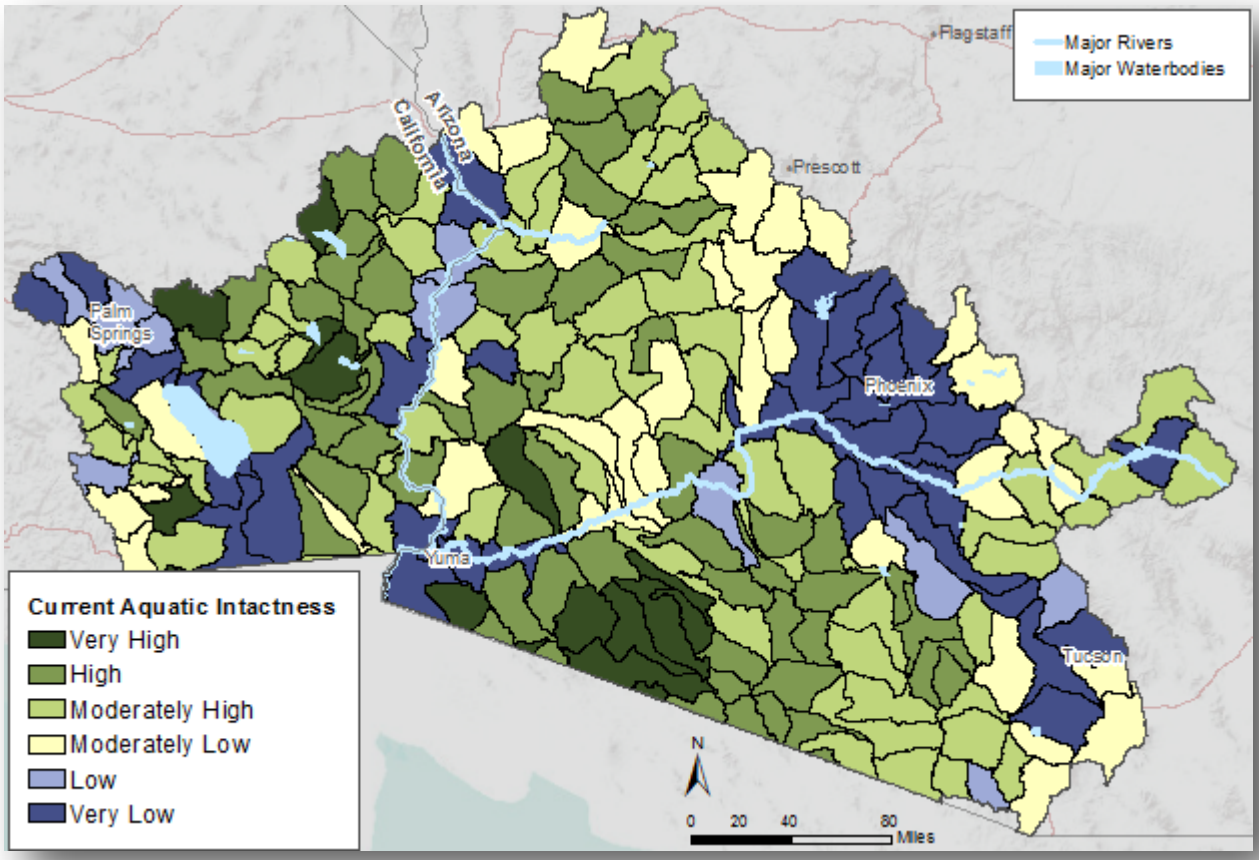


Figure 4-8. Current terrestrial landscape intactness organized by 4 km x 4 km grid cells for the Sonoran Desert ecoregion with associated histogram indicating areal percent of the ecoregion in various intactness classes.



