

Flora of Chihuahuan Desertscrub on Limestone in Northeastern Sonora, Mexico

Thomas R. Van Devender and Ana Lilia Reina-Guerrero
Sky Island Alliance, Tucson, Arizona

J. Jesús Sánchez-Escalante

Departamento de Investigaciones Científicas y Tecnológicas, Universidad de Sonora, Hermosillo, Sonora, Mexico

Abstract—Transects were done in desertscrub on limestone to characterize the flora of the westernmost Chihuahuan Desert. Most of the sites (15) were in the Municipios of Agua Prieta and Naco in northeastern Sonora, with single sites near Ascensión, northwestern Chihuahua and east of Douglas in southeastern Arizona. A total of 236 taxa were recorded on transects. Dicot perennial herbs (66 species) were the most numerous life forms, followed by annual herbs (36 species), subshrubs (36 species), and woody shrubs (33 species). The most diverse limestone floras were on Rancho La Morita in the Municipio of Naco (87 to 119 taxa/transect), Rancho La Calera (88 taxa), and Cerro El Caloso and Cerrito Los Janitos (84 taxa each) in the Municipio of Agua Prieta. Chihuahuan desertscrub at its western limits is a mixture of typical Chihuahuan species that reach Texas and Coahuila with western and tropical species in associations that are regionally distinct from other parts of the Chihuahuan Desert.

Introduction

The Chihuahuan Desert is the largest of the three creosotebush-dominated warm deserts in North America (Shreve, 1942). It primarily occurs from San Luis Potosí northwest through Chihuahua and Coahuila to Texas and New Mexico (Lowe, 1964; Rzedowski, 1978; Brown, 1982). Most (90%) is in Mexico on the Mexican Plateau bounded to the east by the Sierra Madre Oriental and to the west by the Sierra Madre Occidental. Most of this area is above 1000 m elevation and regular incursions of frigid Arctic air from the north have shaped the evolution of the flora. More than 80% of Chihuahuan desertscrub is found on limestone, and the gray gravel of this substratum give the characteristic view of the landscape (Lowe, 1964; Brown, 1982). Throughout the area, there is a mosaic of Chihuahuan desertscrub on limestone bedrock and desert grassland in fine-soiled valley bottoms. In the Santa Catalina Mountains of Arizona, Shreve (1922) and Whittaker and Niering (1968) concluded that vegetation is more xeric and open and that both vegetation and species reach higher elevations on limestone than on other substrates. We have noticed that this effect is most prevalent in northern areas with drier climates, but hardly noticeable in foothills thornscrub on limestone in east-central Sonora and tropical deciduous forest in southern Sonora.

During the spring of 2007, we attempted to relocate the endangered Cochise pincushion cactus (*Coryphantha robbinsorum*) reported from Sonora by Lopresti (1984). Although *C. robbinsorum* was not found, local floras on calcareous substrates were surveyed in northeastern Sonora and adjacent Arizona and Chihuahua (Van Devender and Reina-G., 2007). Here we use the results of these inventories to characterize Chihuahuan desertscrub at its westernmost extension.

Methods

We visited a *C. robbinsorum* population on Permian limestone on the Magoffin Ranch in Cochise County, Arizona, to refine our search image for the plant and its habitat. Potential areas for *C. robbinsorum* were identified in Sonora based on the presence of Paleozoic or lower Cretaceous limestone substrates on Instituto Nacional de Estadística y Geografía (INEGI) geological maps, the proximity to the Arizona *C. robbinsorum* populations, and habitat descriptions in Lopresti (1984). Seven areas in Sonora in the Municipios de Agua Prieta and Naco and one in Chihuahua were selected for plant inventories (table 1, fig. 1).

The climate of the area is arid, with biseasonal rainfall, hot summers, and cold winters. The weather stations nearest all transects are located in Agua Prieta and Naco, Sonora. The mean annual rainfall is 353.5 mm in the Municipio of Agua Prieta, with 40–47% during the summer monsoon season in July–September. The mean annual temperature is 17.3 °C, with a summer maximum of 43 °C in June 1994 and July 1989; a winter minimum of –14 °C and wind chill of –24 °C was registered in February 2011. Low winter temperatures limit biological activities. Another climatic factor is the prevailing wind from the south for more than 60% of the year, with a strength of 5.4 to 8.5 meters/second recorded in the international airport in Douglas, Arizona (Reza et al., 2011; CONAGUA, 2010; Universidad Autónoma de Tamaulipas, 2003).

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1–5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Table 1—Localities for limestone transects in Arizona, Chihuahua, and Sonora.

