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A CONSERVATION PLAN FOR *BERBERIS HARRISONIANA* (KOFA MOUNTAIN BARBERRY, BERBERIDACEAE)

SARAH J. DE GROOT

Illustration by Lucretia B. Hamilton

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1.0 Executive Summary

Berberis harrisoniana Kearney & Peebles, the Kofa Mountain barberry (also known as Harrison's barberry, or red barberry), is known to occur naturally in only four desert mountain ranges: the Kofa, Ajo, and Sand Tank Mountains of southwestern Arizona and the Whipple Mountains of eastern California (Fig. 1; Ander-son and De Groot 2004). The total number of individuals known is around 600. The largest population, supporting 296 plants, is found in the Whipple Mountains Wilderness area, managed by the Bureau of Land Management (BLM). This site also supports the largest num-ber of dead plants, 113. A population in Palm Canyon of the Kofa Mountains had the most plants in fruit in 2005 (72%). No population has been observed recently with a large number of juvenile plants.

The entire distribution of *B. harrisoniana* is probably poorly known because it occurs in rugged terrain that is rarely accessed by humans. Its reproductive biology, population structure, and genetic diversity have not been studied. While *B. harrisoniana* is not Federally or State listed, it is listed as a sensitive species by the California Native Plant Society (CNPS 2007) and the Bureau of Land Management in Arizona (*http://www.azgfd.gov/w_c/edits/documents/Berbharr.d_000.pdf*). Although most populations of *B. harrisoniana* do not appear threatened by human activity at present (with the exception of the lower population in Palm Canyon, which suffers from trail erosion), any reduction of individuals or disturbance of its highly specific habitat within desert mountain ranges may put it immediately in danger of extinction. To reduce this risk, site visits, field surveys, and additional study of its reproductive biology and genetic structure are proposed.

2.0 Scope and Purpose

Berberis harrisoniana does not appear seriously threatened at present. However, little is known about this species. The relatively few extant individuals are restricted to a specific habitat, making the species vulnerable to sto-chastic changes (e.g., climate change). This document addresses the current status of *B. har-risoniana*, including its taxonomy, known distribution, preferred habitat, and identified threats. Recommendations are presented for surveys, detailed study of the species' biology, and conservation that would benefit *B. har-risoniana* and promote its continued viability and survival.

3.0 Background

Berberis harrisoniana previously was thought to be endemic to Arizona (Phillips 1979; Malusa 1995) until a population was discovered in 2001 in the Whipple Mountains of southeast San Bernardino County, California. This population is about 105 km (65 miles) north-northwest of the Kofa Mountains, the site of the nearest populations. All populations are found in relatively mesic, shaded sites in canyons or alcoves that generally receive little direct sunlight (Falk et al. 2001). *Berberis harrison-iana* has been suggested to be a relictual species (Anderson and De Groot 2004; Kearney and Peebles 1939).

Following a search of literature and herbaria for localities, field work conducted by the author in March 2005 relocated five populations in the Kofa Mountains (Yuma County, AZ) and one in the Whipple Mountains. Five additional populations have been reported from the Ajo Mountains (Pima County, AZ), and one population has been reported from the Sand Tank Mountains (Maricopa County, AZ; Appen-dix 1; Phillips 1979; Malusa 1995; herbarium specimens from ARIZ, ASC, ASU, CAS, POM, RSA, SD, and US). Although the total number of reported sites for this taxon is 12, three have not been relocated recently. A population in Pitahaya Canyon of the Ajo Mountains was last seen in 1939 but not during a survey in 1979. Populations in Alamo and Arch Canyons in the Ajo Mountains were not relocated during field work in March 2005, though more thorough searches in Arch Canyon may be successful as *B. harrisoniana* was last collected in Arch Canyon in 1988. The counts of plants performed during fieldwork in March 2005 were simply the apparent number of distinct shrubs; the number of genetically distinct plants may be lower.

The distances separating the four mountain ranges where *B. harrisoniana* has been found are 72 km (45 miles) or more, and may pose an increased risk to the species (Fig. 1). Gene flow between populations over this distance is presumed to be rare or nonexistent (Malusa 1995). Also of concern is a decline in the number of individuals at the lower population in Palm Canyon of the Kofa Mountains. While 76 plants were counted there in 1979 (then the second largest known population), only 25 were found in March 2005. At present, only four sites are known to support more than 30 individuals. Any reduction in numbers could reduce fecundity and genetic diversity of the species, and potentially eliminate one or more populations.

3.1 *Species Description*

Berberis harrisoniana is an evergreen cane shrub, 0.5–1.5 m tall, often straggly, and appears to sprout from roots. Spines are absent from the stems. The leaves are trifoliolate, having leaflets 2.9–5.4 cm long and 2.0–3.5 cm wide, sessile, coriaceous, not glaucous, and with margins prominently toothed with 1–3 pairs of teeth, each tooth bearing a spine. The inflorescences are 1.5–4.0 cm long, corymbiform to racemose, 3–11 flowered. The flowers have 9 sepals, the outer ovate, to 2 mm long, the petals and inner sepals more narrow, yellow, and to 6 mm long. The filaments have two teeth at the apex. The fruit is a spheric to short-ovoid berry, 5–6 mm long, blue-black and subglaucous. The seeds are fusiform, 3–5 mm long, and reddish-brown (Kearney and Peebles 1939; Shreve and Wiggins 1964; Laferrière 1992; Whittemore 1997).

The main distinguishing features of *B. harrisoniana* are its toothed, trifoliolate leaves and blue-black berries (Kearney and Peebles 1939; Shreve and Wiggins 1964; Laferrière 1992; Whittemore 1997). The closest species, morphologically, is *B. tri-foliolata*, which also has trifoliolate leaves, but with narrower leaflets that are frequently glaucous, and red berries (Laferrière 1992; Whittemore 1997). *Berberis harrisoniana* and *B. trifoliolata* are the only North Amer-ican species of *Berberis* with trifoliolate leaves (Ahrendt 1961; Whittemore 1997). *Berberis haematocarpa* Wooton, common in southwest Arizona and occasionally found in similar habitats, may be distinguished by having reddish berries and generally five or more narrow leaflets that are usually prominently glaucous (Whittemore 1997).

3.2 *Taxonomic History and Systematics*

Berberis harrisoniana was first des-cribed by Thomas Kearney and Robert Peebles in 1939. The type specimen is from “a canyon of the Kofa Mountains, Yuma County, Arizona” (Palm Canyon), 31 March 1930, *R. H. Peebles and H. F. Loomis 6768* (holotype US 01468221 [photo!]; isotypes ARIZ [photo!], CAS; Kearney and Peebles 1939, Phillips 1979; see *http://ravenel.si. edu/botany/types/* for an image of the holotype at US). The specific epithet honors George J. Harrison, a botanical collector in Arizona. When first described, it was known only from the type locality (Kearney and Peebles 1939).

Berberis harrisoniana was overlooked in Ahrendt’s (1961)[*] revision of *Berberis* and *Mahonia* (Li 1963), but his keys would have placed it in *Mahonia*, *Occidentales* group, section *Horridae*, with *M. trifoliolata* (Moric.) Fedde, *M. fremontii* (Torr.) Fedde, *M. nevinii* (A.Gray) Fedde, *M. haemato-carpa* (Wooton) Fedde and others (Ahrendt 1961). Section Horridae is a group of ever-green shrubs from the southwestern US and northern Mexico, recognized primarily by their fairly loose, few-flowered umbellate (or subumbellate) inflorescences, and also by their stiff and faintly veined leaves (Ahrendt 1961; Whittemore 1997). This group has been recognized as intermediate between *Berberis* and *Mahonia*, being called “a small exceptional set of *Mahonias* with a *Berberis* inflorescence” (Ahrendt 1961: 24; Whittemore 1997). The species was transferred to *Mahonia* as *M. harrisoniana* (Kearney & Peebles) H.L.Li (Li 1963), but because *Mahonia* is often lumped into *Berberis*, this combination is not often used.

Mahonia is characterized by having pin-nately compound leaves (which are evergreen), no spines on stems, axillary inflorescences, and only one type of shoot (Wolf 1940; Ahrendt 1961; Li 1963; Terabayashi 1985; Whittemore 1997). In contrast, *Berberis* s.s. has predominantly simple leaves, spines on its stems, terminal inflorescences, and dimorphic stems: long shoots, whose leaves are often modified into spines, and short shoots which arise from the axils along the long shoots, and whose leaves are often in fascicles. However, the two genera also have a number of characters in common: similar wood anatomy, same base chromosome number ($x = 7$), similar pollen and seedling morphology, and similar fruits (berry; Moran 1982; Terabayashi 1985; Kim and Jansen 1998). Thus, although some authors have attempted to distinguish *Berberis* and *Mahonia*, neither morphological characters nor phylo-genetic analysis support recognition of separate genera (Meacham 1980; Loconte and Estes 1989; Kim and Jansen 1998; Kim et al. 2004). All of the species are treated together under *Berberis* in recent treatments (Laferrière 1992; Whittemore 1997).

Interestingly, a phylogeny based on nuclear ribosomal Internal Transcribed Spacer (nrITS) DNA sequence data placed members of Ahrendt’s (1961) section *Horridae* in two separate clades of a poly-phyletic *Occidentales* group, suggesting that interspecific relationships merit re-examination. *Berberis harrisoniana* was distantly related to other members of sect. *Horridae*, and located sister to *B. aquifolium* and *B. pinnata* (Kim et al. 2004). These relation-ships, along with packrat midden data from the southwest US, suggest that *B. harrisoniana* was more common about 9570 years before present, and became restricted to its present locations as the climate warmed (R. Felger, S. Rutman, T. Van Devender, and Wilson, Flora of Southwestern Arizona, in prep.). However, this does not necessarily mean *B. harrisoniana* is an “evolutionary dead end” species, since many factors influence biotic distributions.

3.3 *Biology and Ecology*

[*]Ahrendt used (almost exclusively) dried material from K, BM, E, and O, and looked at cultivated material in Britain only (1961: 2). He probably did not see any specimens of *B. harrisoniana*, as these are deposited almost entirely in herbaria in the United States.

Berberis harrisoniana flowers January through March (Shreve and Wiggins 1964; Phillips 1979; Whittemore 1997). Speci-mens have been collected in flower on 18 Jan 2001 (*J. Anderson & C. Bobinski 2001-01*, ASU, ARIZ, RSA!), 26 Feb 1932 (*R.E. Beckett 9079*, ARIZ!), and in late flower and early fruit on 18 Mar 2004 (*S.J. De Groot & K. De Groot 3798*, RSA!; Kearney and Peebles 1939; Anderson and De Groot 2004). The stamens of *Berberis* in general are thigmatropic, and bend inward when touched (Ernst 1964), although this has not been tested in *B. harrisoniana*. Fruiting occurs March through April (Phillips 1979). The type specimen, with fruit, was collected 31 Mar 1930 (*R.H. Peebles & H.F. Loomis 6788*, US (photo!), CAS, ARIZ (photo!); Kearney and Peebles 1939).

