May 25, 2006

Final Report on "Conservation of Arizona Upland Sonoran Desert Habitat. Status and Threats of Buffelgrass (*Pennisetum ciliare*) in Arizona and Sonora. Project #2004-0013-003)".

Thomas R. Van Devender and Mark A. Dimmitt
Arizona-Sonora Desert Museum, 2021 N. Kinney Rd., Tucson, AZ 85743

The African buffelgrass (*Pennisetum ciliare*) has been identified as the most serious ecological threat to the paloverde-saguaro-ironwood desertscrub in the Arizona Upland (AZU) subdivision of the Sonoran Desert. This scenic vegetation is protected in Arizona in Organ Pipe Cactus National Monument, Saguaro National Park, Ironwood Forest National Monument, Sonoran Desert National Monument, Tucson Mountain Park (Pima County), etc., where it is in excellent condition and relatively little impacted by grazing, wood cutting, and recreational activities. However, the introduction of buffelgrass either through pasture development as in Sonora or dispersal along roads and wind-blown seed as in Arizona is a very serious threat to natural communities because it also introduces fire as a new ecological process (Figure 1). Few if any Sonoran Desert or northern Neotropical plants have any adaptations to recurrent fires. In time, buffelgrass fires could convert the Arizona Upland into a savanna-like landscape as saguaro (*Carnegiea gigantea*), foothill paloverde (*Parkinsonia microphylla*), ironwood (*Olneya tesota*), organ pipe cactus (*Stenocereus thurberi*), etc. are killed.

Figure 1. Buffelgrass invasion on south-facing slope in Arizona Upland paloverde-saguaro desertscrub on Pan Quemado in Ironwood Forest National Monument, Arizona. Light tan-yellow

patches are buffelgrass. Photo by Mark A. Dimmitt.

In the present study funded by the Native Plant Conservation Initiative administered by the National Fish and Wildlife Foundation, we surveyed the distribution of buffelgrass along all major roadways and many secondary roads throughout the Arizona Upland and produced a detailed GIS map of its distribution in Arizona and northern Sonora (Figure 2). The impacts of buffelgrass on the flora and vegetation in Arizona Upland Sonoran Desert habitats in southern Arizona and northern Sonora were evaluated quantitatively through paired transects in buffelgrass patches and adjacent natural vegetation in the same habitat. The results of this project will help land managers and the general public understand the magnitude and dynamics of the buffelgrass invasion in the Arizona Upland, and help in management and control programs to protect high priority Sonoran Desert habitats.

METHODS AND RESULTS

Buffelgrass Distributional Data

ASDM staff developed the methodology and terminology to survey buffelgrass along highways. Waypoints were recorded on Garmin 12 GPS units for point occurrences of buffelgrass or the beginning and ending points of extensive patches. Each record included additional information: estimated density (1 to 4), whether the plants extends beyond the highway right-of-way into natural vegetation, potential for burning, and associated non-native species. Record coordinates were downloaded from the GPS unit into an ACCESS database where additional data were added, such as geographic/political locations and vegetation type. The Access tables were then imported into a GIS map using ArcMap version 8.3.

ASDM data managers designed the database and mapping utility. A base map was compiled from existing GIS layers (roads, towns, vegetation, land ownership, etc.) obtained from the University of Arizona, The Nature Conservancy, the Heritage Database of the Non-game Branch of the Arizona Game and Fish Department, the Bureau of Land Management, Pima County, and INEGI (Instituto Nacional de Estádistica Geografía e Informática) in Hermosillo, Sonora.

Buffelgrass was surveyed along all of the major highways in the Arizona Upland subdivision of the Sonoran Desert in Arizona, as well as several highways in the adjacent Lower Colorado River Valley subdivision, chaparral, and desert grassland (Figure 3). It was also mapped along all paved highways in Arizona Upland in northern Sonora including Mexico Federal Highways 2 and 15 (MEX 2, MEX 15). The leaders of the Sonoran Desert Weedwacker group help organize teams of community volunteers to survey the greater Tucson area more intensively. Over 2000 buffelgrass points have been incorporated into the database. The distribution, elevational limits, and the magnitude of the buffelgrass invasion were documented in these areas.

Records from other sources were added to our own survey to create a map of all known data on buffelgrass distribution in Arizona Upland. Saguaro National Park, Organ Pipe National Monument, and the Arizona Highway Department provided data on inventories on park lands and along state highways. Volunteers from the Sonoran Desert Weedwackers, the Arizona Native Plant Society, and the Desert Museum recorded additional buffelgrass observations. Data from over 300 buffelgrass specimens in several Southwestern herbaria were also included in the comprehensive map These records came from the herbaria of the Arizona-Sonora Desert Museum, Arizona State University, California Academy of Sciences, Desert Botanical Garden, Northern Arizona University, San Diego Natural History Museum, Sul Ross State University, University of California at Riverside, University of Arizona, University of Nevada at Las Vegas, University of New Mexico, and the University of Texas at Austin and El Paso, as well as collections in Mexico City, Hermosillo (Sonora), and La Paz (Baja California Sur).

Figure 2. Dense buffelgrass along highway near Sáric, Sonora. Photo by Mark A. Dimmitt.

Buffelgrass Distribution in Arizona Upland Sonoran Desert

The distribution of buffelgrass in Arizona is shaped like a brittle star centered on Tucson, with the legs along the highways radiating out of town. The northward extensions lead into a second concentration in the Phoenix area. Buffelgrass infestation is extensive throughout the greater Tucson area and is ubiquitous along streets in the center and periphery of the city. We found it on nearly every unpaved roadside, median, and vacant lot. We abandoned surveying it within the city, so the data points reveal only the overall urban distribution, not the density. Dense buffelgrass extends west along AZ 86 past Three Points to the Kitt Peak road on the Tohono O'odham Reservation, and less common to Sells. North of Tucson it is very common on U.S. 89 to Oracle Junction, and northwest to Florence junction and the Apache Junction–Phoenix area. North of Phoenix, buffelgrass is along Interstate 17 into the Agua Fría-Black Canyon City area, but does not ascend the scarp into the desert grasslands south of Cordes Junction.

At higher elevations south, east, and north of Tucson, buffelgrass extends beyond Arizona Upland desertscrub into desert grassland, chaparral, and oak woodland on roadsides. Along the Mt. Lemmon Highway in the Santa Catalina Mountains, buffelgrass extends well above Arizona Upland to about 1350 m elevation in desert grassland and interior chaparral above Molino Basin. In the Altar Valley it is scattered in desert grassland as far south as the Buenos Aires National Wildlife refuge. East of Tucson, buffelgrass is common until the transition to desert grassland near the Marsh Station Road exit. Buffelgrass was not seen in desert grassland along AZ 83 from IH 10 near Vail to Sonoita, or along AZ 80 from Benson to Bisbee. A few plants found 11 km west of Douglas at 1265 m elevation on US 80 are the first record of buffelgrass for Cochise County. Buffelgrass extends along IH 19 from Tucson south into desert grassland at 960 m elevation just south of Amado in Santa Cruz County, but not seen along the Arivaca road to the west.

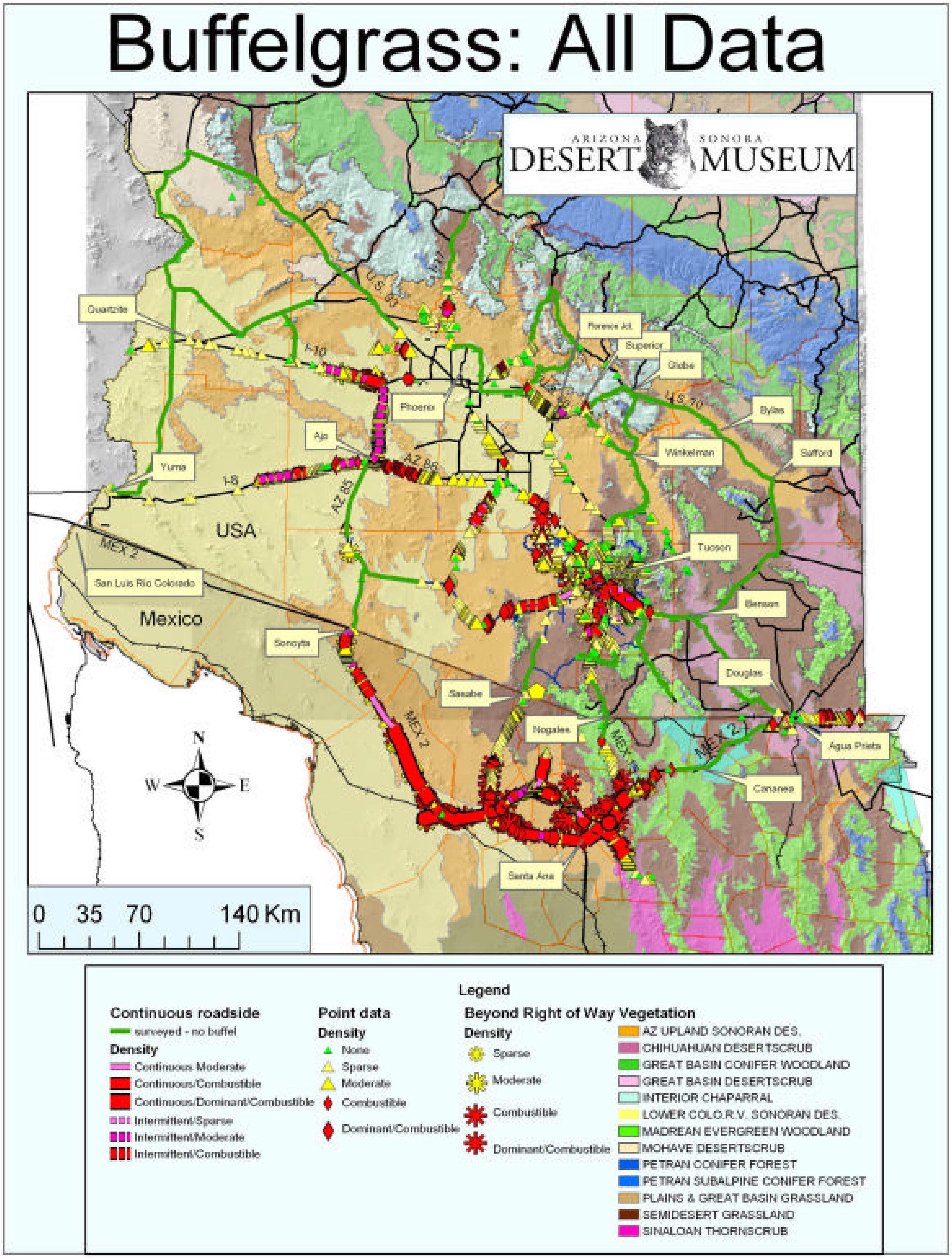

Figure 3. Map of Arizona and northern Sonora with all data points generated in the buffelgrass road survey.