Identification	Location	Elevation	Description
Arizona			
MG 1:	Cochise County: limestone hills on Magoffin Ranch	31°22'13"N 109°08'18"W, 1284 m elevation to 31°22'00"N 109°24"W, 1311 m	(<i>Coryphantha robbinsorum</i> population). Open, grassy Chihuahuan desertscrub-desert grassland mix on very gentle slope with gray limestone bedrock on upper portions of the hill.
Chihuahua: Municipio de Ascensión			
CH1	Cerro de Cal (La Biznaga on geology map), west of Ascensión; two areas combined	31°07'04"N 108°05'23"W, 1380 m elevation and 31°06'35"N 108°05'04"W, 1322 m elevation	Open Chihuahuan desertscrub on dark gray limestone with white and orange secondary veins.
Sonora: Municipio de Agua Prieta			
AL1	Ridge above El Álamo, ca. 21 km south of the Cerro La Minita transect on Rancho Puerta Blanca, north of the Sierra Pitáicachi, ca. 2 km west of Cerro Agua Zarca, 7 km northwest of Rancho El Capadero, 9.7 km (by air) southeast of La Cieneguilla (= Oquita Montenegro) in Cajón Bonito	1239 to 1289 m elevation	Chihuahuan desertscrub on west-facing, gray, fossiliferous limestone; good grass, not heavily grazed.
AP1	ca. 15 km east of Agua Prieta on north side of MEX 2; 31°19'03"N 109°22'36"W	1318 m elevation	Chihuahuan desertscrub on gentle hill, south and northeast slopes, highly modified Cretaceous limestone with bands of whitish quartz; southern slope very grassy, northeast slope dominated by <i>Flourensia cernua</i> and <i>Acacia neoverrucosa</i> .
CA1	Rancho La Calera, ca. 10 km (by air) southwest of Agua Prieta, outlier ridge of Sierra Anibácachi	31°14'07"N 109°37'40"W, 1289 m elevation	Chihuahuan desertscrub on whitish gray limestone upper northeast-facing slope, alluvium below.
CA2	Rancho La Calera, ca. 10 km (by air) southwest of Agua Prieta, outlier ridge of Sierra Anibácachi	31°13'59"N 109°37'37"W, 1297 m elevation	Chihuahuan desertscrub on whitish gray limestone upper northwest-facing slope, alluvium below
CL1	Cerro Caloso (= Calichoso), ca. 8 km (by air) east of Cabullona	lower end: 31°08'23"N 109°28'15"W, 1215 m elevation, upper end: 31°08'14"N 109°27'59"W, 1272 m	Chihuahuan desertscrub on east-northeast facing limestone ridge with most layers nearly vertical, but with lots of bedrock exposed, dark gray (to purple) with lots of secondary white calcite veins.
JN1	Cerrito Los Janitos, east of the north end of the Sierra Anibácachi, ca. 1.5 km (by air) west-southwest of Agua Prieta	lower end: 31°15'57"N 109°40'15"W, 1334 m elevation, upper end: 31°15'56"N 109°40'27"W, 1429 m	Chihuahuan desertscrub on light gray limestone (similar to CA1 and CA2); mostly on east-facing slope.