Although no pollination or seed dis-persal studies have been performed on *B. harrisoniana* specifically, other *Berberis* species are typically pollinated by various species of bees, and seeds are dispersed by birds (Obeso 1989; Allen and Wilson 1992; Lebuhn and Anderson 1994). Some floral visitors for *B. fremontii* and *B. trifoliolata* are bees in the Anthophoridae. Other species of *Berberis* are also visited by bees in the Andrenidae and Megachilidae (Krombein et al. 1979).

Additionally, plants have been observed to sprout from roots or rhizomes, forming thickets (Phillips 1979). This clonal reproduction may be more successful in establishing new plants than reproduction by seed (Phillips 1979; see also Wolf 1940). Rooting of branches was observed in the Whipple Mountains populations in March 2005 (*S. J. De Groot & K. De Groot 4776*, RSA!; see Huffman and Tappeiner 1997 for an example of root sprouting in *B. nervosa* Pursh). It is not known how much of any given popu-lation may be root sprouts from one or a few individuals.

There have been no propagation studies on *B. harrisoniana*, but other species treated traditionally in the genus *Mahonia* are said to be fairly easily propagated from seed, although the germination rate can be increased by scari-fication (Sheat 1948). *Berberis nevinii* [= *Mahonia nevinii* (A.Gray) Fedde], which also has a scattered distribution pattern (Mistretta 1989), was propagated exclusively from seed, although Wolf (1940) observed that "…seed crops rarely set…" in this species. Mistretta (1989) further observed that *B. nevinii* fruit does not necessarily contain fertile seed, but germina-tion rates from fertile seed were high. Other propagation methods proposed for various species of *Berberis* or *Mahonia* include division, layering, cuttings, and suckers (Sheat 1948). Propagation of B. *nevinii* by cuttings has had poor success (Mistretta 1989).

3.4 *Habitat*

Typical habitat of *Berberis harrisoniana* is Sonoran Desert scrub and interior chaparral on steep slopes (25–60°) and along bases of sheer cliffs, between 725 and 1200 m elevation, and usually with a more or less northern exposure (N45°E to N35°W). These microsites often are found in canyons and along drainages, which may offer cooler temperatures and more moisture than the surrounding desert (Shreve and Wiggins 1964; Phillips 1979; Whittemore 1997; Falk et al. 2001). Often these areas receive very little direct sunlight, at most a few hours during the summer (Phillips 1979; Anderson and De Groot 2004). The species is frequently found on volcanic substrates (e.g., the Whipple Moun-tains population; Phillips 1979; Malusa 1995; Falk et al. 2001), but not exclusively. While there are many steep, north-facing slopes in southwest desert mountains, shaded microsites appear to be infrequent.

Some potential habitat has been modeled on the occurrence maps using GIS (Geographic Information System; Fig. 2–5; highlighted areas have an aspect of N35ºW–N45ºE; slope 30–45º; elevation 725–1200 m; run as a weighted model in ArcGIS® 9.2 [aspect 50%, slope 40%, eleva-tion 10%, where the weighting scheme was decided by field observations of critical determining factors of habitat], based on 7.5' USGS 10 m digital elevation models [DEM]). Based on these maps, potential habitat seems to occur in small, scattered areas. Even within a single drainage, there may be many isolated sites. Although known populations fall within the potential habitat for the most part, some very small north-facing chutes support *B. harrison-iana* (e.g., Summit Canyon), and these may be too small to be shown on 10 m DEMs. Therefore, it may not be helpful to model potential habitat using DEMs of a larger scale.

No consistently associated plant species is known to occur at all sites. Plants found at sites in three of the four mountain ranges include *Ephedra* (Mormon-tea, particularly *E. fasci-culata* Nelson), *Lycium* (desert-thorn, particular-ly *L. fremontii* A.Gray), *Parietaria hespera* B.D. Hinton, *Pholistoma auritum* (Lindl.) Lilja (usually var. *arizonicum* (M.E.Jones) Con-stance), *Quercus turbinella* Greene (shrub live oak), and *Simmondsia chinensis* (Link) C.Schneider (jojoba). As would be expected based on geographic proximity, the Ajo and Sand Tank Mountains have the most associated species in common. The Kofa and Whipple Mountains also share a number of associated species with each other, but have fewer in common with the Ajo or Sand Tank Mountains. A few species are found at many *Berberis harrisoniana* localities, but only within a particular mountain range; for example, *Bernardia incana* Morton is found at most *B. harrisoniana* sites in the Kofa Mountains.

3.5 *Distribution and Abundance*

The largest known population of *Berberis harrisoniana* is found on Cupcake Butte in the Whipple Mountains (142 plants). Palm Canyon in the Kofa Mount-ains, the type locality, is home to the second largest known population of the species (123–138 plants). A detailed assessment of known occurrences is presented below (see also Appendix 1).

3.5.1 *Kofa Mountains, Palm Canyon, lower population*.—This population is sit-uated at the base of the cliff on the south side of the canyon, opposite a group of *Washingtonia filifera* Wendl. A few plants were scattered down the steep slope of loose rock debris below the canyon wall. The slope was 40°, with an aspect of N09°W, and elevation was about 725 m. Vegetation was typical Sonoran Desert scrub, and some associated species were *Acacia greggii* A.Gray, *Arabis* cf. *perennans* S.Watson, *Bernardia incana*, *Bromus rubens* L., *Crossosoma bigelovii* S.Watson, *Eucrypta micrantha* (Torr.) A.A.Heller, *Forestiera phillyreoides* (Benth.) Torr., *Galium stellatum* Kellogg var. *eremicum* Hilend & J.T.Howell (bedstraw), *Koeberlina spinosa* Zucc., *Lycium* cf. *torreyi* A.Gray, *Mirabilis laevis* (Benth.) Curran, *Parietaria hespera*, *Penstemon pseudospectabilis* M.E.Jones, *Phacelia distans* Benth., *Pholistoma auritum* var. *arizonicum*, *Pleurocoronis pluriseta* (A.Gray) R.M.King & H.Rob., *Quercus turbinella*, *Rhus trilobata* Nutt. ex Torr. & A.Gray, *Simmondsia chinensis*, *Sphaeralcea ambigua* A.Gray, *Trixis californica* Kellogg, and *Viguiera parishii* Greene (Phillips 1979; herbarium specimens, see Appendix 2). Palm Canyon lies within the Kofa National Wildlife Refuge, which is administered by the U.S. Fish and Wildlife Service (USFWS; Phillips 1979; see Fig. 2 for map).

Twenty-four plants were counted here in March 2005, a rather alarming decline from the 76 plants documented in 1979 (Phillips 1979). An additional plant was seen about 100 m upstream at the base of a V-shaped indentation in the canyon wall, for a total of 25 live plants. Of these, only two had fruit, and the remaining 23 were vegetative. Some older leaves had insect, hail, or debris damage.

This site is the most accessible population of *B. harrisoniana* and consequently experiences the most human disturbance. A number of trails run up and along the slope; most are eroded and gullying (some 0.5 m deep). Seven dead plants were seen on 13 March 2005. They could have been killed by erosion or foot traffic, since many roots were exposed, and there was some soil disturbance on the slope. Rocks or water falling from the canyon wall is another concern, as this appeared to have killed other shrubs nearby.

3.5.2 *Kofa Mountains, Palm Canyon, upper population*.—The upper population was found about 400 m up the canyon from the lower population, in a narrow side canyon of Palm Canyon, with three *Wash-ingtonia filifera* plants. The canyon walls were very tall (over 33 m) and the bottom received very little sunlight. The slope was 35°, aspect N10°W, and elevation about 915 m. Associates included *Acacia greggii*, *Bernardia incana*, *Bromus rubens*, *Eu-crypta chrysanthemifolia* (Benth.) Greene, *Forestiera phillyreoides*, *Galium stellatum* var. *eremicum*, *Garrya flavescens* S.Watson, *Hyptis emoryi* Torr., *Maurandya antirrhinifolia* Humb. & Bonpl. ex Willd., *Nicotiana obtusifolia* M. Martens & Galeotti, *Quercus turbinella*, *Parie-taria hespera*, *Penstemon pseudospectabilis*, *Perityle emoryi* Torr., *Rhus trilobata*, *Sphaeral-cea ambigua*, *Trixis californica*, *Washingtonia filifera*, and *Ziziphus obtusifolia* (Torr. & A. Gray) A.Gray var. *canescens* (A.Gray) M. Johnston (Phillips 1979; herbarium specimens). This area is also in the Kofa National Wildlife Refuge, under the jurisdiction of the US Fish and Wildlife Service (USFWS; Phillips 1979).

This canyon supported 123 plants in March 2005, with 10–15 more seen above a 5 m dry waterfall (pour-off) above the uppermost *W. filifera* plant. Eighty-eight plants had fruit (71.5%). In 1979, 110 plants were counted (Phillips 1979). Plants were very dense, with about 70% overall cover by *B. harrisoniana* (Phillips 1979). A small trail ran from the main trail in Palm Canyon up to the *W. filifera* plants, but it appeared to be infrequently used and there was little evidence of erosion or disturbance in 2005. Some damage from insects, hail, or debris was observed on older *B. harrisoniana* leaves. Probably the most serious threats to this population are flash flooding or rock fall, both of which appear to be infrequent (see also Phillips 1979).

3.5.3 *Kofa Mountains, Indian Canyon*.—Three other canyons in the Kofa Mountains also support a few *B. harrisoniana* plants (Fig. 2; Phillips 1979). One of these is Indian Canyon, about 2.5 km east of Palm Canyon (Phillips 1979). Fieldwork in March 2005 discovered four separate sub-populations in this canyon, with a total of 44 plants, and there could be more. As is typical, plants were found on steep north-facing slopes of volcanic rock. This area is also within the Kofa National Wildlife Refuge, administered by the USFWS.

Indian Canyon (1).—The lowest subpopulation in the canyon was situated on the north side of a rock bluff, just below a 4 m dry waterfall in a small side wash, and downstream from a waterfall of the main drainage. Plants were growing in deep oak leaf litter at the base of the rock face, in a thicket under three

Quercus individuals, with many stems of *Clematis* pervading the trees and shrubs. The elevation was 995 m, slope 30°, and aspect N24°E. Associated taxa were *Bernardia incana*, *Bromus rubens*, *Clematis* sp., *Lycium* cf. *fremontii* (glan-dular), *Parietaria hespera*, *Phacelia distans*, *Pholistoma auritum* var. *arizonicum*, *Poa bigelovii* Vasey & Scribn., *Rafinesquia califor-nica* Nutt., *Quercus* cf. *turbinella*, and *Rhus trilobata*.