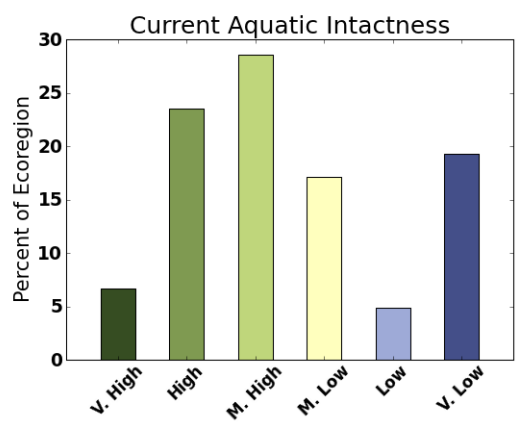


Figure 4-9. Current aquatic intactness organized by 5th level HUCs for the Sonoran Desert ecoregion with associated histogram indicating areal percent of the ecoregion in various intactness classes.

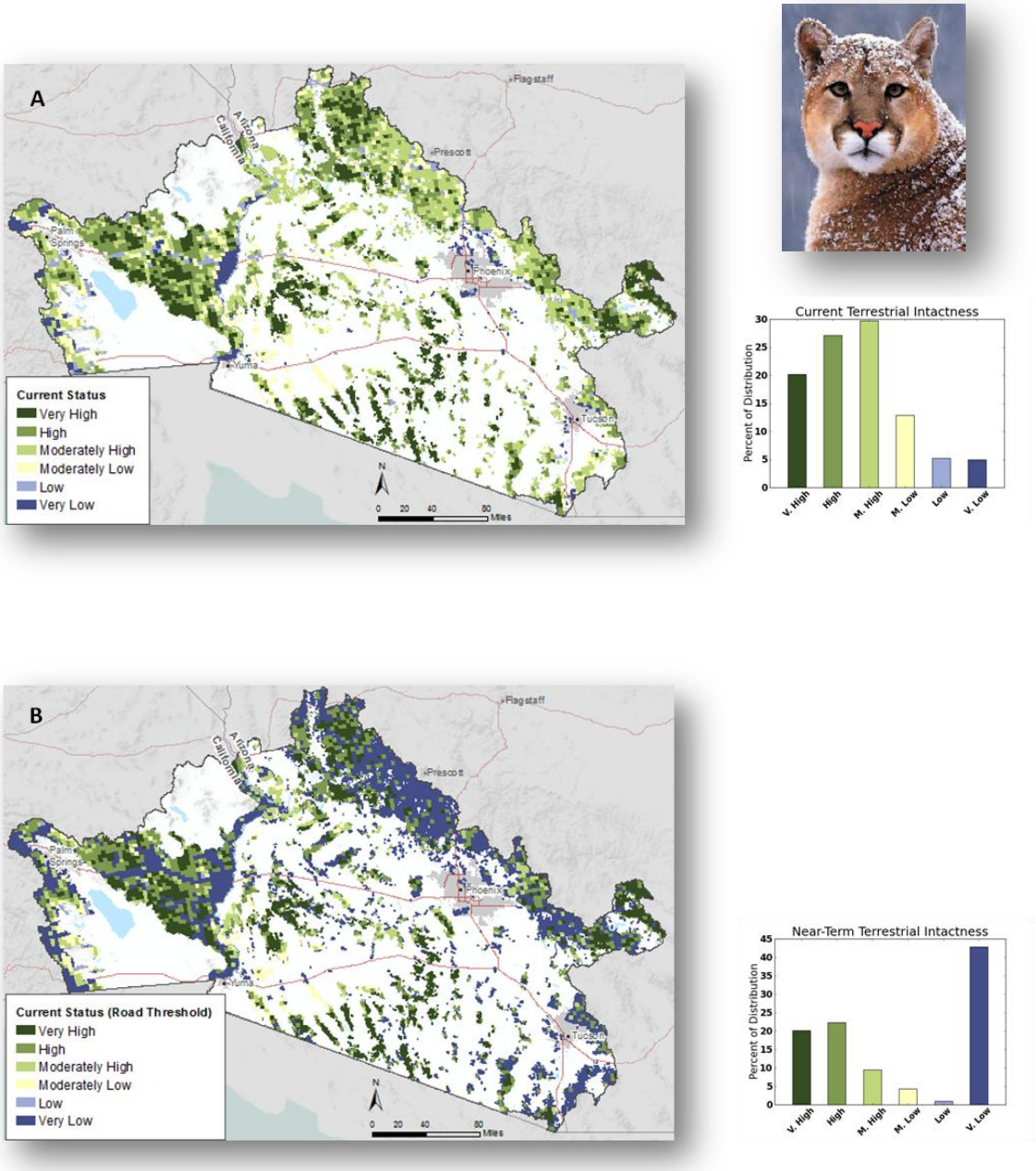


Figure 4-10. Map shows (A) mountain lion status created by overlaying current distribution against the general terrestrial intactness model and (B) mountain lion status according to customized intactness model with a road density tolerance of 0.6 km/km^2 (Van Dyke et al. (1986). Results are organized by 4 km x 4 km grid cells for the Sonoran Desert ecoregion with associated histograms indicating areal percent of the ecoregion in various intactness classes.