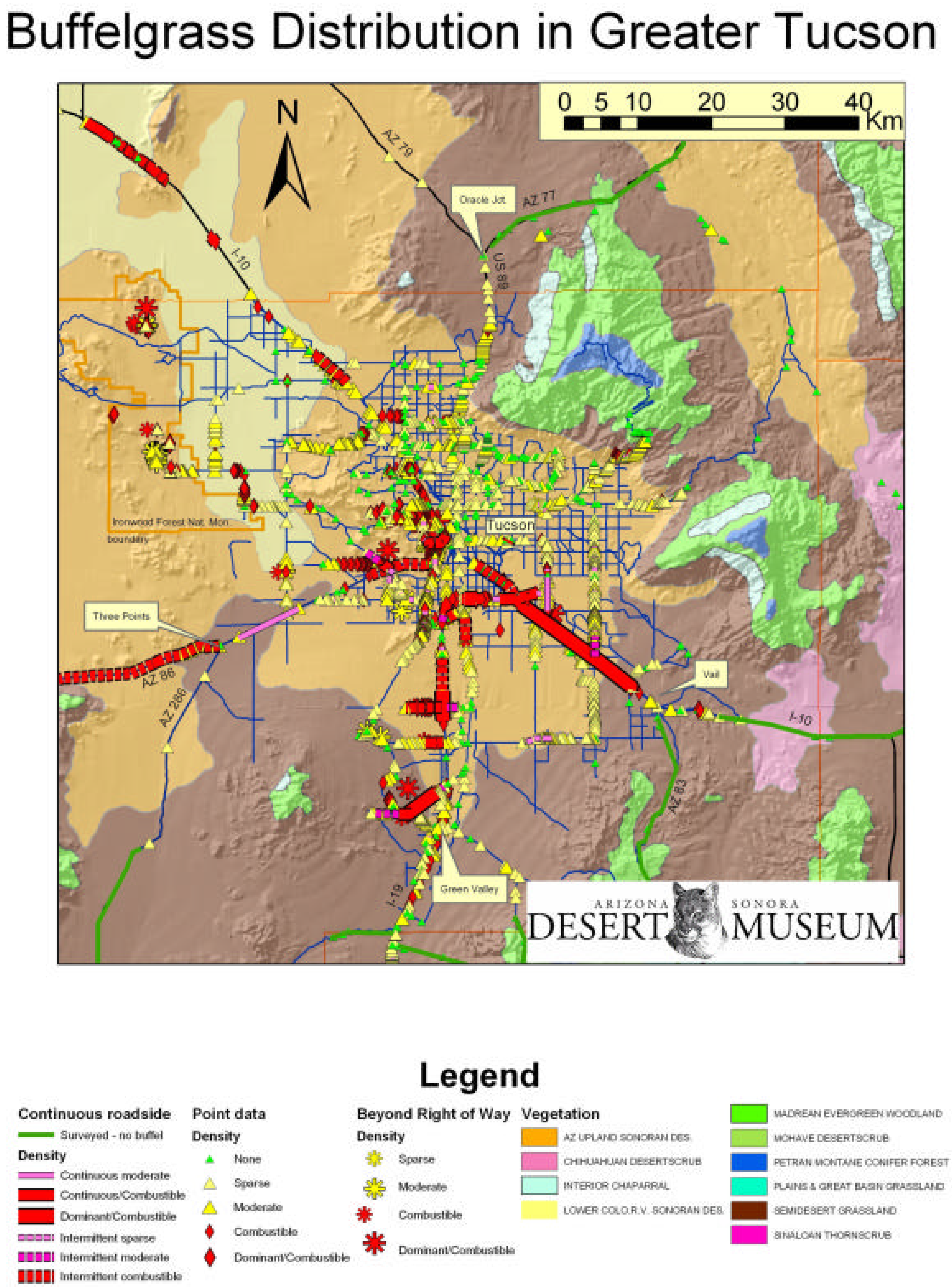

Figure 4. Map of the distribution of buffelgrass in the Tucson area.

Buffelgrass was absent from several likely areas in Arizona Upland including along US 93 from Phoenix northwest to Wickenburg in Yavapai County. Except for one small population 2.1 km south of San Manuel at 993 m elevation, it was not found in the San Pedro River Valley along the river road from Benson north to Winkelman. However, it is moving southward from Superior along AZ 177 into the Kearney area north of Winkelman. It was not seen from Winkelman to Globe along AZ 77 or from Globe to Safford even though lower areas along the Gila River near Winkelman and Bylas appear to be suitable habitat.

Buffelgrass is also spreading along major highways into lower, hotter, drier areas in the Lower Colorado River Valley subdivision of the Sonoran Desert. Along I-8, it gradually becomes less common from Gila Bend westward until it is occasional in the Yuma area including an observation across the Colorado River in Imperial County, California. The Sentinel Plain is an outstanding exception in the Lower Colorado River Valley where buffelgrass is common on the basalt lava flows. Buffelgrass is abundant along Interstate 10 west of Phoenix, decreases in abundance from the Buckeye Road (AZ 85) exit to Tonopah, but is sporadically present all the way to the California state line. We did not find any significant buffelgrass populations away from highway right-of-ways in the Lower Colorado River Valley, likely reflecting the aridity.

In Sonora, buffelgrass forms dense swaths that burn regularly along MEX 15 from Imuris to Santa Ana south through Sonora and into Sinaloa (Figure 2). Similar stands occur throughout the Arizona Upland areas in northern Sonora. Specifically, dense buffelgrass is along MEX 15 from Imuris south to Santa Ana and west along MEX 2 to Caborca, northwest to Sonoyta and westward along the Arizona border just south of Organ Pipe Cactus National Monument. Farther west it is less common, but has been found in the sands of the Gran Desierto (= Lower Colorado River Valley) east of San Luis Río Colorado. Northeast of Imuris along MEX 2, buffelgrass is locally dense in Arizona Upland. It drops out at the desert grassland transition as elevations rise, but reappears locally in a valley (11 km west-southwest of Cuitaca) to northeast. It is absent from the higher grassland and oak woodlands in the Cananea area. Surprisingly, buffelgrass is locally common and relatively continuous along MEX 2 in desert grassland and Chihuahuan desertscrub at 1125-1345 m (or higher) elevation from Agua Prieta area east to the Chihuahua border. North of Imuris, buffelgrass is along MEX 15 in desert grassland well north of Arizona Upland. There is a gap in buffelgrass distribution from just south of Nogales to the I-19 populations near Amado.

Discussion of Distribution Pattern

The present distribution of buffelgrass suggests that it is still expanding its range in many areas, including the Arizona Upland. It can potentially expand into Arizona Upland northwest of Phoenix, the San Pedro River Valley north of Benson, and local areas along the Gila River from Winkelman to Safford. Arizona Upland appears to be the primary area where it can move from roadsides into nearby natural vegetation. Buffelgrass is expanding its range along the major freeways westward into the lowlands of the Lower Colorado River Valley in La Paz and Yuma counties, and adjacent California. It also appears to be expanding its range into higher colder areas in desert grassland in Cochise, Pima, and Santa Cruz counties, Arizona, and the Municipios de Agua Prieta and Altar, Sonora. It has spread northward toward Nogales in the desert grassland/oak woodland ecotone within 15 kilometers of the Arizona border. A few plants were found in desert grassland in a canyon away from a road just south of Sásabe, immediately south of the Altar Valley in Arizona. Buffelgrass may not be invasive in natural habitats in Lower Colorado River Valley or desert grassland.