Table 1—Continued

Identification	Location	Elevation	Description
PB1	Ca. 40 km east of Agua Prieta on Rancho Puerta Blanca, north of Arroyo Guadalupe and MEX 2, just south of Arizona border (below transect PB2)	upper end: 31°18'56"N 109°06'30"W, 1294 m elevation	Chihuahuan deserts scrub on south-southwest slope; lower part limy quartzite, upper gray limestone
PB2	Ca. 40 km east of Agua Prieta on Rancho Puerta Blanca, north of Arroyo Guadalupe and MEX 2, just south of Arizona border (above transect PB1)	upper end: 31°19'22"N 109°06'37"W, 1386 m elevation	Chihuahuan deserts scrub on south-southwest slope; gray limestone.
PB3	Ca. 37 km east of Agua Prieta on Rancho Puerta Blanca, south of MEX 2, east of Arroyo Guadalupe	31°17'58"N 109°08'40"W, 1277 m elevation	Chihuahuan deserts scrub on top of gentle north-south limestone conglomerate ridge
PB4	Ca. 37 km east of Agua Prieta on Rancho Puerta Blanca, south of MEX 2, east of Arroyo Guadalupe	31°18'04"N 109°07'36"W, 1355 m elevation	Chihuahuan deserts scrub on gentle west-facing slope, mostly loose limestone weathering from limestone conglomerate ridge.
Sonora: Municipio de Naco			
MO1	Hill west of Arroyo La Bellota, Rancho La Morita, ca. 25 km west of Agua Prieta	lower end: 31°08'23"N 109°28'15"W, 1215 m elevation, upper end: 31°08'14"N 109°27'59"W, 1272 m	Excellent gray bedrock limestone on gentle slopes (all directions) and large flat area on top; grasses common.
MO2	Hill west of Arroyo La Bellota, Rancho La Morita, ca. 25 km west of Agua Prieta	lower end: 31°15'14"N 109°49'05"W, 1438 m elevation; upper east end: 31°15'21"N 109°48'50"W, 1486 m; upper north end: 31°15'27"N 109°48'55"W, 1486 m	Chihuahuan deserts scrub. Transect began on west-facing slope with scattered gray bedrock limestone on alluvium; then to north slope bedrock on more gentle northeast slopes and hill tops.
MO3	Cerro La Bruja (north), Rancho La Morita, ca. 23 km west, 5.5 km south (by air) of Agua Prieta	lower end: 31°14'39"N 109°48'25"W, 1496 m elevation; upper end: 31°14'42"N 109°48'22"W, 1543 m	Chihuahuan deserts scrub on excellent gray bedrock limestone on steep south-facing slope.
MO4	Cerro La Bruja (north), Rancho La Morita, ca. 23 km west, 5.5 km south (by air) of Agua Prieta (just west of MO3 transect)	lower end: 31°14'40"N 109°48'57"W, 1477 m elevation; upper end: 31°14'46"N 109°48'47"W, 1547 m	Chihuahuan deserts scrub on excellent gray bedrock limestone on steep south-facing, open grassy slope.
MO5	Cerro La Bruja, Rancho La Morita, ca. 23 km west, 5.5 km south (by air) of Agua Prieta (across Arroyo La Bruja, southeast of MO3 and MO4 transects)	lower northwest end: 31°14'17"N 109°47'38"W, 1509 m elevation; east end: 31°14'17"N 109°47'34"W, 1520 m	Chihuahuan deserts scrub on excellent gray bedrock limestone on gentle slopes on north-facing slope and east-west ridgetop; grasses common.

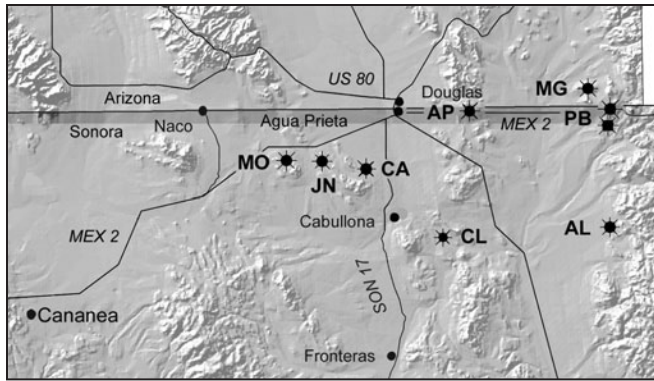


Figure 1—Map of study areas: AL = El Álamo, AP = Agua Prieta, CA = Rancho la Calera, CL = Cerro Caloso, JN = Cerrito Los Janitos, MG = Magoffin Ranch, PB = Rancho Puerta Blanca.

All of the study area except the site in Chihuahua is in the Río Agua Prieta drainage basin, a tributary of the greater Río Yaqui that begins as White Water Draw in Arizona before crossing the border into Sonora in Agua Prieta. The watershed area in Arizona is 2,650 km². From the border south to its junction with Río Fronteras, the Río Agua Prieta basin has an area of 1,444 km². Downstream these tributaries coalesce into the Río Bavispe upstream of the Lázaro Cárdenas (La Angostura) reservoir (CONAGUA 2010). The Río Yaqui itself forms when the Ríos Bavispe and Áros join north of Sahuaripa.

Plant Collections and Relevés

During the spring of 2007, plants were recorded in the seven study areas on March 23-27, April 3-19, and May 2-5 (fig. 1). A total of 17 transects were done on limestone bedrock and limestone derived alluvial surfaces. We surveyed a broad range of habitats, including rocky slopes, peaks, cliffs, alluvial bajadas, arroyos, and cattle tanks. We collected 216 specimens, which were deposited in herbaria in Mexico and the United States, including the University of Arizona (ARIZ), Universidad de Sonora (USON), Arizona State University (ASU), Universidad Autónoma Nacional de México (UNAM), and others. Collections were sponsored under a Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) permit to J. Jesús Sánchez-Escalante (USON). Semi-quantitative relevés were done to characterize the vegetation and assess species abundance. Relevés were about 0.5 hectares (50 x 100 m = 5,000 m²) in area (Mueller-Dombois and Ellenberg, 1974). All perennial plants were recorded and assigned relative abundances of rare (1-2 individuals), uncommon, common, or abundant (the most numerous); annual species were registered as present, whether alive or dead. This is a rapid assessment method readily comparable among different transects. Plant collections, observations from the relevés, and photographs are available online in the Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) database (Madrean.org). Specimens were identified in the University of Arizona herbarium or duplicates were provided to specialists. Nomenclature mostly follows Van Devender et al. (2010) and updates in SEINet. Only taxa identified to the species level were used to compare among transect floras. Plant collections, observations, and photographs are available in the SEINet/MABA database. A complete list of the transect floras will be available as a Research Species list in the database.