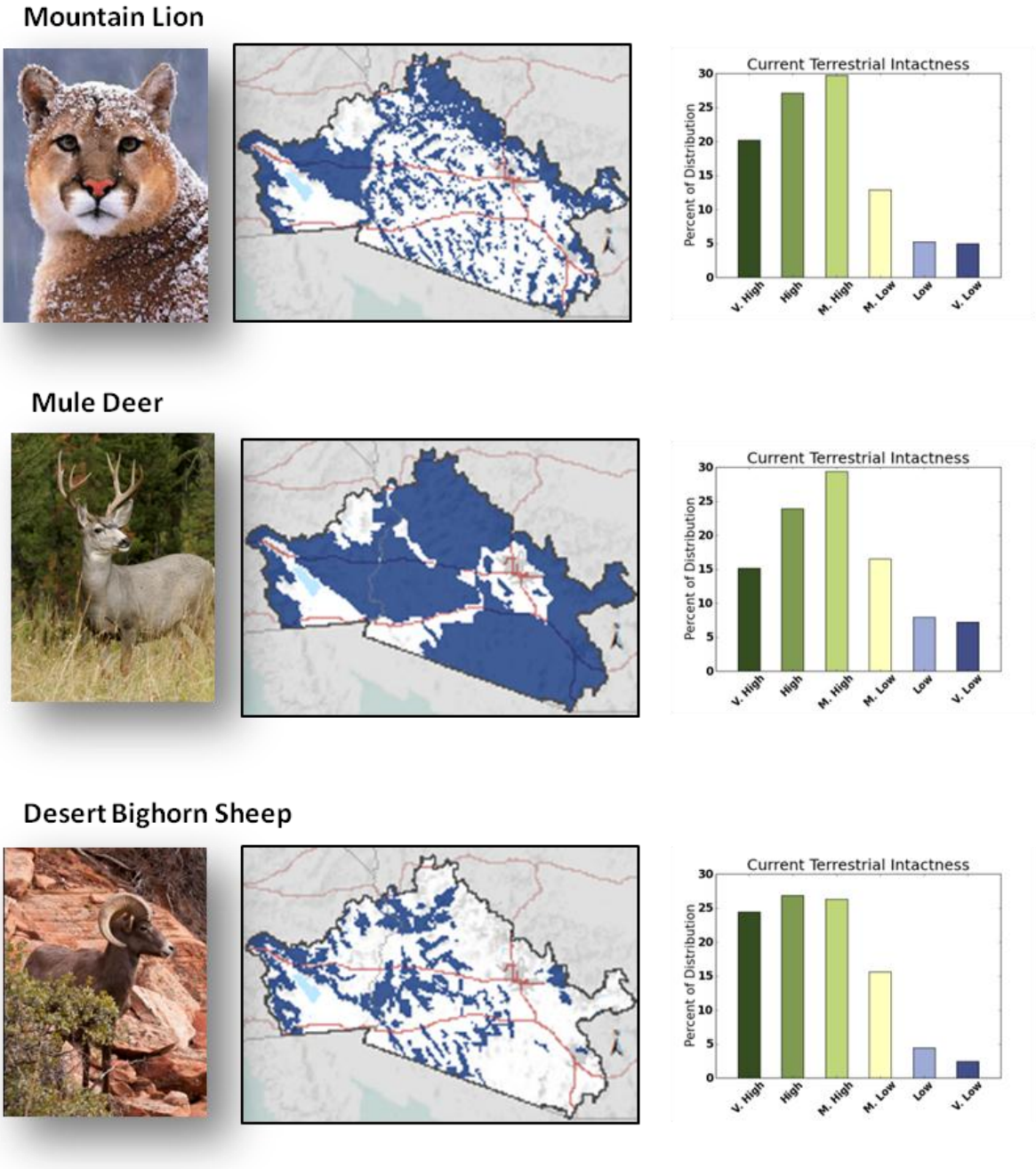


Figure 4-11. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for mountain lion, mule deer, and desert bighorn sheep in the Sonoran Desert ecoregion.