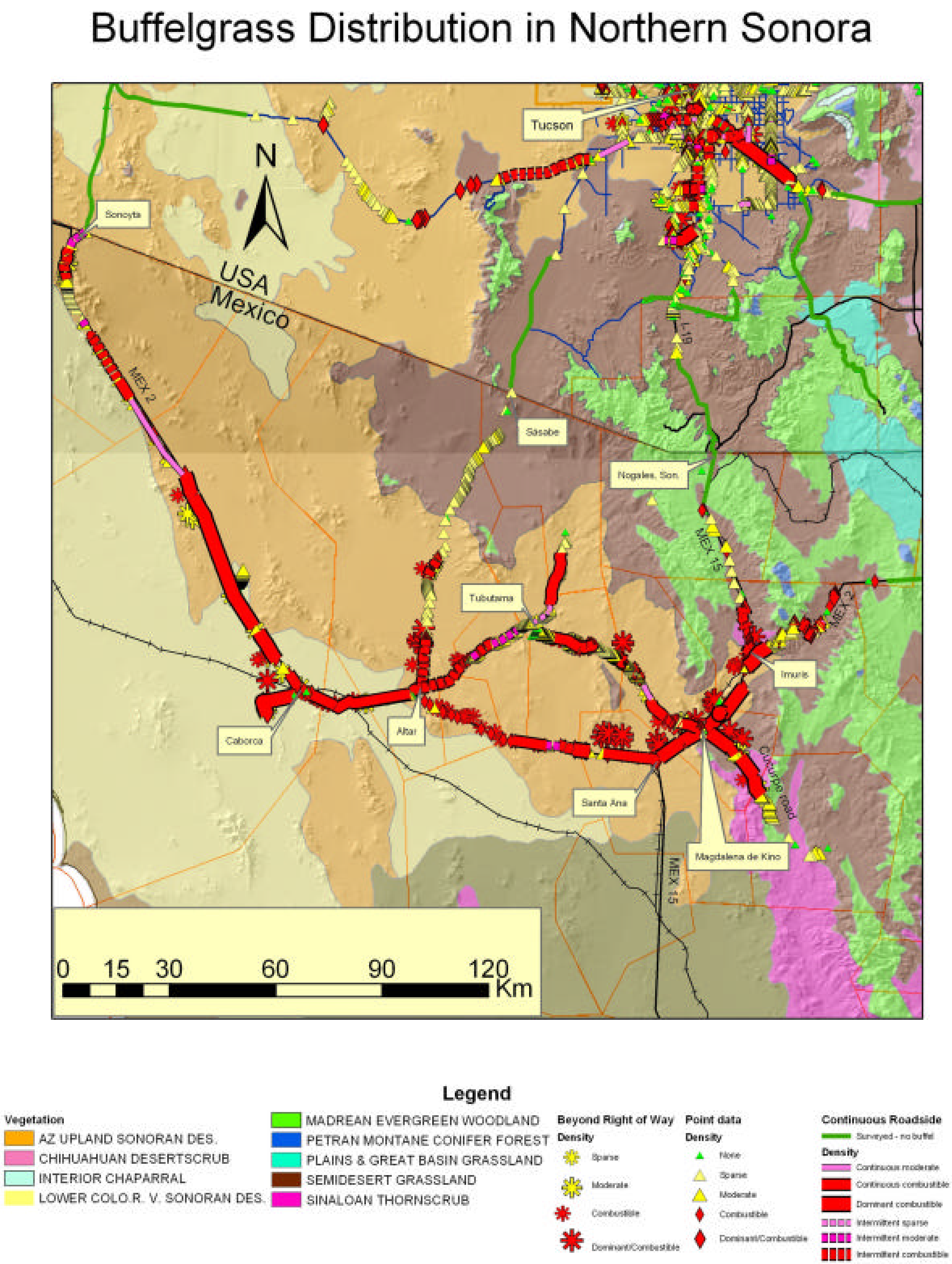

Figure 5. Map of the distribution of buffelgrass in the Arizona Upland portions of northern Sonora and adjacent Arizona.

Buffelgrass has not crossed the Arizona-Sonora border in many places, likely because much of it is at higher elevations in desert grassland or oak woodland. The only area where buffelgrass has significantly crossed the border is from the dense MEX 2 populations into Organ Pipe Cactus National Monument. Resource Manager Sue Rutman and her volunteers have successfully removed it from along AZ 85 and most other areas in the Monument, but need to keep vigilant for new infestations each year. Interestingly, the Organ Pipe buffelgrass population apparently was not continuous with Phoenix or Tucson populations as there are gaps in its distribution along AZ 85 to Gila Bend and AZ 86 on the Tohono O'odham Indian Nation to the east. It is possible that the Sonoran-Organ Pipe Cactus and Tucson-Phoenix buffelgrass populations came from different founder plantings. It is not clear whether the buffelgrass near Sásabe, Sonora are pioneers from the Arizona Upland to the south or from the rare plants in desert grassland along AZ 286 in the Altar Valley to the north. The local population west of Douglas, Arizona, probably is an expansion of the MEX 2 population along MEX 2 in the Agua Prieta from just across the border.

Geological, Geomorphological, and Biological Characteristics of Buffelgrass Sites in Arizona Upland.

Geology.

Robert Scarborough, a geologist under subcontract, described the basic texture and structure, color, horizonation, presence and character of caliche layer, and root descriptions will taken on the soils at selected sites in a characterization of the habitats that have been invaded by

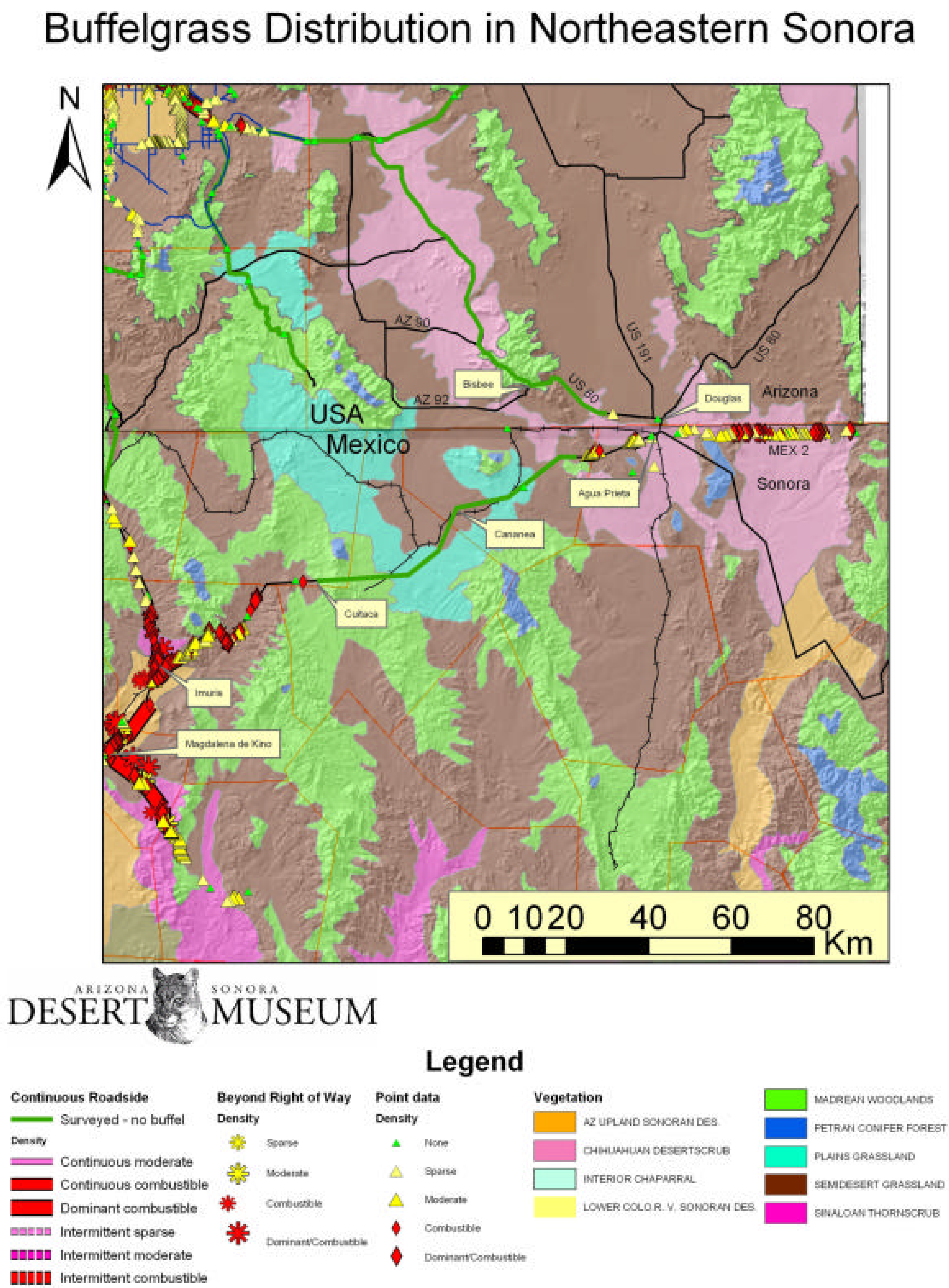

Figure 6. Map of the distribution of buffelgrass in northeastern Sonora and adjacent Cochise County, Arizona.

buffelgrass from geological and geomorphological viewpoints. His report entitled 'Geomorphic-Soils Analysis of Arizona Upland Buffelgrass Sites' was received on July 9, 2005 (Appendix 1).

He visited a total of 22 buffelgrass areas (seven in Sonora, 15 in Arizona), 11 of them ASDM buffelgrass transect sites.

Buffelgrass occurrences are clearly very limited to a few well-defined geomorphic settings, but do not relate in any simple way with standard soil types. Buffelgrass occurs on soils derived from various rock types including volcanic (rhyolite and basaltic), gneissic (= granite), and limestone, where details of soil chemistry and mineralogy vary greatly. It is most common on 1) disturbed rights-of-way, especially on larger highways, especially along larger paved roads that have been repeatedly bladed, 2) undisturbed steep south, southeast, and southwest slope aspects of hills with very poorly developed soils and caliche near the surface, 3) shallowly-incised drainages on hillsides with steep south slope hillsides, and 4) along the upper portions of shallow arroyos in valley flats. In some areas in Sonora, heavy cattle grazing effectively controls buffelgrass, limiting its impact in Arizona Upland desertscrub.

Established populations often invade nearby disturbed areas. In several spots, buffelgrass distribution on hill slopes was correlated very tightly with certain geomorphic conditions and certain slope angles (14-19 degrees) with relict clayey soil. Younger plants are frequently scattered beyond the thicket on similar slope aspects, clearly a result of short-range dispersal. But it was lacking on nearby slopes with slightly different conditions of percent rock cover, greater depth to hard-packed caliche, and slope angle. Buffelgrass is less common on gently sloping bajadas, where it tends to clump in the shade of trees, larger shrubs, or prickly pear cactus. At only one site in Sonora we encountered a concentration of buffelgrass on the very top of a hill.

In short, hillside concentrations of buffelgrass throughout the region are predominantly found on steeper south, southeast, and southwest slope aspects of hills. Exceptions in Ironwood Forest National Monument were buffelgrass patches on an east slope in the Samaniego Hills and on an east-northeast slope in the Sawtooth Mountains. It is important to point out that buffelgrass apparently has a fairly well defined ecological distribution in the Arizona Upland Sonoran Desert, and may not expand into as many areas as feared. Unfortunately, Arizona Upland paloverde-saguaro desertscrub is best developed on the southerly slopes preferred by buffelgrass. Considering that to the south in central Sonora buffelgrass grows on all slopes, global warming, and milder winter temperatures may well allow buffelgrass to move into other microhabitats in the Sonoran Desert in Arizona as well.

Impacts on Natural Vegetation.