Results

Vegetation

The vegetation on all transects was Chihuahuan desertscrub with varying importance of desert grassland plants. Two simple measures of importance were used: (1) the number of transects a species occurred on, and (2) a relative abundance of abundant on at least one transect. A total of 47 species occurred on 10 or more of the 17 transects, and 15 species were abundant on at least one transect (table 2). The data indicate that the shrubs *Acacia neovernicosa*, *Calliandra eriophylla*, *Fouquieria splendens*, *Larrea divaricata*, *Menodora scabra*, *Parthenium incanum*, *Rhus microphylla*, and *Senna wislizenii*; the succulents *Agave palmeri*, *Cylindropuntia spinosior*, *Dasyliirion wheeleri*, *Echinocereus fendleri*, and *Opuntia phaeacantha*; and perennial grasses (seven species) are characteristic plants on limestone. Additional typical limestone plants include the shrubs *Dalea formosa* and *Flourensia cernua*, the perennial herbs *Astrolepis cochisensis*, *Bahia absinthifolia*, *Chamaesaracha sordida*, *Dalea wrightii*, *Physaria fendleri*, *Polygala macradenia*, and *Tiquilia canescens*, the perennial grass *Panicum hallii*; and the annuals *Hedeoma nanum*, *Linum puberulum*, and *Thymophylla pentachaeta*.

Table 2—Plants on ten or more transects on bedrock limestone in Arizona, Chihuahua, and Sonora. Species abundant on at least one transect in bold. NT = number of transects.

Species	NT	Species	NT
SHRUBS			
<i>Fouquieria splendens</i>	17	<i>Yucca baccata</i>	12
<i>Acacia neovernicosa</i>	16	<i>Opuntia engelmannii</i>	11
<i>Rhus microphylla</i>	15	N = 9	
<i>Aloysia wrightii</i>	13	PERENNIAL HERBS	
<i>Larrea divaricata</i>	12	<i>Astrolepis cochisensis</i>	16
<i>Condalia warnockii</i>	11	<i>Croton pottsii</i>	15
<i>Senna wislizenii</i>	11	<i>Chamaesaracha sordida</i>	13
<i>Eysenhardtia orthocarpa</i>	10	<i>Bahia absinthifolia</i>	12
<i>Flourensia cernua</i>	10	<i>Physaria fendleri</i>	12
N = 9		<i>Tiquilia canescens</i>	11
SUBSHRUBS		<i>Dalea wrightii</i>	10
<i>Calliandra eriophylla</i>	16	<i>Polygala macradenia</i>	10
<i>Menodora scabra</i>	16	N = 8	
<i>Parthenium incanum</i>	16	PERENNIAL GRASSES	
<i>Zinnia acerosa</i>	15	<i>Bouteloua curtipendula</i>	16
		<i>Aristida purpurea</i> var.	
<i>Dalea formosa</i>	14	<i>nealleyi</i>	13
<i>Hibiscus coulteri</i>	14	<i>Heteropogon contortus</i>	13
<i>Hibiscus denudatus</i>	13	<i>Bouteloua eriopoda</i>	12
<i>Gutierrezia microcephala</i>	11	<i>Dasyochloa pulchella</i>	11
N = 8		<i>Panicum hallii</i>	11
WOODY VINE		<i>Aristida ternipes</i> var. <i>ternipes</i>	10
<i>Cottisia gracilis</i>	14	N = 7	
N = 1		ANNUALS	
SUCCULENTS		<i>Hedeoma nanum</i>	16
<i>Cylindropuntia spinosior</i>	15	<i>Thymophylla pentachaeta</i>	14
<i>Dasyliirion wheeleri</i>	15	<i>Ditaxis neomexicana</i>	13
<i>Echinocereus fendleri</i>	15	<i>Linum puberulum</i>	12
<i>Opuntia phaeacantha</i>	15	<i>Galium proliferum</i>	10
<i>Agave palmeri</i>	14	N = 5	
<i>Mammillaria grahamii</i>	14	Total: 47 taxa	
<i>Cylindropuntia leptocaulis</i>	12		