Of the 13 *B. harrisoniana* plants counted, only one had immature fruit, and many others had bare inflorescence branches. These either had not set fruit, or their fruit had been removed. Two plants may have been juveniles. There were no apparent threats to this subpopulation in March 2005, the area appearing fairly stable and without hiking trails.

Indian Canyon (2).—This subpopulation was found at the base of a short N-facing rock wall above a small side drainage (not the main drainage), and above a steeply sloped rock outcrop. The slope was 42°, aspect N06°E, and elevation 1018 m. Ass-ociated taxa included *Agave deserti* Engelm. (seedlings), *Arabis* cf. *perennans*, *Artemisia ludoviciana*, *Bernardia incana*, *Bromus rubens*, *Cheilanthes* cf. *tomentosa* Link, *Clematis* sp., *Ericameria laricifolia* (A.Gray) Shinners, *Eriogonum fas-ciculatum* (Benth.) Torr & A.Gray var. *polifolium* (Benth.) Torr. & A.Gray, *Eucrypta chrysanthemifolia*, *Galium stellatum* var. *eremicum*, *Gutierrezia microcephala* A.Gray, *Koeberlinia spinosa*, *Lycium*, cf. *Marchantia*, *Quercus turbinella*, *Parietaria hespera*, *Pellaea truncata* Goodd., *Phacelia distans*, *Pholistoma auritum* var. *arizonicum*, *Poa bigelovii*, *Rhus trilobata*, and *Viguiera parishii*.

Three plants were found in March 2005, all in fruit. There were no trails in this area, no signs of impact by humans, and little threat of rock fall, landslide, or erosion.

Indian Canyon (3).—Plants were observed at the mouth of a narrow canyon running NNE in the upper part of Indian Canyon, east of the waterfall of the main drainage. Vertical rock walls were ≥15 m high and 6–9 m apart. Two chutes contained *B. harrisoniana* plants, one on the west side of the drainage (42° slope), and one on the east side in a very narrow rock crack (60° slope). Aspect was N45°E and elevation was 1057 m. Other plant taxa in the area are *Arabis* sp., *Artemisia* sp., *Brickellia atracty-loides* A.Gray, *Bromus rubens*, *Clematis* sp., *Eucrypta chrysanthemifolia*, *Parietaria hespera*, *Quercus* sp., *Rhus trilobata*, and *Sphaeralcea* cf. *ambigua*.

Six of 13 plants were in fruit in March 2005. Again, there were no hiking trails here and no signs of human impact. The 60° slope may be at risk from landslides or erosion due to its steep-ness. The 42° slope is mostly of loose rock debris, which may similarly pose threats of rock fall or landslide.

Indian Canyon (4).—Found highest up the canyon, this small subpopulation was located in a steeply sloped side canyon above the Indian Canyon 3 population, along a tributary off a side drainage of Indian Canyon. Plants were at the top of a steep narrow rocky chute at the top of the tributary. The slope was 45°, aspect N20°E, and elevation 1179 m. Associates included *Arabis* sp., *Bernardia incana*, *Brickellia atrac-tyloides*, *Clematis* sp., *Dryopteris arguta* (Kaulf.) Watt., *Ericameria laricifolia*, *Eucrypta chrysanthemifolia*, *Galium* cf. *stellatum* var. *eremicum*, *Nolina bigelovii* (Torr.) S.Watson, *Oxalis* cf. *albicans* Kunth, *Parietaria hespera*, *Pellaea truncata*, *Penstemon pseudospectabilis*, *Phacelia distans*, *Quercus* sp., *Rhus trilobata*, perennial grass (*Aristida* or *Achnatherum*).

Fifteen plants were found here in March 2005, seven with fruit and eight vegetative. There was no trail to this area, and the slope appeared to be fairly stable, therefore the main threat seemed to be rock fall from the canyon walls.

3.5.4 *Kofa Mountains, Summit Canyon*.—Another collection of *B. harrisoniana* was made from Summit Canyon, about 4 km east of Palm Canyon, in two rock chutes near the top of the slope on the south side of the canyon, about 200–300 m east of the dry waterfall of the main drainage. The slope was 40°, aspect N36°W, and elevation 1070 m. Associated taxa for the west chute were *Arabis* sp., *Nolina bigelovii*, *Ephedra* sp., *Eriogonum fasciculatum* var. *polifolium*, and *Parietaria hespera*. The east chute had many of the same taxa, with the addition of *Acacia greggii*, *Agave* cf. *deserti*, *Arabis* cf. *perennans*, perennial grass (*Aristida*?), *Artemisia ludo-viciana*, *Bernardia incana*, *Ericameria larici-folia*, *Eucrypta chrysanth-emifolia*, *Galium stel-latum* var. *eremicum*, *Koeberlinia spinosa*, *Pha-celia distans*, *Rhus trilobata*, *Thysanocarpus laciniatus* Torr. & A.Gray, and *Xylorhiza torti-folia* (Torr. & A.Gray) Greene. Land is man-aged by the USFWS, as part of the Kofa National Wild-life Refuge.

Together, the two chutes were home to 29 plants in 2005. The west chute had three plants in fruit, two in flower, and two were both flowering and fruiting. The east chute had 10 plants in fruit. There are no hiking trails in this area, and the slope below the *B. harrisoniana* populations is quite steep. The population appears to have few threats other than possible rock or debris falls.

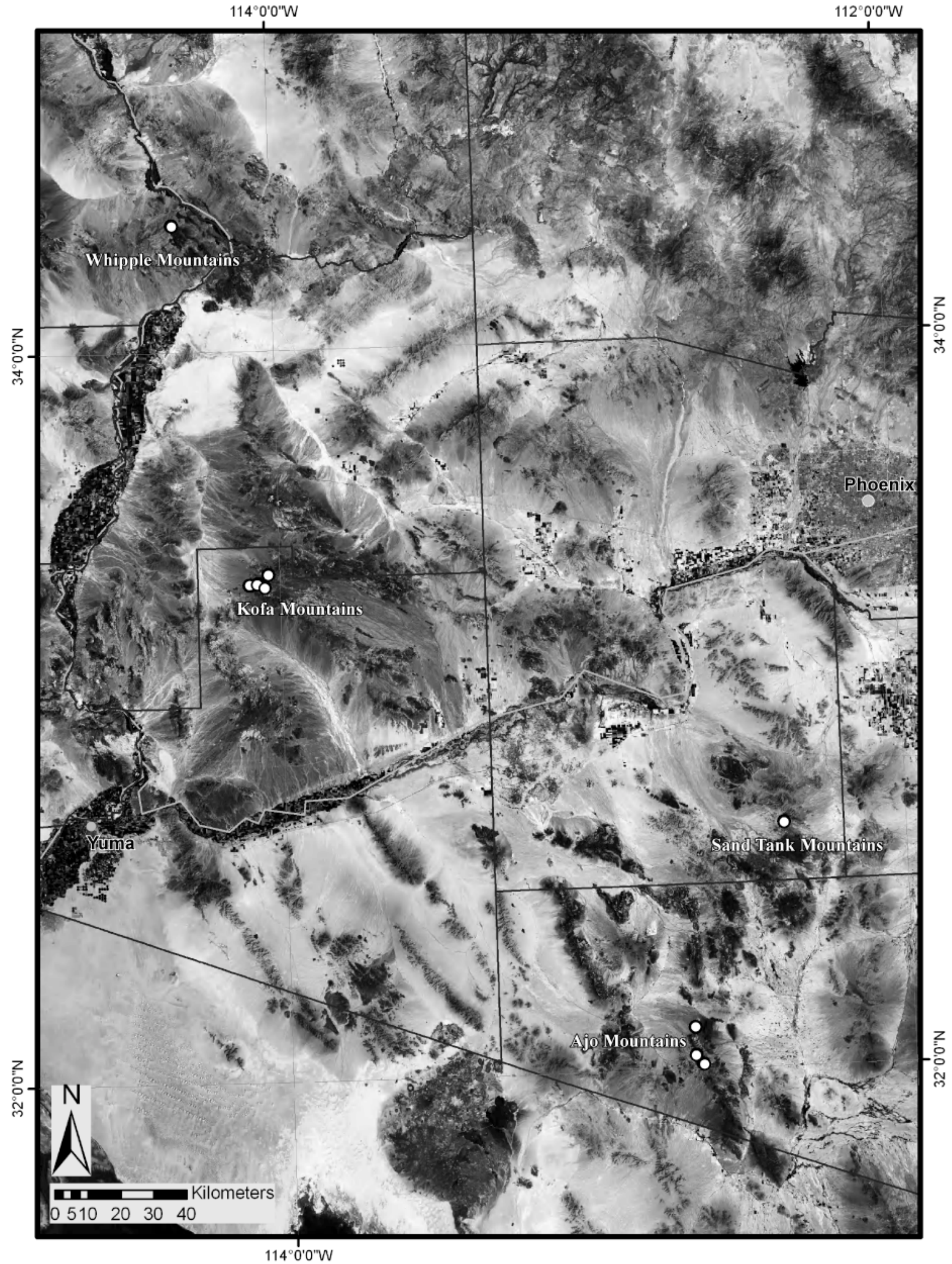

Fig. 1. Distribution map of all known *Berberis harrisoniana* populations, marked with white dots. Dark lines indicate county boundaries.

3.5.5 *Kofa Mountains, Tunnel Spring*.— About 6.5 km northeast of Palm Canyon, plants in the Tunnel Spring area in Tunnel Spring Canyon are documented by one herbarium specimen of *B. harrisoniana*. Plants were found at the base of a rock wall just below Tunnel Spring. The spring was found on the west side in a semi-circular cove of tall rock walls. Another stream was flowing from the east side of the cove. The aspect was N38°E, slope 36°, and elevation 997 m. As with all populations in the Kofa Mountains, this location lies within the Kofa National Wildlife Refuge, managed by the USFWS. Associated plant taxa were *Acacia greggii*, *Bernardia incana*, *Brickellia atrac-tyloides*, *Bromus rubens*, *Galium aparine* L., *Parietaria hespera*, *Phacelia distans*, *Quercus turbinella*, *Rhus trilobata*, and *Simmondsia chinensis*.

The population numbered 14 plants in March 2005, with ten in fruit and four vegetative. One plant may have been a juvenile. A small trail leads from Burro Canyon (to the east) to the spring and there has been some human activity in the area. In 2005, there seemed to be little impact by humans, with the most disturbance to the *B. harrisoniana* plants caused by a *Quercus* individual falling onto them. Since most plants are not in the main drainage areas, they are not threatened by flash flooding unless the water is quite high. Rock fall is a concern, but probably infrequent.