The impacts of buffelgrass on the flora and vegetation in Arizona Upland Sonoran Desert habitats in southern Arizona and northern Sonora were evaluated quantitatively through paired transects in buffelgrass patches and adjacent natural vegetation in the same habitat. Density and cover of plants were studied by measuring crown diameters of all perennial plants on linear belt transects (2 x 40 m = 80 m^2). Plots were located in habitats away from roads in sites visited during road inventories or previous field work in Ironwood Forest National Monument, and reflect various habitat and soil types being invaded by buffelgrass in the Arizona Upland. Such off road buffelgrass invasions were found in surprisingly few areas, and very few of them appeared to have burned. At each transect digital images were taken and the general vegetation in the area was described quantitatively using a relevé (relative abundances of all perennials, presence of annuals). In Arizona, transects were located in Ironwood Forest National Monument (Cerrito El Represo, Pan Quemado, Sanmaniego Hills, Sawtooth Mountains), Helmet Peak, and Tucson Mountain Park (Brown Mountain, Gates Pass), and areas in Sonora near Caborca, Imuris, and Magdalena (Table 1). Botanists from the Arizona-Sonora Desert Museum (7), the Arizona Department of Transportation (1), and the University of Arizona Desert Laboratory (1) spent 48 man-days on 24 transects (11 on BLM land, 11 buffelgrass-control pairs). A summary of the results is presented in Table 2.

A total of 92 species of perennial plants were found on the transects. The number of species per transect ranged from 2 to 27, with 2 to 26 (av. 13.1) on buffelgrass transects and 6 to 27 (av. 17.8) on control transects. Comparison of the buffelgrass and control transects in each paired showed a 20.0 to 66.7% (av. 35.3%) reduction in the species diversity on ten of the buffelgrass transects. A transect in Gates Pass in the Tucson Mountains actually had six more species on the buffelgrass transect. This was probably because the small new linear buffelgrass patch was restricted to a small cliff base while the control transect was just below on an open slope in lower diversity desertscrub.

Number of individuals on the 80 m^2 transects (= density) ranged from 177 to 1087 (av. 393) on the buffelgrass transects and 43 to 860 (av. 294) on the control transect. For eight transect pairs, the buffelgrass transects had 102 to 660% (av. 250.3%) more individual plants, almost all buffelgrass itself. On the three control transects with more individual plants, ferns (*Astrolepis cochisensis*, *Notholaena standleyi*) and brittlebush (*Encelia farinosa,* mostly seedlings) were abundant.

The area covered by plants on each transect was estimated by measuring the crown diameters of each plant and converting them to circular areas. This provides a gross area that exaggerates the actual cover because it does not deal with overlapping and irregular crowns. Total area can be greater than the 80 m^2 total sample area even though some areas were bare ground not covered by plants. The area covered ranged from 9.2 to 125.1 m^2, with 26.1 to 125.1 for buffelgrass transects and 9.2 to 100.9 m^2. The area of buffelgrass on transects was 4.5 to 87.2 m^2 (av. 33.8 m^2) on buffelgrass transects and none to 4.5 m^2 (av. 0.9 m^2) on control transects. It proved to be difficult to locate control transects in the same microhabitats without encountering a few buffelgrass, suggesting that it was actively dispersing away from established patches in most areas.

The impacts on the native species by buffelgrass are dramatic, and not all of them are obvious to observers (Table 3). The only transect that had been burned was B4 on the limestone hill west of Caborca, which may account for an reduction of 63.2% in individuals and a 42.1% in cover of teddybear cholla (*Cylindropuntia bigelovii*) compared to nearby C5. All other reductions in native plants indicated in the paired transects were likely the result of competition for moisture and with buffelgrass. Brittlebush (*Encelia farinosa*) is a soft shrub with brittle stems that appears to be very vulnerable to buffelgrass, especially as seedlings. Reductions of from 37.5 to 98.6% in numbers and 72.2 to 98.7% in cover were observed on four transects. Reductions of 57.1 and 87.0% in numbers and 86.3 to 90.9% for the subshrub/shrub Indian mallow (*Abutilon incanum*) on two transects. On Pan Quemado in Ironwood Forest National Monument, buckhorn cholla (*Cylindropuntia acanthocarpa*) only declined from three to two individual on the buffelgrass transect, but the plants were smaller with a 90.7% reduction in area. For a large group of perennial herbs including ferns (*Astrolepis cochisensis* [200 to 9 individuals], *Notholaena lemmonii* [81 to 26], and *N. standleyi* [388 to 77]), desert vine (*Janusia gracilis*), and others (*Evolvulus alsinoides* [133 to 20 individuals], *Herissantia crispa* [62 to 9, 18 to 1], and *Marina parryi* [149 to 35]) reductions on buffelgrass were huge. In most transects, native perennial grasses were not common. However in the Gates Pass transect in the Tucson Mountains, spidergrass (*Aristida ternipes*) declined from 96 to 19 individuals on the buffelgrass transect. Assessing the impact of buffelgrass on native annual species was not part of this study, but considering its strong negative impact on brittlebush seedlings and short-lived perennial herbs, annuals would surely be inhibited. Previous work on Tumamoc Hill demonstrated that even larger trees and shrubs such as foothill paloverde can be impacted by competition with buffelgrass. We conclude that great harm is done to native plants and natural vegetation through competition with buffelgrass before catastrophic fire ever takes place.

Dissemination of results.

Preliminary digital GIS maps of the distribution of buffelgrass in the Arizona Upland in Arizona and Sonora, in Arizona, and in Pima County were provided to various agencies and groups for use in conservation planning. John Regan, the GIS Coordinator for Pima County, incorporated the map into Pima County's Sonoran Desert Conservation Plan GIS system. The map was also provided to Travis Bean at the Desert Laboratory, University of Arizona, to use in his publicity activities associated with buffelgrass control on Tumamoc Hill and in Pima County, and the formation of the new Pima Cooperative Weed Management Area. In Mexico, copies of the Sonoran portion of the GIS map of buffelgrass distribution were provided to Francisco Molina at the Universidad Autónoma de México in Hermosillo, and Laura Arriaga at the Centro de Investigaciones Biológicas del Noroeste in La Paz, Baja California Sur. The northeastern Sonoran portion of the map was provided to Joe and Valer Austin to help them manage their ranches east of Agua Prieta, Sonora.

Presentations on the threat of buffelgrass in the Sonoran Desert were given to the Desert Tortoise Council Meeting and the Advance Docent Class at the Museum in February. Members of the Sonoran Desert Weedwackers volunteer group provided observations and locality information on buffelgrass in the Tucson Mountains (Figure 7). The maps and project images were incorporated into training materials for the Arizona-Sonora Desert Museum's INVADERS of the Sonoran Desert Region volunteer program, including their internet material on the Arizona-Sonora Desert Museum website (www.desertmuseum.org). The buffelgrass distribution maps were provided to several newspaper reporters and science writers for various articles.

Copies of this final report will be provided to the various land managers and environmental organizations in the Arizona Upland including the Bureau of Land Management, Saguaro National Park, Organ Pipe Cactus National Monument, Coronado National Forest, the U.S. Fish and Wildlife Service, Tucson Mountain Park, Pima County, the Biosphere Reserve, the Arizona State Parks Department, and the Arizona Department of Transportation, University of Arizona Herbarium, Herbario de la Universidad de Sonora, The Nature Conservancy, etc.

Results and Discussion.

In summary, buffelgrass in southern Arizona and northern Sonora is mostly found along roadsides, especially large highways that have been repeatedly graded. Roadside populations seem to be the seed sources for populations that establish in natural habitats away from the roads, most often on steep rocky slopes with southerly exposures. Unfortunately this is the very habitat where Arizona Upland paloverde-saguaro communities are best developed. On slopes buffelgrass is dispersing out of patches into nearby natural vegetation. Buffelgrass is less common on gentler lower slopes and most other slope exposure. It grows on soils derived from various volcanic igneous and calcareous bedrocks, may be absent from heavy clay soils near playas.

Buffelgrass is most common along highways in the Arizona Upland areas in Arizona and Sonora. From this center, buffelgrass is expanding into lower, hotter, drier desertscrub in the Lower Colorado River Valley to the west, and into higher, colder, wetter desert grassland to the east. Populations in desert grassland/oak woodland in the Santa Catalina Mountains above Tucson and in desert grassland and Chihuahuan desertscrub east of Agua Prieta, Sonora are growing up to 1350 meters elevation. Off road buffelgrass infestations were found in relatively few areas, all in the Arizona Upland. Buffelgrass may be less of a threat to natural vegetation in the Lower Colorado Valley or in desert grassland. We found very little evidence of buffelgrass burning in natural vegetation in Arizona. In Sonora where roadside buffelgrass is typically much denser than in Arizona, roadsides burn intensely and often. Away from roads heavy cattle grazing reduces the potential for desert fires and competition with buffelgrass for water, but impacts the vegetation at the same time.

The belt transects comparing off road buffel patches with adjacent natural vegetation demonstrated dramatic impacts species diversity, numbers of individuals, and vegetation composition and structure in Arizona Upland Sonoran desertscrub (Table 3). In most cases the number of species on buffelgrass transects were significantly reduced. On the buffelgrass plots, the numbers of individual plants were often greater, but the increase was just in buffelgrass. Both the numbers and the coverage area of locally common or abundant shrubs (brittlebush, Indian mallow, etc), a desert grass (spider grass), and many perennial herbs (ferns, desert blue-eyes, Herissantia, etc.) were drastically reduced, or they were extirpated, on buffelgrass transects.