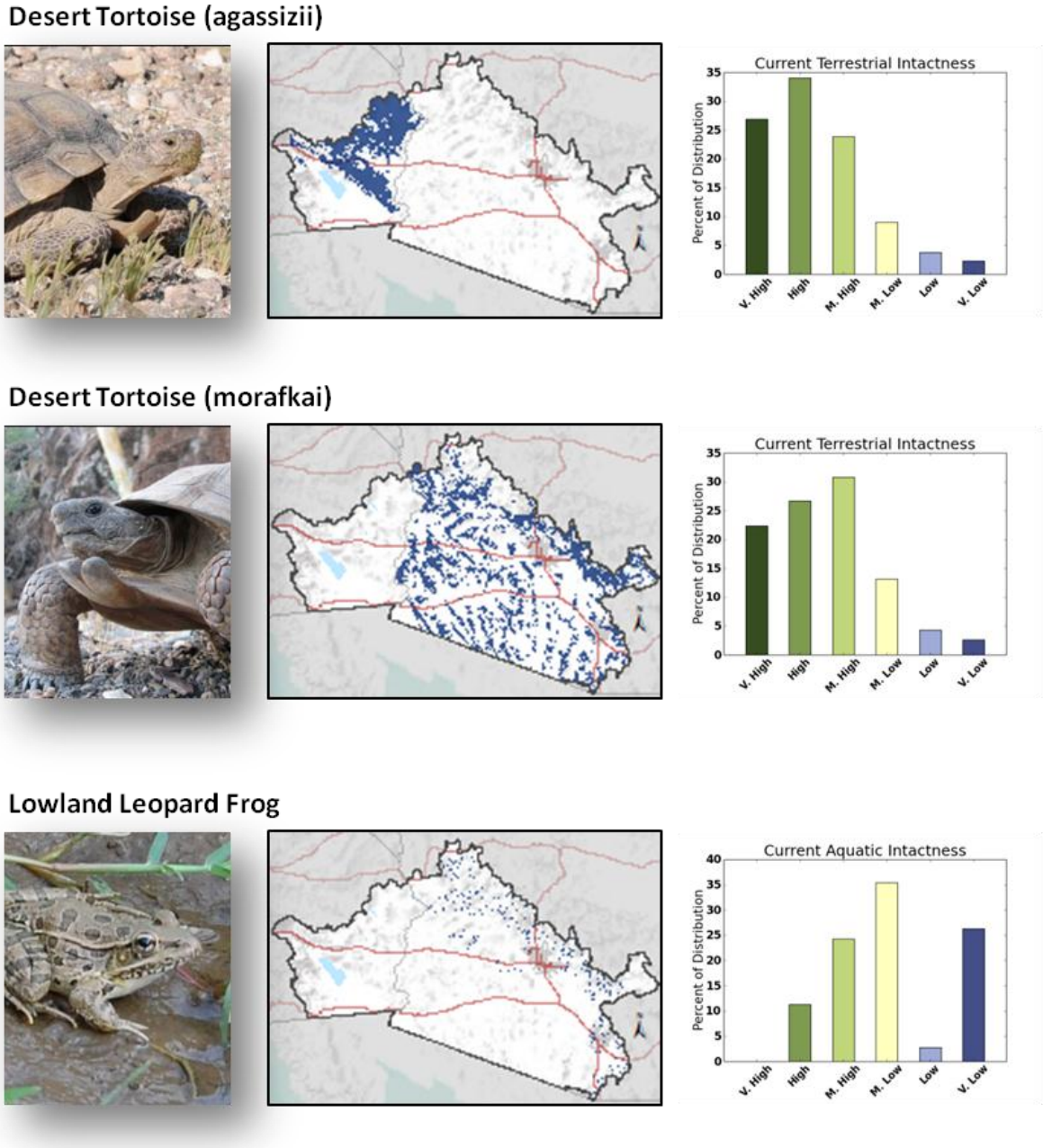


Figure 4-12. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for Mojave desert tortoise (G. *agassizii*), Sonoran desert tortoise (G. *morafkai*), and lowland leopard frog (*Lithobates yavapaiensis*) in the Sonoran Desert ecoregion.

For three bird species (Lucy's Warbler, Golden Eagle, and LeConte's Thrasher), approximately 70% of their current distribution is in Moderately High to Very High terrestrial landscape intactness classes (Figure 4-13). However, the distributions of all three species are over-represented, Le Conte's thrasher in particular. In eight years of canvassing for the Arizona Breeding Bird Atlas, the thrasher was recorded mainly in limited areas in southwestern Arizona. Roughly 30% of the habitat for these species is in Moderately Low to Very Low terrestrial landscape intactness classes. In these areas, especially the Very Low (5-8%) class, the animals would be expected to be under significant stress.