3.5.6 *Kofa Mountains, ambiguous locality*.—The following specimen does not pre-sent detailed locality information, and con-sequently may have been collected at any (or none) of the above localities: Kofa Mountains. 18 May 1937, *L.N. Goodding 2310* (ARIZ). Phillips (1979) also reported one plant from Kofa Queen Canyon, but no herbarium specimens have been found.

3.5.7 *Ajo Mountains, Pitahaya Canyon and Montezuma Head*.—In 1939, *B. harrisoniana* was collected in Pitahaya Canyon in the Ajo Mountains (Kearney and Peebles 1951; Laferrière 1992; Phillips 1979). It has not been rediscovered in the canyon, but a dense patch of 23 plants was found nearby on Montezuma Head in 1976 and 1979 (Phillips 1979). There was no trail to the Montezuma Head site, which is found in a narrow box canyon at the base of a waterfall (Phillips 1979). Some associated species were *Bowlesia incana* Ruiz & Pav., *Celtis pallida* Torr., *Claytonia perfoliata* Donn., *Elymus ely-moides* (Raf.) Swezey, *Juniperus monosperma* (Engelm.) Sarg., *Lyrocarpa coulteri* Hook. & Harv., *Parietaria hespera*, *Pholistoma auritum*, *Rhamnus crocea* Nutt., *Simmondsia chinensis*, and *Ziziphus obtusifolia* (Phillips 1979). This area was not searched in 2005 due to time constraints.

The land is administered by the National Park Service, as a portion of Organ Pipe Cactus National Monument. A possible threat may be flash flooding, but human disturbance is probably minimal (Phillips 1979).

3.5.8 *Ajo Mountains*, *Arch Canyon*.— Twelve plants were counted in Arch Canyon, about 3.2 km south of Alamo Canyon, in 1988 (see *M.A. Baker et al. 7611*, ASU [photo!]). Associated species here included *Ambrosia ambrosioides* (Cav.) W.W.Payne, *Celtis reti-culata* Torr., *C. pallida*, *Dodonaea* [*viscosa* Jacq.], *Juniperus* sp., *Prosopis* sp., and *Vauquelinia* [*californica* (Torr.) Sarg.] (data from herbarium specimens; inferred species in brackets). This canyon also lies within Organ Pipe Cactus National Monument, managed by the National Park Service. No plants were rediscovered in March 2005, but several potential sites in Arch Canyon were not searched due to time constraints.

3.5.9 *Ajo Mountains, Alamo Canyon*.— A few plants were reported in the north fork of Alamo Canyon, 5.5 km south of Pitahaya Canyon, in 1979 (Phillips 1979), but no herbarium specimens have been found to validate this occurrence. Attempts in March 2005 to locate an extant population were not successful. Data from packrat middens indicates that *B. harrisoniana* was very common here about 9570 years before present (Felger, Rutman, Van Devender, and Wilson, Flora of Southwestern Arizona, in prep.). This canyon is part of Organ Pipe Cactus National Monument (ORPI; National Park Service).

3.5.10 *Ajo Mountains, Bull Pasture*.—A population was reported from the Estes Canyon area in spring 2005 (Sue Rutman, ORPI, pers. comm. April 2005). This canyon lies 1.5 miles south of Arch Canyon. Plants were observed in April 2005 along a trail above Bull Pasture, at the head of Estes Canyon (Richard Felger, Drylands Institute, pers. comm. April 2005; Felger et al., in prep.). This site was not visited for this study.

3.5.11 *Sand Tank Mountains*.—The Sand Tank Mountains support a small popu-lation of about 24 plants, discovered in 1995 (Malusa 1995). Again, plants were found along an unnamed drainage on a shady north facing slope, at the base of a steep rock dome, with dense vegetation. Associated species included *Amorpha* sp., *Anisacanthus thurberi* (Torr.) A.Gray, *Atriplex canescens* (Pursh) Nutt., *Canotia holacantha* Torr., *Castilleja* sp., *Celtis pallida*, *Coursetia microphylla* A.Gray, *Cross-osoma* sp., *Ditaxis* sp., *Ephedra* sp., *Juniperus erythrocarpa* Cory, *Koeberlinia* [*spinosa*], *Lycium* sp., *Muhlenbergia emerslyii* Vasey, *Penstemon* sp., *Quercus turbinella*, *Sim-mondsia chinensis*, *Solanum* sp., *Vau-quelinia califor-nica*, and *Viguiera parishii* (John Anderson, BLM, pers. comm.). The land is part of the Barry M. Goldwater Military Range, administered by the U.S. Air Force. The dense vege-tation may increase the threat posed by fire, but it is unclear how frequently fire occurs in this area. This site also was not visited for this study.

3.5.12 *Whipple Mountains*.—In 2001, a population of *B. harrisoniana* was discovered in the Whipple Mountains, in southeast San Bernardino County, California, 105 km from the nearest population (Kofa Mountains). The plants were growing in a steep talus cove between rock outcrops on the northeast side of Cupcake Butte, northwest of Whipple Wash. Field-work in March 2005 discovered two additional rock chutes supporting plants. The plants in all three chutes totaled 296. Lands are administered by the Bureau of Land Management, Needles Field Office, and lie within the BLM Whipple Mountains Wilderness.

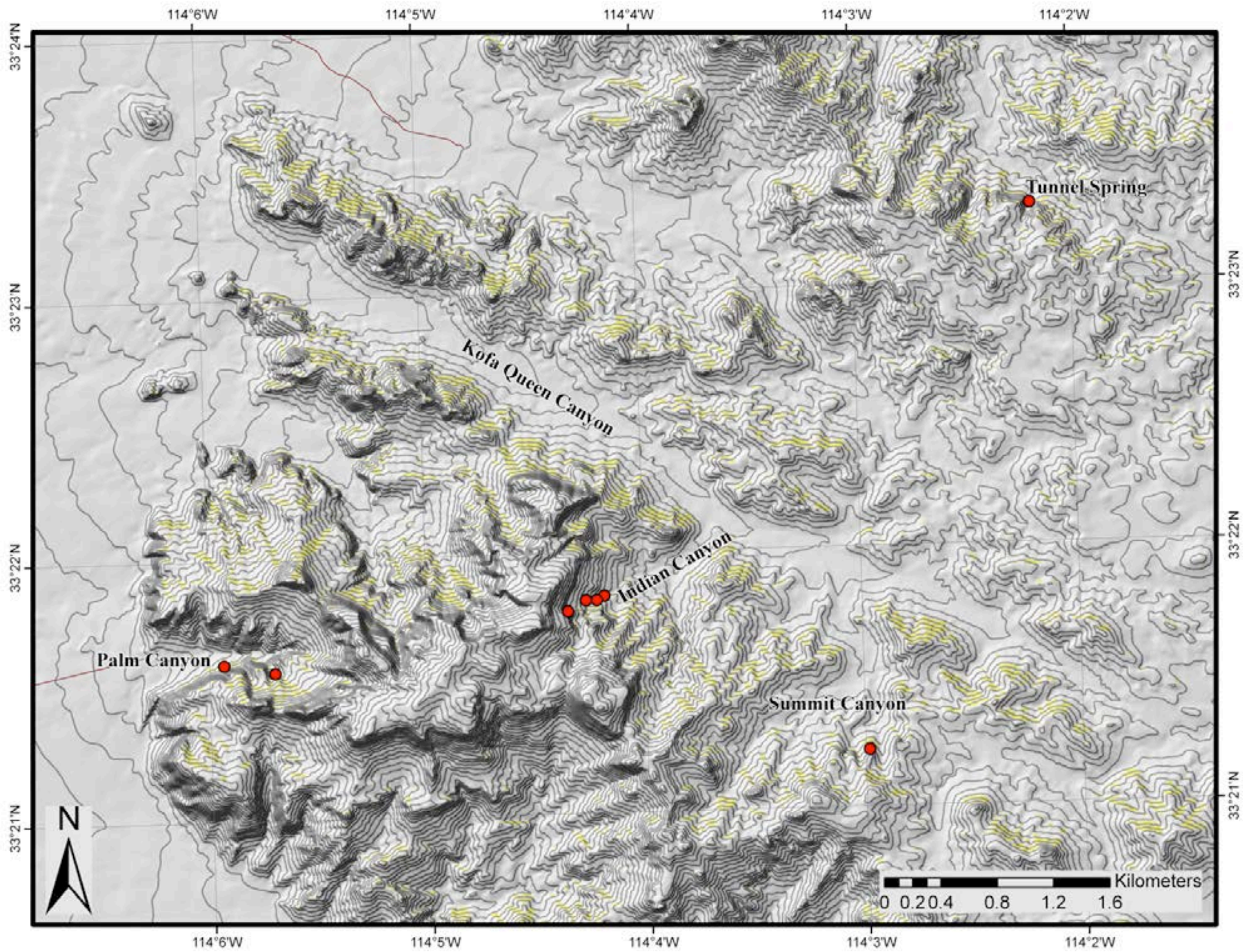

Fig. 2. Map of *Berberis harrisoniana* locations in the Kofa Mountains. Contour interval is 20 m. Yellow areas indicate modeled potential habitat, based on slope, aspect, and elevation of all documented *B. harrisoniana* populations (aspect N35°W–N45°E; slope 30–45°; elevation 725–1200 m; run as a weighted model in ArcGIS® 9.2 [aspect 50%, slope 40%, elevation 10%]).