Other typical limestone plants found on fewer than 10 transects or not scored abundant were the shrubs *Fraxinus gooddingii*, *Mortonia scabrella*, *Quercus pungens*, and *Rhus virens* subsp. *choriophylla*; the subshrubs *Cyphomeris gypsophiloides*, *Mentzelia oligosperma*, *Ruellia parryi*, *Salvia parryi*, and *Thymophylla acerosa*; the perennial herbs *Dalea pogonathera*, *Euphorbia villifera*, *Phyllanthus polygonoides*, *Polygala scoparioides*, *Senna bauhinoides*, *S. lindheimeriana*, *Thamnosma texana*, and *Verbesina longipes*; and the annuals *Dalea nana* var. *carnescens* and *Iva ambrosiifolia*. *Vauquelinia californica* var. *pauciflora* is a prominent shrub in the Magoffin Hills that is rare in Sonora. It was only found in the Rancho La Calera area, where it was a local dominant.

Flora Composition

We documented 236 taxa in 170 genera and 54 families in Chihuahuan desertscrub on the 17 transects. The families with most species were Asteraceae (36 taxa, 15.2%), Poaceae (33 taxa, 13.9%), Cactaceae (21 taxa, 8.8%), Fabaceae (18 taxa, 7.6%), Malvaceae and Pteridaceae (8 taxa each, 3.3%), and Euphorbiaceae (7 taxa, 2.9%). The genera with the most species were *Opuntia* (6 taxa), *Dalea*, *Bouteloua*, *Echinocereus*, and *Polygala* (5 taxa each), *Cylindropuntia*, *Abutilon*, *Aristida*, and *Muhlenbergia* (4 taxa each), and *Brickellia*, *Eragrostis*, *Physaria*, and *Senna* (3 taxa each). The life forms on transects were herbs (57.2%, including grasses), woody plants (31.3%), and succulents (11.4%). Of the dicot herbs (102 taxa), 66 taxa are perennial and 36 taxa annual, while 27 of 33 grass taxa were perennial and six annual taxa. The sampling yielded 51 to 119 taxa/transect (average 73.4 taxa/transect).

Non-Native Species—Floras on limestone in the study area only had six (2.5%) non-native species: *Eragrostis lehmanniana*, *Eragrostis cilianensis*, *Erodium cicutarium*, *Fumaria parviflora*, *Salsola tragus*, and *Sisymbrium irio*. None of them are invasive in these areas. *Eragrostis lehmanniana* is an African bunchgrass that is a serious invasive that displaces native species in desert grassland in southeastern Arizona but less so in adjacent Sonora.

Several invasive species not encountered on the limestone transects are expanding into nearby areas. The African buffelgrass (*Pennisetum ciliare*) has been widely planted in the Sonoran Desert in Arizona and Sonora. This subshrubby grass is an aggressive competitor for water and nutrients and introduces fire as an ecological process into non-fire adapted desertscrub, thornscrub, and tropical deciduous forest. It is a serious invasive species in areas mostly below 1060 m elevation. Van Devender and Dimmitt (2006) reported the expansion of buffelgrass to elevations of 1195 to 1395 m as far east as 44 km east of Agua Prieta in northeastern Sonora. In August 2007, it was found at 1565 m in desert grassland 46.5 km east of Agua Prieta. In September 2006, it was found at 1287 m elevation within a kilometer of the La Calera limestone transects. A modest-sized plant appeared in a small arroyo that had been surveyed a number of times previously. This location is well away from a paved road and the nearest plants observed along the Agua Prieta-Nacozari highway are ca. 5.5 km to the east. Also, two very small individuals were found in desert grassland on a new dirt pile on Rancho El Porvenir, east of Cabullona (close to the El Caloso transect), where dirt roads were recently bulldozed as part of mineral prospecting activities. Either seeds were transported to the area by vehicles, or blown from the highway about 6.5 km to the west. Although buffelgrass is a serious invasive in Chihuahuan desertscrub in the Big Bend of Texas, it mostly does not occur away from paved highways in northeastern Sonora. Increased temperatures

(global warming) could change its status in northeastern Sonora from non-threatening to invasive.