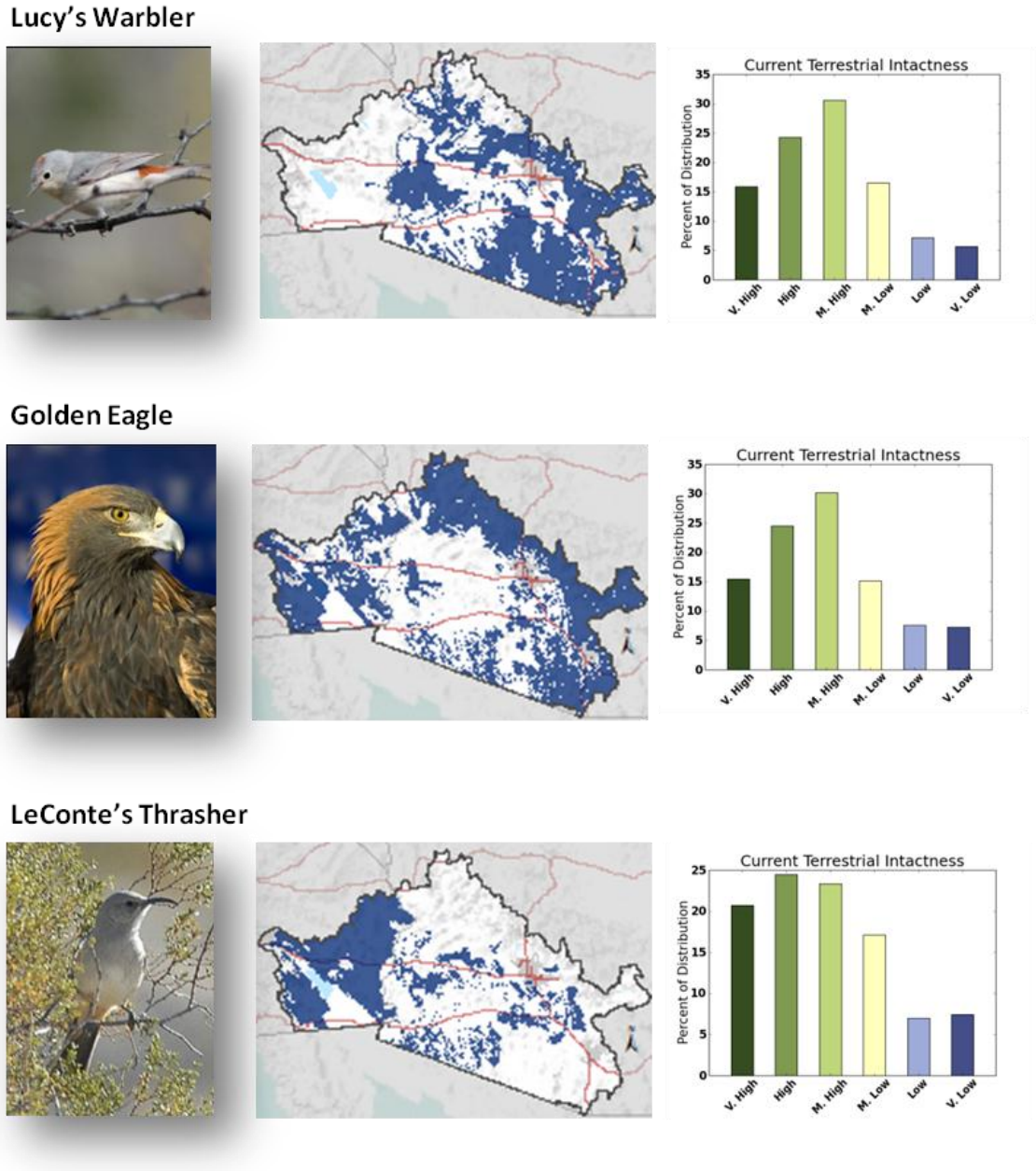


Figure 4-13. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for Lucy's warbler, golden eagle, and Le Conte's thrasher in the Sonoran Desert ecoregion.

For the remaining bird species (Bell's vireo and southwestern willow flycatcher), the intactness profiles are not as positive (Figure 4-14). This is especially true for southwestern willow flycatcher, which has over 70% of its current distribution classified as Moderately Low to Very Low with regard to terrestrial landscape intactness. Although both these species will use tamarisk for nesting, their troubles are not entirely due to the disappearance of native riparian vegetation. Both suffer from nest parasitism by brown-headed cowbird (*Molothrus ater*); where cowbirds have been controlled in least Bell's vireo recovery areas in the Sonoran Desert of California, the vireo has shown a modest recovery. For more details on birds and other wildlife species conservation elements, see Appendix C.