Land managers should be aware that first serious impact of buffelgrass on native vegetation is through intense competition for water and nutrients. In buffelgrass pastures worldwide, the population looses vigor after 12-15 years, leaving nutrient poor soils. If any buffelgrass population in natural habitat burns, the damage will be even more serious as Sonoran Desert plants with no adaptations to fire are killed. Considering the results of our study, we make the following recommendations:

1. Set priorities for the most important areas to protect. Some of the best examples of Arizona Upland paloverde-saguaro desertscrub are already in established protected areas including Saguaro National Park, Organ Pipe National Monument, Ironwood Forest National Monument, and Tucson Mountain Park.
2. Remove buffelgrass from roadsides because this is the primary source of seed for dispersal into natural vegetation. This can be through manual pulling as demonstrated by successful control efforts by Sue Rutman in Organ Pipe and by the Sonoran Desert Weedwackers in Tucson Mountain Park. Extensive buffelgrass stands along major roadsides will need to be controlled by the use of herbicides sprayed from trucks. After buffelgrass was listed as a noxious weed by the State of Arizona in August 2005, glyphosate (RoundUp) spraying by the Arizona Department of Transportation very successfully impacted large areas of roadside buffelgrass (Charles Barclay, pers. com.).
3. Aggressive control programs in off road populations need to be begun as soon as possible, using all possible manual and chemical methods. Manual pulling programs need to involve citizen volunteer groups such as the Weedwackers and INVADERS groups to minimize costs and involve the public in protecting valuable natural resources. Gyphosate can be applied from backpack sprayers to minimize soil loss and damage to archeological resources on steep slopes. Controlled areas should be monitored for several years to be sure the plants are dead and to kill seedlings.
4. There needs to be cooperation between agencies and organizations not to duplicate efforts or inhibit control efforts by neighboring land owners.
5. There needs to be more cooperative efforts to begin buffelgrass control efforts in Sonora in culturally sensitive ways. Buffelgrass is an integral part of the cattle industry in Sonora, and is unlikely to be controlled statewide, or viewed as a noxious weed. It is possible and desirable to begin control programs in high priority Arizona Upland areas. One unique area is a very dense paloverde-saguaro-organpipe stand along the toll bypass on MEX 15 around Magdalena. Such efforts should begin with the new Asociación para Plantas Nativas de Sonora, the Universidad de Sonora-Santa Ana campus, etc. Buffelgrass should be controlled at prehistoric pictographs on the basalt rocks near Caborca because buffelgrass burns at such a high temperature that the weathering surfaces on rocks could exfoliate.
6. Education. There has been a rapid increase in environmental education about invasive species in Arizona, especially in the Tucson area, in recent years. Public education programs by the University of Arizona, the Weedwackers, the Arizona Native Plant Society, the INVADERS program, etc. These programs should be continued and expanded until the threats to natural vegetation and wildlife are common knowledge to all, and citizens will control weeds in their own neighborhoods. Fire departments need to be trained to recognize non-native grasses and correctly report wildfires --- not just as ‘brush fires’ or blaming native wildflowers in wet springs.

Figure 7. Sonoran Desert Weedwacker volunteers manually removing buffelgrass in the Tucson Mountain Park. Photo by Marilyn Hanson.

Table 1. Locations of buffelgrass (B)/control (C) paired belt transects in Arizona Upland vegetation transects for the NPCI buffelgrass project. BLM - Bureau of Land Management, IFNM - Ironwood Forest National Monument, PC – Pima County, PV = private, TMP - Tucson Mountain Park, UA = University of Arizona

Transect	Location	County/Municipio	Owner	Habitat	Slope	Elev. (m)
Sonora						
B3	west of Magdalena	Magdalena de Kino	PV	granitic, rocky slope	SW	873
C2	west of Magdalena	Magdalena de Kino	PV	granitic, rocky slope	SW	865
B4	west of Caborca	Caborca	PV	limestone slope, heavy caliche	SW	296
C5	west of Caborca	Caborca	PV	limestone slope, heavy caliche	SW	294
Arizona						
B7	Samaniego Hills	Pima	BLM-IFNM	steep, volcanic boulder slope	E	670
C6	Samaniego Hills	Pima	BLM-IFNM	steep, volcanic boulder slope	E	651
B9	Cerrito El Represo	Pima	PV-IFNM	rocky hill	SW	718
C10	Cerrito El Represo	Pima	PV	rocky hill	SW	707
B11	Helmet Peak	Pima	UA	very steep limestone slope	S	1140
C12	Helmet Peak	Pima	UA	very steep limestone slope	S	1119
B13	Brown Mt.	Pima	PC-TMP	rocky rhyolitic slope	SW	862
C14	Brown Mt.	Pima	PC-TMP	rocky rhyolitic slope	SW	861
B15	Pan Quemado	Pima	BLM-IFNM	base of rocky volcanic hill	S	672
C16	Pan Quemado	Pima	BLM-IFNM	base of rocky volcanic hill	S	681
B17	Sawtooth Mts.	Pinal	BLM-IFNM	steep slope, rhyolite conglomerate	S	649
C18	Sawtooth Mts.	Pinal	BLM-IFNM	steep slope, rhyolite conglomerate	S	632
B19	Sawtooth Mts.	Pinal	BLM-IFNM	steep slope, rhyolite conglomerate	ENE	539
C20	Sawtooth Mts.	Pinal	BLM-IFNM	steep slope, rhyolite conglomerate	ENE	542
B21	Gates Pass	Pima	PC-TMP	steep rocky slope	S	895
C22	Gates Pass	Pima	BLM-IFNM	steep rocky slope	S	894
B23	Pan Quemado	Pima	BLM-IFNM	rocky volcanic hill	S	726
C24	Pan Quemado	Pima	BLM-IFNM	rocky volcanic hill	S	728

Table 2. Data from paired buffelgrass/control belt transects. A = area in m^2, B = buffelgrass, C = control, D = plant diameters (cm), P = individual plants, T = taxa

Transect	#T	%TB/TC	#P	%#PB/#PC	#PB	AP	%APB/APC	AB	%AB/TotA
B3	18	66.7	373	102	363	79.8	79.1	31.3	39.1
C2	27		368		8	100.9		1.1	1.4
B4	7	63.6	320	219	294	98.3	162.7	51.2	64.1
C5	11		146		75	60.4		3	3.8
B7	2	33.3	277	-35	200	29.4	319.6	29	36.3
C6	6		402		1	9.2		1	1.3
B9	13	72.2	177	147	110	40.3	81.3	4.5	5.6
C10	18		124		1	49.6		0.1	0.1
B11	13	56.5	260	-36	197	27.7	48.9	23.4	29.3
C12	23		407		1	56.7		0.02	0.02
B13	16	80	519	212	394	59.9	137.7	41	51.3
C14	20		236		8	43.5		0.6	0.7
B15	15	60	266	155	222	42.7	83.6	29.3	36.7
C16	25		185		3	51.1		0.005	0.006
B17	10	76.9	473	-43	402	125.1	213.8	87.2	109
C18	13		860		50	58.5		4.5	5.6
B19	7	70	285	663	273	111?	346?	?	?
C20	10		43		1	32.1		0.004	0.005
B21	26	144.4	286	140	103	26.1	219.3	5	6.3
C22	18		191		0	11.9		0	0
B23	17	68	1087	367	1002	28	69.7	15.4	19.3
C24	25		269		20	40.2		0.04	0.5
		av. 71.9				av. 49.2			

Table 3. Major changes in number of individual/cover area (m^2) in buffelgrass/control transect pairs. Growth forms: GP - perennial grass, HP - perennial herb, HPF - herbaceous perennial fern, HS - subshrub, SS - stem succulent cacti, WS - woody shrub, WV - woody vine. Species codes: ABIN - *Abutilon incanum*, ARTE - *Aristida ternipes*, ASCO - *Astrolepis cochisensis*, CYAC - *Cylindropuntia acanthocarpa*, CYBI - *C. bigelovii*, DILA - *Ditaxis lanceolata*, ENCA - *Encelia farinosa*, EVAL - *Evolvulus alsinoides*, HECR - *Herissantia crispa*, HIDE - *Hibiscus denudatus*, JAGR - *Janusia gracilis*, MAPA = *Marina parryi*, NOLE - *Notholaena lemmoni*, NOST - *N. standleyi*.

	ABIN	ENCA	HIDE	CYAC	CYBI	JAGR	DILA	EVAL	HECR	MAPA	ASCO	NOLE	NOST	ARTE
Life Form	WS	WS	HS	SS	SS	WV	HP	HP	HP	HP	HPF	HPF	HPF	GP
Transect														
B3								20/0.2				26/0.2		
C2								133/1.5				81/1.05		
B4			3/0.8		7/3.3									
C5			20/2.6		19/5.7									
B7													77/0.3	
C6													388/1.8	
B9	9/0.1					2/0.3								
C10	21/1.1					9/1.9								
B11		10/1.5				0			9/0.3		9/0.08			
C12		16/5.4				43/8.3			62/1.6		200/3.5			
B13		1/0.04												
C14		70/3.0												
B15	9/1.0			2/0.7										
C16	69/7.3			3/7.5										
B17		35/2.7			2/1.3									
C18		770/13.2			18/4.5									
B19							1/0.001							
C20							5/1.3							
B21						17/?			1/?					19/?
C22						22/1.4			18/0.2					96/0.4
B23		9/1.5								35/0.5				
C24		32/7.9								149/0.2				

Appendix 1. Report Submitted to Arizona-Sonora Desert Museum
July 9, 2005 (Edited by Mark Dimmitt and Tom Van Devender)

GEOMORPHIC-SOILS ANALYSIS OF ARIZONA UPLAND SONORAN DESERT BUFFELGRASS SITES

Robert Scarborough, consulting geologist

In conjunction with the "Conservation of Arizona Upland Sonoran Desert Habitat. Status and Threats of Buffelgrass (*Pennisetum ciliare*) in Arizona and Sonora" project, I observed landform and soil situations in buffelgrass invaded areas in the Arizona Upland subdivision of the Sonoran Desert. On joint trips with Mark Dimmitt and Tom Van Devender of Arizona-Sonora Desert Museum, soils-geomorphic observations were made in the same areas where vegetation transects were done. Seven sites in the Magdalena-Caborca area in northern Sonora, Mexico were visited on December 7-10, 2004, and fifteen sites in Pima County, Arizona between January and late May 2005 (Appendix 1). Simple geomorphic cross-sections were drawn to graphically depict the location of buffelgrass populations and soils were described.

BUFFELGRASS IN DIFFERENT GEOMORPHOLOGIC SETTINGS

Populations in Valley Flats derived from Hillside Populations. In several instances detailed searches were made down slope of dense buffelgrass patches on rocky hillsides. Although seeds are surely scattered down slope and concentrated into rills or arroyos by subsequent rain runoffs, down slope recruitment is usually very spotty to non-existent. In one place in Ironwood Forest National Monument (IFNM; Site A4), buffelgrass is thinly scattered along a micro-terrace about 1 m above the channel bottom of an arroyo down slope of a dense hillside patch which seems to be an older population. The grass is absent in the bottom of the arroyo (almost 2 m deep), and on the adjacent floodplain. Another nearby arroyo is also devoid of buffelgrass, even though there is at least one small patch high in its drainage several hundred meters upslope. The only easy way the seeds got to those sites was to be carried down from the hillside during a flash flood that put a meter depth of water in the arroyo and depositing the seeds on the tiny terrace edge. Then the seeds sprouted while the soil was still moist before being moved again. If another agent like whirlwinds were responsible for the grass here, the distribution pattern would be much more stochastic.