Sahara mustard (*Brassica tournefortii*) is a North African-European spring annual that is a serious invasive in low elevation (below ca. 800 m) Sonoran desertscrub in northwestern Sonora, southwestern Arizona, and southeastern California (Dimmitt and Van Devender, 2009). Its arrival and expansion in other parts of Sonora is more recent, as it disperses mostly along major highways. It was present in agricultural areas near Hermosillo in central Sonora in 1995 and west of Bacobampo in southern Sonora in 1993. Between 2003 and 2005, it spread southward along Mexican Federal Highway 15 (MEX 15) about 180 km from Magdalena de Kino and Santa Ana south to Hermosillo. By 2008, it was in Guaymas, another 128 kilometers to the south. In northern Sonora, it was found in 2005 at 1109 m elevation in Cíbuta, 29 km south of Nogales on the Arizona border. By 2007, it was 25–41 km east of Agua Prieta along MEX 2 (156–172 km east of Nogales) at 1126–1295 m in cottonwood-willow riparian forest, Chihuahuan desertscrub, and desert grassland. By 2010, it was 48.5 km east of Agua Prieta at 1455 m elevation in desert grassland. MEX 2 is the major truck route between Baja California and Chihuahua, which crosses the Lower Colorado River Valley Sonoran desertscrub areas invaded by *B. tournefortii*.

Prior to Kearney and Peebles (1960), the European *Eruca vesicaria* ssp. *sativa* was known in Arizona from a few urban and vegetable garden settings in the Tucson and Phoenix areas. Since 1960, arugula has been known from the agricultural areas in the Sonoran Desert at Gila Bend. In the spring of 2005, it was the most abundant annual for 70 km along Interstate 8 westward from Gila Bend in an area of several hundred square kilometers (Mark A Dimmitt, pers. comm., 2006). The plants reached about a meter tall and carpeted undisturbed valleys and rocky slopes in open Sonoran desertscrub. Alarms were raised concerning its invasive potential in the Sonoran Desert, especially in Organ Pipe Cactus National Monument. In March 2012, it was observed just across the border in Sonoyta, Sonora. Another aspect of its ecological potential was uncovered with its discovery in 2007 along MEX 2 east and west of Agua Prieta, in Chihuahuan desertscrub at 1215 to 1321 m elevation. In 2009–2010, it was found 51.2 to 53.5 km east of Agua Prieta at 1495–1499 m elevation in desert grassland. In 2007, it was common in desert grassland at 1360 to 1533 m elevation in the Janos area in northwestern Chihuahua. These observations suggest that this mustard is potentially invasive in higher elevation habitats. A 2012 collection near Moctezuma in central Sonora in foothills thornscrub at 637 m elevation suggests that it may expand its range into more tropical areas as well.

Bromus rubens is a North African-Eurasian spring annual grass that is a serious invasive in California and Arizona. Fires fueled by dense spring growth are devastating to Mohave and Sonoran desertscrub, whose dominants are not well adapted to fire. It is not common or invasive in Sonora. Prior to this study, it was previously known from the Sierra Pinacate in northwestern Sonora (Felger 2000) and the Sierra el Humo south of Sásabe. In 2007–2008, it was found in Arroyo Guadalupe on Rancho Puerta Blanca, Municipio of Agua Prieta. In May 2010 it was found 41.3 km east of Agua Prieta along MEX 2 at 1323 m in desert grassland. This species appears to be spreading from disturbed areas along the border roads in Arizona into the Río Yaqui drainages and south into Sonora.

Biogeography

Our collections of *Cyphomeris gypsophiloides*, *Echinocereus fasciculatus* var. *fasciculatus*, *Euphorbia villifera*, *Mentzelia oligosperma*, *Polygala lindheimeri* var. *parvifolia*, *Quercus pungens*, and

Zephyranthes longifolia are probably the first records for the species for Sonora. The observation of *Ferocactus wislizenii* at Cerro de Cal may be the first record for Chihuahua. Many more species were previously known from Sonora from only a few records, including *Bernardia myricifolia*, *Castilleja lanata*, *Cheilanthes villosa*, *Linum lewisii*, *Mammillaria lasiacantha*, *Notholaena aschenborniana*, *Petrophytum caespitosum*, *Phyllanthus polygonoides*, *Physaria fendleri*, *Polygala scoparioides*, *Ruellia parryi*, *Salvia parryi*, *Senna lindheimeriana*, and *Vauquelinia californica* ssp. *pauciflora*.

A number of plants on the transects are mostly western species that reach as far east as the El Paso, Texas, area including *Agave palmeri*, *Aristida ternipes* var. *ternipes*, *Bebbia juncea*, *Gutierrezia microcephala*, *Mammillaria grahamii*, and *Yucca baccata*. *Cylindropuntia spinosior* is replaced to the east by the closely related *C. imbricata*. Other transect species clearly are not in the main Chihuahuan desert to the east, including *Echinocereus pseudopectinatus*, *Encelia farinosa*, *Hermannia pauciflora*, and *Vauquelinia californica*. *Cylindropuntia thurberi* and *Eysenhardtia orthocarpa* are tropical/madreal species reaching their northern range limits in northeastern Sonora or southeastern Arizona.