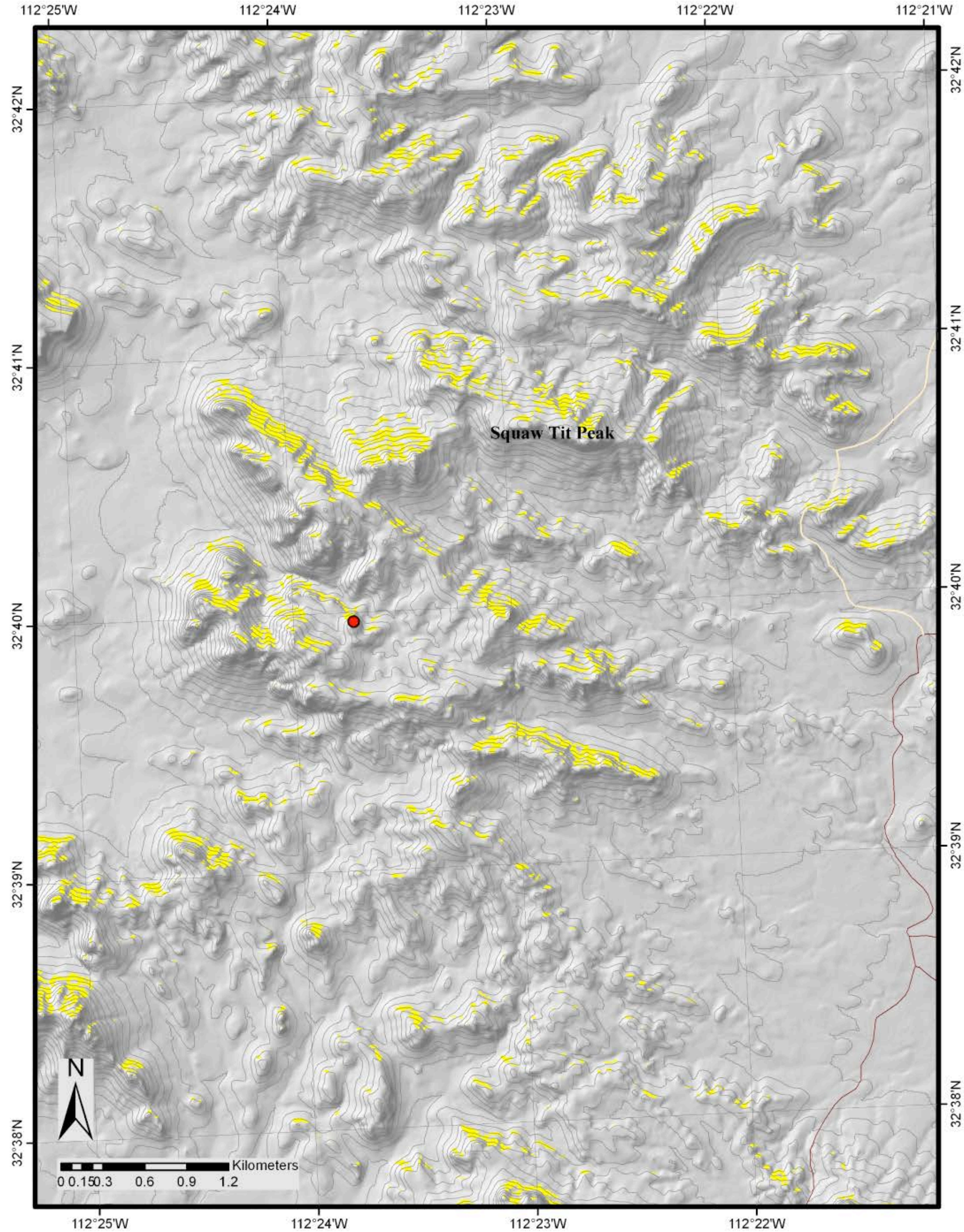

Fig. 4. Map of the *Berberis harrisoniana* location in the Sand Tank Mountains. Contour interval is 20 m. Yellow areas indicate modeled potential habitat, as in Fig. 2.

Fig. 5. Map of *Berberis harrisoniana* locations in the Whipple Mountains. Contour interval is 30 m. Dark lines indicate roads. Yellow areas indicate modeled potential habitat, as in Fig. 2.

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A conservation plan for *Berberis harrisoniana* (Kofa Mountain barberry) by Sarah J. De Groot

Fig. 6. *Berberis harrisoniana*. Photo by Sue Rutman.

Cupcake Butte (1).—Plants were located in a rock chute along the trail to the summit. There is a dry waterfall toward the top of the chute, above which is a steeply sloped cove in rock, where the trail crosses. Below the dry waterfall is a fairly long narrow chute between tall rock walls. The slope was 40°, and aspect N35°W in the upper part; in the lower part the slope was 34°, and aspect N21°E. The elevation was 808–829 m. Associated species included *Acacia greggii*, *Achnatherum speciosum* (Trin. & Rupr.) Barkworth, *Brickellia atractyloides*, occasional *Bromus rubens*, *Ephedra fasciculata* A. Nelson, *Eriogonum fasciculatum* var. *polifolium*, *E. wrightii* Benth. var. *nodosum* (Small) Rev., *Erigeron oxyphyllus* Greene, *Eucrypta chrysan-themifolia*, *Galium stellatum* var. *eremicum*, *Gilia scopulorum* M.E.Jones, *Nicotiana obtusifolia*, *Rafinesquia californica*, *Parietaria hespera*, *Pholistoma auritum* var. *arizonicum, Poa bigelovii*, *Pterostegia drymarioides* Fisch. & C.A.Mey., *Quercus turbinella*, *Salazaria mex-icana* Torr., and *Sphaeralcea* cf. *ambigua*.

The total number of live plants in both portions of this chute was 101. The upper part of the chute supported 18 live plants, with seven in fruit and one that flowered but did not have fruit. Twenty four dead *B. harrisoniana* plants were observed toward the center of this upper part, with live plants along the base of the west wall, at the top, and a few near the dry waterfall and at the base of the east wall. The trail to the top of Cupcake Butte runs through this part of the chute, but leaf litter is deep around most plants and there is little erosion except right at the trail. This does not seem to be affecting the *B. harrisoniana*. A greater threat could be rock fall.

In the lower section, seven plants were observed in fruit in March 2005, along with two plants that were both flowering and fruiting. Nine plants flowered but did not appear to have set any fruit. One possible juvenile (small plant with few stems) was observed, and also three cases of branches rooting (*De Groot 4776*, RSA!). This last observation supports the hypothesis that *B. harrisoniana* reproduces vegetatively. The total number of live plants in this stand was 83. Forty-five dead plants were found primarily against the west wall near the bottom of the chute. Possible causes for this high mortality could be drought during the previous few years, disease, increased temperatures, or excessive sunlight. Some plants appeared to be mostly dead, but were re-sprouting either from the base or from one or a few branches, perhaps in response to the relatively high rainfall of the 2004–2005 winter. There is no trail through this area, but there were signs of minor disturbance from off-trail hikers (litter). There may have been some rock fall in the past (large branches were broken on *Acacia greggii* at the bottom of the chute), and this could still be a threat.

Cupcake Butte (2).—The sub-population was found in a rock chute just west of the trail to the summit and sub-population 1. The steep, narrow chute had a dry waterfall between two large patches of *B. harrisoniana*. The elevation was 781 m, slope 40° (both upper and lower patches), aspect N27°E (lower), and N16°W (upper). Other plant species in the lower area included *Acacia greggii*, *Anemone tuberosa* Rydb., *Ephedra fasciculata*, *Eucrypta chrysan-themifolia*, *Galium stellatum* var. *eremicum*, *Parietaria hespera*, *Pholistoma auritum* var. *arizonicum*, *Phoradendron californicum* Nutt. (in *Acacia greggii*), *Poa bigelovii*, *Quercus turbinella*, *Rafinesquia californica, Senecio mohavensis* A.Gray, and *Uropappus lindleyi* (DC.) Nutt. The upper area had large sections of bare rock, but supported *Achnatherum spe-ciosum*, *Bromus rubens*, *Cryptantha* cf. *holoptera* (A.Gray) J.F.Macbr., *Ephedra fasciculata*, *Eucrypta chrysanthemifolia*, and *Parietaria hespera*.

This chute contained 142 live plants in total, 55 in the lower portion and 87 in the upper. There were 22 dead plants. One possible juvenile was observed, along with 26 plants in fruit, two that flowered but did not have fruit, and one rooted branch. This chute is some distance west of the trail and there were no signs of disturbance by humans in March 2005. Possible threats are rock fall (upper part) or landslide (lower part).

Cupcake Butte (3).—This was the westernmost sub-population along the north face of the butte, over a saddle from the middle chute (Cupcake Butte 2). It was located next to a point of rock that had several holes through it. The chute was fairly wide, with plants scattered along it, particularly at the base of the W (SW) side. The slope was 40°, aspect N22°W, and elevation 801 m. Some associated plants were *Achnatherum speciosum*, *Brickellia atracty-loides*, *Bromus rubens*, *Cymopterus panamin-tensis* J.M.Coult. & Rose, *Ephedra* cf. *fascicu-lata*, *Erigeron oxyphyllus*, *Eriogonum fascicu-latum* var. *polifolium*, *Eucrypta chrysanthem-ifolia*, *Galium stell-atum* var. *eremicum*, *Lycium fremontii*, *Parietaria hespera*, *Pholistoma auritum* var. *arizonicum*, *Poa bigelovii*, *Rafines-quia californica*, *Rhus trilobata*, *Senecio mohavensis*, and *Uropappus lindleyi*.

The slope supported 53 live plants, of which three may be juveniles, and three were seen in fruit in March 2005. Twenty-two dead plants were also observed. There were no signs of any disturbance. Rock fall or landslide may pose threats, but are likely infrequent.

3.5.13 *Misidentifications*.—Several ad-ditional herbarium specimens, including some cited by Phillips (1979), were previously identified as *B. harrisoniana*, but have since been determined to be other species. These are detailed further in Appendix 2.

3.6 *Threats and Limiting Factors*

Berberis harrisoniana is rare, mainly be-cause its suitable habitat is rare (Phillips 1979; Malusa 1995). Although modeled potential habitat (Figs. 2–5) appears to be fairly common, this does not take into account all factors that may affect the distribution of *B. harrisoniana*, such as moisture availability or amount of sunlight. Disturbance by humans is a threat, but probably not severe because most of the localities are rarely visited. One exception is the lower Palm Canyon population, were severe erosion from trails has exposed the root system of a number of plants, and probably contributed to a decline from 76 plants in 1979 to 25 plants in 2005. No sites are near roads, and only five sites are accessible by hiking trails. Off-highway vehicles are not permitted on any of the lands on which *B. harrisoniana* populations are found.

Mining poses little threat. It is not permitted in Kofa NWR, except for valid claims made prior to 1974; it is not allowed at all in Organ Pipe Cactus National Monument; and although it is permitted on BLM lands in the Whipple Mountains, little mining activity has been observed in the range (see *http://www.blm.gov*).

Natural random events such as rock fall, flash flooding or mud flows are perhaps bigger threats than mining, particularly to Arizona populations growing in canyon bottoms (e.g., Upper Palm Canyon, Kofa Mountains), since entire populations could be washed away or covered over instantly (Phillips 1979). Plants have been killed by rock falls (Phillips 1979) or erosion. However, *B. harrisoniana* appears to form thickets by root sprouting or branch rooting to some degree and may be able to recover unless mud flows are severe (Phillips 1979; see also Huffman and Tappeiner 1997). Other natural stresses include increased temperatures, sunlight, heat, or drought, which are very difficult to mitigate.