A rare infestation of buffelgrass in undisturbed (by humans) flats occurs along an arroyo west of the Pan Quemado Mountains (IFNM). The grass is narrowly confined to arroyo edges, and is not present elsewhere on the very shallow floodplain more than 2 meters away from the arroyo edge, or on slightly elevated adjacent bajada surfaces covered by monotypic stands of creosotebush (*Larrea divaricata*). The floodplain is about 20 m wide, and the floodplain depressed only about 0.5 m or less below the adjacent bajada or valley flats.

In this same area an anomalous buffelgrass stand exists at the very base of a south-facing volcanic hillslope (Site A14). It is confined to a lowermost debris cone with only 10-15 degree sloping surface. The steeper rhyolite volcanic hill slopes above have some soil cover and only tanglehead (*Heteropogon contortus*) and slender grama (*Bouteloua repens*) grass stands among colonies of teddy bear cholla (*Cylindropuntia bigelovii*). The buffelgrass grows in a very rocky loam soil with no hard caliche substrate in the upper 30 cm. The stand is confined to just below the lowest rock outcrop on a small debris cone, and only a few buffelgrass plants are found in an adjacent shallow drainage. No buffelgrass is growing down slope of the stand on the more gently sloping bajada surface, nor in a 50 m-wide floodplain or along the banks of an arroyo, all down slope of the dense stand.

In a spot in the central Sawtooth Mountains (Site A9), the steep soil-covered talus beneath a tall east-west trending and south-facing cliff of rhyolite supports a sizable buffelgrass stand for several hundred meters along the cliff base, extending down slope from the base of the cliff for perhaps 20 meters. A sizable arroyo lines the canyon another 50 meters down slope, but the lower slope and arroyo, and north-facing slopes across the canyon are devoid of buffelgrass. A rough, seldom-used jeep trail traverses the valley. Buffelgrass has failed to establish there. The greatest concentration of buffelgrass plants on the soil-covered talus slope is on a horizontal elevated lip of finer aeolian-derived silty soil 2 meters out from the cliff base which has built up apparently by sediment falling from the cliff top above, and producing a better sorted fine-textured, water-retentive soil. Across the canyon to the south, the equivalent cliff that faces north has similar geomorphology, yet totally lacks buffelgrass. The grass is restricted to only the steep south-facing slopes in this locality.

Buffelgrass is spreading across Tumamoc Hill and "A" Mountain near downtown Tucson (Travis Bean, pers. com., 2005). Experimental eradication is under way on Tumamoc Hill according to Jan Bowers (pers. comm. 2005). The floodplain of the Santa Cruz River laps up to the base of the east side of 'A' Mountain, upon which hillside buffelgrass clumps are established. There have been several recent fires on this hillside, caused by Fourth of July fireworks shows staged on the summit. Buffelgrass is establishing on the adjacent Santa Cruz floodplain in a strip hundreds of meters wide, basically to the edge of the Santa Cruz channel in this area. The plants are not concentrated under mesquite trees, but rather out in the open, and tending to concentrate in low disturbed swales and man-made drainages. The presumed seed source is the hillside to the west. But buffelgrass is also growing along embankments of roadcuts along Mission road south of there for some distance, in urbanized areas.

Flats adjacent to Hillslope Populations. An interesting case of lack of recruitment of buffelgrass is seen along Mexican highway 15 between Magdalena de Kino and Imuris in Sonora (Site S1), where thick buffelgrass lines the steep (25°) highway fill slopes, having been spray-planted to arrest erosion on the steep slopes. The highway is divided, with about 50 m of undisturbed flat desert and vegetation between the lanes. And a new resultant arroyo drains along this median parallel to the lanes. Both hillsides facing the median are covered with thick buffelgrass, yet there is virtually no recruitment on the median flats (with sparse mesquite cover), except a few sparse groups along the arroyo embankments, just as in the last example. The flats must be covered with seeds, and there has been no recruitment for many years on the flats. Yet on the outside road right-of-ways, along a hillslope above a roadcut west of the southbound lanes there are drainage ditches cut to channel hillside runoff, within which are growing thickets of buffelgrass. So the buffelgrass is moving upslope to the west, but not down slope to the east, just counter to expectations.

At a place northeast of Imuris along Mexican Highway 2 towards Cananea, the highway rises to the east along a gently sloping bajada surface. The modern wide floodplain of a sizable west-flowing stream is down cut about 10 meters below the bajada which now sits as a terrace, and a second inset terrace is present as well. The higher terrace crest is the site of an ASDM plant transect and Site S2, in Arizona Upland vegetation. Buffelgrass is quite common along the right-of-way of Mexico Federal Highway 2. But beyond the fence, buffelgrass is generally sparse on the gentle 2-3 degree sloping bajada surface, mostly under paloverde trees. A denser buffelgrass stand was along the break in slope at the crest of the scarp where the desertscrub was denser. On the floodplain below buffelgrass was rare or absent even though there is a seed source lining the scarp crest 100m away. The native plains bristlegrass (*Setaria macrostachya*) was more common in this area. Just across the highway to the north, buffelgrass was establishing in some bulldozer-disturbed areas.

The common, almost universal situation along highway rights-of-way is fairly thick buffelgrass stands in the disturbed ground of the right-of-ways, and absolutely no grass on the other side of the fence lines that parallel the highways. Within the right-of-way, it is common to see grasses lined up along where a flat disturbed surface abuts against a plowed furrow ridge, as though the seeds were washed there during rains. This condition is widely noted along both Sonora and Arizona highways. In many cases buffelgrass plants occur beyond the fence lines, which have been grazed heavily by cattle. Perhaps heavy grazing on the flats restricts buffelgrass to the fenced-in highway properties.

Buffelgrass on Hill Slopes in Arizona. An interesting "classic" thick hillside buffelgrass population is found on Cerrito El Represo within IFNM (Site A5), near the manmade study site noted above. A thick population with very heavy spring 2005 recruitment (many seedlings) was found on the south, southeast, and southwest flank of the hill, but extending only on the higher slopes, beginning at slope angle of 10 degrees and extending upwards to the base of low rocky outcrops and low cliffs near the hilltop. Buffelgrass is found on hill slopes facing due west, all across the south slope, and to nearly due east. The hillslope is covered by poorly sorted colluvium (very rocky loam soil material which moves down slope by slow "creep"). Below the 10 degree slope angle there is no grass, and there is only one small spot of recruitment out in the valley flats adjacent to the hill, found along the flanks of arroyos where occasional flooding likely carried seeds. On this hillside is seen a good example of a subtle soil control over buffelgrass distribution. The hill was formerly mantled with a thicker soil cover, probably a thicker clayey B-horizon and a 10 cm-thick hardpan caliche during wetter Pleistocene times. More recent storms have stripped away much of the soil and piled it up as coalescing debris cones all along the hill's base, while exposing the hard and resistant caliche layer on the upper slopes. The lower debris cones lack significant soil cover or a hard caliche layer. The top end of the cones happens to coincide with the 10-degree side slope angle, and this is at the bottom edge of the buffelgrass distribution. Perhaps buffelgrass recruitment has occurred where shallow caliche impounds soil moisture in the thin soil above the caliche, permitting germination. The lower slopes that lack the caliche allow moisture to penetrate deeper, and the necessary moisture content for buffelgrass germination may not be attained as often. This same subtle lower hillslope control has been noted at other sites, particularly in the limestone hills west of Caborca, where lower youthful debris cones lack buffelgrass, but the lowest grass is found just above the top of the lower debris cones just where soil caliche begins to surface, and upslope from there.

In general, buffelgrass concentrations within IFNM are found along the basal parts and mid-parts of steeper hill slopes, but not commonly along upper steepest parts of hill slopes. However, in Sonora, the grass seems common on steeper upper slopes. In many Arizona instances plants thrive near the base of cliff segments, as though the seeds fell from above the cliffs. Again, hillside populations are found on south and southeast slopes, and less commonly on southwest slopes.

A curious study area is Tumamoc Hill near Tucson (Site A11). Buffelgrass has been growing on the hill for many years (established before 1983), and is now dense enough to pose a fire threat on many hill slopes. The biggest patches are growing on east- and west-facing upper slopes, and thickets continue all around the south side of Tumamoc Hill. Less dense stands continue around the north side of the hill, (across the access road to the laboratory buildings), an unusual slope aspect—and the only obvious north side populations noted in this study. This population inhabits a 15-25 degree slope just below the Desert Laboratory buildings, where saguaros and paloverdes are abundant, but ocotillos uncommon. The buffelgrass continues upward into the rock outcrop areas nearer the buildings, where grass grows in spots where soil accumulates, but it does not inhabit the hilltop flats very near the buildings (but has it been eradicated here?). Across the canyon on the east-facing hillslope, buffelgrass has not yet established, but another short grass colored the hillslope yellow in May 2005 (perhaps tanglehead or tobosa), while saguaros and palo verdes are much less common, and ocotillos more common, compared to the opposite hillside. It is assumed that neither of these hillsides has burned in historic times. This small area west of the buildings (both slope aspects) is a good study area for the factors controlling distribution of buffelgrass.

Rather more remote and untrampled hill slopes undergoing buffelgrass infestations are the east and south slopes of Black Mountain on the San Xavier branch of the Tohono O'odham Reservation, visible from south Mission road, some miles south from San Xavier mission. It appears from some distance that these hill slopes have had no visible human disturbance, yet there are many small spots where thickets of buffelgrass are appearing, and one larger thicket. The hill slopes are steep, 25 degrees or so, and the grass thickets are appearing on lower and higher parts of the hill. On the main mass of Black Mountain, there seems to be less grass on the long southeast slope aspect of the hill, and rather greater abundance on a small prong that faces more due south. Martínez Hill, just east of I-19, and also on the Reservation, is becoming totally covered with thick buffelgrass on its southern slope, save one curious diagonal grass-free swath. Saguaros are thick on this slope. While on the northern slope, visible from San Xavier Road, there is much less buffelgrass and saguaros are less dense. Although I did not see buffelgrass with binoculars on the north slope, Van Devender believes he saw some high on the north side earlier in the season when grasses were greener.