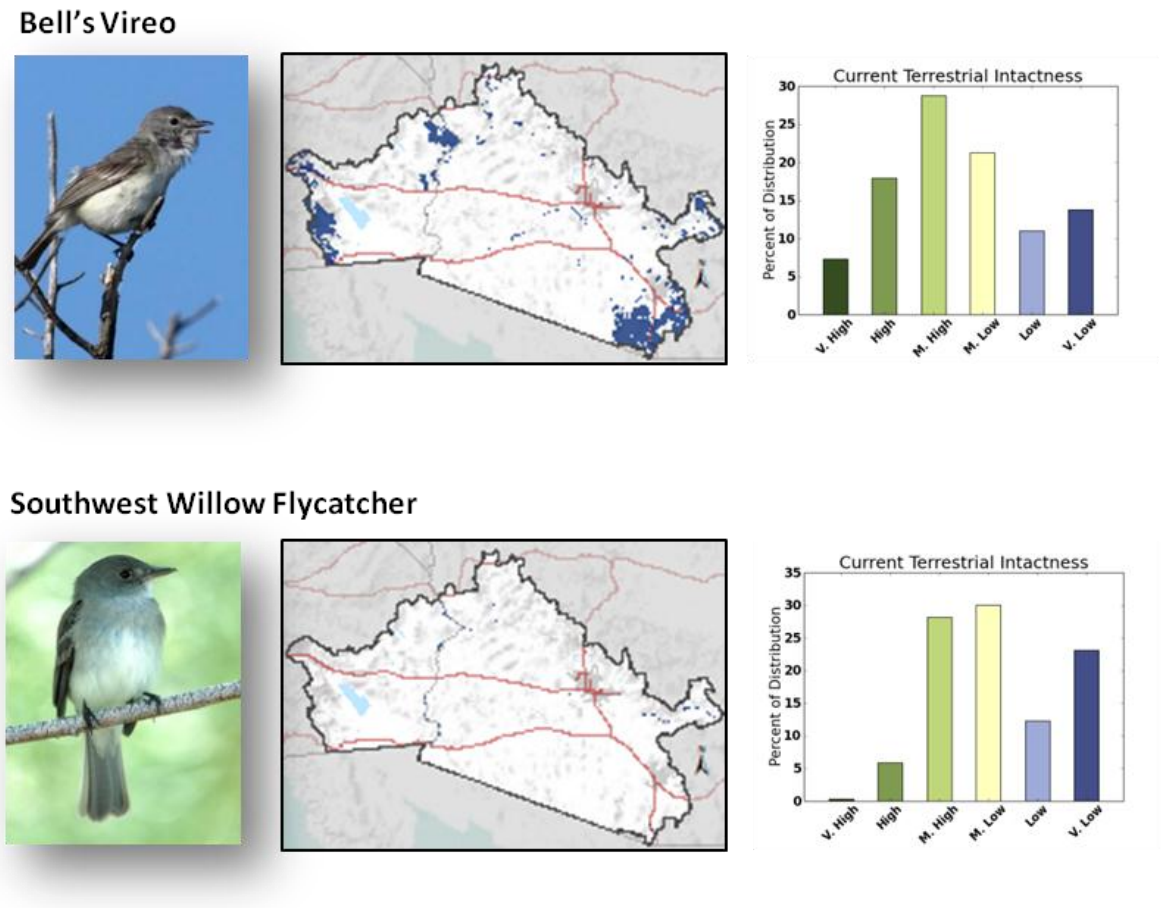


Figure 4-14. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for Bell's vireo and southwestern willow flycatcher in the Sonoran Desert ecoregion.

4.2.2 Wildlife Species Connectivity

This section addresses the management question, Where are potential areas to restore connectivity? Least-cost path analysis for the Natural Landscape Blocks for California (Spencer et al. 2010) combined with general corridor mapping in Arizona (AZDOT 2006) provided a map of key linkage zones for the ecoregion (Figure 4-15). In California, Spencer et al. (2010) identified natural landscape blocks of > 5000 acres and created a cost surface by combining landcover cost and protection status cost. In general, water and highest intensity developed classes from LANDFIRE EVT received the highest costs; agriculture and lower intensity developed classes received moderately high costs; invasive species received moderate costs; and natural vegetation received lowest costs. Costs were also derived from protected areas, such that more highly protected areas (e.g., wilderness) received lower costs, and less protected areas received higher costs. A 25-meter buffer around major highways (converted to 30m raster) and a 30m raster of all roads (BLM ground transportation database) were used to assign road costs (among the highest overall costs). Potential linkages were hand drawn between neighboring natural landscape blocks by connecting each one using a system of drawn sticks (centroid to centroid). ArcGIS Cost Distance and Corridor tools determined the final California Essential Connectivity Areas.