Wentworth (1982) documented the distributions of plant species on limestone bedrock and calcareous soils at 1400 to 1900 m elevations in the Mule Mountain. Of 232 species in these habitats, 127 are shared with the transect floras of this study. The 72 species not on the transects, including *Bouvardia ternifolia*, *Cercocarpus montanus*, *Garrya wrightii*, *Quercus arizonica*, and *Pinus discolor* were in this mesic limestone habitat in oak woodland zone, which is 400 m above the La Calera study area.

Discussion

The Chihuahuan Desert in Sonora is represented by isolated areas in the northeastern corner of the state, mainly in the municipios of Agua Prieta, Naco, Fronteras, Bavispe and Nacozari de García. The transition to the Sonoran Desert is in the west side of the Sierra El Tigre along Presa Angostura on the Río Bavispe. Brown and Lowe (1980) mapped the vegetation as an eastern patch of the Arizona Upland subdivision of the Sonoran Desert, but in actuality, it is a distinct area, perhaps the El Tigre subdivision. Farther west in Arizona (Vekol and Waterman Mountains) and northwestern Sonora (Sierra del Viejo) at lower elevations, limestone substrates support Sonoran desertscrub rather than Chihuahuan desertscrub.

The vegetation and geology on most of the areas surveyed in this study were basically similar i.e., exposed limestone bedrock and Chihuahuan desertscrub with mixed desert grassland elements with the shrubs *Acacia neovernicosa*, *Calliandra eriophylla*, *Fouquieria splendens*, *Parthenium incanum*, and perennial grasses. The abundance of grasses on the bedrock limestone habitats varied, and generally increased with elevation. The areas with the most grasses were the Magoffin Hills and Rancho La Morita habitats at 1400 to 1500 m elevation. The abundance of grasses also reflected grazing pressure. Grasses were lush on portions of Rancho Puerta Blanca on the Cuenca los Ojos Foundation reserve south of MEX 2 where livestock were removed in about 2002, but were sparse on adjacent grazed areas on Ejido Guadalupe.

While recognizing the basic similarities among all limestone habitats surveyed, there were local differences in each area surveyed. The desertscrub on the Cerro de Cal in Chihuahua was the most xerophytic, likely because the Sierra San Luis blocks winter rains and it was heavily grazed. Yet *Eriogonum wrightii* was only seen on the Magoffin Hills and Cerro de Cal transects. *Vauquelinia californica* ssp. *pauciflora* was seen on the Magoffin Hills and Rancho La Calera,

where the vegetation was much more open, with less grass and more limestone species, and much steeper slopes. On Cerrito Los Janitos, the vegetation and substrate were very similar to the nearby Rancho La Calera but without *V. californica*, and with *Mimosa biuncifera*.

Quercus pungens is a shrubby oak found on limestone substrates from Texas to southeastern Arizona. Although not previously known from Sonora, it was found on eight areas in this study, all on steep limestone slopes and ridge tops. *Koeberlinia spinosa* was only seen on two adjacent transects on Rancho Puerta Blanca north of Arroyo El Guadalupe. *Bernardia myricifolia* was only found on the two Rancho La Calera transects. *Dodonaea viscosa* was common on the El Álamo transect, but not found elsewhere. *Bebbia juncea*, *Crossosoma bigelovii*, *Cylindropuntia thurberi*, *Encelia farinosa*, *Hermannia pauciflora*, and *Lantana macropoda* were only found on Cerro El Caloso east of Cabullona. *Dalea nana*, *Elytraria imbricata*, *Euphorbia villifera*, *Petrophytum caespitosum*, *Polygala lindheimeri*, and *Senna lindheimeriana* were only found on the Rancho La Morita transects.

In summary, the species composition of Chihuahuan desertscrub at its western limits is a mixture of typical Chihuahuan species that reach Texas and Coahuila with western and tropical species in associations that are regionally distinct from other parts of the Chihuahuan Desert. This should be considered when evaluating these areas for conservation needs.

Acknowledgments

We thank Mima Falk, Marc A. Baker, Don Jesús Barra-Moreno, Doña Alicia Oroz-Gómez, Don Pedro García, Octavio García, John F. Wiens, Jeffrey Moore, and Manuel Espericueta for help in the field; Section 6 Grant from U.S. Fish and Wildlife Service. We thank Valer and Josiah Austin and Bob Minckley for access to private lands owned by the Cuenca Los Ojos Foundation. We thank Elizabeth Makings and C. David Bertelesen for their careful review of the paper.