Three localities are typical of hillslope occurrences. (1) In the southern Samaniego Hills, three nearby hillsides contain sizable populations (Sites A1, A2, A3). On southern exposures on a taller hill, with a one meter-deep arroyo running along its base, there are two small buffelgrass populations. The lower population (site of ASDM transects, and Site A2) seems confined to a particular south-facing hillslope with rocky soil cover and with only certain well-defined slope angles of 23-26 degrees. Steeper and rockier slopes above and below the patch contain no buffelgrass. Upon closer inspection, it seems as the slope with buffelgrass is rather "spoon-shaped" with a history of mass movement (land sliding). A finer-textured soil at the surface can contain soil moisture for longer periods than the adjacent rocky slopes. The banks of the arroyo below the buffelgrass patch for 200 meters contains very rare to no buffelgrass plants, but seeds should be widely dispersed along this arroyo. But there is a second patch of buffelgrass straight upslope from the first, some 50 meters or so (see the cross-section and map). This patch sits in a very rocky hillslope area forming the toe of another higher landslide with peculiar distribution of rock sizes delineating the landslide. The slide area stands out in stark contrast with the rest of the hillslope where larger rocks with desert varnish litter the surface. Within the slide area there are only smaller rocks that lack such intense varnishing. But here, buffelgrass is missing on the mass of the slide area (where it grows on the lower slide), but is concentrated in the rocky area at the toe end only. A flat, silty soil area at the head of the slide, where buffelgrass could grow, is devoid of the grass. Where the grass is growing in the rocky area, there is a recently dead small paloverde tree near the geometric center of the grass plants, perhaps killed when recent mass movements severed its root system. This same hill contains several small buffelgrass patches in its southeast and east sides. The buffelgrass patches are associated directly with the small part of the hillside that has a Holocene history of mass movements. Some connection apparently exists between the moisture retentivity of this surficial material and the existence of buffelgrass stands. Other nearby parts of the hillside without obvious mass movement effects are mostly barren of the grass. Likely, these mass movement areas actually contain greater and more prolonged soil moisture following heavy winter rains because of slight funneling effects from slopes and cliffs above.

A smaller isolated hill lies nearby to the south, and contains thick buffelgrass infestations on its east side, southern Samaniego Hills (Site A1). This hill is the site of archaeological stone walls, one meter or more tall, of unknown age and origin (archaeologists Paul and Susie Fish do not know the origin of the walls, thinking they may have been built by Mexican sheep or goat herders in the 1800s; others including myself disagree with this assessment—some but not all walls are coated with several kinds of mature lichen colonies). Buffelgrass grows commonly within the confines of the wall complex, which lies only on the east side of the hill where a few natural bedrock steps are found, composed of old lava flow tops. The hill's steeper west side is devoid of walls and buffelgrass, except that the grass surrounds a single mature saguaro on the southwest flank. Other native grasses are doing well on the cooler north slope of the hill. One buffelgrass patch is growing some distance down a talus cone on the south side. Another taller isolated hill sits nearby to the west, but is devoid of both stonewalls and buffelgrass. Thus, a curious correlation exits here of an archaeological disturbed area and a healthy buffelgrass stand. A large patch of buffelgrass is found on yet another nearby steeper hillslope that faces SSE (15-25 degree slope angle) located about 0.3 mile north of the two patches was described first (Site A3), but not closely visited.

An isolated buffelgrass thicket near Green Valley is on a small limestone hill at the old San Xavier Mine (Site A10). The plants are growing on upturned beds of Paleozoic (Permian) limestones of varying shades of gray and black on a steep (ca. 25° slope angle) south-southwest slope. Other buffelgrass stands were not detected on other limestone hills in the area with binoculars, although Tom Van Devender earlier recorded a small patch on a southwestern slope of the taller Helmet Peak.

Buffelgrass on Hill Slopes in Sonora. There is a very interesting buffelgrass population along the north side of the Magdalena-Tubutama highway (Site S4), where multiple buffelgrass thickets occupy numerous hillslope sites. The site consists of a higher NE-SW trending ridge and three side ridges that trend down to the east to southeast. There are at least six larger buffelgrass thickets and many outlying lesser occurrences observed that occur on slopes facing generally south, southeast, and somewhat to the southwest. One thicket faces about eastward. The occurrences are isolated in that there are only rare plants that connect the thickets, yet some thickets are of large size (greater than 15 m in diameter). The greatest concentrations are on hill slopes with 15-25 degrees slope angle. The dense buffelgrass patch on the upper steep rocky hillslope appears to have grown westward across the main canyon drainage path and onto an adjacent east-facing slope while drainage channels contain very sparse grass or none at all. The lack of recruitment down the small stream course is very interesting, as the stream must be littered with buffelgrass seed. Other thick patches are found higher on the steep south slopes of the main ridge, but plants are rare in the less vegetated sandy soils along the ridge crest, and in the flat part of a topographic saddle. Buffelgrass not found on the west side of the ridge.

A hillside buffelgrass infestation is found on lower hill slopes of Paleozoic limestone outcrops just north of the Caborca-Puerto Peñasco highway, just west of Caborca (Site S5). The hills here consist of two parallel tall ridges that trend north-south, both composed of steeply upturned limestone beds. Buffelgrass populations are found on both ridges on their midslopes, but populations in each case are closely confined to very particular geomorphic conditions. On the western flank of the eastern ridge, buffelgrass is found on the hillside for several hundred meters, starting at a slope break with slope angle about 15 degrees, extending upslope basically to the base of bedrock cliffs. In this stretch, clastic soil materials have been largely removed by recent erosion and deposited as debris cones along the base of the hillside, and white caliche layers lining exposed bedrock vugs and lows are seen. In this area of minimal soil cover, buffelgrass is abundant in large clumps on the rocky slope. But it is not found everywhere, as other portions of this part of the hillslope contain teddy bear cholla thickets, and buffelgrass is missing. It appears the two plant types are inversely correlated. Mark Dimmitt (pers. comm. 2005) observed that some of these hillsides have burned, killing the chollas and paloverdes. These areas are now dominated by dense buffelgrass. Buffelgrass is not found growing on the lower debris cones. Some is higher up nearer the ridge crest. And it is virtually absent from the valley flats below, especially in the cholla thicket areas, except along a narrow strip of floodplain (3 m wide) adjacent to the main arroyos, and along the surface of a small inset terrace about 1 m above the channel bottom. Across the valley, buffelgrass thickets are also found on the midslope portions of the east-facing hillside, but only in areas where the soil has been largely stripped from the slope and where caliche and bedrock are at the surface. The lower slope, below the first bedrock outcrop, has thicker soil cover and another grass is exclusively present, no buffelgrass here. The greatest density of buffelgrass at this field site is on the west-facing slope, where it appears to be as concentrated as in other areas with volcanic or granite bedrocks. Dimmitt notes the presence of a buffelgrass population across the highway on another limestone hill, on a NE-facing to N-facing steep slope. Further west of this site along the highway, on dark-colored basalt hills, which are across the highway and south of the rod and gun club shooting range, buffelgrass is establishing on east-facing steep debris-covered slopes. This seems to be private property now, protected by fences and locked gates. The few patches appear small compared to those on the limestone hills, and these hills are less than half the height. The soils on the basalt-capped hill are far different from the limestone slopes, and the buffelgrass is much more extensive on the limestone hill slopes than the basalt hill slopes. But perhaps it's simply been there far longer. A well-used informal rest area exists along the highway near to the extensive buffelgrass stands on the limestone ridges.

Another interesting series of sites is farther west from this site along Highway 2 midway between Caborca and Sonoita. Here, buffelgrass stands are patchier along the highway right-of-way. In a region where the highway traverses a series of low volcanic knobby hills, buffelgrass thickets are seen high on east- to southeast hillsides, and all occupy nearly the same slope aspect. At least 8-10 such hillsides were noted. We did not examine these sites closely, but did not notice patches on the bajadas below the hills.

Figure 8. Buffelgrass along dirt road and south-facing hill slope near Caborca, Sonora. Photo by Mark Dimmitt.

Buffelgrass around Playas. Only one instance was noted during this study where buffelgrass recruitment is occurring around the edge of occasional standing water, along the edge of a small newly formed "playa"-type situation in Sonora, along the dirt road to El Plomo mine, north from Highway 2 west of Caborca (Site S6). The area is in valley flats, and knobby hills to the east are made of granite, and the soils here granite-derived. Some red clay buildup is seen in the valley flat soils, perhaps 10-20 cm thick. These soils probably have a buried immature caliche zone buried some 20-40 cm, but it was not seen in any cuts. The drainages here flow southward, and in part may have been redirected by the presence of the El Plomo mine road. At one place there is a large fenced-in plowed field east of the road, and on the gate the sign reading "Pradera las Flores, SBF." There is some buffelgrass growing in the field, serving as pasture grass for cattle in the last few years. Small buffelgrass stands are now seen along the dirt road on both sides, both growing on the plowed furrows at the road edge and extending out into undisturbed desert vegetation for perhaps 3-4 m out from the roadway, but not past that. At a spot a few kilometers north of the pasture along the road, a small very shallow impoundment has developed on the east side, east of two small arroyos and not quite visible from the road, acting now as a mini-playa, where recent silts and clays are settling out in a very subtle sag. The impoundment is a new one, since there is no playa-edge halophyte plant associations, as are seen around old playas. The area of playa sedimentation tracks northward past our area of investigation; while the "pond" at its south end is some 20 m wide or more. Water flows into the playa from the north. Buffelgrass is found in three situations near the playa. Some buffelgrass is found along the dirt road. Small colonies line the edges of the two small arroyos near the roadway. The arroyos are perhaps 0.5 m deep. Patches also line much of the southern edge and the southern part of the eastern edge of the playa, right at the boundary zone where silt-clay sedimentation of the playa contacts normal sandy gravelly soils of the valley flats. It seems as though buffelgrass seeds are floating down the arroyos during flash floods, where some accumulate on the pond. Then perhaps breezes blew them to the south and east edges, where they lodged and sprouted. This idea suggests that there are considerable buffelgrass populations somewhere upstream to the north, and perhaps in the granite hills. The evidence here points to periodic recruitment of grass when temperature and soil moisture conditions permit.