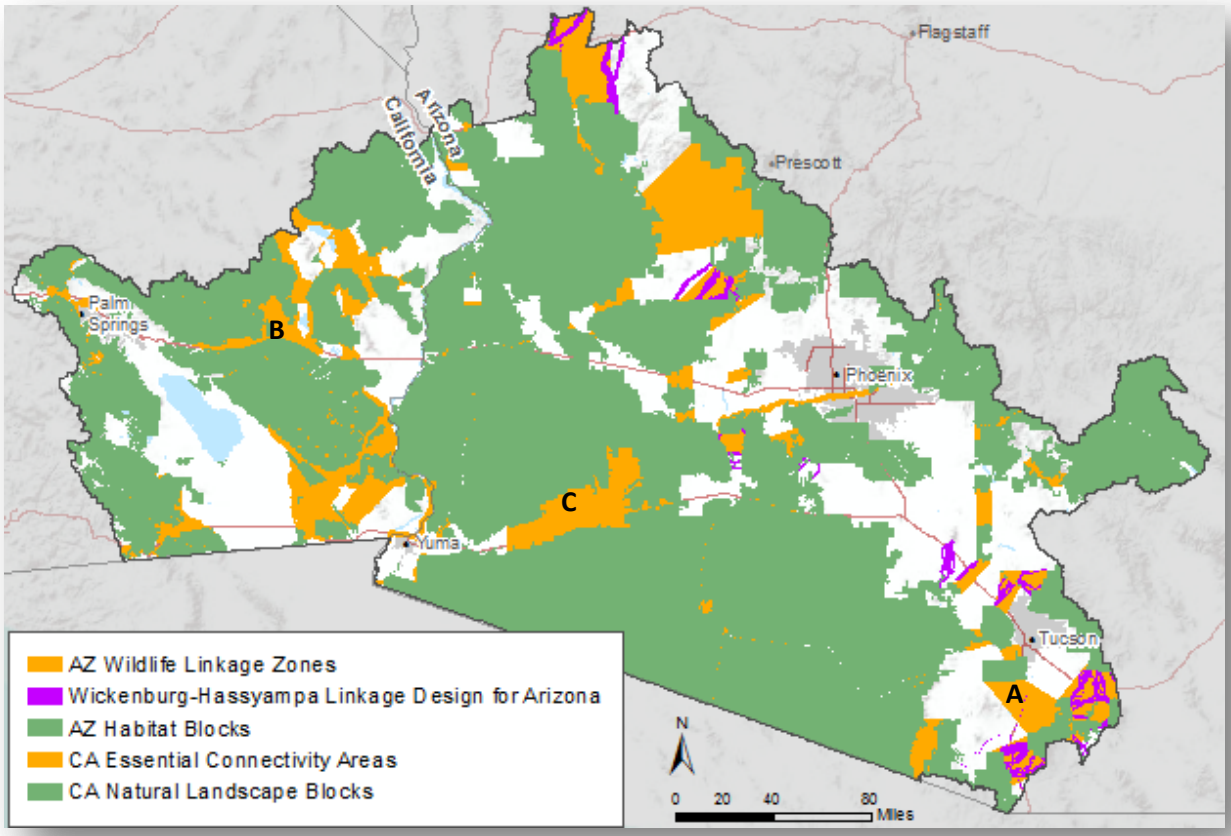


Figure 4-15. Landscape connectivity results based on generic (non-species specific) least-cost path analysis for the Sonoran Desert ecoregion. Connectivity mapping in California based on Spencer et al. (2010) and in Arizona based on Arizona Wildlife Linkages Workgroup (http://www.azdot.gov/inside_adot/OES/AZ_WildLife_Linkages/assessment.asp).

For more details on wildlife connectivity mapping in Arizona, see the Arizona Wildlife Linkages Assessment Document created by the Arizona Wildlife Linkages Workgroup (http://www.azdot.gov/inside_adot/OES/AZ_WildLife_Linkages/assessment.asp). Mapping in both states is ongoing and likely to be revised. Each of the identified corridors contains different types and levels of challenges. Management for some corridors (orange areas) must overcome the complexity of growing urban sprawl as seen in the region between Phoenix and Tucson and south of Tucson (zone A). Others must mitigate major highways (zone B) or deal effectively with invasive species (zone C, Figure 4-15). Both states have mitigated highway barriers with fencing and underpasses (e.g., for desert tortoise) and Arizona has addressed highway mitigation for desert bighorn sheep as well after doing field research to determine common bighorn highway crossing points (photos below).

Photos: Examples of Desert bighorn overpasses on US Hwy 93 just north of the Sonoran Desert ecoregion boundary, Scott Sprague, Arizona Fish and Game Department.