The high number of standing dead plants at some sites is of concern. It is difficult to de-termine why plants have died, but potential causes include drought, increased temperatures, disease, or excessive sunlight. At the Cupcake Butte population, where 69 dead plants were ob-served, other plants that appeared to be mostly dead were resprouting along branches and from roots. This suggests that drought may be a major stressor, or there may be a combination of factors. Dead plants at some sites but not at others seems to indicate local or intermittent causes rather than range-wide problems.

The greatest threat to *B. harrisoniana* is probably the small number of extant plants (about 600). The percentage of juveniles (plants <1m tall) in three populations observed by Phillips in 1979 ranged from 0 to 38%, compared with about 1.5% of the total number of individuals (8 of 531, <0.3m tall and with few branches or stems) observed in March 2005. However, some of these may have been recent root sprouts. Juveniles did not seem to be particularly numerous in any population (Appendix 1). Without sub-stantial seedling recruitment and establishment, the survival of a population will depend on the longevity of the adult plants, which is unknown.

This species probably experiences little to no gene flow among populations in different mountain ranges, because 70–190 km separate these ranges (Malusa 1995). Isolated populations of small size, with little or no outside genetic exchange, are susceptible to inbreeding depression. One sign of inbreeding depression is reduced reproductive success (Hedrick 2000). Localities of *B. harrisoniana* had from 3 to 142 plants, with 13 of 17 sites (76.5%) having fewer than 30 individuals. In March 2005, 33.0% of the individuals observed (175 of 531) had at least one fruit that appeared to have viable seed. At many sites fruiting plants bore less than 20 fruits each. The Upper Palm Canyon population was exceptional, however, with 72% (88 of 123) of plants bearing multiple large clusters of fruit per plant. Inbreeding depression, lack of pollination, or seed predation could be additional threats to these populations. The genetic structure of populations, breeding system, pollination and seed dispersal mechanisms are unknown, as little research has been done on the genetics or reproductive biology of *B. harrisoniana*.

3.7 *Conservation Status*

At present, *Berberis harrisoniana* is not listed under the Federal Endangered Species Act (*http://ecos.fws.gov/tess_public /TESSWebpage*), the California Endangered Species Act (CNPS 2007), or the Arizona Native Plant Law (*http://agriculture.state.az.us/PSD/nativeplants.htm*; *http://www.azgfd.gov/w_c/edits/documents/*

Berbharr.d_000.pdf; Falk et al. 2001). It was considered for federal listing but rejected because it did not appear threatened (Malusa 1995). It is listed by the Bureau of Land Management in Arizona and California as a sensitive species (S), has a Global-rank of G1G2 (less than 20 occurrences, or restricted to less than 10,000 acres) and a California State rank of S1.2 (rare and threatened; CNPS 2007). It was placed on the California Native Plant Society's (CNPS) List 1B.2 in 2006 (rare, threatened, or endangered in California and elsewhere, and fairly endangered in California; CNPS 2007).

Berberis harrisoniana is protected on Federal lands at Organ Pipe Cactus National Monument, the Barry M. Goldwater Air Force Range, and on the Kofa National Wildlife Refuge. The Whipple Mountains population lies within the BLM Whipple Mountains Wilderness area. Other than Phillips' status report (1979), no management plans are in place for this species on these lands, and the species enjoys general protection provided in these areas. The Barry M. Goldwater range has an Integrated Resource Management Plan (INRMP), but *B. harrison-iana* is not mentioned specifically (Richard Whittle, USAF, pers. comm. 15 Apr 2008; see also Ingraldi et al. 2007).

4.0 CONSERVATION

4.1 *Conservation Objectives and Criteria*

Four objectives are proposed to effect the long-term conservation of *Berberis harrison-iana*. Any or all of these objectives may be re-vised according to new information resulting from study or monitoring of this species.

1. Keep human impact minimal
2. Determine the total number of populations and distribution
3. Identify the reproductive mechanisms of the species
4. Measure how much genetic diversity exists within and among populations of the species.

Impact.—Human impact to most populations is minimal at present, but it must be kept minimal or reduced. Impact at the lower population in Palm Canyon must be assessed. This population may be fenced, if necessary. Site visits should monitor the amount of human impact and record any changes or threats. Natural calamities, such as flash flooding or mud flows, are difficult to regulate and are probably best addressed independently at each site.

The number of dead plants is of concern, and more study and monitoring needs to be done to understand reasons for this observed mortality. Human impact may be at fault in the lower Palm Canyon population, due to erosion and foot traffic along unofficial trails, but causes are not so clear for the dead plants seen at the Cupcake Butte population. Frequent site sur-veys and monitoring may also aid in discovering any pattern as to which sites have or are experiencing high mortality.

Distribution.—Field surveys should be conducted to find additional populations, in the modeled habitat identified above (Figs. 2–5), to obtain a more complete picture of the distribution of *B. harrisoniana*. There are many remote canyons in a number of small mountain ranges in southwestern Arizona, eastern California, and northern Mexico, any of which may contain potential habitat or additional populations, although the species has not yet been documented in Mexico. It is possible that *B. harrisoniana* is more common than has been documented to date, simply because only a small percentage of populations have been located.

Reproductive biology.—Clonal reproduction by means of root sprouting (Phillips 1979) or branch rooting has been observed several times in populations of *B. harrisoniana*. Studies should be done to determine how frequently these processes occur and how many genetically distinct individuals (genets) are present in each population. Investigation of pollination mech-anisms, seed viability, seed dispersal, ger-mination rates, and seedling establishment will be useful to understand the low fruit set and observed paucity of young plants. The number of standing dead plants in some populations suggests that disease may be a problem, and it may be useful to study this further.

Genetic study.—Genetic diversity within and among populations should be evaluated. Smaller populations may be less genetically diverse, and consequently may suffer from inbreeding depression. It will be useful to determine if fruit or seed production is correlated with genetic diversity. Study also may reveal if this popu-lation structure and low gene flow are natural, or if *B. harrisoniana* could be helped by the establishment of additional populations. Further knowledge of the population genetic structure of *B. harrisoniana* may also permit assessment of the long-term viability of the species. However, although genetic studies have the potential to provide much useful information, they may not necessarily provide the definitive answers de-sired by management personnel (Mistretta 1994), such as which populations are the most important to protect.

The criteria for successful conservation of *B. harrisoniana* are:

1. Human impact is not causing damage to or death of plants at any population.
2. The majority of promising potential habitat has been surveyed and any additional populations are recorded and vouchered.
3. The amount of clonal reproduction in each population (number of genets), reproductive mechanisms, dispersal mechanisms and disease susceptibility are known.
4. The amount of gene flow and genetic diversity within and among populations are known.

4.2 *General Conservation Actions Recommended*

Site visits.—At a minimum, all known popula-tions of *B. harrisoniana* should be visited periodically and censuses conducted to ensure that plants are still extant and to check for any new threats. These visits could be every 1–10 years, depending on previously observed threats or impact. Data gathered should include, at a minimum, number of plants, number of plants with fruit or flowers, number of juveniles, seedling survival, and any noticeable threats or damage to the plants. These site visits should also monitor seedling recruitment and plant mortality.

Natural threats.—Rock fall, flash flooding or mud flows are natural occurrences, part of the habitat of *B. harrisoniana*, and probably do not need to be prevented or minimized unless it seems likely that an entire population will be lost. Additional steps may need to be taken following study of the reproductive biology and demographics of *B. harrisoniana*.

Surveys.—Potential habitat for *B. harrisoniana* should be identified and surveyed. It may be useful to scan areas by helicopter first and/or model potential habitat with GIS, to identify the most promising sites, then to check these on foot. New populations may be discovered, and potential localities for introduction (if deemed beneficial) may be identified. These surveys should include areas of northern Mexico and the Tohono O'odham (Papago) Reservation, as well as western Arizona and eastern California. Some surveys are already in progress on the Yuma Proving Ground (Blackman et al. 2007; Ingraldi et al. 2007).

Document plant reproductive biology.—Many aspects of the reproductive biology of *B. harrisoniana* are unknown: pollinators, pollination mechanisms (including self-com-patibility or incompatibility), factors limiting seed production, capacity for asexual seed production and relative contributions of sexual and asexual seed production, correlates of seed production (temperature, moisture, etc.), con-sistency of seed production, seed viability, seed predation rates, seed dispersal mechanisms, germination rates, seedling establishment rates, and the frequency of clonal reproduction by means of root sprouting or branch rooting. An understanding of this basic reproductive biology will be critical to create appropriate management strategies, and in determining the effect on *B. harrisoniana* populations of additional gene flow (through artificial outcrossing, trans-planting, or cultivation), climatic change, or ecological change.

Genetic diversity study.—The genetic diversity within and among populations should be evaluated. This should include assessment of (1) the proportion of individuals in each population that are genets vs. ramets, (2) the amount of inbreeding within populations, (3) the amount of gene flow between populations, and (4) if the disjunct population structure of *B. harrisoniana* is natural. These data will aid our understanding of how many genetically distinct plants are present, in comparison with the apparent number of plants. They may also help to assess the long term viability of the species (e.g., whether it is likely to be impacted by climate change). Leaf-lets were collected from every plant in all Kofa Mountains and Whipple Mountains populations in March 2005 and are available for genetic studies (stored at RSA). *Berberis nevinii* has a similar population structure and low fruit set (Mistretta 1989), and may make an interesting comparative study.

Secondary actions.—The fact that *B. harrison-iana* was common in Alamo Canyon 9570 years before present (R. Felger et al., in prep.) but not encountered there in 2005 suggests that it may have become restricted to its present sites during warming after the last ice age, or after periodic pulses of range expansion during optimal conditions. If it lacks the genetic diversity to adapt to these changes, it could be preserved in cultivation, but it may be futile to attempt conservation in the wild. However, many other factors also may influence the species' distribution. Plants may persist naturally for some time.

Following surveys of potential habitat and study of *B. harrisoniana* reproductive biology and population genetic structure, the conservation plan and management actions should be reviewed and updated as needed.

If an increase in genetic diversity within these populations is shown to be desirable, this may be accomplished through increasing gene flow between populations (by establishing additional populations, transporting pollen or seed, reciprocal transplanting, or addition of material propagated *ex situ*). Careful yearly monitoring of the amount of mature fruit produced may be a good measure of population health in this regard, or perhaps coupled with seedling recruitment. If the species could benefit from the establishment of new populations, these may be created by *ex situ* propagation of cuttings or seed. Propagation is more desirable than transplanting since the total number of individuals is already low (~600). There has been limited preliminary success propagating *B. harrisoniana* by cuttings, although other species of *Berberis* or *Mahonia* have usually been pro-pagated by seed (Sheat 1948; Mistretta 1989). Actions to increase gene flow should be taken only after the possibility of local adaptation has been investigated, since moving locally adapted genotypes between populations could be harmful to the species.