No buffelgrass was noted growing along the northern edge of the sizable playa at the south end of the Sawtooth Mountains, south of "The Tooth" hill (about sections 16-17, T10S, R6E). Already noted was an experimental planting of buffelgrass at the small playa southwest of Cerrito El Represo in Ironwood NM farther south. The buffelgrass plantings on the flats have died out. Even normal vegetation like creosote in those plots seems to have suffered because of episodic flooding. But it is noted that in both these cases there are healthy buffelgrass stands on nearby hill slopes.

Buffelgrass in Human Disturbed Areas. In some instances the grass is occupying human-disturbed areas. In one instance buffelgrass is naturally invading a sizable stripped and cleared area on a 5 degree-sloping bajada surface in limestone-derived soil in the Waterman Mountains (Harlow Jones property, 2 miles ESE of Waterman Peak, Site A6), where the surface was bulldozed clear of vegetation some 20 years ago. The site is clearly visible as one drives west on Silverbell Road toward the Silverbell copper mine. In several areas down slope from this patch, individual grass plants are growing along edges of plowed furrows, exactly where seeds would accumulate following sheet flooding. Outside of the cleared area, a fairly careful search [in the area of the endangered Nichol's Turks head cactus (*Echinocactus horizonthalonius nicholii*) study plots] disclosed no buffelgrass recruitment in undisturbed vegetation, except in a band some 3-6 meters wide surrounding the disturbed area mostly on the north side. Specifically, a search upslope from the disturbed area in limestone bedrock canyons failed to disclose any buffelgrass. It is not known how the buffelgrass came to occupy this cleared area.

But in another situation of cleared flats in the Avra and Aguirre valleys, there are mysterious die-offs of native vegetation over the past few decades that have left the ground quite bare (but with no other signs of human-caused soil stripping or plowing), and no buffelgrass is seen to invade these areas. These areas seem to have been affected by flooding events, and in some cases some sedimentation. However, potential causes of this die-off phenomenon include salinization of the soils, which could affect buffelgrass.

Buffelgrass is establishing on disturbed flats of the Santa Cruz floodplain directly east of “A” Mountain near downtown Tucson. A potential seed source is the steep nearby eastern hillslope of ”A” Mountain where grass patches are obvious. On the floodplain, buffelgrass is establishing in open and low areas (swales) and along drainages, but not under cover of mesquite trees, unlike the situation in wilderness areas. Because the grass is establishing in low areas, and not in totally random fashion, it may once again be noted that the seeds seem to move around during times of sheet flow, are carried to the low spots where water sits for some time and wets the soil thoroughly, then the plants sprout in the moist soil.

Summary of Findings

Buffelgrass occurrences are clearly very limited to a few well-defined geomorphic settings, but do not relate in any simple way with standard soil types. It is most common on disturbed roadsides, especially along larger paved roads that have been repeatedly bladed. In some areas in Sonora, heavy cattle grazing effectively controls buffelgrass, limiting its impact in Arizona Upland desertscrub.

Buffelgrass occurs on volcanic (rhyolite and basaltic), and gneissic (= granite), and a few limestone bedrock, where details of soil chemistry and mineralogy vary greatly. The only occurrence of buffelgrass that was clearly correlated with bedrock type (Site S3) was between Magdalena and Tubutama where it was restricted to a patch of dark-colored amphibolite dike rock (containing an iron-rich silicate mineral) within granitic gneiss bedrock. Buffelgrass occurrences seem much more related to certain very well defined geomorphic settings rather than rock type:

-disturbed rights-of-way, especially on larger highways
-undisturbed steep south, southeast, and southwest slope aspects of hills with very poorly developed soils and caliche near the surface
- shallowly incised drainages on hillsides with steep south slope hillsides
-along the upper portions of shallow arroyos in valley flats.

Established populations often invade nearby disturbed areas. Buffelgrass is less common on gently sloping bajadas, where it tends to clump in the shade of trees, larger shrubs, or prickly pear cactus. In many places thickets of buffelgrass capable of sustaining fire occur on fairly steep hillsides (15-30 degree slopes). Younger plants are frequently scattered beyond the thicket on similar slope aspects, clearly a result of short-range dispersal. At only one site in Sonora we encountered a concentration of buffelgrass on the very top of a hill.

In short, hillside concentrations of buffelgrass throughout the region are predominantly found on steeper south, southeast, and southwest slope aspects of hills. In several spots, buffelgrass distribution on hill slopes was correlated very tightly with certain geomorphic conditions and certain slope angles (14-19 degrees) with relict clayey soil. Elsewhere on the slopes with slightly different conditions of percent rock cover, greater depth to hard-packed caliche, and slope angle, buffelgrass was lacking. Considering these observations, it is important to point out that buffelgrass apparently has a fairly well defined ecological distribution in the Arizona Upland Sonoran Desert, and may not expand into as many areas as feared. Unfortunately, the signature paloverde-saguaro desertscrub so unique and characteristic of this area is best developed on the southerly slopes preferred by buffelgrass. To the south in central Sonora, the distribution of buffelgrass is not as restricted and it occurs on all slopes. With increased global warming, milder winter temperature may well allow buffelgrass to move into other microhabitats in the Sonoran Desert in Arizona as well.

Table 1. Geographic coordinates of study plots.

ARIZONA

All Arizona site coordinates are in Township coordinates, as this is the standard for all 7.5' topographic maps. For example SWQ NEQ sec 4, T6S, R11E is the southwest quarter of the northeast quarter of section 4, township 6 south, range 11 east. All Arizona sites are in townships that are surveyed and shown on 7.5-minute map series. Site numbers 1-13 are given. (Site designations, A = Arizona; S = Sonora)

Samaniego Hills

A1—SW Q SW Q sec 15, T11S, R9E (all locations on Silver Bell East 7.5 quad)
A2 – NE Q NW Q sec 22, T11S, R9E, on isolated smaller eastern hill
A3 – NE Q SW Q sec16, T11S, R9E. (isolated larger patch not closely visited)

Pan Quemado Hills

A4 - NW Q SW Q sec 35 and adjacent sec 34, T12S, R9E (Waterman Peak 7.5 quad). Approach road to guzzler spring west of the site.

Roskruge Mountains

A5 – Cerrito El Represo - SW Q sec 13 and SE Q sec 14, and playa encompassing common corner of secs. 13, 14, 23, 24, T13S, R9E (Waterman Peak 7.5 quad), elev 2150-2250 ft. Nearby are sites A14 and A15.

A14 – Hill in shape of 'C', 1.8 miles north of El Represo. Site is on far south edge of hill 2499T, northernmost part of SW Q SW Q sec 1, T13S, R9E (Waterman Peak 7.5). (UTM 3,576,250 N; 463,500 E)

A15 – Patch of buffelgrass along arroyo in valley flats near a 'T' intersection of roads, 1.5 miles NW of El Represo hill, center of W edge sec 11, T13S, R9E (Waterman Peak 7.5) (UTM 3,575,000 N; 461,850 E.)

Waterman Mountains

A6 - Jones Property near Silverbell mine
NW Q sec 30, T12S, R9E (Waterman Mountains 7.5 quad), elev. about 2400 ft.

Sawtooth Mountains

A7 - along east side of hill called "the Tooth" in SE Q sec 8, T10S, R6E (Silver Reef Mountains SE 7.5 quad). Large playa one half mile south of there.

A8 - on south side of hill 2344, in SE Q sec 33, T 9S, R6E (Greene Reservoir 7.5 quad).

A9 - larger northern patch at base of cliff – all along south side of hill 2467 top in SW Q SW Q sec 27, T9S, R6E (Greene Reservoir 7.5 quad)

Helmet Peak

A10 - University of Arizona mining laboratory on Ocotillo Ranch Road, off south Mission Rd., and hill, in south central part of SE Q sec 3, T17S, R12E (Twin Buttes 7.5 quad)

Tumamoc Hill-A Mountain, Tucson Mountains

A11 - Tumamoc Hill – western half sec 15, T14S, R13E (Cat Mountain 7.5 quad).

A12 - 'A' Mountain – SW Q sec 14, T14S, R13E (Tucson 7.5 quad)

Martínez Hill

A13 - Martínez Hill – southern half sec 3, T15S, R13E. (Tucson SW 7.5 quad)

Table 1. Geographic coordinates of study plots.

SONORA

All Sonoran sites given in UTM coordinates, taken off a software map in possession of Mark Dimmitt, no cross-checking for accuracy was done on Mexican 1:100k map series. The digital map files were purchased at INEGI (Instituto Nacional de Estádistica Geografía e Informática) offices in Hermosillo, called 'Toponimia' and 'Capas de Altrimeteria'.

Magdalena area

S1 - Along Mexico I-15 north of Magdalena, just north of the highway bridge called Puente la Batalla, near WP 89 on B082504-938, UTM coordinates within a mile of 515,600 E; 3,410,600N.

S3 - Hills near Magdalena along Magdalena-Tubutama highway, 501,540 E; 3,389,190 N
S4 - Next set of hills to the west of site S3, on north side of Magdalena-Tubutama highway, coordinates of a square that encompasses the study site - -3,390,020 to 3,390,640 N, 495860 to 496225 E.

Imuris area

S2 - Along Mexico I-2 northeast of Imuris, headed for Cananea, just south of highway, this site encompasses Dimmitt's way points 17 and 18, basically at 517,460 E, 3,409,330 N.

Caborca area

S5 - West of Caborca, along the highway to Puerto Peñasco, two N-S trending limestone ridges, north side of highway, two center points are given, 379,262 E, 3,397,530 N for the center point of the N-S line of east side of a square encompassing the site, and the center point of the west side of the square, 378,938 E, 3,396,872 N.

S6 – Along dirt road north from Tajitos on Mexico I-2 (northwest of Caborca on road to Sonoyta highway) to the El Plomo mine. The site includes a newly formed mini-playa impoundment, and is a short distance north from a large fenced-in plowed field with sign on the gate reading "Pradera las Flores, SBF." (pradera = prairie), which is now being overgrown with buffelgrass patches, possibly having been planted there recently. Van Devender did not note buffelgrass here a year ago during earlier visit. UTM coordinates at turn-around point on dirt road, just west of the 'mini-playa' are 372,706 E, 3432972 N. Coordinates at a stop in front of the gate at the field are 371,268 E, 3,429,128 N.

Sierra Cubabi

S7 – Pass in the Sierra Cubabi along Mexico I-2, south of the Sonoita/Lukeville border crossing, on granite hills just west of highway, 322,390 E, 3,514,265 N.