References

- Brown, David E. 1982. Chihuahuan Desertscrub. In Brown, David E. ed. Biotic Communities of the American Southwest – United States and Mexico. Desert Plants. Special Issue. 4 (1-4): 169-179.
- Brown, David E.; and Charles H. Lowe. 1980. Biotic Communities of the Southwest. Gen. Tech. Rep. RM-78 (map). U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
- CONAGUA. 2010. Determinación de la disponibilidad de agua en el acuífero 2629, río Agua Prieta, estado de Sonora. 30 p.
- Dimmitt, Mark A.; and Van Devender, Thomas R. 2009. Sahara mustard (*Brassica tournefortii*): A new, serious threat to low desert ecosystems in the southwestern United States and northwestern Mexico. Pg. 241-246 in Van Devender, Thomas R.; Espinosa-García, Francisco J.; Harper-Lore, Bonnie L.; and Hubbard, Tani eds., *Invasive Plants on the Move. Controlling them in North America. Proceedings of Weeds Across Borders 2006 Conference*, Hermosillo, Sonora, May 25-28, 2006; Tucson, Arizona.
- Felger, Richard S. 2000. *Flora of the Gran Desierto and Río Colorado of northwestern, Mexico*. University of Arizona Press, Tucson, AZ. 673 p.
- Kearney, Thomas H.; and Peebles, Robert H. 1960. *Arizona Flora*, 2nd edition with supplement by J. H. Thomas, J. H.; and E. McClintock, E. University of California Press, Berkeley. 1085 p.
- Lopresti, Vincent 1984. *Coryphantha robbinsorum* en México. *Cactáceas y Suculentas Mexicanas*, 29: 81-83.
- Lowe, Charles H. 1964. *Arizona's Natural Environment. Landscapes and Habitats*. The University of Arizona Press. 136 p.

- Mueller-Dombois, D., and Ellenberg, H. 1974. *Aims and Methods of Vegetation Ecology*. John Wiley & Sons, New York.
- Reza, Francisco; and López, Gerardo. Sonora se congela: -16 °C. El Imparcial. Diario Independiente de Sonora: Hermosillo, México. Febrero 4, 2011. p. A1, col. 1.
- Rzedowski, Jerzy. 1978. *Vegetación de México*. Editorial Limusa. México, D.F. 432 p.
- Shreve, Forrest. 1922. Conditions indirectly affecting vertical distribution on desert mountains. *Journal of Ecology*, 3: 269-274
- Shreve, Forrest. 1942. The desert vegetation of North America. *Botanical Review*, 8: 195-246
- Shreve, Forrest and Wiggins, Ira L. 1964. *Vegetation and Flora of the Sonoran Desert*. Volume one. Stanford University Press. Stanford, California. 840 p.
- Universidad Autónoma de Tamaulipas. 2003. *Manifestación de impacto ambiental modalidad particular*. Comisión Federal de Electricidad. Proyecto ciclo combinado Agua Prieta II. 151 p.
- Van Devender, Thomas R.; Felger, Richard F.; Fishbein, Mark; Molina-Freaner, Francisco; Sánchez-Escalante, J. Jesús; and Reina-Guerrero, Ana L. 2010. Biodiversidad de las plantas vasculares. Pp. 229-262 in Molina-Freaner, Francisco; and Van Devender, Thomas R. eds., *Diversidad Biológica de Sonora*, Universidad Nacional Autónoma de México, Hermosillo. <http://www.skyislandalliance.org/Sonoran%20vascular%20plants-VanDevender%20et%20al.2010.pdf>
- Van Devender, Thomas R.; and Reina-G, Ana Lilia. 2007. Final report on surveys of *Coryphantha robbinsorum* and other rare plants in northern Sonora and adjacent Chihuahua. U.S. Fish and Wildlife Service Section 6 contract.
- Van Devender, Thomas R.; and Dimmitt, Mark A. 2006. Final Report on "Conservation of Arizona Upland Sonoran Desert Habitat. Status and Threats of Buffelgrass (*Pennisetum ciliare*) in Arizona and Sonora." National Plant Conservation Initiative Project #2004-0013-003.
- Wentworth, Thomas R. 1982. Vegetation and flora of the Mule Mountains, Cochise County, Arizona. *Journal of the Arizona-Nevada Academy of Science*, 17: 29-44.
- Whittaker, Robert H. and Niering, William A. 1968. Vegetation of the Santa Catalina Mountains, Arizona. IV. Limestone and acid soils. *Journal of Ecology*, 56: 523-544

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.