On the other hand, if studies indicate that the distribution of this species is more con-tinuous than it appears at present, whether due to the discovery of additional populations, or to evidence of long distance pollen or seed dispersal, no action may be warranted. The species is likely to persist naturally as long as there are sufficient numbers of distinct *B. harrisoniana* individuals, the amount of genetic diversity is adequate, and human impacts are minimal.

4.3 *Site-Specific Actions*

4.3.1 *Kofa Mountains, Lower Palm Canyon*.—The lower Palm Canyon site suffers from severe gullying of unofficial trails, and this may be responsible for a decline in the number of plants from 76 to 25 over 26 years. If uncon-trolled, more root systems may become exposed to the point of plants being effectively uprooted (see Phillips 1979). These trails should be re-routed or well maintained to prevent erosion, or the populations may be fenced. Monitoring of the number of individuals and fruit or seed production is desirable to evaluate population health.

4.3.2 *Kofa Mountains, Upper Palm Canyon*.—The threat posed by flash flooding or mud flows should be evaluated (Phillips 1979). Measures should be taken to protect the population at this site if these natural calamities appear to occur regularly and could easily destroy all or a large portion of a population.

4.3.3 *Kofa Mountains, Indian Canyon, Summit Canyon, and Tunnel Spring*.—Landslide may be a concern for sites found on loose rock debris.

4.3.4 *Ajo Mountains, Pitahaya Canyon and Montezuma Head*.—Pitahaya Canyon should be surveyed extensively for a population, and, if one or more is discovered, plants should be counted and detailed site information recorded (e.g., slope, aspect, latitude, longitude, elevation, and associated species). The Montezuma Head population should be revisited, and the same information recorded. The threat posed by flash flooding or mud flows should be assessed for the population on Montezuma Head (see Phillips 1979).

4.3.5 *Ajo Mountains, Arch and Alamo Canyons*.—These populations should be re-located, the number of plants counted, and detailed site information recorded (as above).

4.3.6 *Sand Tank Mountains*.—This population should be revisited, the number of plants counted, and detailed site information recorded (as above).

4.3.7 *Whipple Mountains, Cupcake Butte*.—The trail through the eastern sub-population on Cupcake Butte (chute 1) has eroded to some degree, and, although it does not appear to have affected the *B. harrisoniana* plants, this should be monitored and action taken if it becomes a threat. Landslide may be a concern for the Cup-cake Butte 1 and 3 populations, as all of these are found on loose rock debris.

4.4 *Conservation Tasks*

The main task of conservation is to prevent a species from becoming extinct. The conser-vation actions detailed in this plan are recom-mended to that end. Actions are summarized in Table 1.

4.5 *Out-of-State Considerations*

Known populations are found in both Ari-zona and California. It may be profitable to search potential habitat in Sonora, Mexico, and on the Tohono O’odham Reservation in Pima, Pinal, and Maricopa Counties, Arizona.

Table 1. Prioritized summary of conservation actions recommended for *Berberis harrisoniana*.

Action	Description	Priority
Site visits	Regular visits (every 1–10 years) to each known site to ensure plants are extant	High
Field survey	Search potential habitat for additional populations (mountain ranges in Pima, Maricopa, Yuma, and La Paz counties, Arizona; Imperial, Riverside, and southern San Bernardino counties, California; Sonora, Mexico; and Tohono O'odham Reservation)	High
Reproductive biology study	Determine pollinators, pollination mechanisms (including self-compatibility/incompatibility), factors limiting seed production, amount of and ability for asexual seed production, correlates of seed production (temperature, moisture, etc.), consistency of seed production, seed viability, seed predation rates, seed dispersal mechanisms, germination rates, seedling establishment rates, and frequency of clonal reproduction	High
Genetic study	Determine number of genets, the amount of inbreeding or outcrossing, and genetic diversity within and among populations	Medium
Ex situ propagation	Plants propagated and cultivated in controlled environments, either for horticultural use, or for conservation purposes (e.g., to augment population sizes, or to establish additional populations)	Secondary; if deemed appropriate
Monitoring	Monitoring is to be performed in conjunction with establishment of additional populations and/or human-mediated increases in outcrossing	Secondary; if deemed appropriate

4.6 *List of Likely Participants*

- Arizona Game and Fish Department
- California Department of Fish and Game
- BLM Lake Havasu City Office (AZ)
- BLM Phoenix Office (AZ)
- BLM Needles Office (CA)
- Kofa National Wildlife Refuge (USFWS)
- Organ Pipe Cactus National Monument (NPS)
- Barry M. Goldwater Air Force Range (DOD)
- California Native Plant Society
- Arizona Native Plant Society
- Tohono O'odham Tribe
- Rancho Santa Ana Botanic Garden (RSA)

5.0 IMPLEMENTATION

5.1 *Action Assessment*

While *B. harrisoniana* does not appear threatened, so little is known about it that few firm conclusions can be drawn. Human impact is minimal for most populations, but is a danger to the Lower Palm Canyon population. Natural disturbance, such as landslide, rock fall, or flash flood, appear to pose less risk than elevated temperatures or prolonged drought. It is of concern that five sites contain relatively high numbers of dead plants (see Appendix 1). These numbers in each case represent significant portions of the plants present at the sites. *Berberis harrisoniana* also is threatened by small population sizes, which may be causing or could lead to low gene flow and inbreeding depression especially if one or more populations are extirpated. It is impossible to understand which threats pose the most danger to the species or to take steps to reduce threats until more study is done.

5.2 *Listing*

Federal or state listing is not warranted at this time unless serious but preventable threats to one or more populations are discovered.

5.3 *Prioritized Implementation Schedule*

1a. Revisit sites where *B. harrisoniana* has not been documented during the past ten years. Continue to visit sites regularly.
1b. Map and survey potential habitat for additional populations. Voucher new populations.
2. Determine mechanisms of reproduction, seed-ling survival, and degree of clonal reproduction.
3. Determine the genetic diversity within and among populations.
4. Re-evaluate conservation and management plans for the species.

5.4 *Potential Difficulties in Implementation*

Funding and qualified investigators pose two potential problems to the implementation of the conservation actions described above. Known populations occur in lands administered by different agencies (see section 3.5 Distribu-tion), and it is not known if all or any of these would provide funding or support for studies, exploration, propagation, or monitoring. Lack of any State or Federal listing status limits alloca-tion of limited conservation funding. Federal, State of Arizona, and State of California agen-cies could be involved, as could authorities and land managers in Mexico or on tribal lands at the Tohono O'odham Reservation. There is no lead investigator or agency coordinating conservation efforts for *B. harrisoniana*. Implementation of any conservation actions may be difficult since the known localities are generally in remote, rough terrain and not easily accessible. Ad-ditional populations, if discovered, are likely to be in similarly difficult sites.

CONCLUSION

Berberis harrisoniana has a limited range and very limited numbers of individuals are known. There is little or no evidence of recent recruitment and some occurrences have sig-nificant numbers of dead individuals present. Very little is known about its reproductive mechanisms, population structure, or genetic diversity. These aspects need to be investigated in order to justify or negate further conservation measures, such as *ex situ* propagation or establishment of additional populations.

However, based on a habitat model, there is a good chance that additional populations may be discovered. *Berberis harrisoniana* may be more common and more genetically diverse than it appears. As long as human impacts are kept to a minimum, it may persist for some time into the foreseeable future.

At present, there are around 600 individuals known from 10 populations in four desert moun-tain ranges, making *B. harrisoniana* both re-stricted in its range and rare where it does occur.

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Appendix 1. Summary of information from known localities of *Berberis harrisoniana*. Unknown or missing values are indicated by --. Latitude and longitude are referenced to NAD 27.

Site	Live plants[1]	Dead plants	Plants with fruit	Juvenile plants	Latitude N, longitude W	Land manager	Conservation or protection agency	Threats
Kofa Mountains, Yuma County, AZ								
Palm Canyon, lower	76 (1979), 25 (2005)	0 (1979); 7 (2005)	0, but 10–40% in flower (1979); 2 (8%, 2005)	3 (1979); 0 (2005)	33.36000 114.09889	USFWS	Kofa National Wildlife Refuge	Erosion from trails, rock fall, many dead plants, no seedling recruitment
Palm Canyon, upper	110 (1979), 123 (2005)	0 (2005)	0, but 20-30% in flower (1979); 88 (72%, 2005)	0 (1979 and 2005)	33.35944 114.09500	USFWS	Kofa NWR	Rock fall, flash flooding, no seedling recruitment
Indian Canyon 1	13 (2005)	0	1 (8%)	2 (15%)	33.36389 114.06972	USFWS	Kofa NWR	None observed
Indian Canyon 2	3 (2005)	0	3 (100%)	0	33.36361 114.07028	USFWS	Kofa NWR	No seedling recruitment
Indian Canyon 3	13 (2005)	0	6 (46%)	0	33.36361 114.07111	USFWS	Kofa NWR	Landslide, no seedling recruitment
Indian Canyon 4	15 (2005)	0	7 (47%)	0	33.36294 114.07250	USFWS	Kofa NWR	Rock fall, no seedling recruitment
Summit Canyon	29 (2005)	0	15 (52%)	0	33.35361 114.04972	USFWS	Kofa NWR	Rock fall, landslide, no seedling recruitment
Tunnel Spring	14 (2005)	0	10 (71%)	1 (7%)	33.38833 114.03639	USFWS	Kofa NWR	Rock fall, landslide, trail access
Totals, Kofa Mountains	235 (2005)	7	132 (56%)	3 (1%)				

Site	Live plants[1]	Dead plants	Plants with fruit	Juvenile plants	Latitude N, longitude W	Land manager	Conservation or protection agency	Threats
Ajo Mountains, Pima County, AZ								
Pitahaya Canyon	-- (1979)	--	--	--	--	NPS	Organ Pipe Cactus National Monument	Location not found in 1979
Montezuma Head	23 (1979)	--	Too early	10 (43%)	32.11475 112.70598	NPS	Organ Pipe Cactus National Monument	Rock fall, erosion, flash flooding
Arch Canyon	12 (1988)	--	Rare	--	32.03889 112.70694	NPS	Organ Pipe Cactus National Monument	Unknown; not found in March 2005
Alamo Canyon	“a few” (1979)	--	--	--	--	NPS	Organ Pipe Cactus National Monument	Unknown; not found in March 2005
Bull Pasture	-- (2005)	--	--	--	32.01403 112.68435	NPS	Organ Pipe Cactus National Monument	Trail access
Totals, Ajo Mountains	35	--	--	10 (29%)				

Site	Live plants[1]	Dead plants	Plants with fruit	Juvenile plants	Latitude N, longitude W	Land manager	Conservation or protection agency	Threats
Sand Tank Mountains, Maricopa County, AZ								
SW of Squaw Tit	24 (2001)	--	--	--	32.66608 112.39556	DOD; USAF	Barry M. Goldwater Air Force Range	Unknown
Whipple Mountains, San Bernardino County, CA								
Cupcake Butte 1, upper	18 (2005)	24	7 (39%)	0	34.34639 114.32389	BLM	Whipple Mountains Wilderness	Rock fall, possibly erosion from trail, possible human disturbance, large number of dead plants, no seedling recruitment
Cupcake Butte 1, lower	83 (2005)	45	7 (8%)	1 (1%)	34.34656 114.32361	BLM	Whipple Mountains Wilderness	Rock fall, possible human disturbance, landslide, large number of dead plants, low seedling recruitment
Cupcake Butte 2	142 (2005)	22	26 (18%)	1 (1%)	34.34694 114.32417	BLM	Whipple Mountains Wilderness	Rock fall, large number of dead plants, low seedling recruitment
Cupcake Butte 3	53 (2005)	22	3 (6%)	3 (6%)	34.34694 114.32472	BLM	Whipple Mountains Wilderness	Rock fall, landslide, large number of dead plants, low seedling recruitment
Totals, Whipple Mountains	296 (2005)	113	43 (15%)	5 (2%)				
Totals, all sites	590	120	175 (33.0%)	18 (3.1%)				

[1]This value is simply the apparent number of distinct shrubs; the number of genetically distinct plants may be lower.

Appendix 2. Specimens studied

Kofa Mountains

Palm Canyon, lower population or ambiguous: Eleven specimens: Palm Canyon of Kofa Mountains. 31 Mar 1930, *R. H. Peebles & H. F. Loomis 6768* (holotype US [photo!], isotypes CAS, ARIZ [photo!]). Near Palm Canyon in Kofa Mountains. 26 Feb 1932, *R. E. Beckett 9079* (ARIZ!). Palm Canyon, Kofa Mountains. 20 Feb 1937, *I. L. Wiggins 8577* (US, photo!). Palm Canyon, Kofa Mountains, 2200 ft. 15 Apr 1939, *T. H. Kearney & R. H. Peebles 14221* (ARIZ!; US, photo!). Palm Canyon, Kofa Mountains, 2800 ft. 17 Apr 1941, *L. Benson & R. A. Darrow 10866* (ARIZ, POM!, ASC). Palm Canyon, Kofa Mountains. 19 May 1950, *C. F. Deaver 2789* (ASC). Near entrance to Palm Canyon, Kofa Mountains, Arizona Desert, 3000 ft. 05 Mar 1950, *G.R. Campbell 14441* (RSA!). Palm Canyon. 24 Mar 1964, *R. J. Barr & K. I. Lange 64198* (ARIZ). Kofa Mountains, Palm Canyon, N slope near wash, 2500 ft. 30 Jun 1968, *M. A. Dimmitt s.n*. (RSA!). Palm Canyon in the Kofa Mountains, S wall at pediment, 2400 ft. 26 Jun 1973, *R. B. Oxford 431* (ASU, ARIZ). Kofa Mountains, Palm Canyon; large canyon, among boulders. 19 May 1976, *E. Lehto & T. Reeves L-20100* (ASU, RSA!).

Palm Canyon, upper population: Five specimens: East gorge, deep in the Palm Canyon of the Kofa Mountains. 12 Oct 1952, *B. C. Stone 262* (SD, photo!). Side ravine in Palm Canyon, Kofa Mountains; N exposure of a narrow rocky side [ravine]. 27 Jan 1965, *C. T. Mason, Jr. & W. E. Niles 2496* (ARIZ). Kofa Mountains, Palm Canyon, upper half of canyon, 2600 ft. 24 Nov 1977, *R. F. Thorne et al. 50837* (RSA!). 1/4 mile up Palm Canyon; 19 miles S of Quartzite on Highway 95, 7 miles E of highway. 15 Feb 1979, *J. Mazzoni 79-3* (ASC). Kofa Mountains, Palm Canyon; narrow rocky canyon. 22 Apr 1979, *E. Lehto L-23640* (ASU).

Indian Canyon: Two specimens: Indian Canyon, Kofa Mountains, Kofa Game Range. 17 Mar 1964, *N. M. Simmons XVI* (ARIZ!). Indian Canyon, Kofa Mountains, Kofa Game Range. 17 Mar 1964, *N. M. Simmons s.n.* (ARIZ!).

Summit Canyon: One specimen: Summit Canyon, Kofa National Wildlife Refuge, 20 mi SE of Quartzite. 03 Mar 1980, *N. J. Whiteman s.n*. (ASC).

Tunnel Spring: One specimen: Growing just below Tunnel Spring— Kofa Mountains 08 Jun 1943, *C. F. Harbison 43.5* (SD, photo!; RSA!).

Kofa Queen Canyon: No specimens

Kofa Mountains, ambiguous locality: Kofa Mountains. 18 May 1937, *L. N. Goodding 2310* (ARIZ).

Ajo Mountains

Pitahaya Canyon and Montezuma Head: Two specimens: Organ Pipe Cactus National Monument; Ajo Mountains, Pitahaya Canyon, 1036 m/3400 ft. 23 Feb 1939, *A. A. Nichol s.n.* (ARIZ!). W slopes of Montezuma Head, above Pitahaya Canyon, N end of Ajo Mountains; Organ Pipe Cactus National Monument, 3400 ft. Mesic area above base of W face of Montezuma Head. 16 Jan 1976, *A. M. Phillips, III, T. R. Van Devender, & W. B. Woolfenden 76-2* (ARIZ!).

Arch Canyon: Three specimens: Organ Pipe Cactus National Monument, Ajo Mountains, rock cut between Arch and Boulder Canyons. 3000 ft. 22 Jan 1950 *G. E. Steele & C. L. Foute s.n.* (US, photo!). Ajo Mountains, S of Arch in Arch Canyon; Organ Pipe Cactus National Monument; deep shaded canyon; wide crack in N-facing cliff. 18 Feb 1978, *M. Fay 738* (ARIZ!). Organ Pipe Cactus National Monument; Arch Canyon, 915–1000 m; mostly shaded by E-facing steep slopes. 12 May 1988 *M. A. Baker, G. Ruffner, & B. Johnson 7611* (ASU, photo!).

Alamo Canyon: No specimens

Bull Pasture: No specimens

Sand Tank Mountains

Three specimens: Sand Tank Mountains, 1 mi SW of Squaw Tit Peak, 1050 m; in shady N-facing alcove in tertiary volcanics, along rocky drainage. 02 Jan 1995, *J. Malusa s.n.* (ARIZ!). Barry M. Goldwater Air Force Range, Sand Tank Mountains; S of Johnson Well, 3360 ft; at base of N-facing tall cliff; thicket 100 yards long below pour-off. 04 May 1995, *J. L. Anderson 95-6* (ASU, photo!). Barry M. Goldwater Military Range, Sand Tank Mountains; 0.6 km (map) WSW of Bender Spring, above Bender Spring, 1 mi SW[?] of Squaw Tit Peak, 3320 ft.; N-facing slopes. 17 Sep 2001, *P. Holm 20010917-9* (ARIZ!).

Whipple Mountains

Cupcake Butte (1): Three specimens (upper part of chute): BLM Whipple Mountains Wilderness, Cupcake Butte; steep talus slope just below summit, 2750 ft. 18 Jan 2001, *J. L. Anderson & C. Bobinski 2001-01* (ASU, ARIZ, RSA!). Just below summit of Cupcake Butte, N of Whipple Wash, 840 m/2750 ft; plants growing in steep talus cove between rock outcrops on NE side of butte, NNE exposure. 10 Oct 2003, *S. J. De Groot & J. M. Porter 3308* (RSA!); 18 Mar 2004, *S. J. De Groot & K. De Groot 3798* (RSA!, RSA Living Collection #21338).

One specimen (lower part of chute): Cupcake Butte (1), chute where trail goes through, lower part below pour-off, slope 34°, aspect N21°E. 19 Mar 2005, *S. J. De Groot & K. De Groot 4776* (RSA!).

Cupcake Butte (2): One specimen: Rock chute just W of the trail to the summit of Cupcake Butte. 19 Mar 2005, *S. J. De Groot & K. De Groot 4786* (RSA!).

Cupcake Butte (3): No specimens

Misidentifications

One specimen (30 Jun 1928, *C. B. Wolf 2422*, RSA!) from Soda Springs on Beaver Creek, 13 mi above Camp Verde, 3600 ft elevation, Yavapai County, Arizona, was annotated "Harrisoniana" in Philip Munz's hand-writing, although originally identified as *B. haematocarpa*. This specimen certainly appears to be *B. haematocarpa*, a more logical identification given its considerable disjunction and habitat differences from other populations.

Similarly, two specimens originally identified as *B. harrisoniana*, collected near and east of Wickenburg, were annotated *B. haematocarpa* by T. Reeves in 1978 [25 Mar 1948, *J. E. Chilton s.n*. (ASU); 25 Mar 1948, *J. C. Dunn s.n*. (ASU)] (Phillips 1979). An additional specimen from the Kofa Mountains [13 May 1941, *C. F. Harbison s.n.* (RSA!)], was annotated "Harrisoniana" in Philip Munz's handwriting, but actually appears to be *B. haematocarpa*.

A specimen of *Berberis* was collected in the Eagletail Mountains ["Eagle Trail Mountains." 23 Mar 1956, *J. T. Wright 74-56* (ARIZ!)]. Apparently it was first identified as *B. harrisoniana* (Phillips 1979), but since has been annotated *B. haematocarpa* by J. B. Urry (01 Jan 1978; *http:// seinet.asu.edu/collections/*). There are no other collections or reports of *B. harrisoniana* from the Eagletails (Phillips 1979).

Two collections of *B. harrisoniana* are reported from the vicinity of Show Low in Navajo County (Sitgreaves National Forest). However, they have since been identified as *B. trifoliolata* Moric. [14 mi NE of Show Low, Show Low-Springerville Road. 19 Oct 1952, *M. E. Caldwell, s.n.* (ARIZ!), det. by S. De Groot] and *B. fremontii* Torr. in Emory ["N of Showlow"; in juniper woodland. 21 July 1969, *R. Krizman s.n.* (ARIZ), see *http://seinet.asu.edu/seinet /index.jsp*]. The *B. fremontii* specimen was reportedly collected "in juniper woodland," not the typical habitat of *B. harrisoniana*. Furthermore, if these specimens were in fact *B. harrisoniana*, they would represent a range extension of at least 275 km, which is 1.4 times the farthest distance separating known populations (see Malusa 1995).